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GUIDES TO INDUSTRIAL PREVENTIVE MAINTENANCE FOR ENERGY CONSERVATION

Bureau of Energy Utilization
Ministry of Energy

National Engineering Center
University of the Philippines

U.P. Engineering Research and Development Foundation, Inc.

United Nations Industrial Development Organization

APRIL 1986
Quezon City, Philippines

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UNIVERSITY OF THE PHILIPPINES
QUEZON CITY

OFFICE OF THE PRESIDENT

MESSAGE

I wish to congratulate the U.P. National Engineering Center, the U.P. Engineering Research and Development Foundation, Inc., the Bureau of Energy Utilization, and the United Nations Industrial Development Organization for developing and publishing this book, Guides to Industrial Preventive Maintenance for Energy Conservation, the third in the series Guide Series for Efficient Energy Use.

This book reflects, in part, efforts of the academe to become a relevant presence in our national life. With the savings realized by the direct application of this manual in maintenance work in industry, the University, along with the other organizations involved in this project, will have contributed in a concrete way to our country's economic development efforts.

The active participation of industry experts has been essential to the success of this project. This manual is another product of the combined resources of the academe, industry and government.

I hope that this collaborative effort will lead to a stronger and closer relationship between the academe and the rest of the economic sectors.

EDGARDO J. ANGARA

21 April 1986

FOREWORD

This book is intended to serve as a practical guide for maintenance engineers, supervisors and managers in carrying out preventive maintenance work. Where tasks can be done by plant personnel, specific procedures and techniques are given. For maintenance services which only trained specialists can provide, the text attempts to give the reader a general understanding of the work involved and references are indicated, in case there is interest in getting more details.

The book is divided into three main parts. Part I, which consists of Chapters 1 and 2, describes the nature and management aspects of industrial preventive maintenance (PM). The importance, objectives and scope of PM programs are defined, and a step-by-step decision guide for the introduction of a plant preventive maintenance program is given. The management aspects cover guidelines in organizing the PM function, motivation of maintenance personnel, and control and evaluation of PM work.

Part II, which includes Chapters 3 to 8, discusses the basics of preventive maintenance: designing for maintainability; the concept of lifecycle costing and failure analysis; condition monitoring techniques; lubrication; corrosion prevention and control; leak prevention; and industrial water treatment. These are general aspects of preventive maintenance which are applicable to industrial plants. Each chapter gives a brief description of the concept involved and its importance. Techniques for the detection and analysis of associated problems and guides for the selection of needed materials and instruments are presented. Specific preventive maintenance measures are outlined in detail.

Part III, which consists of Chapters 9 to 14, covers the application of preventive maintenance to specific industrial equipment, namely: boilers and furnaces; refrigeration and air conditioning facilities; electrical equipment; pumps and air compressors; materials handling equipment; and industrial diesel engines. A brief description of the equipment starts off each chapter. Then follows a section on diagnostics which details the items to be checked, symptoms which indicate troubles, and any tests and instruments necessary for analysis. Preventive maintenance measures and procedures are then specified. A description of a successful preventive maintenance case rounds off the chapter where a documented case is available for a given equipment.

The appendices include a glossary of maintenance terms, decision guides for introducing a PM program in a plant, a sample work order system for effective PM management, a maintainability design checklist, a section on the preventive maintenance of rolling bearings, lubrication and corrosion data, tables on the SI system of units, and a directory of technical assistance centers for maintenance services.

It is hoped that this book will effectively serve its purpose as a handy reference for maintenance practitioners.

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CHAPTER 1

Industrial Preventive Maintenance

1.1 THE NEED FOR A PREVENTIVE MAINTENANCE PROGRAM

Maintenance is defined as a combination of action carried out on an item to retain it in, or restore it to, an acceptable condition. Properly implemented and with strong management support, it contributes significantly to plant productivity and performance in many respects.

The need to manage the maintenance function more effectively is becoming more important for two main reasons:

a. Inflationary effects have resulted in increased wages and spare parts costs. Since maintenance costs are about 1/3 of the controllable manufacturing operating expenses, these increases have a significant effect on operating costs.
b. The high capital investment in equipment, together with the high cost of money, places additional pressure on the company to operate existing equipment at optimum conditions. This means running the plant at high efficiency, high yield, low scrap and rework, and minimum downtime. As a result, some equipment are being operated beyond their design capacity.

It is to the company's advantage to defer and minimize capital expenditure and this increases the necessity to prolong the useful life of equipment and minimize the funds tied up in spare parts inventory.

1.2 THE NATURE OF PREVENTIVE MAINTENANCE

Effective maintenance management involves sound organization, measurement and control practices regarding all actions necessary to keep an item in, or restore it to, a condition of readiness for service. These actions include servicing, repair, modification, overhaul, inspection and condition verification.

1.2.1 Definitions

The diversity of terminologies and definitions used for various aspects of maintenance has tended to cause misunderstanding among maintenance practitioners. In an endeavor to formulate a universal maintenance vocabulary or terminology, the British Standards Institution issued BS 3811:1964 – Glossary of Terms Used in Maintenance Organization, which was later re-issued as BS 3811:1974 – Maintenance Terms in Terotechnology. A list of some commonly used terms and their definitions is in Appendix I.

1.2.2 Basic Approaches to Maintenance

a) *Breakdown Maintenance* is the oldest and most common approach. This is a maintenance of a non-routine, non-repetitive basis performed to restore an item to a satisfactory condition after a failure has occured. The breakdown maintenance cost would include the repair cost plus the cost of production losses.

b) *Preventive maintenance* is a collection of systematic actions performed to retain equipment in satisfactory operational condition and to prevent sudden malfunctions. The essential purpose is to eliminate controllable failures. PM actions include the following activities:

1) Design, purchasing and material control to avoid possible problems in subsequent operation and maintenance of equipment and facilities;

2) Formulation and implementation of proper operating procedures to reduce maintenance and operating problems;

3) Inspection and monitoring to identify incipient failures;

4) Proper lubrication;

5) Analysis of equipment records to identify and solve equipment problems;

6) Analysis of equipment and repair operations to find and solve maintenance and operating problems;

7) Adjustments, calibrations and minor equipment replacement arising from inspection;

8) Scheduled repairs and overhauls.

Preventive maintenance is a formal program which requires a high degree of planning, organizing and control.

c) *Corrective Maintenance* consists of the study of equipment failures and breakdowns and the actions undertaken to prevent their recurrences. This maintenance approach deals primarily with repetitive repairs and normally requires good maintenance records and the creative ability to identify and solve recurring maintenance problems. Often, nagging maintenance problems can be reduced significantly or eliminated by taking deliberate action to improve the performance of the equipment. A careful, systematic study of the breakdown cause and necessary repairs can indicate that improvement can be made by one of the following actions:

1) Changing the process or the duty which the equipment performs.

2) Redesigning the component that failed in order to strengthen or eliminate the weak point.

3) Replacing the defective unit with an improved one (e.g., one made of a new material or alloy).

4) Improving preventive maintenance procedures (e.g., more frequent lubrication or inspection).

5) Reviewing and changing operational procedures (e.g., developing proper startup and shutdown procedures or improving training for operators).

An active corrective maintenance program can result in significant improvement in equipment reliability, reduction in downtime and lower maintenance costs. Each project, however, should be economically justified since there are cases where it is more economical to dispose of a unit than to improve it.

The effective organization is one which recognizes the differences and systematically selects the proper blend of these approaches to meet the organization's objectives.

1.2.3 Basic Principles for Preventive Maintenance

The principles upon which preventive maintenance is based are:

a) **Maintenance is cumulative.** Most failures have minor and seemingly unimportant beginnings. Therefore, breakdowns and large repairs generally start small and grow. The parts of machines and equipment are interdependent. It is a little tear in a belt that leads to rupture, a little vibration that results in fatigue failure, a little heat that develops into a seized bearing, a little corrosion that precedes the failure of a tank.

b) **Evidence of developing failure may be found.** There is normally some sign of the coming failure that can be found if searched for carefully enough. One of the first requirements for detecting incipient breakdowns is the recognition that they are of small beginnings. When this is fully appreciated, the minor variations in the behavior of a machine takes on added significance. These little signs of future failure are not hard to detect if attention is paid to the subject and some patience is exercised. The ability to use physical senses is the key because one can normally see, hear, feel or smell these minor faults, such as heat, cracks, vibration, odor or strange noises. Instruments are available for a more reliable condition monitoring of equipment.

c) **Growth to failure takes time.** Usually, a substantial amount of time elapses between the time of possible detection of the minor fault and the actual breakdown or failure. This time element does vary from one failure to another, but in most cases there is sufficient time in which to act to prevent minor faults from becoming major failures.

d) **Preventive maintenance is less costly.** Corrective action taken in the early stages of a developing failure will be much less costly than those made after the failure has developed. The time and material required to mend small tears and ruptures, and other minor faults are less than for major repairs. The early repair of a minor fault also reduces the chance of that fault becoming a failure which adversely affects interdependent parts.

1.3 THE OBJECTIVES AND SIGNIFICANCE OF A PREVENTIVE MAINTENANCE PROGRAM

The objectives of a preventive maintenance program are:

a. To aid in minimizing the unanticipated failure of equipment in order to avoid the resulting downtime and loss of production.

b. To minimize the cost of emergency repair.

c. To minimize hazards to personnel.

d. To maximize the efficiency and safety of production equipment operation.

e. To prolong the useful life of equipment.

The primary goal of a preventive maintenance program is to reduce the overall maintenance and operating costs. This does not necessarily mean a record of "no breakdowns". Figure 1.1 shows graphs which indicate the effects of preventive maintenance and downtime costs to the overall maintenance costs. The curves illustrate that at low PM activity levels the downtime costs are high. As preventive maintenance is increased, downtime cost decreases. This decrease in downtime cost is very rapid as preventive maintenance begins, but the decrease slows to a point where additional preventive maintenance will do little to reduce the downtime costs. The total maintenance costs decrease to a point where the cost of preventive maintenance exceeds its benefits as far as reduction of maintenance costs is concerned. After this point, the total maintenance cost starts to increase. The level of preventive maintenance activities (PM program) is established on the basis of a cost-benefit analysis and production goals.

Here is a list of benefits which can be derived from a preventive maintenance program:

a. Less production downtime, with all its related savings and advantages;

b. Less overtime costs than for breakdown repairs;

c. Fewer large-scale and repetitive repairs, hence less crowding of maintenance work;

d. Fewer product rejects, less spoilage and better quality control because of properly adjusted equipment;

e. Less standby equipment needed, thus reducing capital investment;

f. Better spare parts control;

g. Identification of items with high maintenance costs, leading to investigation and correction or causes such as misapplication, operator abuse and obsolescence;

h. Greater safety for workers and improved protection of the plant;

i. Lower costs of simple repairs because fewer skilled manpower and parts are needed than for breakdowns.

1.4 THE DECISION TO ESTABLISH A PREVENTIVE MAINTENANCE PROGRAM

Preventive maintenance programs are not easy to "sell" to management because there are no immediate savings to be realized. It is not unusual to have to wait for 2 years to see initial benefits from PM. Management is usually receptive to a well planned cost-reduction program and so a preventive maintenance program must be formulated as such.

The establishment of a PM program is done on an individual plant basis and there is no "off the shelf" plan that can fit the requirements of any particular plant. However, there are five specific phases which can serve as an overall guide for the introduction of a preventive maintenance program:

Phase I — Suitability Study
Phase II — Research
Phase III — Design
Phase IV — Appraisal
Phase V — Operationalization

The detailed steps in undertaking these phases for establishing a PM program are described in Appendix II.

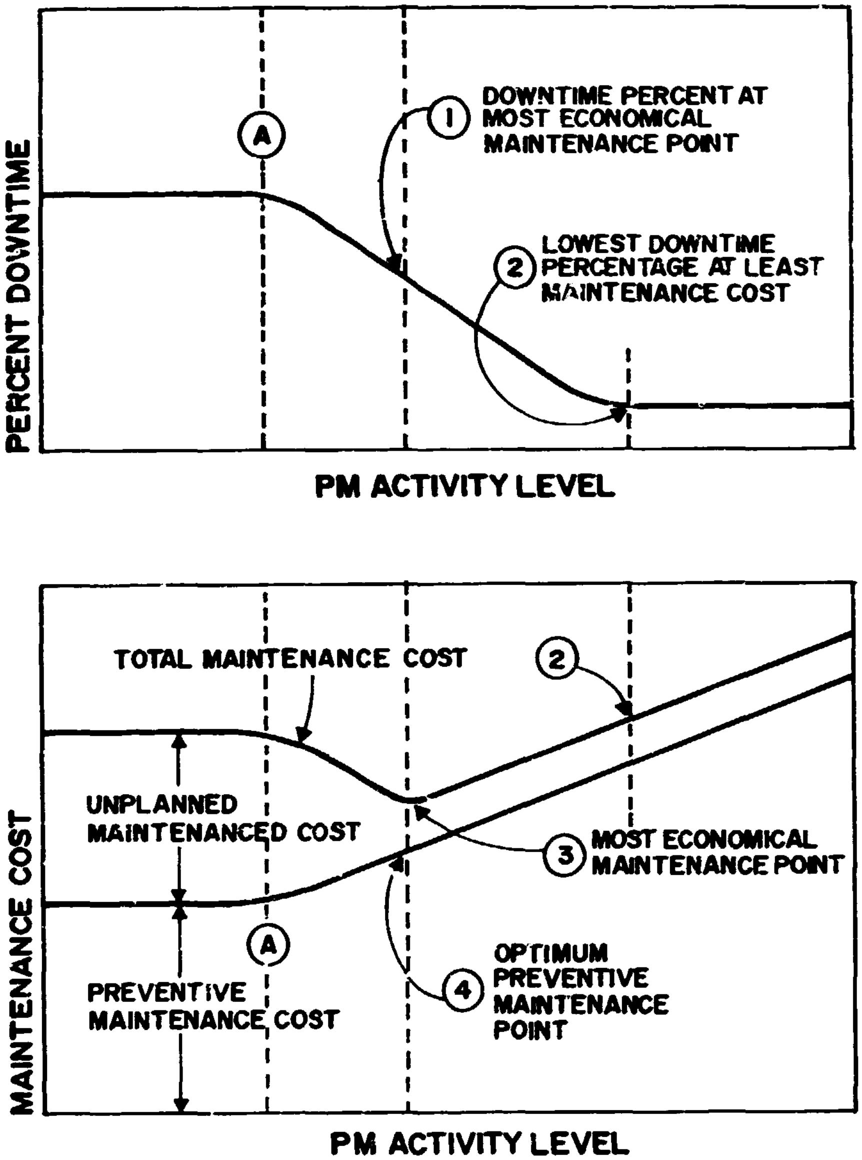

Figure 1.1 PM Optimization

Phase I *(Suitability Study)* involves the efforts of the Maintenance Department to "sell" the idea of a PM program to management. The results of this study would include:

a. A written statement giving a clear definition of preventive maintenance which shall be commonly understood in a particular firm;

b. Cost figures associated with operating the plant without a PM program for the past 2 years;

c. Cost estimates for the implementation of a PM program for the same 2 years;

d. Comparison of maintenance costs to determine the minimum cost of optimum maintenance;

e. The outline of a PM program.

Phase II *(Research)* includes the following activities:

a. Gathering of equipment records and historical repair and maintenance data;

b. Selection of equipment to be included in a pilot PM program;

c. Training of a PM team for the pilot program;

d. Thorough study of past upkeep and maintenance costs, a more reliable estimation of the cost of the desired PM program and computation of expected savings;

e. Determination of other possible benefits besides savings, namely, better product quality and increased productivity;

f. Evaluation of the data and discussion on the merits and extent of coverage for an economically justified PM program;

Phase III *(Design)* consists of the activities in designing the preventive maintenance program for the plant. These include:

a. Designation of members to form the PM design group;

b. Analysis of equipment records to determine the extent of plant-wide PM work to be established;

c. Design of the system for record-keeping and scheduling, whether manual or computerized.

Phase IV *(Appraisal)* consists of putting the plan into a test operation at a scaled-down basis in order to determine the workability of the entire program plan. This phase includes the following activities:

a. Identification of the most critical and troublesome equipment of the plant to be included in the test program;

b. Review of the historical data of the test units;

c. Implementation of the test PM program for one cycle;

d. Recording of data during the conduct of the preventive maintenance work;

e. Analysis and discussion of data and PM results;

f. Establishment of a system for program scheduling, reporting and monitoring;

g. Preparation of the formal written preventive maintenance procedure;

h. Preparation of budget for the plant-wide PM program.

Phase V is the *operationalization* of the plant preventive maintenance program. It is recommended that this should initially cover 50 percent of the machines in the plant and then later expanded to a full-scale program. The following activities are included in this phase:

a. Distribution of copies of the PM schedule to all departments concerned;

b. Preparation of work orders;

c. Carrying out of preventive maintenance work according to the schedule and instructions in the work orders;

d. Preparation of technical and cost data reports;

e. Review of the PM program for possible improvement and expansion of coverage.

The key factors to the successful establishment of an effective PM program are strong support from top management and close cooperation among involved departments. With these and a clear definition of preventive maintenance which is well understood by all in a particular plant, an organization should be able to adopt a PM program which provides the optimum level of attainable benefits.

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CHAPTER 2

Management Aspects of Industrial Preventive Maintenance

2.1 ORGANIZING FOR PREVENTIVE MAINTENANCE

2.1.1 Guiding Principles

The sizes and complexity of industrial plants vary. When organizing the PM function in any plant, the following guiding principles should apply (Reference 6).

a) *Start modestly; establish clear objectives.*

It is a safe rule to start modestly and progress deliberately as experience is gained. The first tasks to be tackled would be the analysis of past production and maintenance records and the establishment of inspection and reporting procedures limited to a few equipment. From these, potential savings can be estimated and succeeding developments can be planned more accurately.

This guideline should be followed even when the engineer in charge is an experienced preventive maintenance man. There is too much unexpected work in launching a full-scale program right away.

It is best to start with selecting key facilities which have immediate effect on production and for which realizable savings can be estimated with confidence. This way, a PM proposal can gain strong management support.

(b) *Organize PM Team carefully; define responsibilities.*

Choose for a PM supervisor or manager an able engineer who is analytical and inclined towards practical research and has no reservations about working with drawings, cost records, burdensome technical data, equipment testing, analysis and technical report writing. He must also have the ability to win cooperation from other groups and departments as well as keep the PM team properly motivated.

If no employee really has the capability, a qualified man should be hired rather than put somebody of doubtful ability and hope that somehow he will make the grade.

Select clerical staff who have the aptitude for keeping records and some knowledge of blueprint reading and office procedure. Do not get a mechanic with no clerical experience to do the work.

Maintenance mechanics should be technically competent and able to reason clearly, write legibly and work with little supervision.

Responsibilities of all team members should be clearly defined. The team should be under the direct authority of the PM supervisor.

PM work should be classed as a major staff function and provided with adequate office facilities from the start of the PM program.

(c) *Streamline procedures; establish checkpoints.*

There is no standard PM clerical system. The optimal system should ensure that information collected is accurate, in sufficient detail, promptly used and economical on supplies, facilities and time requirements.

It is practical to use standard forms. Checklists should be used whenever appropriate for recording maintenance work as it saves writing time.

(d) *Keep the PM Team intact for a reasonable period.*

The PM Team must be kept intact for at least one year, or until such time that the PM program is fully operational. As much as possible, there should be no change in the membership of the team, to ensure continuity of the work.

2.1.2 Organizational Structure

When the PM program becomes fully operational, the function is integrated into the maintenance department.

For small plants, the preventive maintenance function may be carried out by staff engineers in a centralized technical department.

For large plants the work of engineers in the maintenance department includes developing budgets, installing capital projects, etc. Without a defined PM function, PM-related problems would not receive the proper attention on a daily basis. It is not uncommon to find that repairs are made on damaged parts but little time is given to analysis and diagnosis of symptoms in order to arrive at the true cause of failure. The total maintenance function is not carried out effectively due to divided management directions.

Figure 2.1 shows an organizational chart where engineers are placed in two separate locations in the maintenance department. Maintenance engineers in the planning function may not be receiving proper direction due to heavy non-technical administrative demands placed on their supervisor. Engineers in the field execution may experience too many problems for two reasons. First, there can be continual pressure from execution management to complete jobs as soon as possible at the expense of quality or reliability. Secondly, their motivation and effectiveness may have been undercut due to their relatively low positions in the organizational structure This opens up another problem; how do you attract top engineers into maintenance work?

A better organizational arrangement is to combine all technical requirements into one Maintenance Engineering Section (MES) at a level reporting directly to the maintenance manager. This is shown in Figure 2.2. This is necessary to enable new programs to be installed and receive management support on a continuing basis. Inevitably, situations will arise where PM decision which have to be implemented would contradict past practice and traditions and temporarily increase department expenses. Centralizing the engineers eliminates overlapping of effort on problem solving and provides for a more effective manpower utilization.

2.1.3 Factors for Establishing the Maintenance Engineering Function

In defining the functions of the Maintenance Engineering Section, a number of important aspects need to be considered:

(a) The program is long term and affects not only the maintenance department but the plant as a whole. It is necessary that management clearly understand its objectives and is fully committed towards achieving these goals.

(b) Maintenance management needs to adopt and develop formal 5-year plans rather than work on yearly cycles. In particular, investment strategies need to be developed in greater detail for 5-year objectives to achieve improved reliability and extended equipment life.

(c) The function requires technical expertise in both mechanical and instrument/electrical equipment.

(d) The use of diagnostic tools to provide accurate measurement of equipment condition is an integral and essential part of the maintenance engineering function. Development in this area requires specialized knowledge and a significant increase in the skill levels of engineers, supervisors and tradesmen.

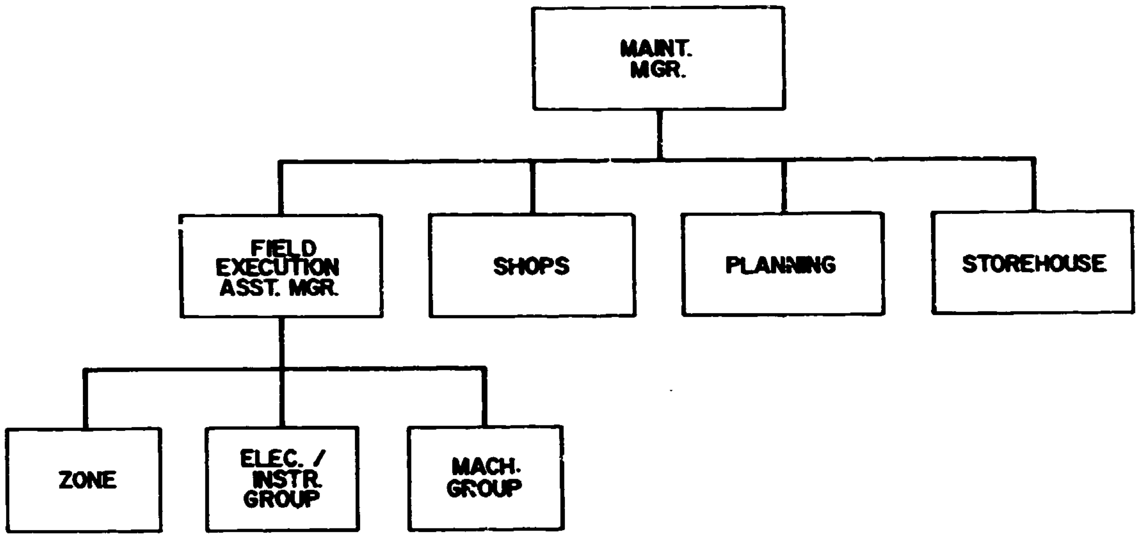

Figure 2.1 Maintenance Department Where Engineers are Placed in Different Locations

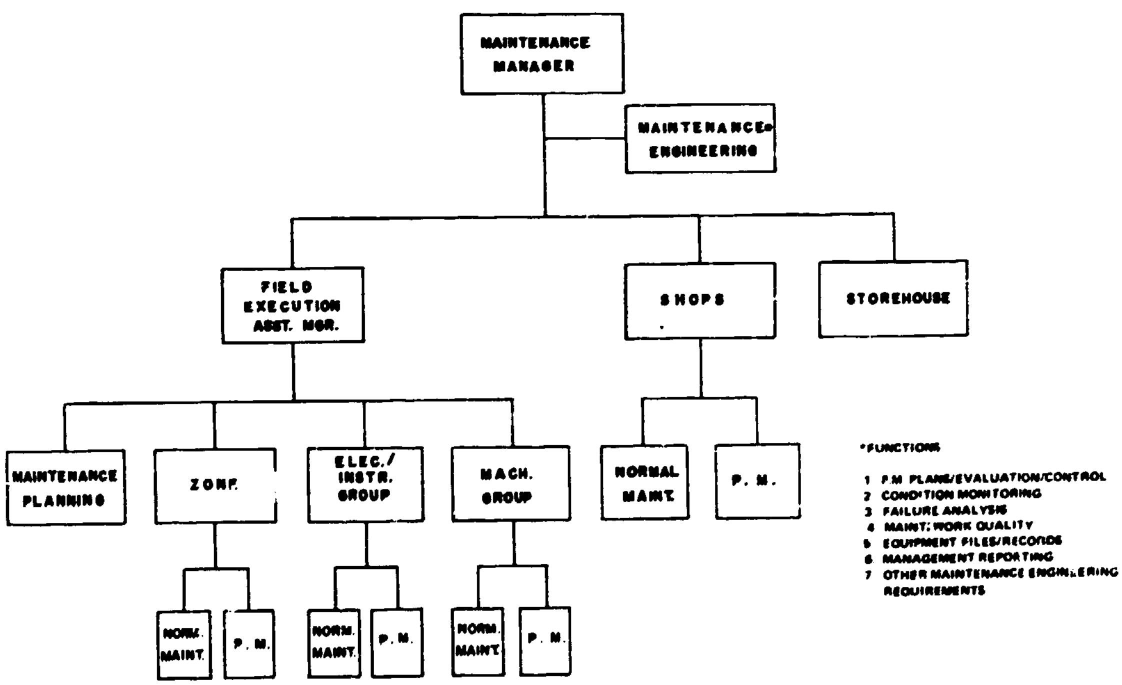

Figure 2.2 Maintenance Organization for Effective P. M.

2.2 PLANNING AND SCHEDULING

Planning and scheduling as applied to PM should provide answers to the following:

(a) *Planning the PM*

1. What to inspect (program)
2. What to inspect for (checklist)
3. How often to inspect (frequency)

(b) *Scheduling PM work*

1. When to inspect (schedules)
2. Which to inspect first (priorities)

2.2.1 Planning the PM program

There is no hard and fast rule on what to include in a PM program. But a good program will include most of the plant's physical property. As earlier discussed, the most appropriate approach for plants which are just starting to adopt a PM program would be to start modestly-gradually expanding PM coverage from the more valued equipment to the less valued equipment.

The ABC method for classifying equipment, shown in Table 2.1, is a very good basis for determining the extent of PM program. It is not unusual to find that only 5-15% of a plant's equipment comprise 60 to 70% of the operating income and that 60 to 70% of a plant's equipment are contributing only to 5 to 10% to the income. Therefore, in this case, by controlling only 15% of the equipment, 70% of the plant's income is assured. The A equipment are given the highest priority for PM work and C the last.

Table 2.1 The ABC Method for Classifying Equipment

Category	Description	Level of Performance Required
A	Critical to operation, outage unsafe and/ or costly due to interruption of production or affects product yield/ quality	95% service factor
B	Non-critical, outage primarily a matter of high mechanical expense	90% service factor
C	a) Idle equipment or b) Low cost and support equipment with no direct tie-in to general production schedule.	85% service factor

(a) *What to Inspect*

(1) Process equipment - furnaces, heat exchangers, piping, pumps, compressors, motors, stills, instruments.

(2) Safety equipment - vacuum and pressure relief valves, flame arrestors, breathing and emergency relief equipment.

(3) Utility equipment - boilers, electric generators, supply/storage/distribution systems for water/steam/air.

(4) Tanks and auxiliary equipment - storage tanks, pipelines, dikes, drains, gages and instruments.

(5) Plant buildings - shipping and storage areas, including transport equipment.

(6) Fire Protection Equipment - firewater system, extinguishers, foam installations, fire trucks, alarm system.

(b) *What to Inspect For (Checklist)*

The best source for a PM checklist is the service manual issued by the manufacturer. This may be adjusted by adding or subtracting items based on actual maintenance experience. In principle, a checklist itemizes for the inspector all the points to be checked on any one piece or type of equipment. It also provides spaces for dates and initials to show when an equipment was inspected and by whom. Checklists assure uniform and complete inspection regardless of who does the job. Figure 2.3 and 2.4 are examples of PM checklists.

(c) *How Often to Inspect (Frequency)*

The decision on how often to inspect probably has the most bearing on costs and savings on a PM program. Over-inspection is needless expense. Under-inspection results in more breakdowns. Good balance is needed to bring optimum savings. To come up with program inspection frequencies, a suggested way would be to come up with an initial frequency program and gradually refine this during implementation. The initial frequency program should consider:

(1) The equipment classification as discussed earlier. The A class equipment should get more frequent attention.

(2) Engineering analysis of each equipment from viewpoints of age and condition, severity of service, safety requirements, hours of operation, susceptibility to wear, susceptibility to losing adjustment.

(3) Equipment/material manufacturer's recommendations.

(d) *When to Inspect (Schedules)*

Schedules in a PM program are either:

(1) Routine - done at regular intervals.

(2) Periodic - done at prescribed intervals (normally on plant shutdown or turnaround).

(3) Contingent - done at indefinite intervals.

Schedules are generally of two types:

(1) Overall charts showing schedules of all pieces of equipment (usually by category).

(2) Individual cards for each piece of equipment.

P.M. CHECKLIST
(Pump/Motor; Pump/Turbine; Compressors)

Date ______________

APS No.3 SEC. 3100/800
2M - 01/03W - 02

CHECKLIST / EQUIPT. NUMBER	B-3201	B-3202	C-3201	P-3031 A	B	P-3101 A	B	P-3102	P-3201 A	B	P-3202 A	B	P-3203 A	B	P-3204 A	B	P-3205	P-3206 A	B	P-3207 A	B	P-3208 A	B	P-3209 A	B	C	P-3210 A	B	C	P-3211	P-3212 A	B	P-3213	P-3214		
1. Status of equipment (O, I, U, S)																																				
2. Hand rotate idle unit																																				
3. Check flushing oil/quench system																																				
4. Check steam tracing line																																				
5. Check packing /seal for leaks																																				
6. Check oil (gear & tube) condition																																				
7. Check cooling system																																				
8. Check bearing temperature																																				
9. Check vibration and noise levels																																				
10. Check operating temp./pressure																																				
11. Cleanliness																																				
Additional for Pump/Turbine Set																																				
12. Check governor linkages																																				
13. Check RPM																																				
14. Check steam leak																																				

Legend: O - Operating; I - idle; U - under repair; S - out of service - Obsolete/unusable
- if satisfactory; X - if not satisfactory; use space below for explanation

Remarks: ______________

Any suggestion to improve our P.M. ______________

Inspection conducted by: ______________

Figure 2.3 Sample PM Checklist Form for Pump, Motor, Turbine and Compressor

P.M. CHECKLIST

(Tank Agitators/Airfincoolers/Sootblowers)

Date ____________

SEC. 200/300/400/1900
IM-2W-02

CHECKLIST / EQUIPT. NUMBER	E-1901/05 E	W	E-1902 BE	" BW	" AE	" AW	E-206 E	" W	E-210/207 E	" W	E-205 -1	-2	-3	-4	E-304/306 E	" W	E-302 -1N	" -2N	E-302 -1	" -2	E-302 -1	" -2	" -3	" -4	E-308 -1	" -2	" -3	" -4	E-450 -E	" -W	E-406 -1	" -2	E-108 -1	" -2		
Tank Agitators/Air fin Coolers																																				
1. Status of equipment (O, I, U, S)																																				
2. Check free turn of idle fan by hand																																				
3. Check lubrication of driving units																																				
4. Check oil level on gear reducer																																				
5. Check bearing temperature																																				
6. Check vibration and noise																																				
7. Cleanliness																																				
Sootblowers																																				
1. Check oil level in gear reducer																																				
2. Check lubrication of driving unit																																				
3. Check packing for leaks																																				
4. Check throttle valve																																				
5. Check chain for grease / position																																				

Legend: O - operating; I - idle; U - under repair; S - out of service - Obsolete/unusable
- if satisfactory; X - if not satisfactory; use space below for explanation

Remarks: ______________________________

Any suggestion to improve our P.M. ____________ Inspection conducted by: ____________

Figure 2.4 Sample PM Checklist Form for Tank Agitator, Aircooler, Sootblower

It has been found to be convenient to adopt both types. Use the overall charts for control and the individual cards to ensure proper inspection and recording. Figures 2.3 and 2.4 show examples of the individual cards. Figure 2.5 is an example of a portion of the overall charts.

Another useful and very effective document schedule is the PM Master Chart, an example of which is shown in Figure 2.6.

As in any other maintenance work, planning and scheduling for PM must include the following:

(1) A work order priority system for all the PM work.

(2) A standard on each work order prior to accomplishment task.

ROTATING EQUIPMENT SCHEDULE
(PROCESS AREA)

APS No. 2
2M-01/03-01 (Twice a Month, First and Third Week, Monday)

B-2101	A	-	APS No. 2 FDF of F-2101
B-2101	B	-	Ditto
P-2101	A	-	Crude Feed
P-2101	B	-	Ditto
P-2102	A	-	APS Reflux
P-2102	B	-	Ditto
P-2103	A	-	APS Distillate
P-2103	B	-	Ditto
P-2104	A	-	APS SS Product
P-2104	B	-	Ditto
P-2105	A	-	APS Bottoms
P-2105	B	-	Ditto
P-2106	A	-	Caustic/Inhibitor Injection
P-2106	B	-	Ditto
P-2107		-	APS Sour Water
P-2108		-	Chemical Feed Pump
P-2109		-	Demulsifier
P-2110		-	Crude Desalter Process Water Pump
P-2111	A	-	Crude Desalter
P-2111	B	-	Ditto
P-2113		-	APS No. 2 Pumparound
C-2201	A	-	CHF Gas Compressor
C-2201	B	-	Ditto
C-2301		-	PWF Gas Compressor
B-2301		-	PWF FDF
B-2302		-	Ditto
B-2303		-	Ditto
P-2301	A	-	Steam Cond. H_2O
P-2301	B	-	Ditto
P-2414	A	-	Kero Product
P-2414	B	-	Kero Product
P-3001	A	-	Deodorizer Feed
P-3001	B	-	Deodorizer Feed
P-2302		-	Water Injection
P-2302	A	-	
P-2303	B	-	
P-2304	A	-	
P-2304	B	-	
P-2401	A	-	Crude Debut Reflux
P-2401	B	-	Ditto
P-2402	A	-	Charge Pump
P-2402	B	-	Ditto
P-2403	A	-	Napth/Kero Split Reflux
P-2403	B	-	Ditto
P-2404	A	-	APS No. 2 PWF Charge
P-2404	B	-	Ditto
P-2405	A	-	LVN Product
P-2405	B	-	Ditto
P-2406	A	-	Deisopent. Reflux
P-2406	B	-	Ditto
P-2407	A	-	Isopentane Product
P-2407	B	-	Ditto
P-2408	A	-	Deethanizer Reflux
P-2408	B	-	Ditto
P-2409	A	-	Lean Oil
P-2409	B	-	Ditto
P-2410	A	-	LPG/PWF Split Reflux
P-2410	B	-	Ditto
P-2411	A	-	LPG Product
P-2411	B	-	Ditto
P-2412	A	-	Hot Oil Pump
P-2412	B	-	Ditto
P-2413		-	HVN Product

Figure 2.5 Sample Portion of Overall Chart for PM Schedule

(3) A day's planned work for each craftsman at least a day in advance.

(4) An up-to-date master plan for all PM programs by agreement category indicating planned date, duration, and warning.

(5) The master plan distributed or reviewed weekly by plant supervision or the MES.

(6) The master plan updated as to progress weekly or more often.

(7) The " bread and butter" PM work accomplished on schedule and not delayed due to a large job getting preferential treatment.

(8) PM work completed on time in line with planned dates.

1st week	2nd Week	3rd Week	4th Week
I. R/E			
1. Process			
Inspection of R/E using check-list, updating of charts 2M-01/03-01 to 05 1M-02-01 to 01	Vibration readings of 2M-01/03-01 to 05 updating of charts (note with 1 C/P)	Lubrication of A/F coolers based on 6 mos. interval schedule (note: with representative)	Selective vibration readings high vib. level), SPM, change oil of pumps and others.
2. Utilities/CM&S			
Same as above Updating of charts.	-do- (with 1 C/P)	-do- (with 1 C/P)	-do- (with 1 C/P)
3. Airconditioning centralized A/C (2 units/day)	Centralized A/C 2 units per day	Window type A/C or other refrig. equipt.	Window type A/C or other refrig. equipt.
(with 1 CP)	(with 1 CP)	(with 1 C/P)	(with 1 C/P)
4. Service Vehicles			
S-1 to S-5 + S-21	S-6 to S-10	S-11 to S-15	S-16 to S-20
5. Pump Switching Process area only)		Schedule pump switching	
6. Monthly Report (1st or 2nd Week)			
PM Communications			
a) Memo PM findings to area supervisors.	Memo PM findings to area supervisors.	Memo PM findings to area supervisors.	Memo PM findings to area supervisors

Figure 2.6 Sample of a PM Master Schedule

2.3 MATERIALS AND COST CONTROL

2.3.1 The Work Order System

As in any other maintenance work, the basic tool used in material and cost control in PM is the Work Order System (see Appendix II). Basically, the work order system provides the mechanics for initiation, authorization and control of work. Labor, materials, and duration are pre-estimated prior to approval, with actual data reflected after completion of work. The essential elements of a work system are:

(a) A standardized work order form. Some plants use a two-form system: One form for non-routine, special or blanket jobs and a simpler form for routine items which are in turn covered under a blanket work order form. This system is the type described in Appendix II.

(b) A work order system written procedure.

(c) A single person responsible for the control of all work orders.

(d) A confined group of staff and supervision who have authorization to request maintenance services.

(e) All work classified control-wise as to nature e.g., equipment repairs, yard work, capital work, etc.

(f) Restrictions more severe for approval of "Rube Goldbergs" jobs as contrasted to "normal" repairs.

(g) A reasonable "date required" on each work order and do not permit "A.S.A.P." (i.e., as soon as possible), "at once", etc.

(h) A written work order in evidence prior to starting a job for all work except genuine "emergency work".

2.3.2 Work Measurement

For effective cost control, the work order system must be supplemented by a work measurement system and a cost budgeting/review system. A typical work measurement system will include:

(a) Labor standards covering all recurring jobs
(b) Labor standards covering all non-recurring jobs
(c) A labor productivity report
(d) A productivity incentive system

Standards may be based on either time-and-motion study results, definitive estimates or historical data. Actual time standards used in an oil refinery plant are shown in Figures 2.7 and 2.8.

Other than skill-related productivity factors, maintenance labor productivity is oftentimes lowered by certain common delays such as:

(a) Waiting for orders in the morning and at noon.
(b) Looking for the foreman to find out what the next job is.
(c) Visiting the site to find out what must be done.
(d) Unnecessary trips to stores.
(e) Return trips for tools.
(f) Searching for the foreman in order to get a stores - withdrawal authorization.
(g) Unnecessary trips back to the shop when another job is in the vicinity of one just completed.
(h) Dispatching three men to a job which two could very easily do.

JOB STANDARD NO. RE - 01

JOB: INSTALLATION OF MACHINE

DATE SET : 01/15/75

LATEST REV. NO. : 03

DATE REVISED :01/01/84

		A	B	C	D	E
	JOB ELEMENTS	NO. OF MEN	NO. OF OCCUR.	TIME PER OCCUR.	TOTAL TIME	TOTAL M H
				(minutes)	(minutes)	
1	Remove skid bolts 3/4	1	4	1.1	4.4	0.07
2	Hitch machine (12,000 lbs. max.)	2	1	21.3	21.3	0.71
3	Position crane to load	1	1	5.0	6.0	0.10
4	Raise machine move to position and release	2	1	7.0	7.0	0.23
5	Install anchor bolts to machine 3/4"	1	4	1.8	7.2	0.12
6	Align machine to anchor holes	2	1	25.7	25.7	0.86
7	Assemble steel base to anchor holes	1	1	0.5	2.0	0.03
8	Grout in 4 anchor bolt holes	1	1	22.0	22.0	0.37
9	Level machine	2	1	41.3	41.3	1.38
10	Pick-up/load skids on hand-truck (200 lbs.)	2	2	2.0	4.0	0.13
11	Take skids to drump	2	7	0.5	3.5	0.12
12	Unload skids	2	2	2.0	4.0	0.13
	Direct job				148.4	4.25
	Auxiliary time				70.0	0.95
	Sub total				218.4	5.20
	Personnel time at 15%				32.7	0.78
	TOTAL				251.1	5.98
	HOURS/MH				4.2	5.98

Figure 2.7 Job Standards for the Installation of a Machine

(i) Waiting for workers from other crafts to start or finish.
(j) Looking for the job site.
(k) Losing time because of countermanded orders.
(l) Waiting for production to hand over a machine.
(m) Trying to make up for insufficient information on blueprints.
(n) Finding materials which are on order but not available.

A continuous watch on activities like those mentioned above will go a long way towards improving labor productivity.

JOB STANDARD NO. EI - 01

JOB: ELECTRICAL CONNECTIONS FOR MACHINE TYPE 1

DATE SET : 02/12/75

LATEST REV. NO. : 04

DATE REVISED : 03/12/77

	JOB ELEMENTS	A NO. OF MEN	B NO. OF OCCUR.	C TIME PER OCCUR. (minutes)	D TOTAL TIME (minutes)	E TOTAL M H
1	Machine cut conduit 3/4	1	8	1.1	8.8	0.15
2	Machine thread conduit 3/4	1	16	1.9	30.4	0.51
3	Bend pipe conduit 3/4	1	4	4.7	18.8	0.31
4	Knock outs (hand) 1/2	1	7	0.5	3.5	0.06
5	Knock out (punch) 3/4	1	8	3.9	31.2	0.52
6	Mount pull boxes (on steel)	2	2	12.1	24.2	0.81
7	Mount 60 amp. switch	1	1	6 9	6.9	0.12
8	Conduit joints 3/4	1	10	0.9	9.0	0.15
9	Lock nuts & adolets	1	24	0.4	9.6	0.16
10	Sealtite 3 feet	1	1	8.9	8.9	0.15
11	Connectors (angle)	1	2	2.9	5.8	0.09
12	Pull wire	2	40	0.5	20.0	0.67
13	Connectors	1	6	3.9	23.4	0.39
	Direct job time				200.5	4.09
	Auxiliary time				220.0	4.48
	Sub total				420.5	8.57
	Personal time at 15%				63.0	1.28
	TOTAL				483.0	9.85
	HOURS/MH				8.1	9.85

Figures 2.8 Job Standards for Installing Electrical Connection on a Machine

2.4 MOTIVATION OF MAINTENANCE PERSONNEL

Maintenance managers influence the later careers of staff who continue to work in the same organization in their periodic performance evaluations. At the same time, the managers do not usually have full administrative authority for raises or terminations. On complex technical tasks such as PM work, a good many people may be indispensable, either because their expertise is irreplaceable, or because PM schedules have to be met and there is insufficient time to replace them. In these circumstances, the maintenance manager must do the following to enhance the sources of motivation:

(a) *Create a sense of professionalism.*

There must be a commitment to the standards for task and personnel behavior set by professional peers in other maintenance functions. The manager must share the same standards so he can act as a natural pace-setter.

(b) *Provide the basic need to exercise competence.*

Giving people the opportunity to use existing knowledge, to develop ideas, and to leave something new, provides a sense of competence and satisfaction which in turn strengthens motivation.

When people are struggling with a job for which they are not sufficiently qualified, it is difficult for them to feel confident or competent. When people are in idle waiting period, which creates boredom, when they are so overworked that they do not have time to do anything well, or when they are uncertain about what is expected of them, then their motivation also drops. A workflow that is even in volume or only slightly exceeds present capabilities is therefore ideal. In other words, the opportunity to exercise competence requires a fairly precise definition of the job, a good match with the individual's capabilities, and a reasonable workload.

(c) *Satisfy the need for approval and appreciation.*

Maintenance managers must be sensitive to and responsive in working with maintenance personnel. Workers and engineers are usually pleased to know that the manager values and appreciates both their technical and personal abilities. A genuine yet discriminating approval and encouragement will free prople's anxiety over acceptance of their work. This enables them to go on performing as well or better even when they are tired. Ability to express appreciation articulately and non-verbally is a key factor in creating an encouraging climate for subordinates.

Not too many maintenance managers have the ability to provide clean, realistic and positive feedback on subordinates' work.

Most managers would tend to emphasize the negative and are embarrased at either giving or receiving praise. A conscious effort must be made to overcome this.

Finally, a manager must learn the "culture" of his organization. In expressing approval, he must find the "language" that sounds natural both to the organization and to him personally.

(d) *Satisfy long term career self-interest.*

Engineers are attracted to maintenance work when the manager's reputation and past success is such that they hope to enhance their own professional reputation through both the high quality of work they expect to accomplish under his direction and their association in a job like PM work which they hope to be a major success.

Similarly, people who are looking for career growth and financial rewards in the maintenance organization tend to be keenly aware of the effects of present performance on future assignments. To create optimum balance between personal aspiration and job needs, the manager must find time to discuss with his people their career plans and to listen to what they have to say about them. People are likely to be motivated as much by the knowledge that their manager is making an effort to understand and take account of their interests as they are by any actual opportunities for growth that managers offer them.

(e) *Establish proper working relationships*

Managers must avoid damaging people's sense of confidence and competence even to the extent of giving recognition for successful efforts. This is a basic element in encouraging creativity - the highest level of motivation.

Another key element in establishing proper working relationship is the proper use of leadership style – the manager's ability to distinguish between the "idea-generating" and "decision-making" periods as they occur and alternate in his organization: to determine how much overlap he wishes to encourage between them; and find ways of relating to subordinates according to their engagement in either of these phases. The manager needs to orchestrate the two appropriately. For while being authoritarian when ideas are needed certainly skills creativity, being appreciative and acceptant when a major decision is needed can depress progress on undertakings. The manager's own personal behavior is a very important source of motivation.

Reactions to the statements in Table 2.2 can provide an insight into one's attitudes and motivations.

Table 2.2 A Sample Test for Managerial Style

1. Most people dislike work and will avoid it if they can. (Agree or disagree).
2. Most people must be coerced, controlled, and threatened to get them to put forth adequate effort in achieving organization objectives. (Agree or disagree).
3. Most people prefer to be directed and wish to avoid responsibility. (Agree or disagree).
4. Most people have relatively little ambition and want security above all. (Agree or disagree).
5. Expenditure of physical and mental effort in work is as natural as play or rest. (Agree or disagree).
6. Man will exercise self-direction and self-control in the service of objectives to which he is committed. (Agree or disagree).
7. Most people can learn, under proper conditions, not only to accept but to seek responsibility. (Agree or disagree).
8. The capacity to exercise imagination, ingenuity, and creativity in the solution of problems is widely, not narrowly, distributed in the population. (Agree or disagree).
9. Under conditions of modern industrial life, the intellectual potentials of the average person are only partially utiiized. (Agree or disagree).

Agreement with statements 1 to 4 indicate the philosophy of a manager who tends to use authoritarian methods. Statements 5 to 10 embody the philosophy of a manager who believes in participative practices. People will not work effectively for dictators. They will work effectively if they feel they participate in decisions.

2.5 CONTROL AND EVALUATION OF PM

In preventive maintenance control, the first step to take is the definition of responsibilities within both the Maintenance Department and Production Department. Effective control and evaluation of PM require four elements:

(a) **Generation of proper reports.**

As applied to PM, reports to cover the various management functions should include those listed in Table 2.3.

Table 2.3 Reports at Various Phases of the PM Program

Phase	Reports	User
Planning and Scheduling	Equipment Records PM Schedules PM Labor/Material Forecast PM Feedback Reports	Supervisors Superintendents
Work Assignments	Work Orders Manpower/Material/ Equipment Allocation	Supervisors Superintendents
Work Measurement	Cost by equipment and by category Labor Usage Materials Usage	Supervisors Superintendents
Evaluation and Control	Status Reports Efficiency Reports Backlog Reports Failure Trends Failure Analysis Cost Trends	Superintendents Managers

(b) **Periodic review of PM with operating department manager**

Ideally, aside from weekly review of failures, it should be made a policy to conduct a semi-annual or quarterly review of the entire PM program by the manager of each department. Basically, the review should consist of:

(1) Thorough review of all records by the production department manager including individual PM cards and unit equipment records.
(2) Review of repair costs.
(3) Review of "production lost" because of maintenance work or breakdowns.
(4) Review of backlog of repair work and readjustment or priorities as needed.
(5) Review of anticipated or scheduled "shutdowns" and "overhauls".

(c) **Review of Reports**

The following is what to look for in reviewing monthly reports:

(1) *Number of inspections incomplete.* If there are several outstanding inspections, this may indicate a lack of priority given to preventive maintenance or a possible need for assistance by the maintenance department to make the inspection,

especially for "unattended" units. As a general rule the incomplete inspections should be maximum of only 10 per cent of the inspections scheduled.

(2) *Number of jobs resulting.* Since the inspection is the backbone of any preventive maintenance program, the number of jobs resulting should indicate how good the inspections are. In general, the number of jobs resulting should be 20 to 30 per cent of the inspection completed. This is referred to as the "R" factor. If the frequency of inspections is correct, the "R" factor for a particular plant should be fairly constant. If there are drastic fluctuations in the jobs resulting, there may be a need to investigate the reason for this. The jobs resulting from the inspections should be completed within the current month.

(3) *Jobs incomplete.* There should be no jobs incomplete for any particular month. If there are, the following conditions may exist:

- o Repair work is being reported too late in the month to be completed.
- o If the jobs resulting are being reported early and still incomplete by the end of the month, then there may be trouble with the planning and scheduling program.
- o Jobs resulting are not getting their deserved priority; jobs resulting should be given priority I or II classification.

(4) *Number of breakdowns.* Over a period of time this figure should be a decreasing number. If an increase is noted, immediate investigation is compulsory. If the number of breakdowns is too low to be realistic, then it is apparent that they are not being reported. All breakdowns should be reported.

(5) *Failure analysis.* Look for the following items:

- o Check the amount of hours lost and production lost as compared to previous months.
- o Are repetitive breakdowns occuring? If so, are they being analyzed and is corrective action being planned?
- o Are descriptions of breakdowns adequate for future reference?
- o Each breakdown should have an entry in the corrective maintenance column, either a full description of corrective maintenance required or the word "none".
- o Are the corrective maintenance suggestions being followed up? Job sheets should be written by the end of the current month.

(d) Analytical Evaluation

This involves, basically, the relationships among:

(1) the number of inspections completed
(2) the number of jobs resulting
(3) and the number of breakdowns

Since the number of inspections completed directly affects the number of jobs resulting, it is desirable to have a fairly constant number of inspections completed so that the number of jobs resulting will not change drastically from month to month. The number of breakdowns decreases as the number of jobs resulting increases. This inverse proportion is the objective of PM. The following formulas are commonly used for evaluating PM programs:

$$\frac{\text{Inspections incomplete}}{\text{Inspections scheduled}} \times 100 = 10 \text{ percent}$$

$$\frac{\text{Jobs resulting}}{\text{Inspections completed}} \times 100 = 20 \text{ to } 30 \text{ percent}$$

The effectiveness of preventive maintenance is reflected in the ability to plan and schedule maintenance work. The scheduling performance is dependent upon the effectiveness of the production schedule, on the preventive maintenance program, and on planning. The production schedule controls the down time of equipment, which permits work to be forecast. A good preventive maintenance program will locate and correct equipment failures before a breakdown occurs. The planning effectiveness will be reflected in the scheduling performance since the estimated labor requirements constitute the basis for the weekly forecast. Scheduling performance is calculated as in the accompanying formula.

$$\frac{\text{Hours worked as forecast jobs}}{\text{Total hours worked}} \times 100 = \text{Percentage of Performance}$$

When the percentage of performance is plotted on a graph, it indicates either an increasing or a decreasing trend. The trend sho' ' be increasing or should be stabilized above 80 per cent. If it is not, then an i stigation should be made to see if it is being affected by interruptions in the schedules that can be attributed to breakdowns.

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PART II

BASICS OF PREVENTIVE MAINTENANCE

Maintainability, Lifecycle Costing and Failure Analysis

3.1 MAINTAINABILITY AS A FACTOR IN EQUIPMENT DESIGN

In equipment design, maintainability should be given equal importance as technical performance, reliability, quality and safety. It is not unusual to find several junked but still serviceable equipment around because maintainability was not given due consideration at the design stage. Design features related to maintainability must ensure that the equipment would last up to its expected life with normal operation and maintenance.

The prevention of excessive maintenance costs begins with design. Maintenance costs are affected by such things as:

a. Equipment standardization
b. Parts interchangeability
c. Service accessibility
d. Selection of materials known to perform well in the local environment

While these factors are very familiar to designers, there is a need for a clear guide to ensure that they are actually incorporated in the design. This should also be useful in analyzing the maintainability of equipment to be purchased, and to some extent, of existing installations as well. Figure 3.1 provides such a guide. It outlines the essential tasks to be undertaken and the corresponding major outputs in considering the maintainability factor in the design process. This guide should interface with other steps in design.

The first step is to conduct a maintainability analysis, a process of translating the following information into detailed qualitative and quantitative design criteria:

a. Preliminary equipment design data
b. Information on other factors/activities that affect equipment design
c. Information and constraints in procurement terms.

From these information and criteria, an effective and economical maintenance concept should be formulated. On the basis of this concept, the detailed maintenance plan can be made. This plan includes enough information on each type of scheduled maintenance activity such as:

a. Depth and frequency of maintenance requirements
b. Facilities, support equipment and tools required
c. Needed maintenance skills.

In establishing maintainability design criteria, the general maintainability guidelines shown in Table 3.1 as well as the more detailed checklist in Appendix IV may be used as reference.

Any design changes made should be reflected in the maintainability analysis. In many cases, it is more cost effective to adopt features which reduce repair time than those that decrease the frequency of conducting repairs.

Design reviews should be conducted either formally or informally to ensure that the design meets the maintainability requirements.

TASKS	MAJOR OUTPUTS
PERFORM MAINTAINABILITY ANALYSIS	ESTABLISH QUANTITATIVE AND QUALITATIVE MAINTAINABILITY REQUIREMENTS
PREPARE INPUTS TO MAINTENANCE CONCEPT PLAN	DETAILED MAINTENANCE CONCEPT FOR EQUIPMENT DESIGN
ESTABLISH MAINTAINABILITY DESIGN CRITERIA	DETAILED MAINTAINABILITY DESIGN CRITERIA AND REQUIREMENTS
PERFORM DESIGN TRADEOFFS	ANY DESIGN CHANGES
PREDICT MAINTAINABILITY PARAMETER VALUES	PARAMETER VALUES TO BE USED FOR EVALUATION OF PROPOSED DESIGNS
INCORPORATE MAINTAINABILITY REQUIREMENTS INCLUDING SUBCONTRACT & VENDOR SPECS.	ASSURANCE OF SUBCONTRACTOR AND VENDOR COMPLIANCE WITH ALL MAINTAINABILITY REQUIREMENTS
INTEGRATE REQUIRED ASSOCIATED EQUIPMENT	QUANTITATIVE REQUIREMENTS FOR CONTRACT SPECIFICATIONS
PARTICIPATE IN DESIGN REVIEWS	EFFECTS OF DESIGN CHANGES ON MAINTAINABILITY DESIGN REQUIREMENTS
ESTABLISH SYSTEM FOR DATA COLLECTION AND ANALYSIS	DATA COLLECTION FOR PREDICTION AND DEMONSTRATION OF EQUIPMENT
DEMONSTRATE MAINTAINABILITY REQUIREMENTS	VERIFICATION FOR ACHIEVING MAINTAINABILITY DESIGN REQUIREMENTS
REPORT ON STATUS	ACCOUNTING OF THE REQUIRED, ALLOCATED, PREDICTED AND OBSERVED VALUES OF MAINTAINABILITY REQUIREMENTS

Figure 3.1 Main Tasks and Outputs of Equipment Maintainability Design

Source : Reference 3

A data collection and analysis system should be prepared, to be used in:

a. making predictions on equipment maintainability during the design stage; and

b. evaluation of equipment demonstration test results.

Once the equipment has been designed and built, a maintainability demonstration test should be conducted either in an operational or a simulated environment. This is integrated with other testing requirements for prototype technical performance, production and acceptance testing. Maintainability demonstration test procedures outlined in Reference 4 may be followed. The conduct of the demonstration test should include the following (Reference 2);

a. Demonstration conditions:
   1. Quantitative maintainability requirements
   2. Maintenance concept
   3. Maintenance demonstration environment
   4. Level (s) of maintenance to be demonstrated
   5. Demonstration sites
   6. Facility requirements
   7. Participating agencies
   8. Mode of operation for the demonstration tests
   9. Items to be subjected to demonstration tests

b. Simulation of faults or failures. Fault simulation is usually done by introducing faulty parts and deliberate misalignment. Failure modes and simulation activities should be decided by the designer and the user such that the equipment will not be damaged during the test.

As earlier mentioned, the demonstration test data would be used to verify the parameter values established in the maintainability analysis and the maintainability predictions. These data should include the following:

a. All maintainability test data collected
b. Factors that influence the data
c. Analysis of data
d. Results of the demonstration
e. Assessment of qualitative factors
f. Deficiencies
g. Recommendations for:
   1. Correcting deficiencies
   2. Suggesting improvements
h. Results of retest, if available.

3.2 THE LIFE CYCLE COSTING CONCEPT

It is commonplace for many industries to purchase equipment based on lowest first cost. Specifications are sent to equipment suppliers and the lowest bidder who meets the specs wins the job, with no consideration for recurring costs during operation of the equipment.

A better basis for purchase decision is the life cycle cost (LCC). It refers to the total cost associated with the acquisition and use of an equipment throughout its lifetime. Operational, maintenance and energy costs are considered in the purchase decision.

The following is a list of factors considered for the entire life of the equipment:

a. Initial costs - including freight and installation
b. Training costs - for equipment operators
c. Energy costs

Table 3.1 General Maintainability Design Guidelines

Source: Reference 3

Maintainability Design Criteria	Specific Considerations
1. Reduce complexity of maintenance by:	a. Providing adequate accessibility work clearance b. Providing for interchangeability of like components, materials, parts within the equipment c. Utilizing standard parts and items when available d. Limiting the number and variety of tools, accessories and support equipment e. Ensuring compatibility among equipment and facilities
2. Reduce the need for and frequency of design-dictated maintenance activities by using:	a. Fail-safe features b. Components which require little or no preventive maintenance c. Tolerances which allow for use and wear throughout life d. Adequate corrosion prevention and/or control features
3. Reduce maintenance downtime by designing for:	a. Rapid and positive detection of equipment malfunction or performance degradation b. Rapid and complete preparation to begin maintenance tasks c. Rapid and positive localization of malfunctions to the repair level of which skills, spares, and test equipment are planned d. Ease of fault correction e. Rapid and positive adjustment and calibration f. Rapid and positive verification of correction
4. Reduce design-dictated maintenance support costs by reducing:	a. The need for specialized maintenance tools, support equipment and facilities b. The requirements for depot or factory maintenance, consistent with system/cost effectiveness c. The need for extensive maintenance technical data.
5. Limit maintenance personnel requirements by applying:	a. Identification and accessibility of parts, test points, adjustments and corrections b. Easy handling, mobility, transportability and storeability c. Logically sequenced maintenance tasks d. A feasible range of relevant personnel physiological parameters
6. Reduce the potential for maintenance error by designing to eliminate	a. The possibility of incorrect connection, assembly, and installation b. Awkward and tedious maintenance tasks c. Ambiguity in maintenance labeling coding, and required technical documentation

d. Operation and maintenance costs - labor, parts, technical service
e. Disposal costs at the end of life and/or salvage value
f. Useful life of the equipment
g. Escalation rates - estimated inflation rates to calculate future costs (rates may vary for each cost item)
h. Discount rate - the rate used in computing the present value of all costs and benefits for the entire life.

The last two factors are used in adjusting the cost items to the same reference time in which the total costs are compared. LCC analysis may use Net Present Value (NPV) and Internal Rate of Return (IRR) methods of evaluation.

In estimating maintenance costs, a level of repair (LOR) must be determined for each component or assembly. LOR sets the threshold level for repairs beyond which replacement is resorted to. Thus, repair and replacement cost components of maintenance can be estimated. The elements which are considered in determining LOR include the following (Reference 2):

a. Number and geographical/distribution of using locations
b. Replacement parts
    1. Procurement
    2. Storage
    3. Transportation
    4. Handling
c. Repair facilities
d. Tools and test equipment
e. Labor
f. Records and administration

Life cycle costing is useful not only in making purchase decisions between different equipment sources but also against other means of acquisition, namely, leasing and rental.

3.3 FAILURE ANALYSIS

Analysis of equipment breakdown is essential to determine the cause of the failure so as to prevent it from recurring. Correct analysis can lead to improved safety, better materials or methods and better service life – with attendant higher production rates. Failure analysis is one area of preventive maintenance which can show appreciable monetary savings to management.

The types of failure data for analysis are:

a. Overall failure rates
b. Failure rates on individual failure modes. Some important categories of failure modes are:
    1. condition
    2. performance
    3. safety
    4. detection
c. Variation of failure rates with time
d. Repair times

In the failure category based on condition, the failure mode can be exemplified by a faulty seal on a pump or by a defective gearbox. It is this category that is normally used in preventive maintenance.

Failures classified by performance are shown by a pump's inability to give the specified head or by a heat exchanger not providing the required heat transfer. The safety category makes a distinction between fail-safe and fail-danger types of failure. The detection classification can be a revealed or unrevealed failure.

The sources of failure data are the equipment literature, data banks or within the works. One data is the Systems Reliability Service in the U.K. It has an Event Data Store of basic faults, failure rates and repair times.

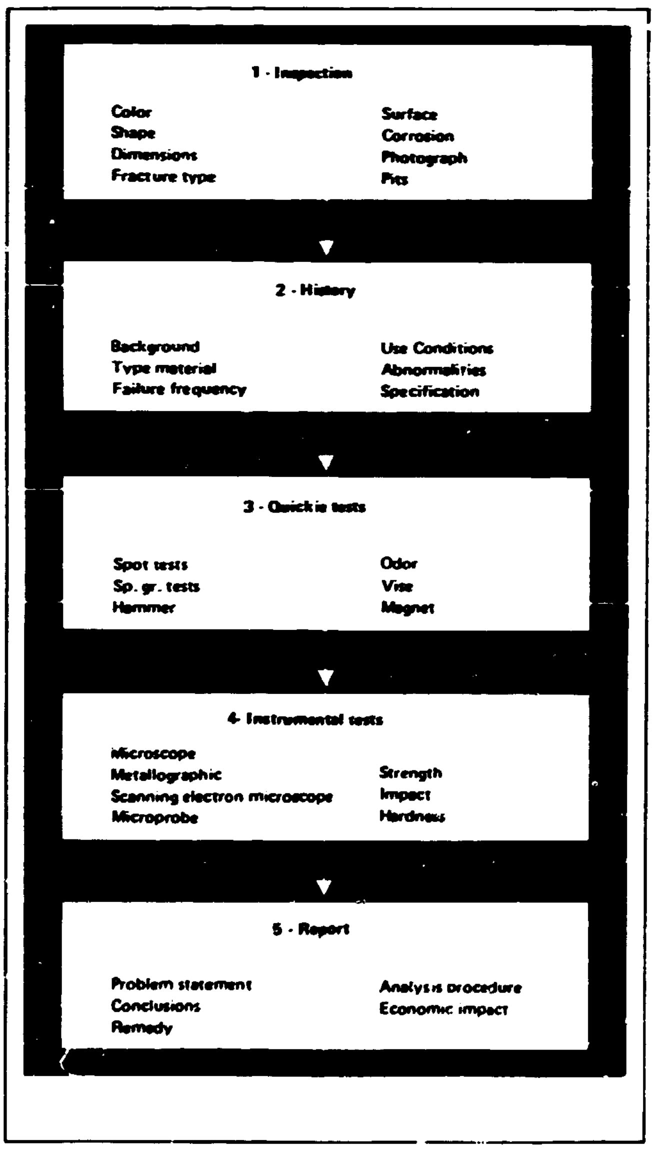
Collection of data within the plant must be designed appropriately. Failures of plant equipment should be recorded and investigated so that they can be analyzed and acted upon.

3.3.2 Diagnostic Procedure

A diagnostic procedure for data collection and analysis of failure is shown in Figure 3.2. The first stage is inspection which includes observations of color, corrosion products, presence of foreign material, dimensions, fracture characteristics, surface roughness and other phenomena. The second stage is the investigation of the history of the component or equipment involved.

Table 3.2 Diagnostic Procedure

Source: Reference 5



After inspection and history investigation, diagnosis is conducted. Diagnostic procedures for quick analysis are available. A more accurate analysis is done with the use of appropriate instruments. Condition monitoring techniques and instruments are discussed in Chapter 4. The final step is the preparation of the report which serves as the formal basis for maintenance works on the equipment.

The data also serve as inputs for reliability calculations which are conducted in large installations.

3.4 USE OF FAULT TREE DIAGRAM

3.4.1 Description

The graphical methods used in the assessment of failures and hazards include (1) a full unsteady-state model, (2) fault tree, (3) event tree, and (4) cause consequence diagram. The fault tree is the most widely used method and will be substantively described here.

The full unsteady-state model puts together the state of continuous variables in a continuum and is not made discrete, preserves the time delay and time order of events, including repairs.

An event tree starts with a bottom event, which is usually a fault event and is developed upwards to obtain the possible consequence events. A cause-consequence diagram starts with a critical event, which is normally a fault or deviation event and is developed in both directions to obtain both the cause events and the consequence events. These methods are discussed in Reference 6.

A fault tree starts with a top event, which is a fault or undesirable event and is developed downwards to obtain the possible main cause events. Figure 3.3 shows the symbols used in the construction of a fault tree diagram. Its application for analyzing the possible causes of the overheating of a motor is illustrated in Figure 3.4. The fault tree diagram for the explosion of a compressed air tank is shown in Figure 3.5.

The advantages of using fault tree analysis are:

(a) It leads to the identification of the causes of failure;
(b) Points out the aspects of the system which are important with respect to the failure involved;
(c) Allows the analyst to concentrate on one particular system failure at a time;
(d) In its graphical form, it gives a quick and systematic grasp of the sequence of causes which lead to failure;
(e) It provides the analyst a genuine insight into system behavior;
(f) It provides options for qualitative or quantitative system reliability analysis.

Developments in the fault tree methodology are described in Reference 7. The basic steps in fault tree analysis are:

(a) System definition
(b) Fault tree construction
(c) Qualitative evaluation
(d) Quantitative evaluation

System definition is the most difficult part of the analysis. Physical boundaries need to be drawn carefully and system interrelationships must be thoroughly understood.

A fault tree deals with only one top event. Thus, for a comprehensive analysis of failures and hazards, a fault tree must be constructed for all significant events.

The fault tree draws attention to features which should be considered in design. It also brings out unrevealed faults which would require periodic inspection. Some groups of faults may have one common cause of failure such as dirt in Figure 3.5 This should be given more attention in preventive maintenance work.

The possibility of the occurence of the top event failure can be calculated using the fault tree if probabilities of the sub-events are estimated. If necessary, a Monte Carlo simulation can be done to generate probability values for the primary failures, and the probability of the top event can be evaluated using these values.

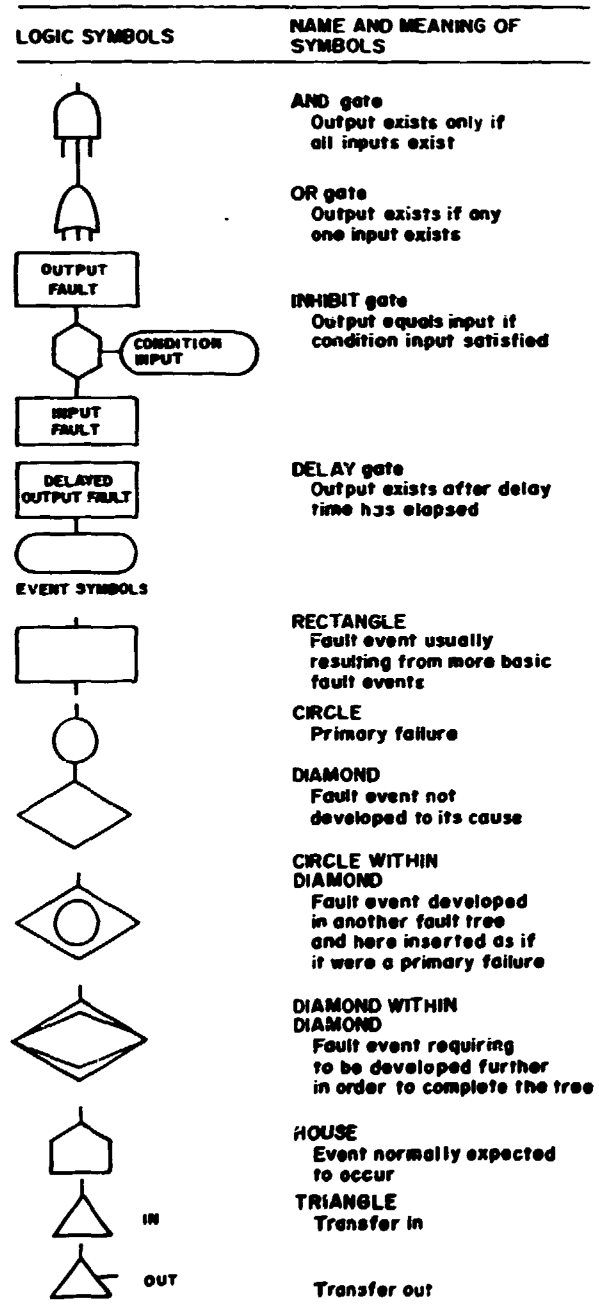


Figure 3.3 Fault Tree Logic and Event Symbols
Source: Reference 6

3.4.2 Minimum Cut Sets

A powerful means of analyzing a fault tree is to obtain minimum cut sets. A cut set of primary failures or undeveloped faults which can give rise to the top event. A minimum cut set is the smallest possible set, i.e., it does not contain another cut set within itself.

To illustrate the use of this method, let us use Figure 3.4 to analyze the overheating of a motor. The data inputs and gates are tabulated as follows:

Gate	Gate Type	No. of Inputs	Input	Code No.
A	OR	2	1	3
B	AND	2	C	2
C	OR	2	4	3

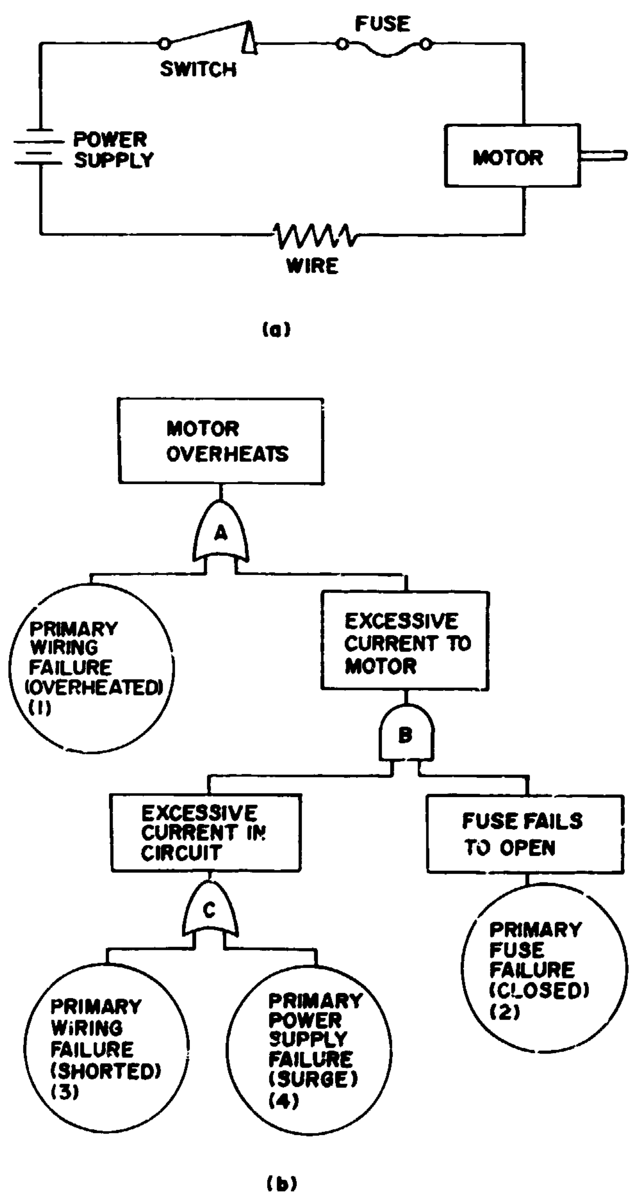


Figure 3.4 (a) Motor System and (b) Fault Tree for Overheating of the Motor
Source: Reference 6

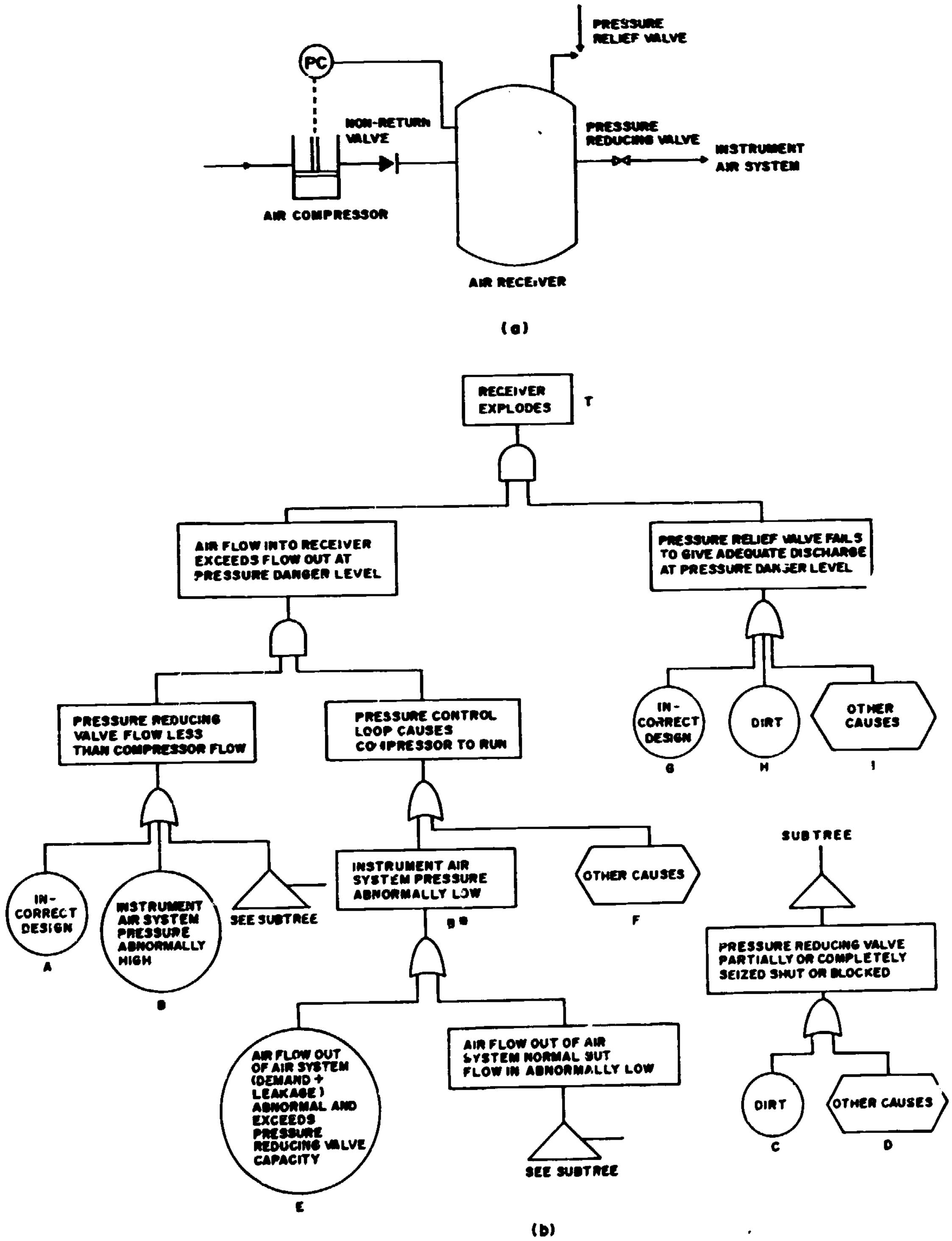


Figure 3.5 (a) Diagram of Compressed Air System and (b) Fault Tree for Explosion of Air Tank
Source: Reference 6

The analysis starts with the evaluation of the first gate, gate A and proceeds downward. This procedure is based on the successive elimination of causes to obtain the minimum cut set. This is illustrated in Figure 3.6.

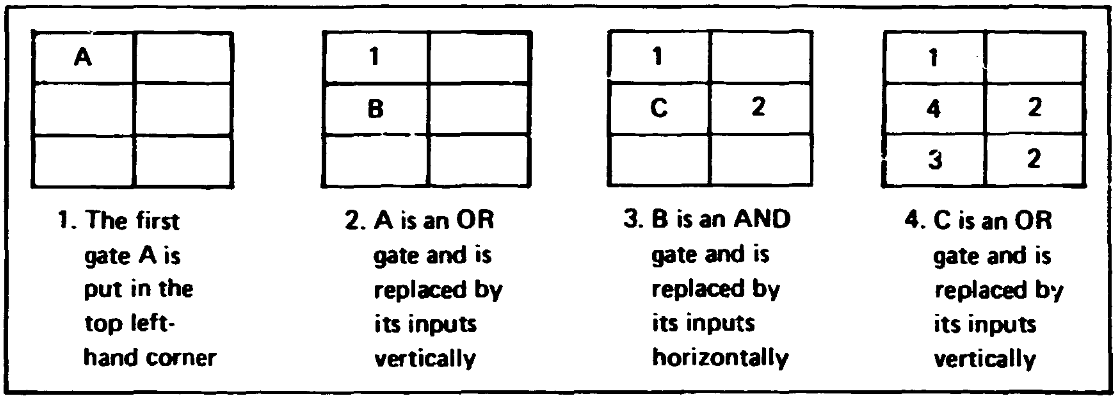


Figure 3.6 Minimum Cut Set Analysis of Fault Tree in Figure 3.4

It should be noted that when C is replaced by 4 and 3, the event 2 is listed with both events 4 and 3. The minimum cut sets are then

(1); (4,2); (3, 2)

This means that overheating of the motor can be caused by either of the following events:

(a) Primary motor failure (1)
(b) Primary power supply failure (4) and primary fuse failure (2)
(c) Primary wiring failure (3) and primary fuse failure (2)

Other methods of determining the minimum cut set are described in References 6 and 7.

The construction of fault trees is a time consuming task and could be developed to have complicated branches. A practical procedure is to decompose the system into its individual components and mini-fault trees are constructed. The overall fault tree is drawn by indicating as inputs the smaller component outputs.

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CHAPTER 4

Condition Monitoring

4.1 DESCRIPTION AND SIGNIFICANCE

Condition monitoring is the inspection and measurement of some parameters which give an indication of the condition of equipment. Preventive maintenance is carried out in response to an indicated deterioration of a unit's condition.

There are two types of condition monitoring: (a) on-load monitoring, which is carried out while the unit is in operation, and (b) off-load monitoring, which can be done only when the equipment is shut off from service. General purpose monitoring techniques may serve either on-load or off-load monitoring.

Condition monitoring is a very efficient approach to preventive maintenance. It is more adaptable and flexible than the use of statistical failure data as a basis for planned repair or replacement. It provides significant benefits in terms of safety, increased machine availability, higher rate of net output and improved quality of service (See Table 4.1). Condition monitoring is cost effective and its level of applicability depends on the nature and size of the industrial plant.

There is no shortage of condition monitoring techniques. The problem is how to determine the appropriate technique, the inspection interval and the action level.

4.2 CONDITIONS TO BE MONITORED

The usual conditions that are monitored in industrial equipment and facilities are:

a. Temperature
b. Lubricant condition
c. Leaks
d. Vibration
e. Noise
f. Corrosion
g. Cracks

For large machines, specific performance monitoring is normally carried out. The performances monitored include: (a) equipment pressure drop, (b) heat exchanger efficiency and (c) compressor, turbine characteristic and efficiency.

4.3 METHODS OF CONDITION MONITORING

An evaluation of the common methods of condition monitoring is shown in Table 4.2. This table briefly describes the application of the techniques as to fault diagnosis and extent of coverage, provides estimates of the equipment costs and indicates the level of skills required for the operator.

4.3.1 General Purpose Monitoring Techniques

The three general purpose monitoring techniques are thermal, vibration and lubricant monitoring. These are used for monitoring changes in parameters (temperature, vibration and

Table 4.1 Advantages Provided by Condition Monitoring

Source: Reference 1

	Advantages obtained		Methods by which condition monitoring gives these advantages: Trend monitoring	Methods by which condition monitoring gives these advantages: Condition checking
Safety	Reduced injuries and fatal accidents to personnel caused by machinery		Enables plant to be stopped safely when instant shutdown is not permissible	Machine condition, as indicated by an alarm is adequate if instant shutdown is permitted
Output	Increased machine availability	More running time	Enables machine shutdown for maintenance to be related to required production or service, and various consequential losses from unexpected shut downs to be avoided	Allows time between planned machine overhauls to be maximized and, if necessary, allows a machine to be nursed through to the next planned overhaul
		Less Maintenance Time	Enables machine to be shutdown without destruction or major damage requiring a long repair time Enables the maintenance team to be ready, with spare parts, to start work as soon as machine is shut down	Reduces inspection time after shut down and speeds up the start of correct remedial action
	Increased rate of output			Allows some types of machine to be run at increased load and/or speed Can detect reduction in machine efficiency or increased energy consumption
	Improved quality of product or service		Allows advanced planning to reduce the effect of impending breakdowns on the customer for the product or Service, and thereby enhances company reputation	Can be used to reduce the amount of product or service produced at sub-standard quality levels

Table 4.2 Summary of Condition Monitoring Techniques
Source: Reference 1

Method	On/Off load	Location of fault	Equipment costs (1977 level)	Skill required of Operator	Comments
1. Visual	On	Surface only	nil	Predominantly experience	Covers a wide range of ad hoc methods
	Off	Can be extended to interior components considered at design stage	Optical probes about $900 $3500 television	No special skill required	Extensively used in aircraft engine industry for "turn round" inspections
2. Temperature (General purpose technique)	On	Surface or internal	Varies widely	Little skill required for most methods	instruments range from direct reading thermometers to infra-red scanners
3. Lubricant monitoring (General purpose technique)	On	Any lubricated component - via magnetic plug, filters or oil samples	< $90 except for ferrography and spectrography equipment	Skill is required to distinguish between damage debris and normal wear debris	Spectrographic and ferrographic analysis services are available to show what elements are present
4. Leak detection	On and Off	Any pressure containing component	< $1800	Skill in use of the specialized equipment readily acquired	
5. Crack detection					
(a) Dye penetrant	On and Off	At clean surface	< $90	Some skill required	Only detects cracks breaking surface
(b) Magnetic flux	On and Off	Near to clean smooth surface	< $90	Some skill required Easy to miss crack	Limited to magnetic materials. Sensitive to crack orientation
(c) Electrical resistance	On and Off	Near to clean smooth surface	< $180	Some skill required	Sensitive to crack orientation. Useful for estimating crack depth
(d) Eddy current	On and Off	Near to surface. Closeness of probe to surface affects results	< $180-$1800	Skill essential	Detects a wide range of material discontinuities; cracks, inclusions, hardness, etc.

Cont. (Table 4.2)

Method	On/off load	Location of fault	Equipment costs (1977 level)	Skill required of operator	Comments
(e) Ultrasonic	On and Off	Anywhere in any component to which there is access via a clean smooth surface	$900-$1800 (Battery operated)	Skill essential if cracks not to be overlooked	Directional sensitivity therefore general searches lengthy. Used to back up diagnostic techniques
(f) Radiography	Off	Access to both sides necessary	>$850	Considerable skill required in setting up and interpreting radiographs	Covers when plant stripped time. Security required because of radiation hazard. Limited to sections less than 55 mm (steel)
6. Vibration monitoring (general purpose technique). total signal, band frequency	On and Off	Any moving component. Any object containing moving parts. Transducer placed in path of vibration transmission, e.g. bearing housing	>$850	Some skill required	Methods vary from the simple to the sophisticated. Routine measurements taken rapidly and do not affect operation of the machine
7. Corrosion Monitoring		In pipes and vessels			
(a) Corrosometer (electrical element)	On		Potentiometer <$350	Some skill required	Will detect 1 μm corrosion loss
(b) Polarization resistance and corrosion potential	On		Meters $900	Some skill required	Only indicates that corrosion is occuring
(c) Hydrogen probe	On		$200	No skill	Hydrogen evolved diffuses and causes pressure rise
(d) Probe indicator holes	On		—	Skill required in drilling to exact depth	Indicates when preset amount of corrosion has occured
(e) Weight loss coupons	Off		—		Monitored when plant stripped down
(f) Ultrasonics	Off		$900-1800	Skill essential	Will detect 0.5 mm thinning

lubricant condition) and not actual changes in the component involved (e.g., cracks, corrosion, etc.). A comparison of these methods is shown in Table 4.3.

(a) Thermal Monitoring

Malfunctions that can be detected from temperature changes and the corresponding appropriate monitoring techniques are described in Table 4.4.

Thermal monitoring measures either surface or immersion temperature. The latter describes termperature monitoring at points within the body of the plant like boiler water temperature. Surface measurements indicate heat transmission from inside an equipment to its surface or to heat exchangers. Surface temperatures are more difficult to monitor. For this reason, surface thermal monitoring techniques are limited to small devices like thermocouples or non-contact instruments such as radiation meters. Temperature sensors are of two general classifications: contact and non-contact.

(1) *Contact Sensors.* The temperature sensors most commonly used for maitenance diagnositics are thermocouples, temperature paints, crayons and pellets.

i. *Thermocouple sensors.* These are the smallest and most adaptable sensors and can be used for high temperatures. Two dissimilar metal wires are joined at the point of contact. The temperature generates a thermoelectric potential across the wires and is measured by a voltmeter or a potentiometer, which is calibrated to indicate temperature reading. Thermocouple sensors are applicable for surface measurements.

ii. *Temperature paints, crayons, and pellets.* These devices indicate temperature by their change of color. Pellets indicate temperature by melting. Materials are available for a temperature range of 40 - 1400 °C in steps of 3 °C at lower temperatures to 30 °C at the higher end. Accuracy is approximately 2% or 5 °C.

(2) *Non-contact Sensors.* Non-contact sensors indicate temperature by measuring the heat radiation from a body. The main source of inaccuracy is the variation in the emissivity. These devices are used to measure very high temperatures. Under this classification are the following devices:

i. *Optical pyrometer.* This instrument uses a heated filament for comparison with the color of the hot surface or gas whose temperature is to be measured. Accuracy is about 2%. This device is the least expensive among the three types of non - contact sensors described here.

ii. *Radiation pyrometer.* This uses thermopiles or lead - sulphide cells to measure heat radiation. The temperature range is about 50 - 4000 °C, with an accuracy of 2%. The viewing angle for radiation pyrometers varies from 3° to 15 °C.

iii. *Scanning Infrared Camera.* This device scans a field of view and displays the thermal profile on a TV monitor. The range is 20 - 2000 °C. This is a very expensive equipment and is useful for locating hot spots.

(b) Vibration and Noise Monitoring

Just by the human senses, significant vibrations and noise can be easily detected. It must be noted that decrease in vibration and noise can also mean incipient trouble, as in the stoppage of a cooling fan which later results in overheating.

Sources of vibrations include the following:

(1) unbalanced rotating parts
(2) accelerated linear movements of components and materials

Table 4.3 Comparison of General Purpose Condition-Monitoring Techniques

Source: Reference 1

	Thermal monitoring	Lubricant monitoring	Vibration monitoring
Medium for transmission of information through machine	Solid - casing, shaft body Fluid - lubricant, cooling water or air Depends on thermal conductivity	Oil used for lubrication and/or cooling Depends on lubricant being pumped round the machine	Any solid part of machine Depends on elastic and mass characteristics of solids
Components monitored	Any heat generating devices (combustion in cylinder or electrically generated heat in motor). Condition of bearings. Fluid flow in heat exchangers (fouling of passages)	Any component which is lubricated bearings, transmission components (gears, couplings, cams), lubrication pump	Any component that moves, surfaces between components with relative motion, clearances.
Faults detected	Failure of drives, blockage of ducts, loss of cooling, fouling of coolers, over-use (e.g., overloading motors)	Any form of wear or failure that results in lubricated surface failure. Leakage of other contaminants into lubricant	Change in any moving components, wear or failure of bearings, misbalance, change in clearances
Monitoring equipment	Fluid or bimetallic thermometers, thermocouples, resistance thermometer, thermistor plus associated instruments, temperature paints/craycns, infra-red detectors, optical pyrometers, infra-red scanning camera.	On-load removable filters, magnetic plugs for visual examination of debris using microscope, spectroscope for analysis of material in suspension, ferroscope for separating debris, pressure gauge across filters	Accelerometer plus electronic processing equipment to display time average values. Frequency filters and recorders for analysis of vibrations
Frequency	Continuous and periodic	Primarily periodic	Periodic but also continuous

Table 4.4 Some Thermally-Monitored Malfunctions

Source: Reference 1

Malfunction	Indication	Monitoring Technique
1. Bearing damages	Bearing heats up.	Use either a surface-mounted sensor (e.g., a thermocouple) or two sensors - one on the surface and the other below - to indicate temperature difference.
2. Coolant failure	Surface of a component heats up.	Use a surface-mounted sensor. Coolant failure may indicate blockage of a pipe, valve or filter; damaged heat exchanger; pump failure; internal or drive fault.
3. Incorrect heat generation	Casing surfaces have uneven temperatures	Use a series of thermocouple sensors, temperature paints or a scanning infra-red camera to indicate uneven temperature distribution and changes.
4. Build-up of unwanted materials	Build-up of sludge or sediments in pipes, of ash or dust in boilers or ducts, and of corrosion by-products create insulation effect.	Use surface temperature sensors and note temperature changes (decrease) from normal operation.
5. Damage to insulating materials	Cracks in refractory linings and damage to lagging show up as hot or cold spots.	It is best to use a scanning infra-red camera.
6. Faults in electrical components	Poor electrical connection heats up especially for high voltage lines. Failed rectifiers, thyristors or windings show cold spots.	Use a scanning infra-red camera.

(3) relative motion of adjacent rough surfaces
(4) loose fits between mating components
(5) deflected load bearing components under cyclic loads.

Machine vibrations cause noise. Noise levels are usually more conveniently measured than vibration levels because non-contact sensors are used. However, extraneous noise can not be easily isolated and this causes inaccuracy of measurement. Vibration monitoring is more selective and can be easily repeated. Thus, vibration monitoring is generally preferred to noise monitoring.

The device used for vibration monitoring is the vibration transducer. The most common type is the piezoelectric accelerometer which is available in small sizes. It is of strong construction and wide dynamic and frequency ranges.

Different vibration monitoring instruments may have different features. Continuous monitoring devices are usually equipped with alarms which are triggered by abnormal vibration levels. Some methods used for monitoring vibration are the following:

(1) *Total signal monitoring.* This is the most straight-forward technique. The total signal picked up by the transducer is amplified, time-averaged and displayed on a meter or a recorder.
(2) *Frequency analysis.* This method uses an electrical filter network which screens the vibration signals picked up by the transducer and selects only the random frequency which is indicative of trouble.
(3) *Peak signal monitoring.* Machine faults which cause the emission of vibration to register peak values are determined.
(4) *Shock pulse monitoring.* This method is particularly applicable to monitoring bearings. The instrument uses a transducer which resonates at 32 kHz, a frequency that is not usually influenced by general machine vibrations. Impulses generated by impacts between damaged surfaces are magnified and are metered as shock value levels (SVL).

   Table 4.5 serves as a guide for using a shock pulse meter based on the following equation:

   Rise in SVL = Measured SVL - Initial SVL

(5) *Computerized vibration monitoring.* In large installations where plant costs and shutdown are high or where many machines are operating, it may be appropriate to use a computerized system for continuous or scanned vibration monitoring, with transducers permanently planted on the machines.

Table 4.5 Shock Value Levels (SVL) Indicating Bearing Condition

Source: Reference 1

Rise in SVL	Bearing Condition
less than 20	Good Condition
15 - 25	Undamaged bearing but lacking lubrication or improperly installed
20 - 35	Damage developing
35 - 50	Visible damage
50 - 60	Risk of breakdown

Table 4.6 shows some commercial vibration monitoring instruments. There are more sophisticated and specialized vibration monitoring systems but the methods described above are adequate for most requirements.

The location of tranducers depends on the type of malfunction to be monitored. Table 4.7 provides some guides on the location and orientation for mounting transducers.

Most vibrations are associated with moving mechanical parts. Thus, the most common locations for vibration transducers are the bearings. If the transducer is axially mounted, it detects vibrations due to bearing noise and is least affected by shaft imbalance.

Since the level of vibration measured by a transducer varies with location, the mounting point should be clearly marked. Figure 4.1 shows some ways of locating and mounting transducers, namely: the use of center punch marks to identify the site for attaching pointer, magnet or lever-grip mounted transducers; a welded or glued mounting block; and the use of a threaded hole or a stud.

For machines mounted directly on the factory floor, measured horizontal vibrations are more meaningful. If machines are mounted several floors up in a building, horizontal vibrations may be difficult to measure accurately as these would be affected by other machinery.

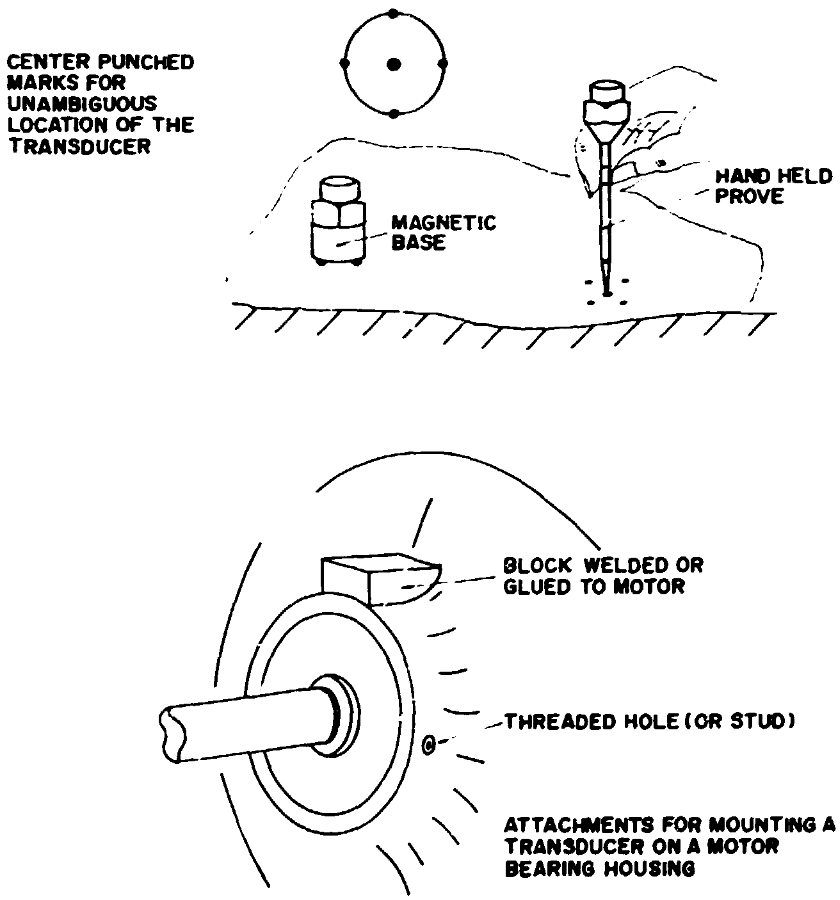

Figure 4.1 Methods of Locating or Mounting the Transducer

Table 4.6 Some Commercial Vibration Measuring Devices

(Source: Reference 3

Name of Instrument	Services Rendered	Application
SPM Shock Pulse Meter	Checking of bearing condition	Scheduled bearing inspection
IRD 308	Vibration meter	For routine measurement
IRD 320	Vibration analysis	For vibration analysis and fault finding
IRD 350	Vibration analysis and Balances	Vibration analysis and dynamic balancing and phase plotting
IRD 360	Vibration analysis	For phase studies
X Recorders	Spectrum analysis	For recording vibration signatures
Noise Meter	Measures sound pressure levels and machinery noise analysis	Noise measurement

Table 4.7 Characteristics of Some Machine Faults

Source: Reference 1

Fault	Dominant frequency	Direction position*	Comments
1. Rotating imbalance	Rotation speed (n)	R B	Machinery running wear or above a critical speed can change balance with speed, multiplane balancing is then required
2. Reciprocating imbalance	1n, 2n, 3n, 4n, etc.	R B	Fundamental (n) may be balanced leaving only higher orders of imbalance
3. Mechanical looseness	2n, 3n, etc.	R, A B	Affected by temperature and speed
4. Bent shaft or coupling	1n	R B	Can be caused by thermal effects. Often occurs with imbalance
5. Misalignment	1n or 2n, sometimes 3n, 4n	R, A B	Common fault. Can be masked by characteristics of flexible couplings
6. Cracked shaft Asymmetric shaft	1n, 2n, 3n	R B	Transverse stiffness varies direction and results in deflection under gravity

Cont. (Table 4.7)

			excited vibration. Best detected when machine is run-down through resonance. Deep crack has small effect
7. Damaged hydro-dynamic or hydrostatic	Change in higher frequencies as debris causes rubbing	R B	Sometimes reduced clearance causes reduction in vibration due to other effects
8. Journal bearing loose in shaft or housing	n/2, n/3	R B	Looseness affected by temperature or centrifugal effects
9. Oil film whirl	0.4n to 0.5n	R B	Oil properties (hence temperature) affect whirl
10. Hysteresis whirl	Shaft speeds above critical	R	Due to hysteristic damping in shaft. Excited when passing through critical speed and does not die away as speed is increased. To cure, reduce hysteresis or increase external damping, e.g. bearings
11. Damaged rolling element bearing	Input frequencies for bearing components and high frequencies in the range 500 - 5000 Hz and shock pulse detectable at very high frequencies, 10 - 100 kHz	R, A B	Impact frequencies for rolling element dia. d. pitch dia. D, contact angle, B, and bearing speed, f. Defect in one ball $f_b = \frac{fD}{d}\left[1 - \left(\frac{d \cos B}{D}\right)^2\right]$ Defect in inner/outer race $f_r = \frac{fn}{2}\left[1 \pm \frac{d \cos B}{D}\right]$ Roller bearing, B = 0°, thrust ball, B = 90° Taper roller d is dia. of roller at pitch dia., D, and B = inclination of roller axis
12. Damaged, worn or misaligned gears	Tooth meshing frequency + harmonics shocks	R, A B	Sideband frequencies, detectable with very narrow band analysers, indicate gear eccentricity. Increased peak to r.m.s. ratio indicates damaged teeth
13. Damaged belt or chain drive	Multiple of belt or chain speed	R B	
14. Cavitation or turbulence	Increase in mid to high frequencies, 0.5-10 kHz	C	Indicates, wrong flow, passage block or passage damage
15. Damaged blades, vanes, guides, tubes, etc.	Increase in frequencies associated with blade passing or vortex shedding	C	Usually designed to avoid worst frequencies but damage may induce flow fluctuations
16. Electrical faults	Multiples of supply frequency	C B	Burnt out phase induces cycling forces. Can also cause shaft imbalance

R = Radial, A = axial, B = bearing housing, C = casing

(c) Lubricant Monitoring

The condition of used lubricant carries evidence on the condition of the equipment. Lubricant examination covers the condition of the oil, the debris deposited and the debris in suspension. It can be carried out during shutdown or while the equipment is in operation.

The amount of debris entrained in the used oil from new equipment should decrease with time. For used machines in good condition, the debris collection should have a fairly constant amount, size and shape. Table 4.8 provides a guide to equipment condition from the shape of these debris.

Table 4.8 Indications About Equipment Condition from the Shape of Debris in Used Oil

Source: Reference 1

Debris Shape	Indication
flat-shaped	normal wear
spiral shaped	cutting or abrasive wear
large and angular	surface fatigue failure

The faults indicated by analysis of oil debris could indicate bearing damage or damage to a sliding or load bearing surface.

The condition of the oil itself serves as a basis for appropriate actions. (See Table 4.9)

Debris deposited are relatively large particles which can be collected by filters or magnetic collectors.

(1) *Filters.* Entrainment of debris in a lubricant filter can be indicated by measuring the pressure drop across the filter during on-stream operation. During shut down or in some cases, even on-load, the filter may be removed and the deposited debris taken out for examination under a microscope to determine size and shape or with a spectrometer to determine the element content.

(2) *Magnetic Debris Collectors.* Magnetic plugs are the common devices used to collect ferrous debris. The installation can be made so that these plugs are removable during operation. Another type of magnetic debris collector which can be monitored without removal is also available.

Debris in suspension are smaller particles entrained in the lubricant. Two methods are generally used for analysis:

(1) *Spectrographic (or spectrometric) Oil Analysis (SOA).* The more common acronym is SOAP, which means Spectrometric Oil Analysis Program. There are two types of instruments available: the emission spectrograph and the atomic absorption spectrometer. Both instruments indicate which metallic elements are present and in what concentrations. However the size and shape of debris are not determined by this technique.

(2) *Ferrographic Oil Analysis.* This technique consists of the analysis of an oil sample which is made to flow over a substrate and with the use of magnet causes the particles to settle according to size distribution and density. The examination determines debris concentration, size distribution and shape.

Table 4.9 Used Oil Conditions and Corresponding PM Actions
Source: Reference 1

Oil condition	Cause	Action
Foaming	Excess churning or passage under pressure through a restriction	Check system
	Detergent Contamination	Change oil
Emulsion o separates out readily	Water ingested	Drain off water
o separates with centrifuge	Water	Change oil
Darkened color	Overheating of system; oxidization of the oil	Change oil
	Combustion or other products reaching the oil	Change oil

4.3.2. On-Load Monitoring Techniques

There are several methods of condition monitoring that can be used while equipment are running. Through direct observation or with the use of instruments, malfunctions can be detected from changes of certain parameters.

(a) Visual, Aural and Tactile Inspection of Accessible Components.

Without using any instruments, an operator can easily detect several signs of incipient failure. Finger touch can determine relative motion between two adjacent components. Visual examination can detect wear or corrosion debris. Sound is generated from loose moving parts. By using optical aids, some inaccessible internal parts of equipment can be examined . The main requirement in using this method effectively is the experience of the operator.

(b) Thermal Monitoring

Appropriate instruments of either contact and non-contact sensor types can be used for on-load monitoring of temperature. The most commonly used are contact thermometers, themocouples, temperature chalks and paints, and infra-red detectors. This technique is discussed in detail in Section 4.3.1.

(c) Lubricant Monitoring

Oil condition is normally checked by visual inspection. The common device used to indicate entrained debris is the magnetic drain plug. Lubricant monitoring is discussed extensively in Section 4.3.1.

(d) Leak Detection

The use of soap and water is the most common technique for leak detection. The ultrasonic leak detector senses the high frequency sound generated by fluid leaks through holes as small as 50 micrometers under a pressure of 0.1 bar. Halogen testing is another leak detection method and uses a search gas introduced inside a system. The presence of the gas outside the system indicates a leak.

(e) Vibration Monitoring

Among instrument-aided condition monitoring techniques, vibration measurement has the widest application. These applications include the detection of:

(1) damaged bearing
(2) damaged transmission components
(3) shaft misalignments
(4) cavitation of a pump
(5) damaged glass

A substantive discussion on vibration monitoring is given in Section 4.3.1.

(f) Noise Monitoring

The technique of Acoustic Emission (AE) measurement has been developed for noise monitoring. It detects short impulsive stress waves that emanate from the source of failure. Its applications include monitoring of (1) pressure vessels, (2) high pressure leaks and (3) pump cavitation.

(g) Corrosion Monitoring

Electrical Resistance (ER) Probes and Linear Polarization Probes (LPR) are normally used for on-load corrosion monitoring. Sentinel holes drilled from outside a vessel wall provide warning that the corrosion allowance thickness has been eaten up. A substantive discussion of these techniques is presented in Chapter 6.

4.3.3 Off-load Monitoring Techniques

These monitoring techniques are used with the equipment shut off from service.

(a) Visual, Aural and Tactile Inspection of Normally Inaccessible or Moving Parts

Visual inspection of gear teeth and other transmission components can indicate problems of over-load, fatigue failure, wear and poor lubrication. There are many optical instruments used for inspection of off-load equipment. They include:

(1) borescopes
(2) fiber optic interoscopes
(3) tank periscopes
(4) mirror sets
(5) closed circuit TV cameras

(b) Crack Detection

The point of stress concentration may cause a minute crack growth which is not visible to the naked eye. Unless this is checked, it may develop into a serious failure. The folowing techniques are used for crack detection:

(1) *Dye penetration into surface cracks.* This makes visible cracks as small as 0.025 micrometer .

(2) *Flux testing of magnetic materials*. Magnetism is induced in the material surface using U-type magnets. Magnetic powder spread onto the surface indicate the existence of a crack.

(3) *Electrical Resistance Testing.* Two probes in contact with the surface of a material indicate the existence of a crack if the measured resistance indicates a deviation from the expected value.

(4) *Eddy current testing.* This method uses a current-carrying coil placed close to the surface to induce eddy currents in the material. The existence of a crack is determined by a change in the inductance of the generator coil or by a separate search coil.

(5) *Ultrasonic Testing.* High frequency sound in the range of 0.25-10 MHz is directed to and reflected from the surface. Non-uniformity of the reflected sound indicates imperfections such as cracks. This techniques is applicable to a thickness range of 5-15 mm for steel.

(6) *Radiographic examination.* X-ray or gamma ray photography is used in this method and it usually requires removal of the part to be examined. It is applicable for materials with a maximum thickness of 50 mm.

(c) Leak Detection

The same methods discussed in Section 4.3.2 are used for off-load leak detection. The ultrasonic leak detector can be used for internal components.

(d) Vibration Testing

Run-down tests are usually conducted for units taken off service to monitor system vibrations. The techniques discussed in Section 4.3.2 are also used for these tests.

(e) Corrosion Monitoring

Besides the techniques mentioned in Section 4.3.2, off-load corrosion monitoring methods include ultrasonic measurements, radiography, and the use of corrosion coupons. All these are described in Chapter 6.

4.4 ADOPTING A CONDITION MONITORING PROGRAM

The following, which is based on Reference 1, is a guide for setting up a condition monitoring program:

(a) **Select the equipment to be monitored.** The main criteria should include the progress rate of a particular failure, the frequency of equipment breakdown and their effects on the plant operations. Initially, one or more of the machines which have bad maintenance records should be selected and other equipment will be included later.

(b) **Determine the type of monitoring required.** Periodic measurements are appropriate for long term monitoring. Continuous monitoring provides early warning or indications of incipient failure.

(c) **Select the appropriate instruments and train one engineer responsible for monitoring.** A good rule for selection is to get the simplest instruments appropriate for the needs which have provisions for expanding their capability for more complex requirements. In any case, the advice of experts and suppliers should be sought.

(d) **Select the location of monitor points and choose the interval between periodic checks.** The pertinent parameter should be determined and the monitor point located and oriented accordingly. Interval between checks is usually determined by experience or from manufacturer's instructions.

(e) **Determine the normal conditions of the machine.** Several measurements with proper data recording are required to establish which conditions are normal as indicated by parameters.

(f) **Determine action when abnormal conditions are indicated.** The last step is to establish thresholds or tolerances or deviation from normal conditions and to determine the appropriate action required for certain levels of deviation. On this basis, a decision can be made at any time whether to continue operation, operate at certain conditions or to shut down.

The key feature of condition monitoring is the accumulation of data. Only when sufficient data are collected can normal conditions and allowable deviations be established. It is usual that redundant measurements are done at the early stages of the program. Redundancy is cut down as experience is gained.

It must be understood that normal conditions would show that equipment have early life defects and final life defects. In between, the normal conditions are indicated by a fairly constant level of the parameter measured. This is illustrated in Figure 4.2.

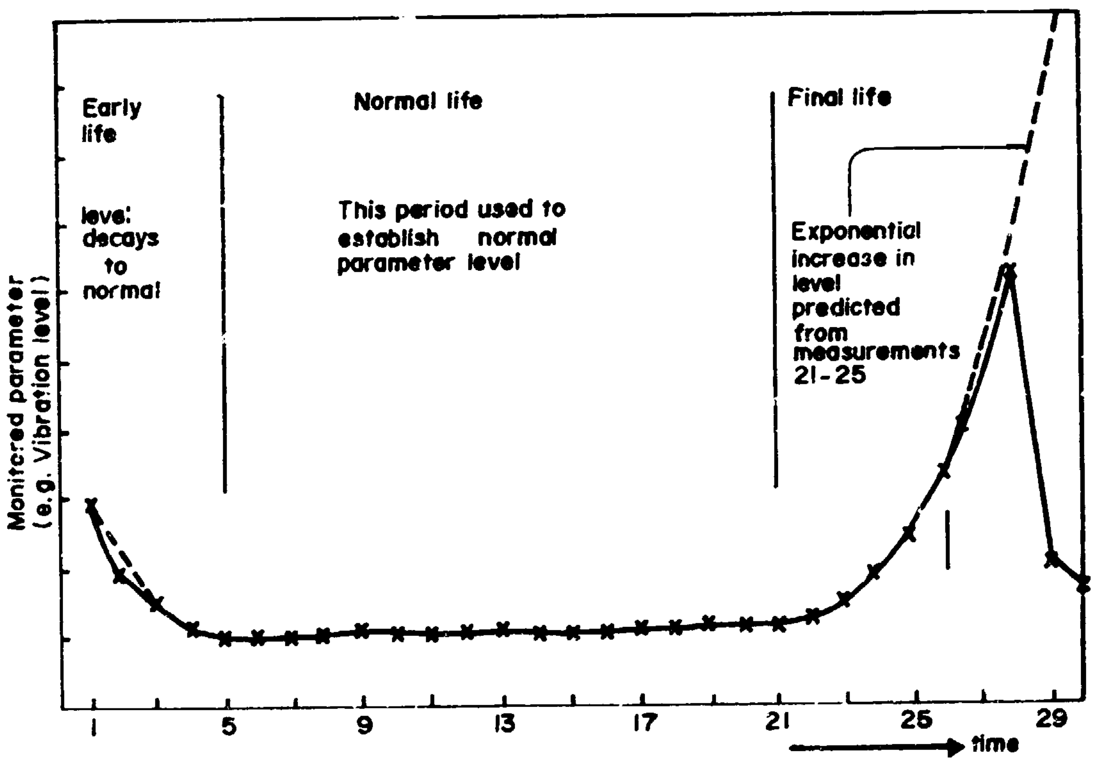

Figure 4.2 Typical Monitored Parameter-Life Curve Condition. Monitoring Engineer Recommends Repair at Measurement 26. Repair Carried out Between Measurement 28 and 29.

Source: Reference 1

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CHAPTER 5

Lubrication

5.1 DESCRIPTION AND SIGNIFICANCE

5.1.1 Lubricants and Their Functions

Lubrication is the process of introducing a film of lubricant between two contacting or rubbing surfaces of mechanical equipment. This film is either in liquid or solid form.

The major function of this film is to reduce friction and to reduce wear. Unless an adequate lubricant is present between the moving parts that are in contact, friction and wear will be excessive and the machine will soon cease to operate.

Lubricants also have other important functions:

(a) They carry away heat from bearings and running parts;
(b) They aid in sealing equipment parts against dirt;
(c) They protect metal surfaces against rust and corrosion;
(d) Sometimes, as in hydraulic equipment, the lubricant actually serves to transmit power from one part of a machine to another.

Lubrication of operating equipment is an essential aspect of maintenance. It is an important factor in sustaining production, reducing delays, and lowering maintenance costs.

If an equipment is expected to produce enormous tonnages and operate under increasingly heavier loads, it is necessary to maintain it in such a way that it can operate for the longest possible time without excessive wear and breakdown. The men who lubricate the equipment play a key role in the achievement of this aim.

Lubrication means equipment conservation since it prevents wear. It also means energy conservation since it reduces friction, thereby reducing the energy usage of the equipment itself.

5.1.2 Types of Lubricants

Lubricants can be conveniently divided into four basic types:

a) *Oils.* This is a general term used to cover all liquid lubricants which include mir ,
petroleum oils, natural oils, synthetics and emulsions. Almost 95% of all lubricants are petroleum based, giving the best cost effectiveness for most applications. However, for extremely low and very high temperatures (i.e., beyond the threshold limit of petroleum oils, 470°C), very expensive synthetic oils become more cost effective.
b) *Greases.* Technically, these are oils which contain a thickening agent to make them semi-solid. Included are the anti-seize pastes and the semi-fluid greases.
c) *Dry Lubricants.* These are lubricants in solid form: bulk solids, paint-like coatings or loose powders.
d) *Gases.* Usually air is used but any gas which will not attack the equipment is suitable.

While oils and greases have varying degrees of toxicity, special processing could remove toxicity, as for food-grade lubricants which are safe even when they come into incidental contact with the food being processed.

5.2 SELECTION OF LUBRICANTS

5.2.1 Choosing the Lubricant Type

The primary objective in choosing a lubricant for a particular application is to obtain the lowest overall, long term cost. This does not necessarily mean that the cheapest lubricant should be used. The prime consideration should be how well for how long the particular lubricant will perform its functions.

How well and how long a lubricant will do its intended job for a particular application depends on its physical and chemical properties. Chemical properties not originally in the lubricant are imparted by additives while certain physical properties can also be enhanced by these substances (see Appendix VI for a listing). Generally, the physical properties determine the lubricant's *initial suitability* while the chemical properties determine the *quality* which, in turn, affects the "how well" and the "how long" aspects of the lubricant's service capability.

The selection of lubricants is guided by commercial specifications and standards that govern both initial suitability and quality.

5.2.2 Choosing the Lubricating Oil

Initial suitability of a lubricating oil is described by viscosity, viscosity index, pour point and floc point. Viscosity is governed by two standards, namely: SAE viscosity classification for automotive oils and ISO viscosity classification for industrial oils. Appendix VI gives equivalents among these units of viscosity.

Quality for automotive oils, is standardized by the API Classification system (Appendix VI), while for industrial oils, there is no one standard system, but various equipment manufacturers and governmental standards agencies (e.g. British Standards, DIN standards of Germany, etc.) have specifications limits for each of the required properties for a particular industrial oil.

5.2.3 Choosing the Lubricating Grease

Initial suitability is determined by its consistency which is the hardness or softness, expressed in terms of NLGI number. The appendix VI shows the NLGI Classification. Dropping point is another property that initially tells the temperature range suitability of the grease.

Quality is not governed by any standard due to the very wide variation in grease quality demanded by the variety of applications and environments. Rather, quality is described by specifications as to structural stability, mechanical stability, anti-rust property, bearing protection property, thermal stability, etc.

5.2.4 Choosing the Dry Lubricant

Table 5.1 describes some materials used as dry lubricants. The selection process depends on the properties of the individual solid lubricants. However, compromises can be obtained by combining two or more of them in a composite.

5.2.5 Choosing the Lubricating Gas

Any gas can be used as a lubricant provided that it is clean enough. It will usually be the one most readily available.

5.3 METHODS OF APPLYING LUBRICANTS

5.3.1 Oil-Feed Systems

To make oil lubrication more effective, different oil-feed systems are available. An effective oil-feed system must be able to:

Table 5.1 Properties of Dry Lubricants
Source: Reference 5

MATERIALS	PROPERTIES
Graphite	Low friction 0.05 to 0.15 depending on pressure. Maximum PV* 42,058 kPa x m/min. Good Adhesion. High thermal and electrical conductivity. Usable at low temperature and to 540°C in air. Good performance in vacuum or when very dry. Very complex and variable materials. Black and therefore unacceptable for certain processes.
Molybdenum disulphide	Low friction 0.03 to 0.2 depending on load. Maximum PV probably about 210,290 kPa x m/min. Excellent adhesion, especially when dry. Usable at low temperature and to 350°C in air. Excelent performance in vacuum. Temperature limit in vacuum appraoches 1000°C. Very high load-carrying capacity. Black, and therefore unacceptable for some processes.
Calcium flouride	Usable in the range of 350-1000°C. Low friction, low wear rate
Graphite flouride	Low friction, fairly low wear rate, slightly abrasive. (Less readily available than molybdenum disulophide.
Molybdenum trioxide	Usable in the range of 300 - 1000°C Friction fairly low, adhesion fair.
Boron nitride	Usable in the range of 300-750°C (1700°C if no oxygen present). Friction about 0.2-0.3.
Lead monoxide	Usable in the range of 250-750°C. Friction and wear rate low.
PTFE (polytetrafluoroethylene)	Very low friction, from 0.03 to 0.1. High wear rate in unfilled state. Deforms slowly under load in unfilled state. Reinforcing fillers reduce wear rate and deformation. Usable from – 200°C to 1 300°C. Highly resistant to chemical attack. White colour useful in some applications. Easily machined.
Nylon	Friction 0.1-0.4 Maximum temperature 200°C. Wear resistance-fair.
Acetal	Friction 0.1-0.4, Maximum temperature 110°C fair wear resistance, good for intermittent lubrication, difficult to attach to metal components.
Metals	Friction 0.3, good conductor of heat and electricity, temperature-before melting.

*PV is a useful property for assessing the lubrication capacity of a solid lubricant. It is the highest product of pressure and velocity at which it can be used.

(a) replace used oil by fresh oil
(b) remove contaminants such as wear debris
(c) cool the equipment

To facilitate the appropriate selection, an enumeration of the different oil-feed systems, along with their advantages and disadvantages, are presented in Table 5.2.

5.3.2 Methods of Applying Greases

For simple cases, grease is often applied by hand. In large bearings or gear boxes, "paddles" shaped like small table-tennis bats may be used. To increase the supply of grease into the component in service, a reservoir may be supplied in the form of a cup or block of grease. But by far, the most common method of re-greasing a mechanism is by means of a grease-gun, applied through a nipple. Where numerous grease points and/or complicated machinery are concerned, automatic centralized lubrication systems are available. Cost reduction or savings results from lower lubrication labor, less failures due to more positive and continuous lubrication, less lubricant spillages and contamination, better safety, etc., provided the centralized system is properly maintained.

5.3.3 Applying the Solid Lubricant

Solid lubricants in the form of a bonded film are applied according to the suppliers' instructions. In the case of bulk solid lubricants, they are machined to the required shape and introduced into the system.

Generally, solid lubricants cannot be replenished in service but a few techniques have been used. Molybdenum disulphide powder has been supplied by means of an air jet. Introduction with a volatile solvent which evaporates is also possible. PTFE and molybdenum disulphide composite can be replenished by mounting the oil-feeder in a position where it is in sliding contact directly or indirectly with the parts which require lubrication.

5.3.4 Application of Gas Lubricants

Gas lubricants are generally used for bearings. There are two types of application -- self-pressurizing and externally-pressurized. For self-pressurized gas bearings, the gas is initially incorporated into the system while for externally pressurized gas bearings, a compressed gas supply is required.

5.4 PLANNED LUBRICATION

5.4.1 The Lubrication Function

An essential function in any plant is the proper lubrication of equipment. To effect proper lubrication, each plant must have a plant lubrication schedule. And the program must be coordinated among involved departments, to be successful on a plant-wide basis.

In most plants, the maintenance department is responsible for establishing and carrying out the lubrication program. For this reason, the lubrication engineer is in the maintenance department. Plant-wide lubrication, therefore, is the job of the lubrication engineer. To describe the program is to define the scope of the function of the lubrication engineer. To create and effect a successful plant lubrication program, the lubrication engineer must collaborate with the designated supervisors and lubrication personnel in the operating program units.

The plant program outlines the lubrication engineer's activities. These include all the essential factors recognized as being part of every successful plant lubrication program from lubricant selection, lubricant application, control, feedback and changes.

Table 5.2 Advantages and Disadvantages of Different Oil-Feed Systems

Source: Reference 5

System	Description	Advantages	Disadvantages
Hand-held Oil can		Low initial cost Simple Easy to check	High labor cost Reliability depends on user No cooling Easy to use wrong oil Requires close approach to machinery No recovery of used oil
Drip feed	Supplies a small quantity to oil, without any attempt to control or collect the old oil which is being replaced, or any excess of fresh oil which is supplied.	Low initial cost Low labor cost	Requires close approach to machinery Care needed to check flow No cooling No recovery of used oil
Centralized total loss		Low labor cost High reliability Little risk of wrong oil	High initial cost Higher maintenance cost No cooling No recovery of used oil
Oil mist or fog systems	A new development in the total loss system where oil is circulated in the form of minute droplets dispersed in a stream of air.	Low labor cost High reliability Low consumption of oil Useful cooling	High initial cost Careful flow control needed No recovery of used oil
Wick or pad lubrication	Transfers the oil by wick or pad in direct contact to the component (capillary or wicking action).	Low initial cost Low labor cost	No cooling May become blocked
Ring or disc	Oil is fed to the component by rotating discs or rings which dip into the oil and transfers it to the top.	Low labor cost Generally reliable Some cooling Recovery of used oil	Fairly high initial cost Limited speed range
Splash	Partly submerged moving parts in oil splash the oil on parts above the oil level.	Low initial cost Low labor cost Recovery of used oil	Limited speed range
Circulation System	Basically consists of a reservoir, a pump, a feed line one or more lubrication points and a return line.	Wide range of use Generally reliable Effective cooling Recovery of used oil.	High initial cost High maintenance cost

5.4.2 Lubrication Survey

The first step toward a successful lubrication program is the gathering of lubrication information by conducting a plant-wide survey. In the survey, detailed information on current lubrication practice is compiled. Information to be gathered includes the type of the lubricant, the part to be lubricated and the frequency of lubrication.

From an inspection of operating equipment, the lubrication engineer can determine the location and number of lubrication points, method of lubrication and maintenance responsibility. Contact with the operating personnel will permit questions to be asked about each operating unit. For this reason, information should be gathered from only one operating unit at a time. Each piece of equipment should be inspected where special or abnormal conditions occur. If it becomes necessary to clarify equuipment design, reference to the blueprints should be made.

To conduct the survey, a standard form should be used for collecting detailed information. The accomplished form may also be posted and used to give lubrication instructions to plant personnel.

When the plant-wide survey is completed, a report should be made to summarize the findings and recommend necessary changes. This summary forms the basis for action to improve the lubrication of equipment.

A reputable oil company contracted to supply lubricants will usually undertake a comprehensive and detailed lubrication survey of all the company's plant and equipment for free. This should be detailed and written on a lubrication survey form such as that illustrated in Figure 5.1.

LUBRICATION SURVEY FORM

DEPARTMENT/SECTION ______________________________

EQUIPMENT	PARTS TO BE LUBRICATED	LUBRICANT RECOMMENDED	HOW APPLIED	INTERVAL
________	________	________	________	________
	________	________	________	________
	________	________	________	________
	________	________	________	________
________	________	________	________	________
	________	________	________	________
	________	________	________	________
	________	________	________	________
________	________	________	________	________
	________	________	________	________
	________	________	________	________
	________	________	________	________

Figure 5.1 Example of a Lubrication Survey Form

Based on the survey, the oil company will recommend rationalization of the grades of lubricant to be used in order to simplify the problems of storage and application and to reduce costs. The possibility of errors in application are considerably reduced by rationalization.

5.4.3 Setting Up the Lubrication Schedule

Lubricants have a certain "service life". Lubricants, therefore, have to be changed regularly, or equipment have to be re-lubricated regularly. Lubrication scheduling can become complicated, depending on the size and number of equipment involved.

Planned lubrication is, of course, an integral part of planned maintenance. Daily and weekly lubrication tasks are carried out separately from the mechanical and electrical schedules. Monthly lubrication tasks and oil changing are usually fully integrated with maintenance schedules.

There are many ways of organizing the plant lubrication schedule. The following is a guide for lubrication scheduling:

(a) Estimate the time and frequency required for each lubricating point and revise the plant lubrication specifications if necessary to obtain a realistic work load. For daily application, the following questions may be considered:

  (1) Can these be undertaken by the plant operator?
  (2) Can multiple points be piped in to battery plates, and larger oil reservoir fitted?
  (3) Can the machine be economically fitted with an automatic lubricator?

(b) Consider whether lubrication activities that do not have to be done daily can be incorporated with the mechanical and/or electrical preventive maintenance schedules at the weekly, monthly and less frequent inspections.

(c) Estimate the number of oilers-greasers required to undertake the estimated work load. Will the work be done in the daytime or other shifts? Has allowance been made for holidays and other non-working days?

(d) Do oilers-greasers require training? This will surely be necessary in newly installed plants.

(e) How much lubrication can be done during on-stream operation? 'Fitting in' lubrication at random when a machine is not in use will not do. This invariably results in an inadequate lubrication service.

(f) Have all the aspects of safety been considered? Will it be necessary to remove guards in order to reach lubrication points? Is a ladder required? Are machines which are driven by under-floor equipment covered by floor plates?

(g) Prepare a lubrication specification sheet per machine. This is to be used by the lubricator. In certain special cases a number of machines can be combined on one lubrication specification sheet.

(h) Ensure that the correct grades of lubrication are applied.

5.4.4 Carrying Out the Lubrication

(a) Prepare a route card for the oiler-greaser.

(b) It is essential that the oiler-greaser submits a report daily to the maintenance supervisor of any apparent defects noticed on the machines he has lubricated during the day. This will include cases of excessive or inadequate lubrication, abnormal levels of noise, vibration or temperature, oil leaks, or cases where an abnormally large amount of 'topping-up' appears necessary.

(c) Plant history records, already maintained for the planned-maintenance program, are entered up from job reports received from the oiler-greaser. Experience may indicate that the lubrication schedules and job specifications may have to be revised in certain instances where excessive or inadequate lubrication is evident.

(d) Adequate oil storage records mut be kept to indicate the quantities of each grade consumed.

(e) A wide range of lubricant dispensing equipment is now available in the market. Some form of mobile trolley is essential, unless the area allocated to the oiler-greaser is small.

(f) Consider wherever possible the standardization of grease nipples, to reduce the number of combinations of greases and connectors.

5.5 LUBRICANT STORAGE AND HANDLING

5.5.1 Supplier's Responsibility

Reputable suppliers usually exercise extreme care during blending, manufacture and packaging of its products. A system of control for product quality is instituted to meet exacting industry demands on product performance. Efficient handling of lubricants from the supplier's warehouse to the customer's plant site is standard practice to ensure plant-approved quality. However, non-adherence to the basic rules of handling and storage can contaminate a product or render it off-specifications and standards may lead to costly consequences like faulty operation or machinery breakdowns

5.5.2 Storage of Lubricants

(a) *Inventory.* Store only the quantity required for a reasonable period of time. Too low an inventory may ultimately result in product runouts and disruption of plant operations. Too high an inventory ties up money.

(b) *Withdrawal of Lubricants.* Use the "first-in-first-out" system. This keeps the remaining products always relatively new. While oils can be stored for a long time, it is best to keep the storage period short to prevent possible deterioration. Greases should not be stored for more than a year.

(c) *Requirements of a Good Storage Facility*

(1) Accessible. They should be stored near the machines or equipment which use them. This is to facilitate transfers and save on man-hours.

(2) Separate. Lubricants are a class by themselves. Store them separately from other materials like spare parts, chemicals, solvents, etc., to avoid mix-ups.

(3) Not too hot nor too cold. Lubricants are affected by extremes in temperature.

(4) Protected. Keep all lubricants indoors. If this is not possible, keep the following suggestions in mind:

i. Do not stand barrels on end, but stock them lying on their sides. This allows for expansion and contraction of the lubricant for varying temperatures. When the barrel is hot, the contents expand and forces air out. When it is cold, the contents contract, drawing in water and dirt into the drum.

ii. Never store the following products outdoors:

Grease. Water contamination will render the grease unsuitable for further use.

Transformer Oils. A few parts per million of water-contamination will greatly lower the dielectric strength of the oil and render it unsuitable for use in transformers and other electrical equipment.

Refrigeration Oils. Water contamination is undesirable in refrigeration oils because water can be frozen and clog up expansion valves.

5.5.3 Handling of Lubricants

(a) *Requirements for Handling Oil:*

(1) Provide drip pans under faucets. This not only makes the storage area clean but also prevents accidents.

(2) Provide racks for barrels lying sideways. This prevents the barrels from rolling accidentally.

(3) Use a hand-operated or pneumatic oil pump when transferring lubricant from the drum standing on its end.

(4) Provide a strainer in the transfer line if necessary.

(5) Use proper oil handling equipment.

(b) *Requirements for Handling Grease:*

(1) Provide covers for drums and pails. A small amount of contaminant in the grease will alter its intended performance and cause bearing damage.

(2) Use proper transfer equipment. Avoid if you can, using bare hands in transferring grease from the drum to smaller containers.

(3) Use proper grease dispensing equipment for different size containers.

(4) Provide facilities for cleaning up lubricant spills to avoid unsightly floors and accidents.

(5) Provide facilities for cleaning tools and equipment after use. This prevents contamination of different products handled with the same dispensing equipment.

5.6 ANALYSIS OF USED OIL

Sooner or later the oil in the system needs to be changed. When a new equipment is to be purchased, the manufacturer will recommend that the oil be changed after certain number of hours (or kilometers) of operation. While this is an excellent guideline, it is based on a conservative estimate of the operating conditions. Oil analysis can help establish a drain interval which is appropriate to the actual conditions of operation. It also serves to determine the level of quality of the oil being used.

Establishing drain interval with the help of oil analysis can:

- save the cost of unnecessary oil changes.
- prevent expensive repair jobs.

Used oil analysis is the inspection of in-service, drained or reclaimed lubricants, which enables the lubricant user to:

1. Determine the condition of the oil. Once it has reached its limit of usefulness it should be replaced.
2. Know some clues which may suggest that an engine or a mechanical part is having mechanical problems. If we learn how to interpret these clues, these problems can be fixed before they grow worse and cause permanent damage. Progressive analyses of metals present in the oil could be used to measure the wearing out process of equipment parts.

Major oil suppliers normally provide this laboratory service free of charge. In most cases the laboratory reports include comments and recommendations.

The analytical tests on used oil are conducted for the following parameters:

a) API Gravity
b) Kinematic or Saybolt Viscosity
c) ASTM Dilution (gasoline engine oils)
d) Estimated Dilution
e) Color
f) Normal Pentane Insoluble
g) Benzene Insolubles
h) Ash
i) Analysis of Ash
j) Neutralization Number
k) Moisture Content
l) Flash Point

Decreases or increases in parameter measurements between new and used oil give indication of contamination and deterioration, or evidence of trouble in the lubricated component. Table 5.3 shows these indications.

Sending oil samples to oil company laboratories for analysis and transmittal of test results to the oil user take time. Hence, in situations where results need to be known immediately, say, to verify certain oil properties critical to the equipment welfare quick on-the-plant or field methods of testing could be done. Field Test Kits are available for this purpose.

5.7 OIL RECYCLING

To conserve oil, interest in oil recycling has been given much interest. ASTM has proposed the following definition for this purpose:

a. *Used oil* – oil whose characteristics have changed since being originally manufactured, but which may be suitable for further use, and is economically recyclable.
b. *Waste oil* – oil whose characteristics have changed markedly since being originally manufactured, has become unsuitable for further use, and is not considered economically recyclable
c. *Recycling* – the generic term for processing used oil in order to recover useful material. There are two types:
    1. *Re-refining* - The use of refining processes on used oil to produce base stocks, which could be made of good quality depending on the degree of refining for blending again with the appropriate additives to meet certain specifications/standards Re-refining may include distillation, hydro-treating, and/or treatments employing acid caustic, clay, etc.
    2. *Reclaiming* - the use of cleaning methods on used oil primarily to remove insoluble contaminants, thus, making the oil suitable for further use. The methods may include setting, heating, dehydration, filtration and centrifuging.

A good re-refined oil, just like straight-mineral oil, contains no additives and therefore while it may have initial suitability, say the correct viscosity, it doesn't have the quality required for non-once through applications. On the other hand, a reclaimed oil may still contain sufficient additives and therefore suitable for further service if through dehydration, centrifuging or other appropriate process.

Table 5.3 Significance of Changes in Test Results

Source: Reference 10

TEST	DECREASES	INCREASES
API Gravity	1. Mixture with heavier oil. 2. Mixture with bunker fuel. 3. Accumulation of sediment or sludge. 4. Water contamination.	1. Mixture with higher oil. 2. Mixture with diesel fuel.
Flash Point	1. Contamination with gasoline or diesel fuel. 2. Mixture with a low flash point oil.	1. Source of fuel contamination removed. 2. Addition of make-up oil.
Viscosity	1. Dilution with fuel. 2. Mixture with a high-bodied oil.	1. Mixture with a heavy-bodied oil. 2. Accumulation of sediment or sludge. 3. Deterioration of the oil. 4. Water emulsified with oil.
Sediment	1. Removal of filters. 2. Addition of make-up oil. 3. Reduction in rate of contamination.	1. Filters cartridge dirty. 2. Contamination with dirt. 3. Increase in blow-by in engines. 4. Wear.
Water	1. Settling out in system. 2. Removal of additives by activated clay filter. 3. Reduced water leakage	1. Cooling water leak. 2. Steam condensation.
Ash	1. Sediment removal by filter. 2. Removal of additives by activated clay filter. 3. Addition of "Straight Mineral" oil. 4. Reaction with acidic products of combustion.	1. Contamination with dirt or rust. 2. Wear.
Neutralization Number	1. Addition of make-up oil. 2. Removal of sediment or sludge.	1. Contamination with acidic combustion products 2. Deterioration of the oil
Fuel Dilution	1. Addition of make-up oil. 2. Elimination of fuel leaks.	1. Leakage of diesel fuel into the oil. 2. Faulty injection. 3. Cold operation or excessive "choking" of gasoline engines.

For used oil that could no longer be acceptably reclaimed in the plant, two choices are available: sell it to re-refiners (there are 4 major ones in the Philippines) or burn it as fuel, either with bunker, or with diesel fuel for automotive application as described in Reference 11

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CHAPTER 6

Corrosion Prevention and Control

6.1 DESCRIPTION AND SIGNIFICANCE

6.1.1 Description

Corrosion is defined as the destruction or deterioration of a material by chemical or electrochemical reaction with its environment. In common practice, the term "corrosion" applies to metals, but it is preferable to use the broader definition. Deterioration by physical causes is called erosion, galling or wear. "Rusting" applies to the corrosion of iron and steel, resulting in the formation of oxides.

The rate of corrosion usually depends on the following factors:

- (a) the material itself
- (b) the corrodent
- (c) the nature of the corrosion product formed
- (d) temperature
- (e) pressure of containment
- (f) electrical potential between the two materials
- (g) the relative velocity between the metal and the corrodent.

The relationship between these factors and their relative importance determines the type of the corrosion damage. (See References 2, 4, 5 and 6). Corrosion rate has been expressed in various ways as shown in Table 6.1. Mils per year (mpy) is the most desirable unit of measure. Table 6.2 shows the conversion factors for corrosion rate units.

The primary elements involved in the occurrence of corrosion are the materials and the environment. A working classification of the various metals that comprise most of our construction materials is shown in Table 6.3. Four typical environmental exposures are described in Table 6.4.

6.1.2 Significance of Corrosion Control

Unless corrosion is checked, the following unexpected failures could occur:

- (a) Plant Shutdown. A corroded part of an equipment which is critical to plant operation, like a boiler, can cause the shutdown of the entire plant.
- (b) Loss of Product. Leak of a valuable product in fluid form through a corroded pipe can be very costly.
- (c) Contamination of Product. Quality and value of a product can be severely affected by contamination due to corrosion.
- (d) Degradation of Appearance. Corroded surfaces do not look pleasant to observers.
- (e) Reduced Efficiency. Heat transfer and flow of electricity through a corroded material could be diminished significantly. Clogging of pipes with rust hampers the flow of fluids.

Table 6.1 Comparison of Corrosion-Rate Expressions for Engineering Applications
Source: Reference 2

Expression	Comment
Weight loss, g or mg Percent weight change	Poor – sample shape and exposure time influence results.
Milligrams per square decimeter per day (mdd) Grams per square decimeter per day Grams per square centimeter per hour Grams per square meter per hour Grams per square inch per hour Moles per square centimeter per hour	Good – but expressions do not give penetration rates.
Inches per year (ipy) Inches per month (ipm) Millimeters per year	Better – expressions give penetration rates.
Mils per year (mpy)	Best – express penetration without decimals or large numbers

Table 6.2 Conversion of Corrosion-Rate Units

Given Units	Dimensions	Multiplier To Convert To mpy, mils/yr
ipy	in/yr	1,000
ipm	in/mo	12,000
mm/yr	mm/yr	39.4
μm/yr	μm/yr	0.039
pm/sec	pm/s	1.24
g/(sqm)/(hr)	$g/m^2/h$	$345/\rho$*
mdd	$mg/dm^2/d$	$1.44/\rho$
g/(sqm)/(sec)	$g/m^2/s$	$1.24/\rho$

* ρ is metal density, g/cu cm

Table 6.3 Common Construction Materials

- a. Light Metals – magnesium, aluminum and their alloys
- b. Ferrous Metals – cast iron and alloy cast irons, carbon steel, low alloy steel and alloy steels
- c. Stainless Steels – martensitic, ferritic, superferritic, austenitic, precipitation – hardening and special grades.
- d. Lead, Tin and Zinc
- e. Copper, Brass and Bronzes
- f. Nickel and its alloys
- g. Chromium-bearing Nickel Alloys – N06600 (Alloy 6001), N06625 (Alloy 625), N06007 (Alloy G), N10276 (Alloy C276).
- h. Cobalt-based alloys
- i. Reactive Metals – Titanium, Zirconium and Tantalum
- j. Precious Metals – Silver, Platinum and Gold

Table 6.4 Four Typical Environmental Exposures

a.	Atmospheric Exposure. This includes not only natural environments (traditionally considered to be rural, marine or industrial; or some combination of these), but also specifically contaminated atmospheres such as those containing hydrogen sulfide, ammonia, sulfur dioxide, etc.
b.	Aqueous Environments. This include natural or industrial waters, as well as extremely dilute solutions of inorganic or organic chemicals.
c.	Soil. This includes underground installations of piping or vessels and the soil-side of structures such as tank bottoms.
d.	Process. This includes organic or inorganic synthesis and other processing environments that affect materials.

The engineer might then overdesign his equipment, which would be costly and sometimes ineffective. It pays to have an adequate knowledge of the technology of corrosion, especially its prevention and control.

6.2 TYPES OF CORROSION DAMAGE

Corrosion damage can be classified into three groups:

Group I. Corrosion damage which is readily identifiable by visual examination

a. *Uniform Corrosion.* This is corrosion over the general surface of the material exposed to the corrodent, without appreciable localization of attack. Examples are the rusting of iron, tarnishing of silver and "fogging" of nickel.
b. *Localized Corrosion.* This is a corrosive attack limited to a specific, relatively small surface area whereas the remaining area is largely unattacked. Depth of corrosion is usually described by the pitting factor, which is the ratio of the deepest metal penetration to the average penetration. A pitting factor of unity represents uniform attack. Examples: iron buried in soil forms shallow pits when corroded; stainless steel immersed in seawater forms deep pits.
c. *Galvanic Corrosion.* This is a form of corrosion that occurs when a metal or alloy is electrically coupled to another or to a conducting material in the same electrolyte, the two materials being of two different electrical potentials.

Group II. Types of corrosion which may require supplementary means of examination other than visual.

a. *Velocity Effects.* These are forms of corrosive attack associated with the motion of a fluid relative to the metal. There are three types of corrosion due to velocity effects.

   1. Erosion-corrosion or impingement attack. This occurs in flowing mediums containing no abrasive particles whereby the velocity of the fluid is sufficient to remove weakly adhered corrosion products from the surface, reducing their polarizing or inhibitive effect resulting in an accelerated corrosion process.
   2. Cavitation. This is a mechanical damage process caused by collapsing bubbles in a flowing liquid with no significant contribution by hard particles or corrosion but rather often induced by sharp surface discontinuities, such as sharp-edged holes or shoulders and changes in fluid pressures.

3. Fretting. This occurs due to the relative motion and sliding contact of two surfaces which are not intended to move in that fashion resulting to loosening of hubs on shafts, fouling of precision mechanisms by debris and accelerated fatigue when both fretting and fatigue load patterns are present.

b. *Intergranular Corrosion.* This is localized corrosion occuring at or adjacent to the grain boundaries of a metal. An example is sulfur attack on the grain boundaries of heated nickle.

c. *De-alloying Corrosion.* This is a corrosion process whereby one constituent of an alloy is preferentially removed, leaving an altered residual structure. An example is dezincification or the loss of zinc from a zinc-copper alloy, leaving a porous surface of corrosion products and residues on the remaining metal.

Group III. Types of corrosion which may usually be verified by microscopy of one kind or another (optical, electron scanning, etc.). These are sometimes apparent to the naked eye.

Cracking. This is a phenomenon which occurs under two different conditions or causes:

1. Corrosion fatigue. This is the cracking of a metal when subjected to repeated or alternate tensile stresses in a corrosive atmosphere.
2. Stress corrosion cracking. This is the cracking of a metal due to a constant tensile stress and exposure to a specific corrosive environment. Intergranular corrosion failures under conditions of tensile stress fall under this classification

6.3 DETECTION AND ANALYSIS OF CORROSION PROBLEMS

Inspection tests and procedures for corrosion problems are generally either visual or instrumental. They can also be classified according to: (a) direct observation, (b) nondestructive testing methods, (c) conventional chemical and electrochemical methods and (d) onstream monitoring techniques. The common techniques of corrosion monitoring are listed in the Table 6.5.

Table 6.5 Common Corrosion Monitoring Techniques

Direct observation	Visual/optical techniques Coupon testing Sentinel holes
Nondestructive testing methods	Radiography Ultrasonics Eddy-current measurements Thermography Accoustic emission
Conventional chemical and electrochemical methods	Analytic measurements Potential measurements Galvanic measurements
Onstream monitoring techniques	Electrical-resistance measurements Polarization-resistance measurements (complex impedance methods)

In selecting the monitoring technique to be used, the following questions may serve as guides:

a. What does the technique measure?
b. In what range of environments can it operate?
c. Does it give information about plant or probe?
d. How rapidly can a reading be obtained?
e. How rapidly does it respond to change?
f. Are specialist skills required for interpretation?
g. Is sophisticated technical backup required?

The characteristics of the common corrosion-monitoring techniques which provide answers to the above questions are shown in Table 6.6. Investigation of the costs involved in using these techniques will help in making a decision as to which to adopt.

The direct observation methods and electrical monitoring devices are briefly described here. They are the most commonly used techniques. A more substantive discussion of the other techniques is found in Reference 8.

Visual inspection is the simplest method of corrosion monitoring. It is basically qualitative and can be semi-quantitative when gages, closed-circuit TV or other instruments are used. This technique is normally limited to accessible areas that may be examined on shutdown.

The *coupon technique* is widely used and is more flexible than visual inspections. A sample of the material to be evaluated is prepared, usually as a rectangle or a circle. This is exposed to the corrosive environment. From the weight loss, surface area and exposure time of the coupon, the penetration rate can be calculated in mils per year. This represents the average uniform corrosion rate on one side of the metal exposed to the particular environment.

If localized corrosion is suspected, it is necessary to visually examine the coupon usually with low power magnification. The general corrosion rate is fairly useful if the localized attack is surface roughening. This method does not apply to pitting, stress corrosion cracking or intergranular corrosion.

Sentinel holes are drilled at selected points of a metal up to a depth equal to the minimum allowable thickness. When the remaining thickness of corrosion allowance is corroded, leaking will occur and this serves as a warning that the minimum allowable thickness has been reached. The leak can be plugged until repair or replacement is done. This method is convenient in some cases but may not be appropriate in other applications.

Electrical Resistance (ER) Probes use the increasing electrical resistivity of a conductor with decreasing cross-sectional areas as a gauge of corrosion rate.

Linear Polarization Resistance (LPR) Probes measure the corrosion rate of a metal surface by interacting electrically with the minute currents resulting from ionizing of the metal atoms in the corrosion process. These provide instantaneous estimate of corrosion rate.

The following is a prescribed procedure for plant investigation of corrosion failures (Reference 8):

1. Get as close to the failure as possible.
2. Sketch or photograph failed and adjacent areas.
3. Determine the function of the material giving problems.
4. Get information on the corrodent, such as concentration, temperature, pH, agitation and impurities.
5. Examine all available records that define the time in service, startup procedure, fluctuations in temperature, pH, etc.
6. Find out what experience and data were used to make the original material selection.

Table 6.6 Characteristics of Corrosion-Monitoring Techniques

Source: Reference 9

Technique	Type of information	Type of Corrosion	Environment	Relation to plant	Time for measurement	Response to change	Ease of interpretation
Visual/ optical	distribution (rate of attack)	localized	any	accessible areas on plant	slow	slow	easy
Coupons	average rate; type of attack	general or localized	any	probe	long exposure	slow	easy
Sentinel holes	"go/no go" on thickness	general	any, gas or vapor preferred	localized on plant	slow	slow	easy
Radiography	distribution thickness	pitting, possibly cracking	any	localized on plant	fairly slow	slow	generally easy
Ultrasonics	remaining thickness, presence of cracks, pits	general or localized	any	localized on plant	fairly rapid	fairly slow	needs experience, otherwise easy
Eddy current	cracks, pits	localized	any	localized on plant	fairly rapid	fairly slow	needs experience
Thermography (infrared)	distribution of attack	localized	any; temperatures warm or subambient	localized on plant	rapid	slow	easy
Acoustic emission	cracking, cavitation leaks	–	any	generally on plant	instantaneous	rapid	generally easy
Analytical and related	state; total corrosion; item corroding	general	any	generally on plant	normally fairly rapid	normally fairly rapid	generally easy, needs plant knowledge
Potential measurement	state; indirect indication of rate of attack	general or localized	electrolyte	probe or plant in general	instantaneous	rapid	generally easy, needs experience
Galvanic (zero-resistance ammeter)	state; galvanic effects	general or unfavorable conditions localized	electrolyte	probe or, occasionally, plant in general	instantaneous	rapid	generally easy, needs experience
Electrical resistance	integrated corrosion	general	any	probe	instantaneous	moderate	generally easy
Polarization resistance	rate	general	electrolyte	probe	instantaneous	rapid	generally easy

7. Evaluate whatever neighboring equipment is a factor (e.g., by galvanic effects, or by emitting corrosive product).
8. Listen to and ask questions of the personnel who operate and maintain the equipment as well as those responsible for its design and replacement.
9. Avoid preconceived judgements as to the cause of failure by unqualified personnel.
10. Avoid giving an immediate analysis of the problem if you plan to do more work on it.
11. Give precise instructions as to what samples, if any, are to be taken for laboratory work. Also, how they should be identified or packaged.
12. Give plant personnel an outline of what else you plan to do, and specifically when you will report back to them.
13. Write a report of your visit.

6.4 PREVENTION AND CONTROL MEASURES AGAINST CORROSION

Unexpected failures due to corrosion are caused by one or more of the following:

a. Poor choice of material
b. Improper design
c. Defective material
d. Defective fabrication
e. Operating conditions different from those anticipated
f. Inadequate maintenance

There are at least five types of methods used for corrosion prevention and control: a) materials selection, b) alteration of the environment, c) design, d) cathodic and anodic protection and e) coatings.

6.4.1 Materials Selection

Proper selection of the material to be used for a given environment is the most common way of preventing the occurrence of corrosion damage.

Three general rules for materials selection are:

(a) For reducing or non-oxidizing environments such as air-free acids and aqueous solutions, nickle, copper and their alloys are good materials against corrosion.
(b) For oxidizing environments, chromium-containing alloys are appropriate.
(c) For highly oxidizing conditions, titanium and its alloys are corrosion-resistant.

Tantalum is considered as an "ultimate" corrosion resistant material, resisting most acids at all concentrations and temperatures.

Table 6.7 is a guide for the selection of materials which are resistant to certain environments.

It should also be useful to know the environments in which certain materials are vulnerable to corrosion. Table 6.8 shows combinations of some alloys and environments that have been proven to prompt stress corrosion cracking.

Mild steel, which is commonly used as a material of construction, is corrosion-resistant in sulfuric acid but is easily corroded by nitric acid.

Rubbers and plastics are generally more resistant than metals and alloys in the presence of chlorides and hydrochloric acid. They are, however, more vulnerable to strong sulfuric acid, solvents and nitric acid. Ceramics are very resistant to corrosion and high temperatures but can fail under tensile stresses.

Tables in Appendix VI provide a list of metals of the electromotive force series and the galvanic series. From these tables, one can easily predict the relative tendency of a metal to corrode in a given environment over another metal in the series. In both tables, the metal with the higher absolute electrode potential is more susceptible to corrosion. The EMF series is useful in the theoretical explanation of the relative anodic and cathodic tendencies of various metals. Values in the galvanic series were obtained under more practical conditions of exposure to seawater. Besides giving an indication as to which metals are more corrosion-resistant in seawater, the table is useful in determining whether a galvanic couple of dissimilar metals will result in a corrosion problem or not.

Certainly, there are other factors to consider in selecting materials of construction besides resistance to corrosion. These include cost, availability of the material, ease of fabrication and appearance. The best material is what effectively serves its intended application with the least cost throughout its lifecycle.

Table 6.7 Corrosion-Resistant Materials for Given Environments

Source: Reference 2

Corrosion-Resistant Material	Environment
1. Stainless steels	– Nitric acid
2. Nickle and nickel alloys	– Caustic
3. Monel	– Hydrofluoric acid
4. Hastelloys (Chlorimets)	– Hot hydrochloric acid
5. Lead	– Dilute sulfuric acid
6. Aluminum	– Nonstaining atmosphere exposure
7. Tin	– Distilled water
8. Titanium	– Hot strong oxidizing solutions
9. Steel	– Concentrated sulfuric acid
10. Tantalum	– Almost any environment

Table 6.8 Material-Environment Combinations That Promote Stress Corrosion Cracking

Source: Reference 13

Material	Environments
Al alloys	Chlorides, moist air
Mg alloys	Chloride-chromate mixture, moist air Nitric acid, flourides Sodium hydroxide
Cu alloys	Ammonia, moist air, moist sulphur dioxide
C steels	Nitrates, hydroxides, carbonates Anhydrous ammonia
Austenitic steels	Chlorides, sulphuric acid
High strength steels	Moist air, water, chlorides, sulphates, sulphides
Ni alloys	Hydroxides
Ti alloys	Halides, methanol

6.4.2 Corrosion Control at the Design Stage

Mechanical design of a component is based on the material of construction. An effective design approach considers the following technical factors:

(a) strength
(b) mechanical characteristics
(c) allowance for corrosion

The most commonly encountered design problem against corrosion is determining the wall thickness. A rule of thumb is to specify a thickness twice that which would give the desired life. For example, if a tank is to last for 10 years and the corrosion rate of the material is 12 mpy, then the expected thickness to be corroded in this lifetime is 3.2 mm. The design should specify a thickness of 6.4 mm. against corrosion. This thickness is evaluated with respect to the other design factors, like weight, pressure and stress. Table 6.9 and 6.10 indicate the corrosion rates of some metals in given environments.

Figure 6.1 shows design details which are vulnerable to corrosion due to the collection of debris.

Some design rules that can be followed to minimize the occurence of corrosion, as given in Reference 1, are:

(a) Tanks and other containers are better welded than riveted. Crevice corrosion is more likely in riveted joints.
(b) Tanks and other containers must be designed with provision for drainage and easy cleaning. Tank bottoms should slope toward drain holes. Any detail that can trap water is more vulnerable to corrosion. Figure 6.2 shows a few tips in designing with provision for drainage.
(c) Parts and components that are likely to fail should be so designed and installed that easy replacement can be done. In chemical plants, pumps are usually installed in such a way that they can be easily removed when they fail.
(d) Mechanical stresses and stress concentrations should be avoided in components exposed to corrosive mediums. This rule applies particularly to stainless steels and brasses which are vulnerable to stress-corrosion cracking.
(e) In using dissimilar metals, electric contact should be avoided to prevent galvanic corrosion. Insulators can be used at the areas of contact particularly for materials which have a significant potential difference. Figure 6.3 shows some designs for insulating joints.
(f) Sharp bends in piping systems should be avoided because they tend to promote corrosion. This aspect of design is considered most particularly for lead, copper, and their alloys which are vulnerable to this type of corrosion.
(g) Hot spots in heat transfer equipment should be avoided. Corrosion rates are high in hot spots. Uniform temperature gradients can be ensured through proper design of heat exchangers and other heat transfer devices.
(h) Design to prevent air entrainment. If oxygen is eliminated, corrosion due to oxidizing reactions can be prevented. Attention should be focused on areas where air can enter like liquid inlets and agitators. This rule does not apply when the materials used are active-passive metals and alloys such as titanium and stainless steels which are more resistant to acids containing dissolved air and other oxidizers.
(i) The general design rule is: avoid heterogeneity. Uneven heat and stress distributions, use of dissimilar metals, existence of vapor spaces and other differences between points in the system make it more susceptible to corrosion. The design approach should be to make all conditions as uniform as possible throughout the entire system.

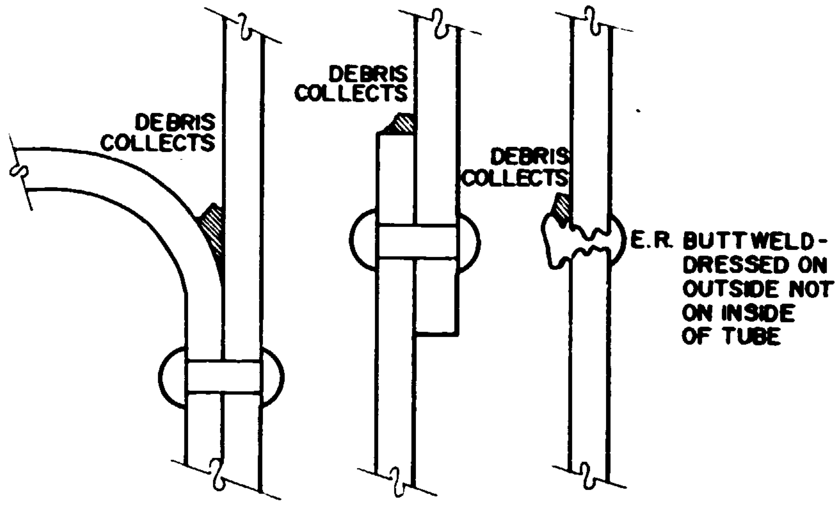

Figure 6.1 Design Details Likely to Result in Corrosion Because of the Entrapment of Debris

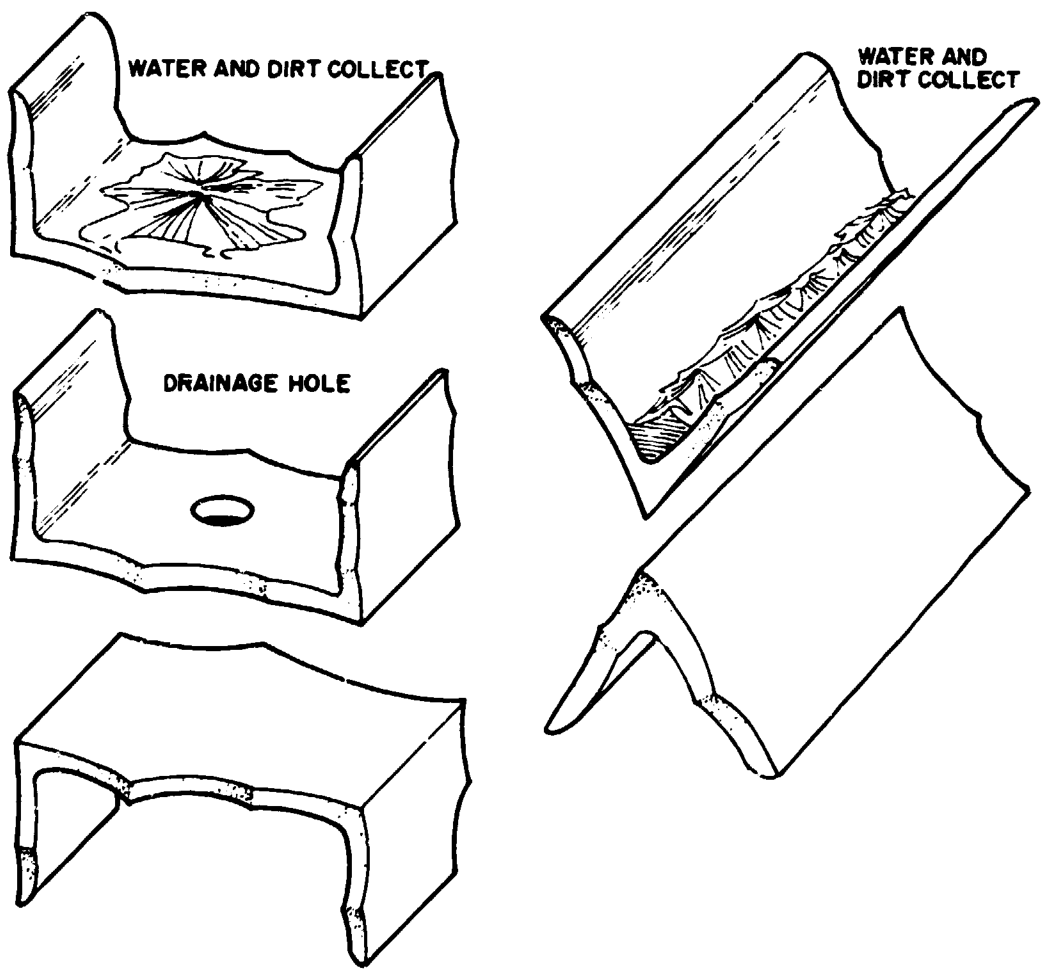

Figure 6.2 The Importance of Drainage Facilities in Corrosion Control

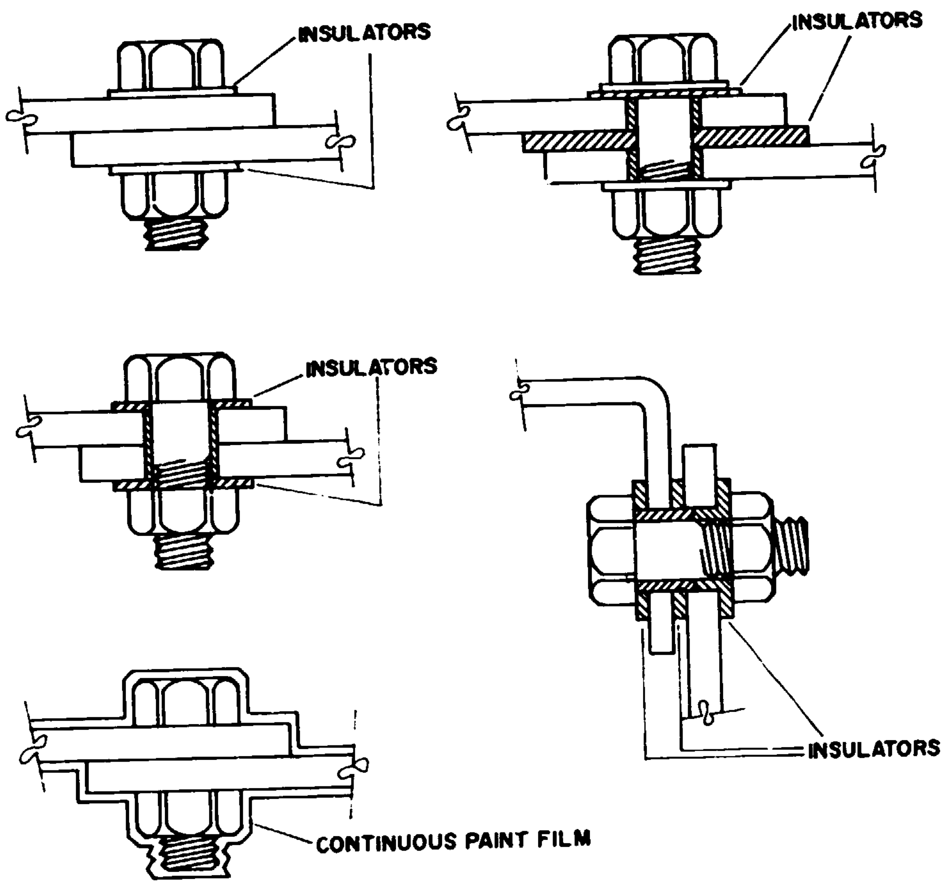

Figure 6.3 Designs for Insulating Joints to Avoid Possible Corrosion

Table 6.9 Penetration Rates of Various Metals Exposed to Different Atmospheric Conditions (mm x 10^{-3} per year after 10 years of exposure)

Source: Reference 11

Metal	Atmosphere		
	Industrial	Marine	Rural
Aluminum	0.81	0.71	0.025
Copper	1.91	1.32	0.58
Lead	0.43	0.41	0.48
Zinc	5.13	1.60	0.86
Mild Steel	13.72	6.35	5.08
'Cor-Ten' Steel (0.4% Coopers 1% Chromium 0.1% Phosporous)	2.54	3.81	1.27

Table 6.10 Penetration Rates for Various Steels in Different Acids (mm/yr)

Source: Reference 11

Steel	70% Nitric Acid 60°C	20% Hydrochloric Acid 20°C	80% Sulphuric Acid 20°C
Mild Steel	Very High	38	0.4
13% Chromium	0.15	120	4.5
12% Chromium 12% Nickel	0.05	5	0.5
17% Chromium	0.1	35	0.7
18% Chromium 8% Nickel	Nil	25	1.5

6.4.3 Alteration of the Environment

(a) Typical Changes

To reduce corrosion, some conditions of the corroding medium or environment can be changed using the following techniques:

(1) *Lower the temperature.* For many environments, application of this method results in a significant decrease in corrosion rate. There are some exceptions where temperature changes have little effect on corrosion attack (see Reference 1).

(2) *Reduce the velocity.* Very high velocities cause erosion-corrosion effects. For most applications, decrease in velocity reduces corrosion rate. Exceptions are metals and alloys that passivate, like stainless steels, which are more corrosion-resistant to flowing mediums than stagnant solutions.

(3) *Remove oxygen or oxidizers.* Deaeration, vacuum treatment, inert gas sparging and the use of oxygen scavengers are the techniques used. These are used for most applications except active-passive metals or alloys, which require oxidizers to form this protective films and are vulnerable to reducing or non-oxidizing environments (see Reference 1).

(4) *Change the concentration.* Normally, the corrosion rate is reduced by decreasing the concentration. On the other hand, many acids like sulfuric and phosphoric acids are less corrosive at higher concentrations at moderate temperatures.

(b) Use of Inhibitors

Inhibitors are substances which, when added in small concentrations to a corroding medium, reduces the corrosion rate.

The types of inhibitors are:

(1) *Passivating Inhibitors.* These consist of oxidizing anions such as chromate, nitrate, and nitrates.

(2) *Cathodic Inhibitors.* These work through inhibition by polarization of the cathodic reaction, i.e. taking over the reaction with the excess dissolved oxygen in the electrolyte. These include cathodic poisons, i.e. sulfides, selenides, or arsenates ;cathode precipitates such as car-

bonates of calcium and magnesium and zinc sulfate; and lastly, the more popular oxygen scavengers such as sodium sulfite and sulfur dioxide.

(3) *Organic Inhibitors.* These constitute a broad class of corrosion inhibitors which cannot be designated specifically as cathodic or anodic. Probably both anodic and cathodic areas are inhibited but to varying degrees depending on potential of the metal, chemical structure and size of the inhibitor molecule.

(4) *Precipitation Inhibitors.* These are precipitate – inducing inhibitors that form a general film over the metal surface and interfere with both anodes and cathodes indirectly.

(5) *Vapor Phase Inhibitors.* These are compounds which are transported in a closed system to the site of corrosion by volatilization from a source.

There a.. three prominent mechanisms by which the rate of corrosive attack of the environment on the metal is reduced by inhibition namely:

(1) Absorption on the metal surface of an invisible thin protective film formed by the reaction between the inhibitor with the oxygen content of the surrounding electrolyte or other corrosion products on the surface of the metal.

(2) Formation of bulky visible precipitates on the metal surface acting in some manner as a protective coating.

(3) Adsorption of a passive layer of corrosion products on the surface of the metal.

Inhibitors can be introduced into the system onstream or even during storage by the following techniques:

(1) *Continuous Injection.* This is practiced in once-through ··· tems where slugs or batch treatment cannot be distributed evenly through the fluid.

(2) *Batch Treatment.* A quantity of inhibitor is added at one time to provide protection for an extended period with additional treatment done periodica'

(3) *Squeeze Treatment.* This is a method of continuously feed... e inhibitor into an oil well.

(4) *Volatilization.* This is applied to vapor phase inhibitor· commonly introduced into boilers and closed containers.

(5) *Coatings.* This is used in coatings exposed to the atmosphere, by being leached out of the paint when water comes in contact with the paint coa..ng.

6.4.4 Cathodic and Anodic Protection

(a) *Cathodic Protection*

Cathodic protection is the reduction or elimination of corrosion by making the metal a cathode either by an electrical power supply or by appropriate galvanic coupling to a sacrificial anode (usually magnesium, aluminum or zinc). Its application belongs to the hands of experienced specialists.

Corrosion occurs when electricity flows from the metal (positively charged) to the corroding environment (negatively charged). Cathodic protection reverses the flow of current.

(1) Cathodic Protection by Impressed Current

Figure 6.4 illustrates cathodic protection by impressed current. An external DC power supply is used with the negative terminal attached to the underground tank which is to be protected, and the positive terminal to an inert anode like graphite. The electric connectors are carefully insulated to prevent leakage of current. The anode is normally imbedded in a backfill of coke breeze, gypsum or bentonite. This improves the conduction of electricity from the anode through the soil to the tank. In common practice AC power supply is converted by a rectifier to low voltage DC which is used in the cathodic protection system.

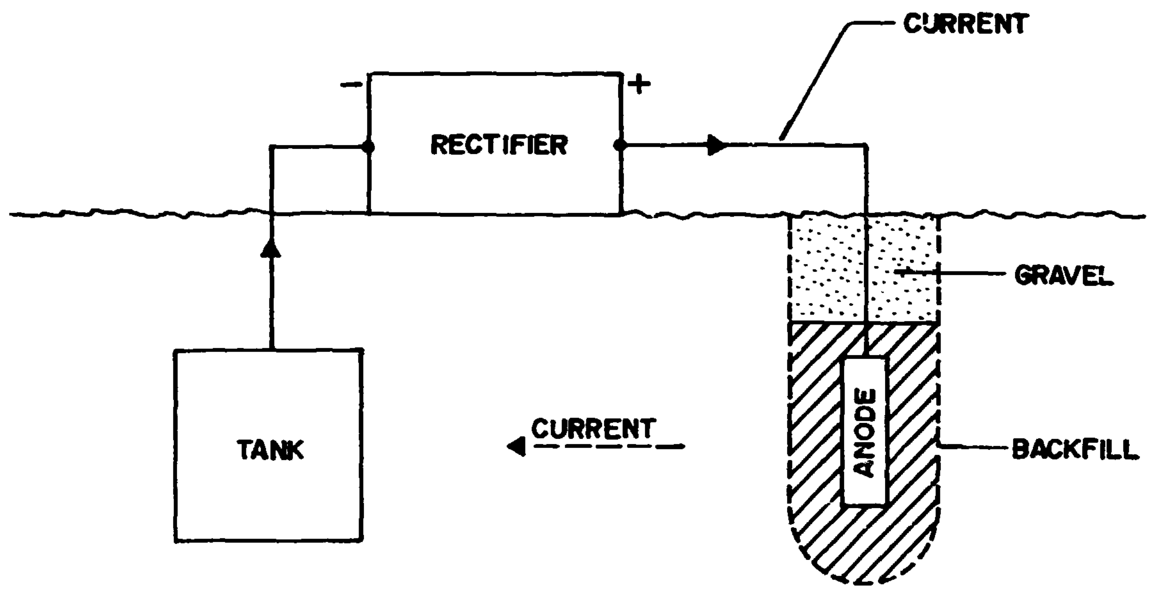

Figure 6.4 Cathodic Protection of an Underground Tank Using Impressed Currents
Source: Reference 2

(2) Cathodic Protection by Galvanic Anodes

Cathodic protection by galvanic coupling to an anode is illustrated in Figure 6.5. Here a structure made of mild steel is protected by including a magnesium sacrificial anode in the corrosion cell system. Connecting magnesium with mild steel in a given electrolyte, say, water, by a wire/conductor, will result in a spontaneous corrosion process where the magnesium is consumed as the anode and the mild steel is spared as a cathode. The selection of the sacrificial anode is based on the Galvanic Series and EMF Series Tables which indicate the relative potential of metals (see Appendix VI).

The current generated from galvanic anodes is limited by their potential values given in the Series. For this reason, cathodic protection by galvanic anodes is normally used where the current requirement for protection is small.

Cathodic protection is now widely used in three broad areas namely:

i. Buried Structures – pipeline and utilities, underground cables and conduits, underground tanks, bottoms of above grade storage tanks, structural foundations, electrical transmission tower footings, sewage lift stations, etc.
ii. Interiors of Tanks and Vessels – water tanks and settling basins, sewage disposal plants, ships' cargo spaces, hot water and filter tanks, elevated fresh water storage tanks, etc.
iii. Submerged Structures, Fresh Water or Salt Water – locks, dams and gates, ship and barge hulls, piers piling and offshore structures, and bridges.

The application of cathodic protection, however, does not replace the use of other protective measures such as the coating systems, inhibitors, appropriate material selection and, control at the design stage. Rather, it is a cost effective application of one or a combination of two or more of these measures to protect the system.

(b) *Anodic Protection*

Anodic protection is based on the formation of a protective film on metals by externally applied anodic currents. This is done through the use of an electronic device called a potentiostat which maintains a metal at a constant potential with respect to a reference electrode. Figure 6.6 shows a schematic diagram of an anodic protection setup.

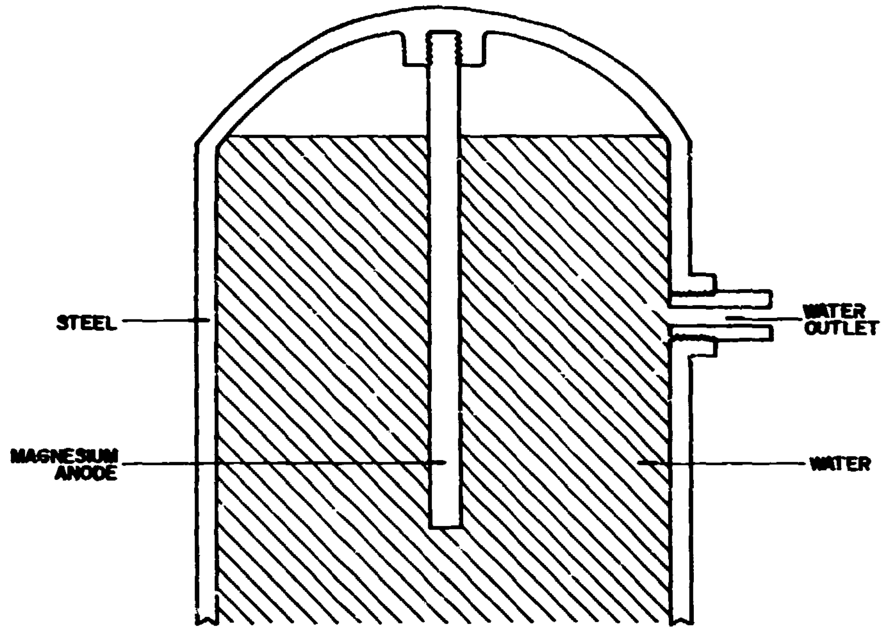

Figure 6.5 Cathodic Protection of a Domestic Hot-Water Tank Using a Sacrificial Anode
Source: Reference 2

The installation of an anodic protection system entails complex intrumentation and high cost. Its primary advantages are: applicability in highly corrosive environments and low power requirements.

Table 6.11 shows a comparison between cathodic and anodic protection.

6.4.5 Protective Coatings

Coatings serve as a barrier between the metal and the environment.

The different mechanisms by which coatings protect can be summarized as follows:

(a) preventing contact between substrate and the environment;
(b) restricting contact between the environment and the substrate;
(c) releasing substances which are inhibitive of attack by the environment on the substrate;
(d) producing an electrical current which is protective of the substrate.

The common classifications of protective coatings are: conversion coatings, metallic coatings, inorganic coatings and organic coatings.

(a) *Conversion Coatings (commonly known as rust converters).* These are inorganic films formed by controlled corrosion on the metal surface. The metal atoms at the surface are converted into metallic coatings that become an integral part of the surface. Phosphate, chromate and oxide coatings are the most common conversion coatings.

The sequence of procedures to produce conversion coatings is presented in Table 6.12.

Generally, phosphate coatings by themselves do not improve corrosion resistance sufficiently to merit the cost of operation. They are almost always used (1) as a base for paint or (2) to absorb corrosion-preventive oils or waxes. Their usual applications are for the protection of complex parts and assemblies.

Chromate coatings are applied to various non-ferrous metals (Zn, Cd, Mg, Al, Cu, Ag, Be). They are increasingly used on aluminum as an alternative to anodizing. They serve as a paint base or as a final coating. Chromates are generally more corrosion resistant than phosphates but are not as effective for absorbing oils or waxes.

Table 6.11 Comparison of Anodic and Cathodic Protection

	Anodic protection	Cathodic protection
Applicability:		
Metals	Active-passive metals only	All metals
Corrosives	Weak to aggressive	Weak to moderate
Relative cost:		
Installation	High	Low
Operation	Very low	Medium to high
Throwing power	Very high	Low
Significance of applied current	Often a direct measure of protected corrosion rate	Complex; does not indicate corrosion rate
Operating conditions	Can be accurately and rapidly determined by electrochemical measurements	Must usually be determined by empirical testing

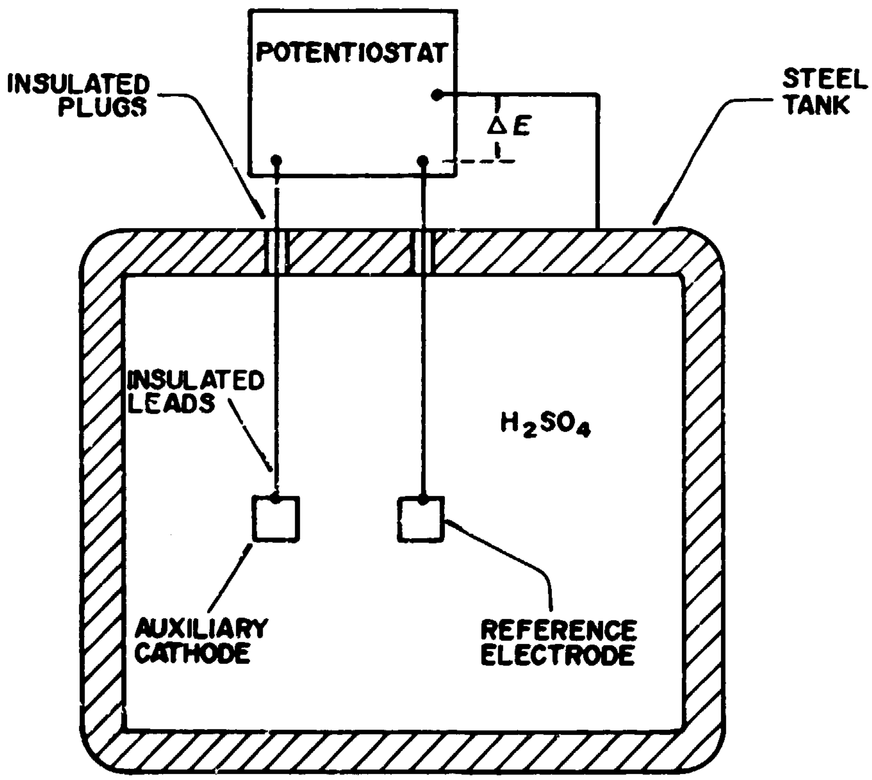

Figure 6.6 Anodic Protection of a Steel Storage Tank Containing Sulfuric Acid

Source: Reference 2

Oxide coatings are applied to a wide variety of metals. Black oxide coating on steel is one of the most common applications, serving to improve appearance and/or abrasion but this can be improved with the addition of oils, waxes or lacquers.

Anodizing is a widely used type of oxide coating technique. A common application is anodized aluminum. Anodizing serves to increase resistance to corrosion and abrasion or as a paint base.

(b) *Metallic Coatings.* Metals can be applied as coating to other metals and alloys, by using one or more of the techniques listed in Table 6.13.

Hot dipping is done by immersing the material in a molten batch of the coating. Galvanizing or zinc-coating of steel is the most common application. This method is used when a relatively thick coating is required, when the material is not very complex in form, or when there is no particular requirement for coating thickness.

Metal spraying, flame spraying or metallizing involves the application of a spray of molten metal droplets. This technique is applicable to large structures in the field and is useful for repair

Table 6.12 Sequence of Procedures to Produce Conversion Coatings

Source: Reference 12

Zinc Phosphate Coating
(such as for steel)

1. Pickle to remove scale, etc., by mechanical or chemical means.
2. Preclean in alkaline cleaner for 4 min. at 77°C
3. Rinse twice in water at 32°C for 1/2 min.
4. Treat with conversion mixture (zinc phosphate) at 71°C for 4 min.
5. Rinse with water for 1/2 min. at 32°C
6. Treat with chromate for 1/2 min. for corrosion protection.
7. Dry

Chromate Coating
(such as for zinc)

1. Pickle to remove scale, etc., by mechanical or chemical means.
2. Degrease with vapor-phase material.
3. Clean with alkaline cleaner at 77°C
4. Rinse
5. Treat with chromate at 27°C for 10 sec. to 1 min.
6. Rinse
7. Dry 66°C maximum

Anodizing
(such as for aluminum)

1. Clean
2. Anodize by making the material the anode in sulfuric acid bath.
3. Rinse
4. Seal by boiling in 4% sodium dichromate for 10 to 20 min.

work. Sandblasting, metal spraying and sealing may be cost-effective for structural steelwork compared with the application of several paint layers. Wire, powder and plasma are the three types of metal-spraying processes used.

Cladding is the bonding of a corrosion-resistant material over the material to be protected. The common materials used for cladding steel are copper, stainless steel, nickle alloys and titanium. The usual applications are pressure vessels, kettles, heat exchangers, reactors and storage tanks. The bonding process is normally done by hot rolling and sometimes by explosive forming. While cladding is a very effective corrosion prevention technique, the following possible problems must be avoided:

(1) Diffusion of unwanted elements from the basic material to the cladding metal during the cladding process or due to welding.
(2) Undesirable metallurgical changes due to heat exposure.

Problems due to welding can be minimized by welding the basic material first before the clad metal.

Electroplating or electrodeposition provides a more uniform coating than hot dipping, a less porous surface than metal spraying and a generally thinner coating. The common design rules for electroplating a metal are: ensure a smooth surface on the basic material, avoid sharp edges and, if possible, concave surfaces.

Table 6.13 Techniques for Applying Metallic Coating

1. Hot Dipping
2. Metal Spraying
3. Cladding
4. Cementation
5. Vapor Deposition
6. Electroplating
7. Electroless Plating
8. Mechanical Plating
9. Metalliding

Chemical vapor-deposition is normally used for coating aluminum on ferrous alloys. Zinc and cadmium powders are sometimes mechanically plated as well as electroless chemical plating have the advantage of eliminating hydrogen embrittlement.

(c) *Inorganic Coatings.* Glass, ceramics and hydraulic cements are the usual inorganic coating fused on to metals for corrosion protection. These coatings do not provide sacrificial protection or inhibitive action and should therefore completely isolate the material from the corrodent. Brittleness and vulnerability to cracking when heated are the main weaknesses of these coatings.

(d) *Organic Coatings.* These are of two types: (1) linings and laminates and (2) synthetic coatings. To this group belongs painting which is the most popular type of coating.

The painting job consists of three basic steps: coating material selection, surface preparation and the final stage of paint application.

(a) *Coating Material Selection*

The prime requirement of a paint of coating material is that it must be suitable for the environment and the service conditions of its use. Selection must be made on an adequate consideration of: its chemical and physical properties with corrosion resistance on top of the list; the environment and service condition that the coating material in such an environment, previous experience and exposure tests available with the material; and finally, the cost of the material.

With respect to service conditions, additional factors must essentially be noted in selecting an appropriate paint system: climatic temperature, sunlight exposure, abrasion on the substrate, and the type of surface to be coated.

(b) *Surface Preparation*

Surface preparation is the most important factor affecting paint and coating performance. Most coating failures are due to improper surface preparation. The methods of surface preparation are described in Table 6.14. Every specific paint system has a minimum surface preparation requirement of any or a combination of these methods.

Coating failures can be classified as follows:

(1) Loss of paint adhesion. Improper surface preparation may leave the mill scale on new construction steel; and rust, old paint, dirt, grease and oil on old construction structural materials. Painting over these materials will result in loss of paint adhesion.

(2) Osmotic blistering. If acids, alkalies, soluble salts and other corrosive contaminants are trapped between the protective coating and the substrate, blistering will destroy the painting system applied.

(3) Under-film corrosion. With the combined effect of loss of adhesion and osmotic blistering corrosion can easily initiate on the surface of the structure being protected even under the coating material. Such can be very obvious on the hills and valleys on the contour of the base metal.

(c) *Paint Application*

Application is nearly as important as surface preparation. The suitability of each method is based on the limitations of working space, surface area of protected structure, and the type of painting system to be used.

(1) Brushing — the most widely used method but also the most misused. Four common faults are:

i. brushing where spray is best

ii. wrong bristle for the type of paint

iii. wrong size of brush

iv. cheap, inefficient brush

(2) Roller — fast, efficient for tanks, walls and fences and even for roofs.

(3) Spray — results in even thickness, fast and efficient for large areas.

The thickness of applied paint is also a measure of the quality of application such that the dry film thickness of any paint system must be noted as a final step.

The painting job, however, must not end at the application stage. Maintenance of the protective coating system must be given special attention as a vital aspect of the protective system's life. Many good coating systems with adequate surface preparation and application tech-

Table 6.14 Surface Preparation Specifications
Source: Reference 13

Specification and subject		Purpose
SSPC-SP 1	Solvent Cleaning	Removal of oil, grease, dirt, soil, salts, and contaminants by cleaning with solvent, vapor, alkali, emulsion or steam.
SSPC-SP 2	Hand Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by hand chipping, scraping, sanding and wire brushing.
SSPC-SP 3	Power Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by power tool chipping, descaling, sanding,, wire brushing and grinding.
SSPC-SP 4	Flame Cleaning of New Steel	Dehydrating and removal of rust, loose mill scale, and some tight mill scale by use of flame, followed by wire brushing.
SSPC-SP 5	White Metal Blast Cleaning	Removal of all visible rust, mill scale, paint and foreign matter by blast cleaning by wheel or nozzle (dry or wet) using sand, grit or shot. (For very corrosive atmosphere where high cost of cleaning is warranted.)
SSPC-SP 10	Near-White Blast Cleaning	Blast cleaning nearly to white metal cleanliness, until at least 95% or each element of surface area is free of all visible residues. (For high humidity, chemical atmosphere, marine or other corrosive environment.)
SSPC-SP 6	Commercial Blast Cleaning	Blast cleaning until at least two-thirds of each element of surface area is free of all visible residues. (For rather severe conditions of exposure.)
SSPC SP 7	Brush-Off Blast Cleaning	Blast cleaning of all except tightly adhering residues of mill scale, rust and coatings, exposing numerous evenly distributed flecks of underlying metal.
SSPC-SP 8	Pickling	Complete removal of rust and mill scale by acid pickling, duplex pickling or electrolytic pickling. May passify surface.

nique have failed without surviving its estimated minimum life because of lack of preventive maintenance awareness on the part of the user.

(d) *New Coating Techniques*

Recent developments in coating techniques include electrostatic spraying, powder coating, force drying and electron beam curing. These are described in Table 6.15.

Table 6.15 Latest Coating Techniques

Electrostatic Spraying. An electric charge is applied to the paint by the spray gun. The charged paint particles are attracted toward the grounded object being coated, depositing at points of maximum electrostatic attraction (thin areas). Can be combined with air and airless spray methods. Advantages: Minimizes overspray, has "wrap-around" effect, edges and protruding irregularities receive heavier coatings. Disadvantages: Requires electric source, electrostatic attraction diminishes as paint thickness increases; water base paints or those using highly polar solvents or containing metallic pigments may be too conductive to be applied by electrostatic spray. The object being coated must be grounded and electrically conductive.
Powder Coating. Coating resins in powder form that are applied by electrostatic spray, fluidized bed or other methods. The coated object is heated, melting and sintering the powder to form a continuous coating. Advantages: Insoluble resins can be applied such as polyethylene, polypropylene, nylon and flourocarbons, as well as other thermoplastic resins. Either thick or thin coatings can be applied in one application. The object can be handled immediately upon cooling. Disadvantages: Powdered materials present health and explosion hazard unless proper precautions are taken; expensive.
Force Drying. This involves the heating of coated object after application to accelerate drying or rate of coating cure. Ventilation system prevents solvent escape into atmosphere. Advantage: Dry time to topcoat or handle shortened. Disadvantage: Expensive to install and operate.
Electron Beam Curing. This is a recent innovation in which electrons are accelerated through a vacuum and directed toward the object being coated by conventional means with a coating capable of being crosslinked. The electron beam excites the reacting molecules, completing crosslinking and cure within seconds. Advantages: Rapid handling and cure times, less solvents in paint. Disadvantages: Cost; only a few coatings can be crosslinked at present (polyesters and acrylics); coatings in excess of seven mils cannot be cured.

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CHAPTER 7

Leak Prevention

7.1 DESCRIPTION AND SIGNIFICANCE

A very common cause of plant shutdown and leak damage to motors and nearby equipment is the failure of a dynamic seal on a high-pressure pump or valve. Significant costs are associated with leaks from equipment like a compressed air system. Proper sealing in a boiler feed pump is necessary to prevent water leak which represents energy loss and water treatment costs.

The leaking of a fluid is a waste of material and energy, and creates an environmental or cleanup problem. Leak prevention is especially significant when safety is involved – the fluid could be an acid, a highly flammable liquid, a toxic gas or scalding steam. In any case, all fluid leaks must be prevented.

In general, it is easy to prevent a fluid from escaping provided that no moving parts are involved. Any openings in a container can be effectively closed with lids or stoppers. Containers may be made of steel, glass, rubber or paper and the fluid could be difficult to contain but some suitable seal or replacement container can always be found.

The problem is much more difficult when a moving shaft has to pass through the seal. The seal has to cope with movement between its own surface and that of the shaft. Much of this chapter will deal with this type of leak.

7.2 LEAK DETECTION AND TESTING

Leak testing for vacuum/pressure vessels is described in Reference 1.

Methods of leak detection and testing include:

a. Visual inspection
b. Use of ultrasonic detector
c. Search gas methods
d. Dye injection
e. Use of radioactive material
f. Vessel pressure methods
   1. isolation/pressure decrease
   2. makeup
g. Acoustic emission technique

A number of visual leak detection techniques are available. The equipment may be pressurized hydraulically and liquid leaks observed. Some kind of coating may be applied on the surface to reveal any leaks more clearly. Alternatively, pneumatic pressurization may be used and detection done using a soap bubble or similar technique. If the container is small, it can be immersed in a liquid, and the air bubbles would indicate the presence and location of leaks.

The use of an ultrasonic detector is a more powerful technique. The high frequency sound of the leak is picked up by the instrument distinctly from other noise.

The search gas methods involve the introduction of a search gas into the pressurizing air and leak is detected by a suitable device. The common gases and corresponding detectors are shown in Table 7.1.

Table 7.1 Search Gases and Detectors for Leak Testing
Source: Reference 3

Search Gas	Detector
Halogen Gas	Halide torch Halogen diode detector
Hydrogen	Thermal conductivity detector
Helium	Thermal conductivity detector
Nitrous oxide	Infrared absorption detector

Injection of a dye or a radioactive material are techniques which make use of tracing the injected matter to detect leaks.

Vessel pressure methods indicate the presence of a leak using pressure as the parameter. One method is to pressurize the system, isolate it and measure the rate of pressure decrease. Another technique is to measure the inlet flow required to maintain the pressure constant.

The acoustic emission (AE) technique detects sub-audible sounds emitted by high pressure leaks and the growth of a crack in a stressed structure.

Visual inspection, ultrasonic detection search gas methods and dye injection are the more common techniques for locating leaks. Search gas and vessel pressure methods are good for leak measurement. The ultrasonic detector and the more advanced acoustic emission technique are particularly useful for leak detection during onstream operation.

7.3 GENERAL LEAK PREVENTION TECHNIQUES

Leak prevention is always associated with sealing. The general classifications of sealing techniques are:

a. Permanent seals
b. Demountable seals
c. Electrical lead-throughs
d. Seals for transfer of materials

7.3.1 Permanent Seals

Different techniques are used for different materials in making permanent seals. Table 7.2 gives the permanent sealing methods for metal parts, glass-to-glass, glass-to-metal and ceramic-to-metal.

Some recommended arrangements of welded joints for vacuum seals are shown in Figure 7.1 together with incorrect practices which are to be avoided. The following points should be observed in the design and construction of welded seals for vacuum applications (Reference 3):

a. The joints must be designed and welded with full penetration, avoiding trapped volumes which may collect contaminants.
b. Single-pass welds should be applied whenever possible. Double-pass welds create trapped volumes which make leak detection difficult.

Table 7.2 Permanent Sealing Techniques for Different Materials

Source Reference 3

MATERIAL	PERMANENT SEALING TECHNIQUE
Metal parts	Welding, brazing
Glass-to-glass	Fusion
Glass-to-metal	Techniques specific to the metal used
Ceramic-to-metal	Use of glass as intermediate material Sintered metal techniques

c. Welds should be made on the vacuum side of the vessel.
d. If for reasons of strength a double weld is necessary, the inside weld should be the leak-tight one. Drilled and plugged holes should be provided on the outside weld for purposes of leak detection.
e. Any necessary structural welds inside the vessel should be made discontinuous to allow easy flow of gases from any pocket. These structural welds should not cross the sealing ones.
f. The welded assembly should be designed so that a maximum number of welds could be tested separately in the construction stage and corrected before final assembly.

For making brazed joints, the following points should be observed:

a. The smallest quantities of brazing alloy should be used. Better joints are obtained with small clearances and clean surfaces than when applying big quantities of brazing alloy.
b. Wide or irregular spaces between parts are to be avoided.
c. The overlap between two parts to be brazed must be a minimum of 3 mm, in order to allow capillary forces to suck in the brazing alloy.

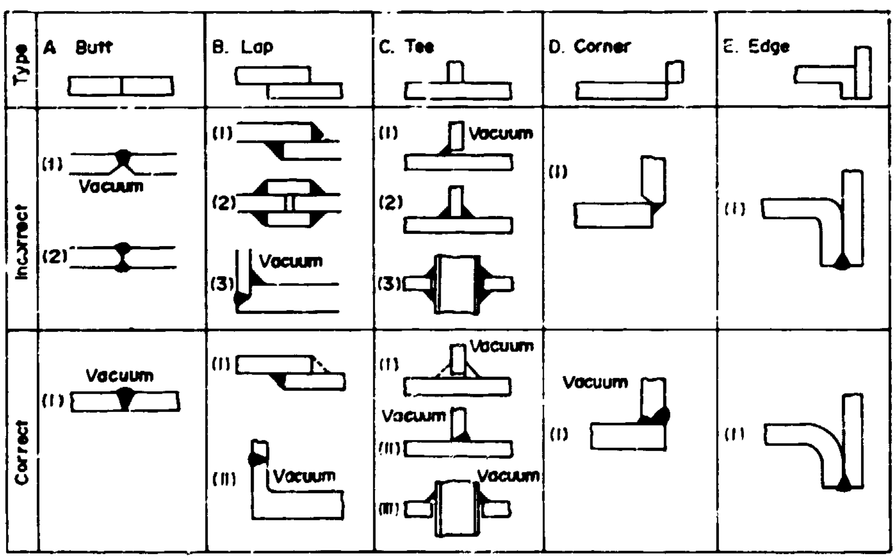

Figure 7.1 Welded Joints

Source: Reference 3

d. If different metals are to be brazed, the assembly must be arranged so that the metal with the bigger thermal expansion is the outer part. This would tend to compress the brazing alloy during the cooling.
e. The flow of the brazing alloy can be controlled by the construction of the joint. Figure 7.2 illustrates this.

1. Square corners (Figure 7.2a) will give a good flow of the brazing alloy, resulting in a strong and leak-tight joint.
2. If the first corner, from the side where the brazing alloy is applied is round (Figure 7.2b), the alloy will not pass this corner.
3. When only the second corner is round (Figure 7.2c), the joint will be strong and leak-tight.
4. A square edge against a round corner (Figure 7.2d) would not be a good joint for brazing.

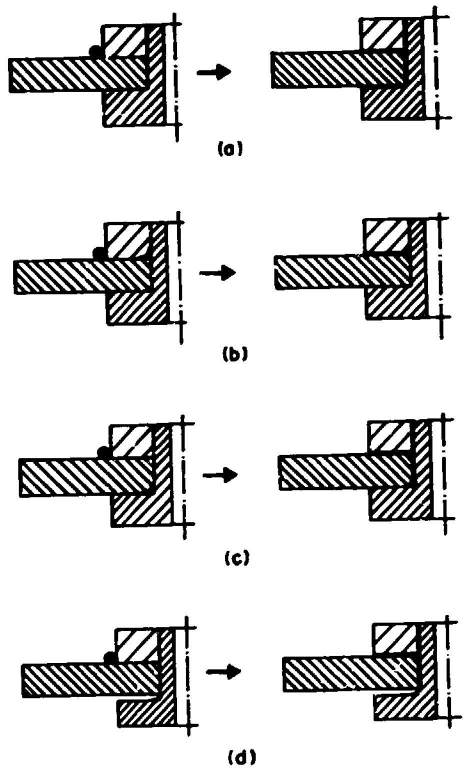

Figure 7.2 Flow of Brazing Alloy for Different Edges of Joining Elements
Source: Reference 3

f. If the flow of brazing alloy is to be avoided on a surface, an effective solution is to coat the area with carbon or chromium.
g. As illustrated in Figure 7.3, lap joints or step joints are to be preferred in brazing for vacuum sealing applications.

7.3.2 Semi-Permanent and Demountable Seals

The methods used for vacuum sealing of components which have to be opened from time to time are waxes or adhesives, ground joints, liquids or gaskets. Reference 3 gives tabulated data on particular types and their properties.

Waxes are mainly used for temporary sealing and for unique applications. For vacuum work, their long-term use should be avoided. They can be used for the temporary joining of metal, glass, quartz, ceramic (or plastic) parts or for the temporary sealing of pin-holes or leaky joints.

Adhesives are applicable for sealing pinholes or porous walls (using sealing lacquers) and for sealing edges (using sealants). Selection of particular adhesives to be used depends on the shape of the seal, the thickness of the joint, the material to be joined and the requirement for heating or curing. Epoxy adhesives are useful for high vacuum seals since they are very stable and have tolerable outgassing rates.

Silver chloride is applicable for vacuum seals at higher temperatures where waxes and adhesive seals are likely to fail. It is useful in sealing metals, glass, mica, and other materials. The familiar applications of silver chloride sealing are glass windows.

Ground seals are either plane, conical, spherical or socket types. Plane ground joints are used in applications where the joint must be closed and opened without moving the parts axially, or where the diameter is too large to use conical or spherical joints. Spherical and socket ground joints were developed for applications where the alignment of the parts to be joined is difficult or where angular motion of the parts relative to each other is required. Ground seals can be used in vacuum applications only if they are properly selected, assembled and maintained.

Liquid seals use liquid material to seal the gap between connected parts. When the liquid seal separates spaces having a pressure difference of one atmosphere, the sealing action is based on hydrostatic pressure or on the surface tension of the sealing liquid. Oil seals are used when simultaneous lubrication is required, as in the cylinder seal of rotary pumps. Mercury seals are used in applications which require the seal to be permanently liquid.

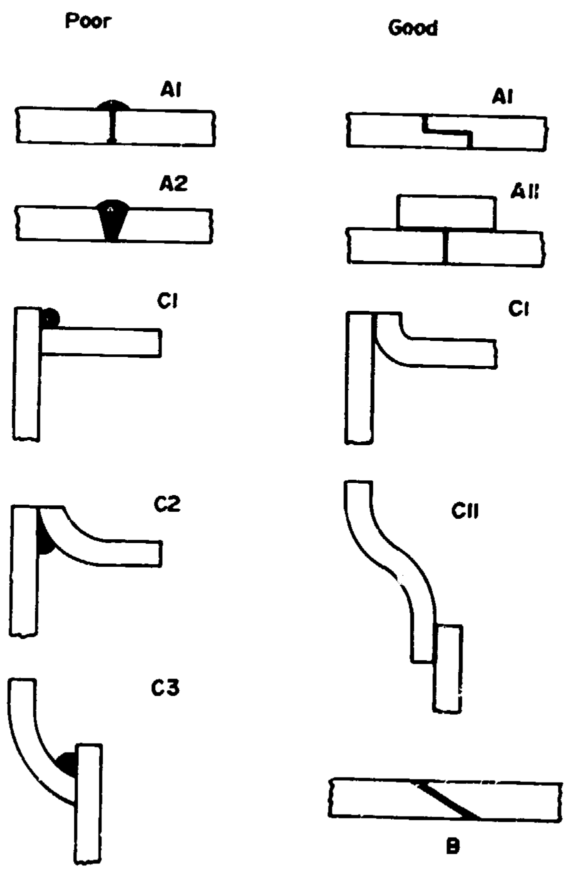

Figure 7.3 Brazed Joints
Source: Reference 3

7.3.3 Gasket Seals

Gaskets are used between two connecting flanges to prevent leaks. Different materials are available for specific applications.

An O-ring seal is a demountable joint which uses a gasket of circular cross-section. If the main compression force is exerted axially, it is known as a flange seal; if the force works radially, it is called a shaft seal. An O-ring installed in a grooved area of a machine part is sometimes called a grooved seal. O-rings are usually made of elastomer, especially for limited compression sealing. Designs for unlimited compression seals use Teflon and metal gaskets.

7.3.4 Electrical Lead-throughs

Electrical lead-throughs are paths for electrical connections into a vacuum system or envelope which are joined by vacuum-tight seals. Permanent lead-throughs are usually glass-metal or ceramic-metal seals. They are available from vacuum equipment suppliers in different shapes and accordingly are called rod seals, stem seals, ribbon seals, disc or cup seals. Demountable lead-throughs can be removed as a whole from the vacuum vessel or can be disassembled by separating the electrical lead from the insulating part and this part from the vacuum vessel.

7.3.5 Seals for the Transfer of Materials

Vacuum seals used in connection with material transfer allow a port to be open during the transfer, while keeping the rest of the vacuum system leak tight.

For the transfer of gases and liquids, cut-offs and stop-cocks or valves are used for large throughputs and controlled leaks for small throughputs. A cut-off is a device which uses a liquid for sealing, as shown in Figure 7.4.

For the transfer of solids (specimens, tools, etc.) across the wall of a vacuum chamber, vacuum locks are used.

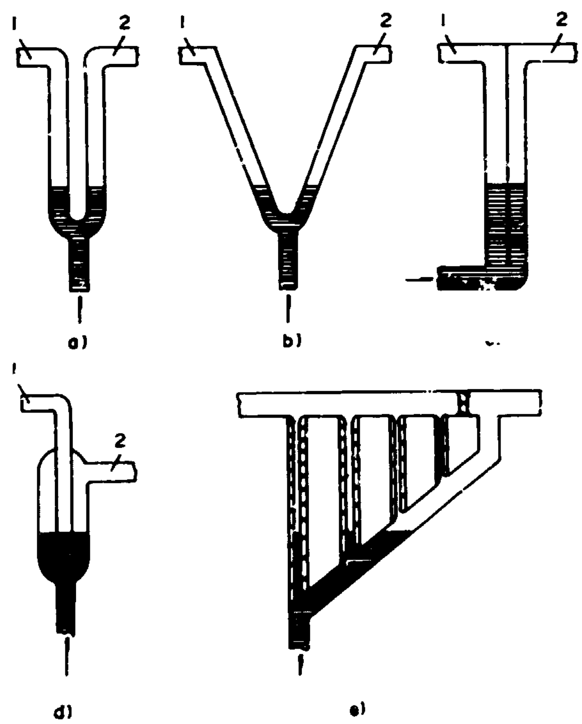

Figure 7.4 Cut-offs With Liquid Seal; (a) U-shape; (b) V-shape; (c) With Separating Wall; (d) Concentric Pipes; (e) For Variable Flow

Source: Reference 3

7.4 LEAK PREVENTION TECHNIQUES IN MOVING SHAFTS

7.4.1 Types of Seals

Leak prevention in moving shafts is usually associated with packings and seals. A packing is a soft, rope-like material squeezed into a ring space around a shaft. Seals are precisely formed mechanical parts working to a design clearance or even interference. Sealing technique for moving components can be conveniently classified into four groups, namely:

a. static
b. semi-static
c. rotating
d. reciprocating

The last two groups are known as dynamic seals.

7.4.2 Static Seals

A static seal is essentially a stationary container which surrounds the shaft to be sealed. This shaft is driven from outside without physical contact by means of a rotating magnetic or electromagnetic force.

A simple system is shown in Figure 7.5. Two shafts sealed off from each other have magnets mounted on their ends. The rotation of the drive shaft attracts the magnet of the other shaft to turn in the same direction. Friction, however, causes the driven shaft to lag behind. Thus this system is limited in application to non-precision machinery like magnetic stirrers, children's toys and advertising demonstrations.

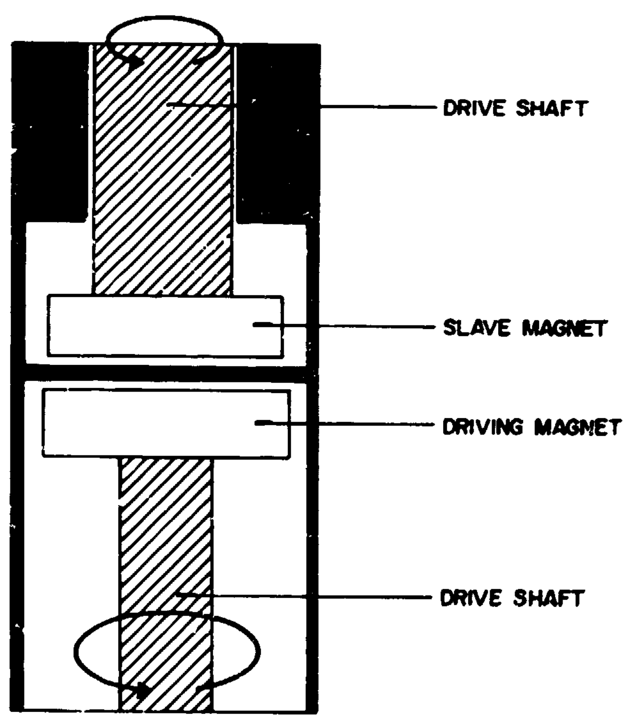

Figure 7.5 Magnetic Drive Through Static Seal
Source: Reference 4

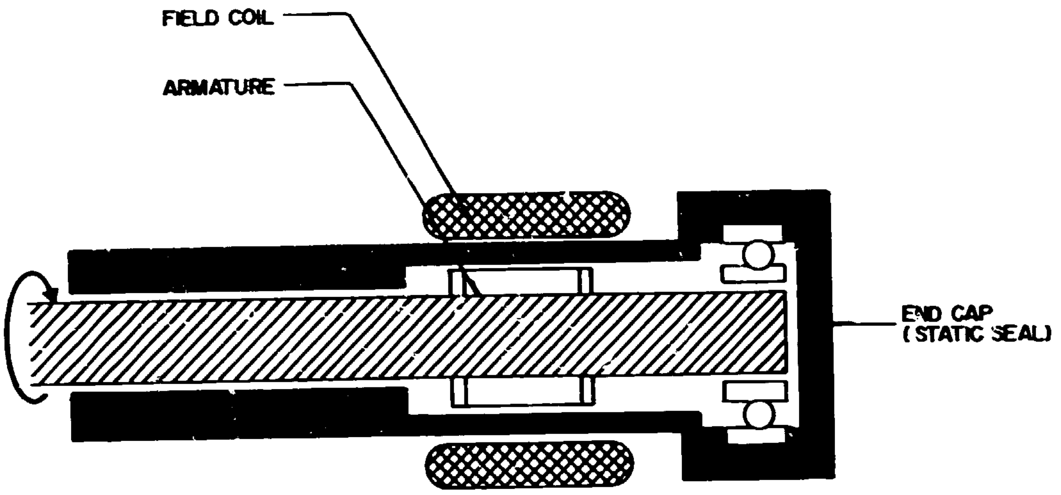

Figure 7.6 Split Electric Motor Drive With Static Sealing
Source: Reference 4

A more sophisticated system for driving a sealed shaft is to mount the field coil of an electric motor outside the sealing container and the armature on the rotary shaft inside it, as shown in Figure 7.6. This provides better control on the driven shaft. This system has been used in spacecraft and in some other high-technology applications.

7.4.3 Semi-Static Seals

A semi-static seal is basically a flexible sleeve or shroud which is tightly fitted to moving parts. There is no relative motion at the area of contact between the seal and the component; the flexibility of the seal allows for movement.

The most familiar seal of this type is the rubber sleeve used around the transmission lever of cars to protect the gearbox. Another example is the rubber muff which is used to enclose a universal coupling to ensure that the lubricant is not contaminated or exposed. A wide variety of shapes and sizes can be designed to suit different applications.

7.4.3 Rotary Seals

This group of seals has the widest application. There are many kinds of rotary seals, and this discussion will be limited to the more useful ones.

(a) Lip-seals

The commonly known oil seal is a lip seal. The lip of the seal has a V-shaped section and is held against the shaft by a slight interference fit, by the pressure of a garter spring and by the pressure of the lubricant.

Simple lip-seals are limited to a maximum oil pressure of about 100 kPa because of the flexibility of the rubber. Steel-supported lip-seals and used for pressure as high as 1000 kPa.

It is important that the lip-seal is mounted correctly. The garter spring should always be on the oil side.

(b) Bearing Seals

Thin supported lip seals without a garter spring are used to cover the gap between the outer and inner races of a ball-bearing. This keeps the lubricant in the bearing and protects it from dust or dirt.

(c) Clearance Seals

A clearance seal does not rub against the moving component. It is used for sealing against splashing or creeping liquids but not when the liquid floods the seal location. Labyrinths and bush seals, shown in Figure 7.7, are the most common types. The floating bush-seal is very widely used, especially when there is shaft eccentricity. A helical labyrinth, called a *Viscoseal,* is sometimes used when the direction of shaft rotation is constant so as to pump the liquid back by screw-feed mechanism.

(d) Flinger Rings

A flinger ring is mounted on the rotating shaft and flings off the liquid by centrifugal action. This is used when the liquid reaches the seal location mainly by flow along the shaft.

(e) Compression Packings or Packed Glands

These are rings of flexible material mounted in an annular space around the shaft and are loaded against the shaft surface by some form of axial compression, as shown in Figure 7.8. Compression packings can withstand pressures as high as 30 MPa but are limited to lower rubbing speeds. They are used in pumps, valves and other high-pressure hydraulic systems.

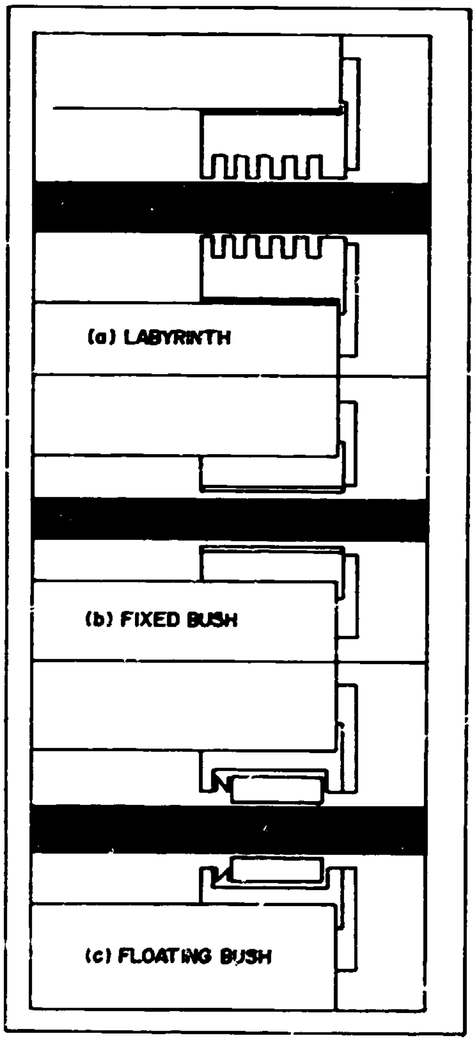

Figure 7.7 Various Clearance Seals
Source: Reference 4

Packings are available in a wide range of materials and forms. Table 7.3 describes the appropriate properties of some materials which are considered in the selection for a particular application.

The forms and shapes of packings are illustrated in Figure 7.9. "A" is a flexible all-metal packing made by wrapping thin ribbons of babbit foil, and is used for close-tolerance rods and shafts. "B" consists of simple twisted yarns for high flexibility. It is suitable for small-valve stems. "C" has a core of extruded asbestos and graphite for flexibility and sensitivity to gland adjustment. It is jacketed by braided asbestos which is reinforced with inconel wire.

"D" is similar to "C" except that the jacket is of finer yarns to allow for die forming. "E" is a braid-over-braid form, designed for high pressure requirements at slow speed, as in valve packing boxes. The interbraid form of "F" is resistant to raveling, having each strand passing through the entire section.

"G" is becoming a more common form because of its application to rings made of graphite foil. Ribbon-form foil is wound around a shaft to suitable ring width, then die-formed to what looks like a solid ring.

These different structural forms of packings have been designed for reasons of nature of expected service, the form and tolerances of the stuffing box or enclosure and the packing gland which compresses the packing.

The characteristics usually desired of a packing are:

(1) Largely impermeable to the fluid being sealed. However, complete impermeability is usually not desirable because fluid absorption prevents glazing and burning of the packing. Controlled leakage may be allowed at high shaft speeds (e.g., in a centrifugal pump) but absolute leak prevention may be required for low shaft movements as in a valve stem.

(2) Resistant to physical damage. This is the reason for braiding. Sometimes, the yarns are impregnated with oil or graphite.

(3) Structural integrity to maintain its shape. A packing must retain its form to resist pressure.

(4) Resistant to abrasion. This is a basic characteristic of a good packing material.

(5) Ability to dissipate heat outwardly is important in most applications.

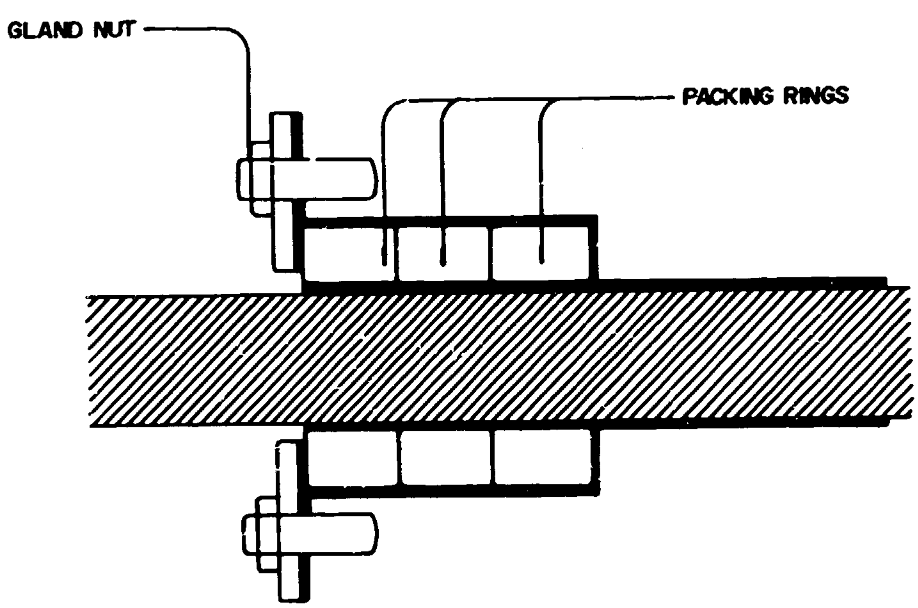

Figure 7.8 Compression Packing
Source: Reference 4

Table 7.3 Packing Materials Properties Used as Basis for Selection
Source: Reference 5

Material	Description
Asbestos	This packing material has been used for a long time because of its resistance to heat and pressure. It can be braided and reinforced for sealing pumps and valves.
Carbon	Resists fairly high temperature (up to around 650°C) and dissipates heat well. It has high chemical resistance and withstands high surface speeds.
Graphite	A purer, more expensive form of carbon with slightly better packing properties. In yarn or foil form, it can meet nearly every power plant packing need, and is used where other less expensive materials fail.
TFE	This material, tetrafluoroethylene, is highly resistant to chemicals and has low friction. However, its poor heat transmission causes heat building if surface speeds and gland pressures are excessive. Temperature limit is around 260°C. It is gentle on shafts and has low extrusion tendency.
Aramid	This is a very strong material, with outstanding resistance to chemicals over a wide pH range. It is resistant to tearing, but has a temperature limit of about 260°C. As a shaft abrader, it surpasses asbestos.
Glass fiber	Generally mixed with other materials, glass fiber has high strength and chemical resistance. It resists wear and abrasion but can damage shafts. Dimensionally stable, it does not cold flow when under compression.
Metals	To meet the requirements of sealing and accommodating to the walls of the packing box, most metals for packing are in the form of foil or ribbon that is twisted or rolled, often in combination with other materials, to make a shape that will compare with the square cross-section of braided or die-formed packing. Examples are babbitt, aluminum and copper.

For sealing high-pressure steam, carbon and graphite have the best advantage. Tetrafluoroethylene (TFE) is used against various chemicals at relatively low temperature of operation.

(f) Mechanical Seals

A mechanical seal effects sealing by the pressure of two bushes against each other on their radial faces, so shown in Figure 7.10. One of the bushes is fixed and sealed to the rotating shaft and the other to the housing. One of the two bushes is made of, or faced with a dry bearing material such as graphite or polytetrafluoroethylene (PTFE or Teflon) and this is commonly called the bush. The other is made of hard material such as steel or tungsten carbide, and is known as the

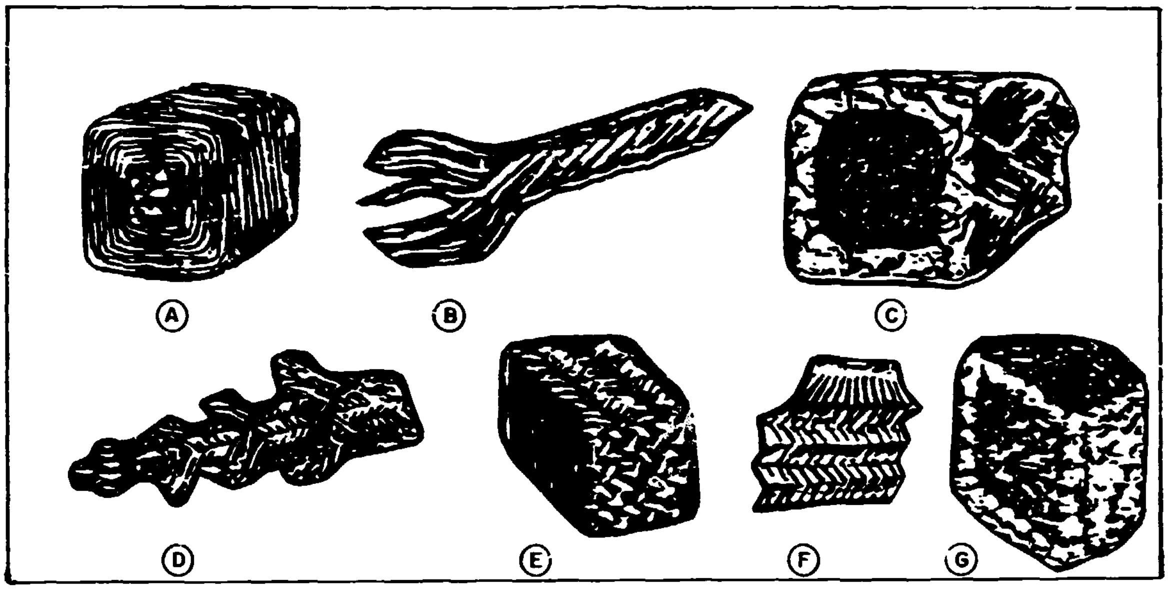

Figure 7.9 Principal Forms of Compression Packing
Source: Reference 5

seat. The basic idea behind this design is that the clearance between the bushes would be so small that practically no liquid could escape even though a film of liquid would be there to prevent solid-to-solid contact.

The axial load which presses one bush against the other can be provided by a helical spring, a Belville washer or hydraulic pressure. A stationary seal is provided between the bush or seat and the shaft or housing. This static seal can be a rubber sleeve, one or more O-rings, or a lip seal. An example of a mechanical seal is shown in Figure 7.11.

Damage to the seal is normally by cratering or grooving of the radial faces. Repairs can sometimes be done by relapping, but usually replacement with new rings is required. Thus, it is important that the seal face material resist corrosion and wear. Reference 5 gives some common manufacturer-recommended seal face combinations for several conditions of service.

Besides seal faces, the other design areas of the mechanical seal where the materials must be properly selected are the secondary sealing elements, the seal-head components and the material of the seal rings.

Pumps are the most common applications for mechanical seals.

7.4.4 Seals for Reciprocating Shafts

Many of the seals already described are suitable for use with reciprocating shafts. For small distances of shaft movement, bellows or diaphragms may be applicable while for low speeds with good lubricants, O-rings, packed glands and lip-seals can be used.

Additionally, there are seals specially designed for reciprocating movement and these include U-ring chevron packings and piston rings.

(a) U-rings

A typical U-ring installed for a hydraulic actuator rod is shown in Figure 7.12. The deformation of the ring shape by compression indicates the loading of the lip against the rod surface.

The U-ring should be installed such that the rod moves away from the open side of the U when that side is under pressure. All rubber ring seals in reciprocating shafts should have greater axial thickness than the clearance between the shaft and the housing bore.

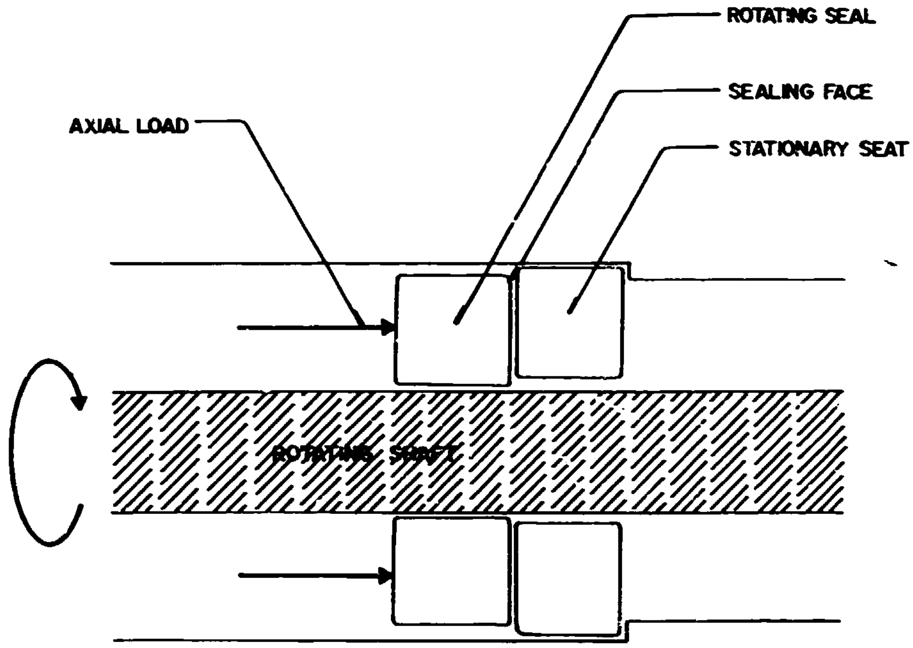

Figure 7.10 Basic Design of Mechanical Seal
Source: Reference 4

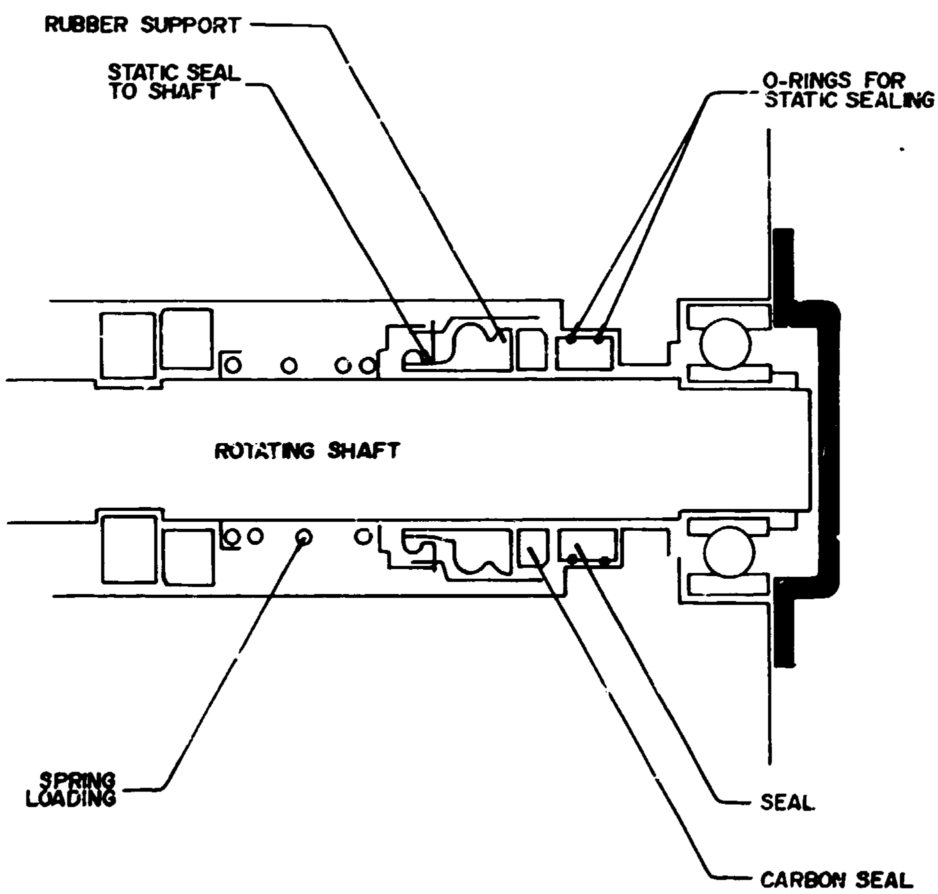

Figure 7.11 Example of a Mechanical Seal
Source: Reference 4

(b) Chevron Packings

A chevron packing is one in which the cross-section of the compressible ring is in the form of a broad V. This type is particularly suitable for reciprocating systems and are usually mounted between shaped metal rings with litue or no mechanical pressure. Slight tightening is done to eliminate play of the rod. In case of excessive leakage, the chevron is sometimes compressed, but only as a stop-gap measure, to reduce leakage until repair is done.

(c) Piston Rings

The most common piston ring is the split metal type used in a car engine. The all metal piston ring withstands high temperatures and oxidizing conditions but must be used with lubrication. For lower temperatures and where liquid lubrication is not possible, the suitable piston ring material can be reinforced PTFE or carbon. Graphite or other lubricating composites can be used.

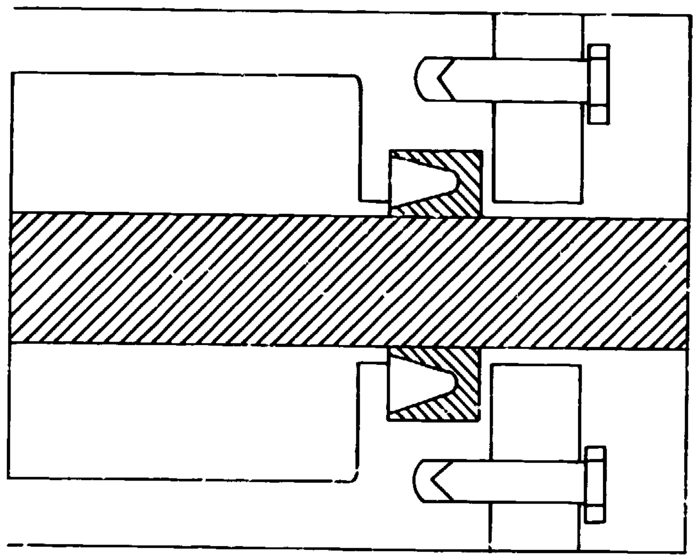

Figure 7.12 U-Ring Seal for a Hydraulic Actuator Rod
Source: Reference 4

7.5 TIPS FOR SEAL HANDLING AND INSTALLATION

The following are useful guides that must be observed in the installation of seals.

a. Be clean and accurate. Dirt allowed into the stuffing box may cause serious damage, the least of which is scratching the seal faces.
b. Flexible seal materials should be handled carefully because they are mostly soft and vulnerable to handling damage.
c. Make sure that the counterface surfaces are smooth and that the seal's shape and size conforms properly to the groove for it.

7.6 REPAIRING LEAKS

Some common sources of leaks and possible methods of repair are listed below (Reference 6).

a. Static gasket seals.
   1. Tighten seal but not too much.
   2. If method 1 does not work, shut down the system and examine the gasket and gasket surfaces.

3. Replace any damaged gasket and smooth rough surfaces (use fine emery cloth).
4. When the gasket is not damaged, clean (with acetone, etc.), coat with light film of good quality vacuum grease (when permitted), and re-assemble seal.
5. Do not use sealing materials such as glyptal to stop the leak. This procedure is temporary and the gasket can not be used again.

b. Movable, gasketed seals (Wilson, chevron, etc.).
1. Add a small quantity of good quality vacuum grease to the moving member and operate this member a few times through the seal.
2. If method 1 does not work, try tightening the retaining rings on the seal.
3. If method 2 does not work, dismantle the seal and examine the component parts. Replace all damaged parts.

c. Flare fittings (and similar metal-to-metal seals).
1. Tighten the compression nut moderately. Too much tightening is likely to twist the tubing passing through the fitting.
2. If method 1 does not work, take the joint apart.
3. Try annealing the copper flare.
4. If method 3 does not work, use a thin coating of a suitable sealant (glyptal, etc.) on the surfaces that make contact.

d. Soldered, brazed, and welded joints.
1. For temporary repair, use a cement. This method works for small leaks where the diffusion pumps are in their operating range. A "thin" cement (clear glyptal, Eastman Kodak Resin 910, etc.) can be used for the smallest leak. For somewhat larger leaks use a "thicker" cement such as red glyptal.
2. For permanent repair, rework the joint or replace the part.

e. Leaks through metal parts.
1. For temporary repair, use a cement as in the case of soldered, brazed, and welded joints.
2. For permanent repair, rework the part involved (as appropriate) or replace the part.
3. Peening the leak is not reliable.

f. Glass-to-metal seals
1. A temporary seal can be made with a cement or wax (heat part appropriately).
2. Rework wax seals. Such seals are not recommended for joining these materials.
3. For permanent repair, replace the seal.

g. Glass-to-glass joints, cracks, and pinholes in a glass system.
1. For small leaks, use a cement (at room temperature) or heat the glass and apply a suitable wax (picein, sealing wax, etc.)
2. For a large leak, rework the glass or replace the part of the system where the leak is located.

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CHAPTER 8

Industrial Water Treatment

8.1 DESCRIPTION AND SIGNIFICANCE

8.1.1 Importance of Water Treatment

Water plays an important role in almost all industrial processes. It is either used directly as a raw material in manufacturing processes or indirectly as an important utility for washing, cleaning, steam generation and cooling. While water is considered the lifeblood of industrial processes, it is also the source of most intricate problems in industry. A water treatment program is an effective approach to the preventive maintenance of water/steam carrying equipment and lines. Plant performance is strongly affected by the quality of water used. The proper water treatment techniques should therefore be applied to preclude water related problems.

The setting up of industrial water treatment programs properly belongs to the hands of specialists. Reputable suppliers of water treatment chemicals in the Philippines usually provide free services in program setup for prospective clients.

8.1.2 The Properties of Water

Water is often referred to as the universal solvent and thus always contains dissolved impurities in its natural state. Even rainwater which can be considered as pure water has dissolved gases in it. Surface waters contain various kinds of minerals and microorganisms leached out from rocks, sediments and the soil. The quality of water, which is measured by the amount of entrained and dissolved impurities, varies depending upon several factors such as season, weather, temperature and biological activity. This is particularly true in inland waters such as lakes, rivers, estuaries (where rivers meet the sea) and most surface waters. Underground water quality on the other hand is relatively constant inasmuch as the flow of underground water compared to surface water is very slow.

Anything in water that is not water is a contaminant or an impurity. The identification and quantification of each impurity is very important in specifying a cost effective treatment program to obtain good quality water. Table 8.1 lists the common impurities found in water.

8.2 WATER-RELATED PROBLEMS

The three major problems in water systems are scale deposition, corrosion and fouling.

8.2.1 Scale Deposition

Scale is a dense coating of predominantly inorganic materials and results from supersaturation of water soluble salts. The primary effect of scales is the retardation of heat transfer in boilers, heaters and other heat exchange equipment; blockage of water flow through filters, water lines and headers and the deposition in turbine blades in the case of steam. The common scales found in steam and cooling water systems are calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), calcium phosphate ($Ca_3(PO_4)_2$), magnesium silicate ($MgSiO_3$) and silica (SiO_2).

Table 8.1 Water Characteristics/Impurities and the Difficulties They Cause

Characteristic/Impurity	Difficulties Caused
Turbidity	o Interference in most process uses o Deposits in water lines, process equipment, etc.
Color	o Hindered precipitation methods such as in iron removal and softening o Foaming in boilers o Stained product in process use
Hardness	o Scaling in heat exchange equipment, boilers, pipelines, etc. o Formation of curds with soap o Interference in processes such as dyeing
Alkalinity	o Foaming and carryover of solids with steam o Embrittlement of boiler steel o Formation of carbon dioxide in steam from decomposition of bicarbonates and carbonates
Free Mineral Acid	o Corrosion of metal in water systems
Carbon Dioxide	o Corrosion in water lines and particularly in steam and condensate lines
Sulfate	o Increased solid content of water o Formation of scale with calcium hardness (Calcium sulfate)
Chloride	o Increased solid content of water o Increased corrosive character of water
Nitrate	o Increased solid content of water o Growth of microorganisms
Silica	o Scaling in boilers and cooling water lines o Deposits in steam turbine blades
Iron	o Water discoloration on precipitation o Deposits in waterlines, boilers, etc. o Interference in several industrial process e.g. dyeing, tanning o Interference in the action of some water treatment chemicals
Oxygen	o Corrosion of water lines, heat exchange equipment, boilers, condensate lines, etc.
Hydrogen Sulfide	o "Rotten egg" odor o Corrosion of metals in water systems
Ammonia	o Corrosion of copper and zinc alloys
Dissolved Solids	o Foaming in boilers o Interference in industrial processes
Suspended Solids	o Deposits in heat exchange equipment, boilers, waterlines, etc.

8.2.2 Corrosion

Corrosion is usually caused by the presence of oxygen (O_2) in water. It can also be caused by the presence of other acid gases such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S), and free mineral acids such as hydrochloric and sulfuric acids (HCl and H_2SO_4) in the water. The primary cause of corrosion in steam/condensate systems are O_2 and CO_2. In cooling water systems, corrosion is caused by dissolved O_2 and foulants.

8.2.3 Fouling

This problem is brought about by water-suspended materials (inorganic and/or organic) which accumulate on metal surfaces particularly in low flow regions and heat transfer surfaces. Some foulants occur naturally and some are produced artificially in water and in the system. Natural occuring foulants are mud, silt, natural organics, dissolved solids and biological growths. Foulants produced artificially in the water system are sewage, coagulants and flocculants, corrosion products, sludges and precipitated mineral deposits and process contaminants.

8.3 DETECTION AND ANALYSIS OF WATER-RELATED PROBLEMS

The existence and extent of water-related problems are determined through the monitoring and evaluation of important water parameters. These observations and measurements also indicate the level of effectivity of water treatment techniques used.

As a rule, system control is based on both the absolute value of a parameter reading and the trend indicated by several readings. These are compared against specified limits and previous experience.

8.3.1 Steam Systems

The parameters and the location of points where they are measured in a steam system are shown in Figure 8.1. With the information gathered from regular and on-line measurements, the analysis and prediction of deposition, oxidation and corrosion damage can be made with considerable accuracy. Table 8.2 summarizes the important parameter ranges and limits for a steam system.

8.3.2 Cooling Water Systems

The water parameters determined in steam systems are similarly analyzed in cooling water systems. Figure 8.2 shows the sampling locations for a cooling water system. Additionally, there are specific monitoring techniques used for detecting corrosion, deposition and fouling.

(a) Corrosion Monitoring

The common techniques used for detecting corrosion in a cooling water system are:

(1) Corrosion Coupons

(2) Electrical Monitoring Devices — namely, Electrical Resistance (ER) Probes and Linear Polarization Resistance (LPR) Probes

Uses of these techniques are discussed in Chapter 6.

(b) Deposit Monitoring

The technique in deposit monitoring involves measurement of heat flux through a heat transfer surface under water velocity and temperature conditions matched to those of the system's heat exchange equipment. The decay of the heat transfer coefficient is a measure of the amount of fouling that has accumulated up to the time of measurement.

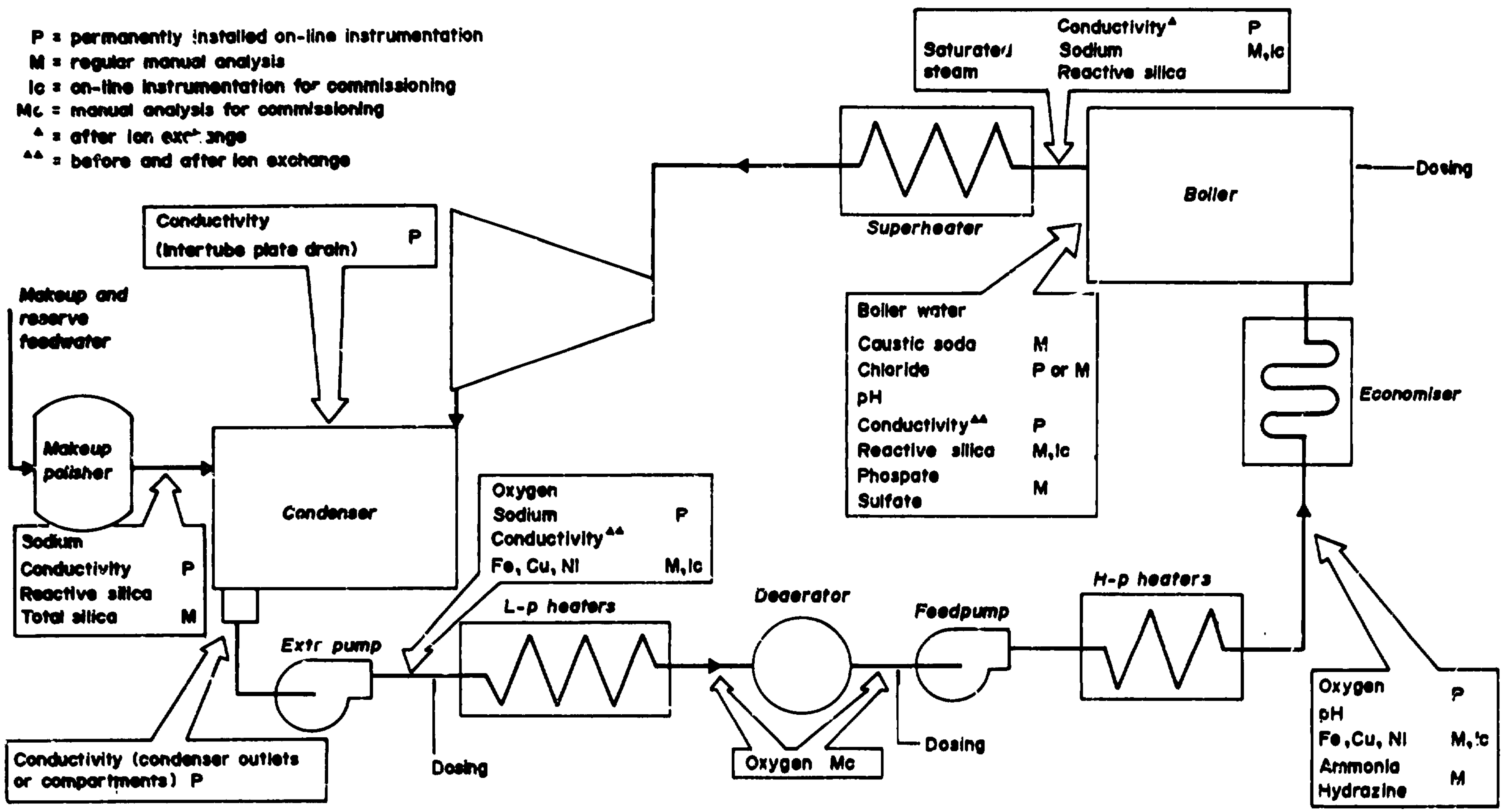

Figure 8. 1 Location of Principal Sampling and Chemical - Injection Point and Instrumentation Required for High-Pressure Drum - Type Systems.

Table 8.2 Boiler Water Limits and Associated Steam Purity

Drum Pressure (kPa)	Range of TDS in Boiler Water (ppm) See Note 1	Range of Total Alkalinity in Boiler Water (ppm)	Maximum Suspended Solids in Boiler Water (ppm)	Range of TDS in Steam (ppm) See Note 2	Silica in Boiler Water (ppm)
Drum Type Boilers					
0 – 2068	700 – 3500	140 – 700	15	0.2 – 1.0	150
2069 – 3102	600 – 3000	120 – 600	10	0.2 – 1.0	90
3103 – 4137	500 – 3000	100 – 500	8	0.2 – 1.0	40
4138 – 5171	400 – 3000	80 – 400	6	0.2 – 1.0	30
5172 – 6502	300 – 1500	60 – 300	4	0.2 – 1.0	20
6206 – 6894	250 – 1250	50 – 250	2	0.2 – 1.0	8
6895 – 1800	100	See Note 3	1	0.10	5
12,411 – 16,201	50		N/A	0.10	1
16,202 – 17,925	25		N/A	0.10	0.5
17,926 – 19,993	15		N/A	0.10	0.1
Once Through Boilers					
1400 and Above	0.05	N/A		0.05	

Notes:
1. Actual values within the range reflect the TDS in feed water, higher values are for high solids; lower values are for low solids in the feedwater
2. Actual values within the range are directly proportional to the actual value of TDS of boiler water. Higher values are for the high solids lower values are for low solids in the boiler water.
3. Dictated by boiler water treatment; should not exceed 100 ppm.

(c) Biological Fouling Monitoring

The assessment of the effectiveness of biocides and biological treatment programs can be done through total plate counts and direct biofouling monitoring. Biocide selection can also be optimized using such methods as the Realtive Population Density Test and the Zone of Inhibition Test. These methods are described in Table 8.3.

8.4 WATER TREATMENT TECHNIQUES

The two (2) broad classification of water treatment used in industries are the internal and external treatment techniques. Depending on the end-use, either one of the combination of the two can be applied.

8.4.1 External Treatment

This is also called pre-treatment and is aimed at the removal of bulk suspended and dissolved matter which could otherwise find their way to heat exchange equipment, boilers, cooling towers, pipings and turbines to produce scaling, fouling and corrosion. The different external water treatment methods are described in Table 8.5.

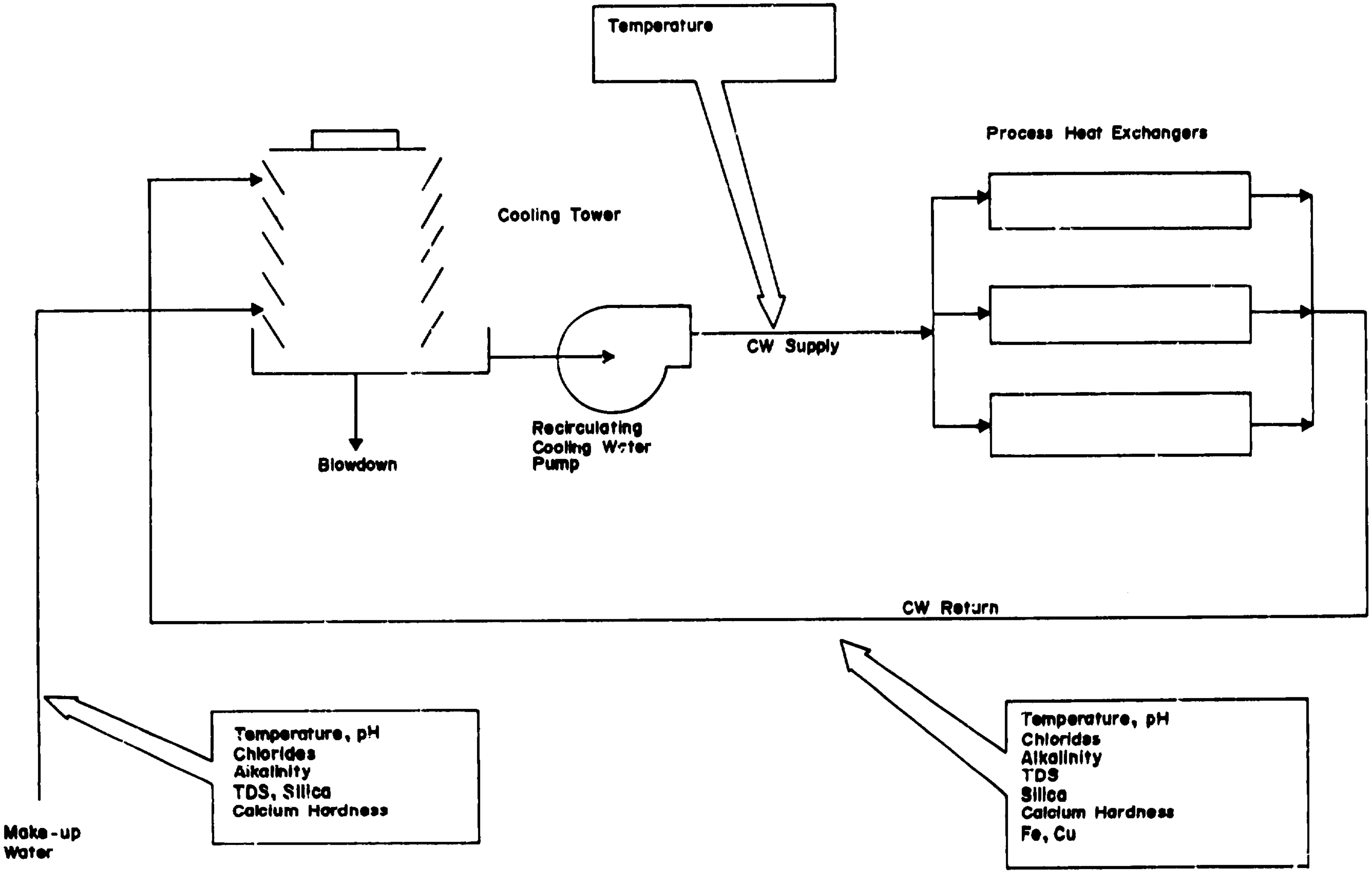

Figure 8.2 Cooling Water System Sampling Locations

Table 8.3 Techniques for Monitoring Biological Fouling

1. *Total Plate Counts.* This is carried out using prepared samples of the water with definite concentration of biocide. After a suitable incubation period, any organism present will have grown into a countable culture. The effectiveness of the biocide and the optimum concentration can be ascertained by comparing the population of microbial cultures in each sample. For evaluating the treatment program, a record of total counts over a long period of time can be correlated to the system performance. Analysis of the biological trend indicates whether or not a system is under control.
2. *Direct Biofouling Monitoring.* This uses the physical effect created by biological film (slime), which is the inordinately large pressure drop created in a flow passage, as the basis for assessing the degree of fouling. The equipment used, which is some sort of a test heat exchanger, monitors the pressure drop in the biofilm. The friction factor can then be correlated with the development of biofilm in the cooling water system.
3. *Relative Population Density Test.* In this test, representative water samples are dosed with various microbiocides at different concentrations. The percentage by which the concentration of organisms is reduced in the samples is found by conducting plate counts before and after inoculation. The microbiocide providing the highest % reduction at the most economical concentration is generally the preferred product.
4. *Zone Inhibition Test.* In this test, a small pad saturated with a particular biocide is placed in the center of a petri dish containing nutrient agar. The water sample is introduced to the plate. While no growth will be found on the pad itself, a concentric ring that is free of microbial growth will be seen (zone of inhibition). The larger this zone, the more effective the microbiocide.

Table 8.4 Guidelines for Assessing Biological Counts

Count Range	Indications
0 – 10,000	Essentially sterile
10,000 – 500,000	System under control
500,000 – 1,000,000	System may be under control but should be monitored
1,000,000 – 10,000,000	System out of control requires biocide
over 10,000,000	Serious fouling problems may be occuring; immediate biocide additive required

8.4.2 Internal Treatment

With all the attention given to removal of impurities from make-up water (external treatment), the water used in the main system (e.g. boiler water and recirculating cooling water) still demands additional treatment to further prevent the occurence of any water related problems. Operational upsets, procedural errors, inaccurate water analysis will make possible the intrusion of impurities in the main system. Hence, to further safeguard the system, supplementary treatment in the form of chemicals are necessary. The following sections discuss the internal chemical treatment methods which are applicable to boiler water, condensate and cooling water systems.

Table 8.5 External Water Treatment Methods

Method	Equipment	Application	Notes
1. Direct Filtration	Gravity Filters, Pressure Filters	For removal of 90-98% of particles larger than 2/cm in moderate turbidity water of up to 200 ppm suspended solids	Filters consist of one or more media graded from coarsest to finest
	Steel Screens	For removal of large suspended solids (down to 0.5 mm size) in water intakes	Uses one relatively coarse and a second screen finer by less than an order of magnitude
2. Sidestream Filtration	Pressure Filters	On stream water filtration in open recirculating systems	Generally, 1-5% of the circulating water flow is passed through filter
3. Fine Filtration	Filter Cartrides, Precoat, magnetic and ultra filters (UF)	For removal of fine solid particles in low turbidity waters	
4. Aeration	Aerator	For removal of dissolved gases in water	
5. Coagulation/ Flocculation	Solid Contact Clarifiers	For removal of dissolved impurities in highly colored surface	Coagulants such as $Al_2(SO_4)_3$ and $FeCl_3$ are used to coagulate the dissolved impurities to form settleable solid
6. Lime/Lime Soda Softening	Lime/Lime Soda Softeners	For reduction of hardness and soluble silica in hard water	Can be carried out hot (102-110°C) or cold (4-32°C). Uses lime and soda ash for hardness removal (down 35-50 ppm range) with the added benefit of silica removal via adsorption on $Mg(OH)_2$ precipitate. MgO is added if the amount of magnesium in water is not enough.

Cont. (Table 8.5)

Method	Equipment	Application	Notes
7. Ion Exchange	Sodium Cation Exchange Unit	Hardness removal (water softening)	Uses Sodium zeolite resin Regenerant
	Hydrogen Cation Exchange Unit	Hardness and alkalinity removal	(NaCl)
	Hydroxyl Anion Exchange Unit	Alkalinity, CO_2 and silica removal	Use Hydrogen (Strong Acid) (Strong Acid) resin
	Weak Base Anion Exchange Unit*	Bicarbonate removal	Uses Hydroxyl (strong base) resin
	Weak Acid Cation Exchange Unit*	Bicarbonate and carbonate removal	Uses Weak Base Anion Resin
			Uses Weak Acid Cation Resin
	Strong Acid Cation and strong Base Anion Exchange Units*	Removal of all impurities	Demineralization process
8. Deaeration	Deaerator	Removal of uncondensable gases primarily O_2	Operate at 99-107°C and 34 kPa gage. Uses steam for heating.
9. Electrodialysis	Electrodialysis (ED) Cells	For removal of dissolved ionized impurities (90-99% removal)	Operation is based on principle of electrical charges, i.e., opposite charges attract and similar charges repel
10. Reverse Osmosis	Reverse Osmosis (RO) Unit	For removal of dissolved ionized and unionized impurities (90-99% removal)	Operates on the principle of reverse osmosis, i.e., flow of solvent through a semipermeable membrane is from low concentration to high concentration.

*With decarbonator tower for removal of H_2CO_3 and evolved CO_2

(a) Scale Inhibition

The basic methods for preventing the formation of scale are as follows:

- o keep the scale forming constituents in solution; and
- o allow the impurity to precipitate as a removable sludge rather than as a hard deposit

(1) Boiler Water Systems

Preventive treatment for scale inhibition in boiler water systems involves the use of either phosphates or chelants. The former precipitates an insoluble sludge while the latter prevents sludge formation. In either case deposits are avoided.

Phosphates are considered the standard chemical for treating low hardness water. The forms commonly used are: monosodium (acid), disodium (neutral) and trisodium (alkali) phosphates.

i. Conventional Phosphate Treatment

This is applicable to boilers operating below 8270 kPa gage. Phosphate is added to remove calcium hardness as a non-adherent phosphate sludge which can be removed by blowdown when enough alkalinity is present. Calcium is not precipitated properly when pH is below 9.5. The disadvantage of the treatment is that the phosphate reactions increase the alkalinity and adds to the solids content of the boiler water.

ii. Coordinated pH/Phosphate Treatment

This method was developed to do away with the disadvantages of conventional phosphate treatment and make possible use of such chemicals at higher boiler pressures. The treatment ensures adequate alkalinity without the addition of caustic soda or formation of free caustic in the boiler water. The quantity of phosphate used depends on the sodium-to-phosphate ratio (Na/PO_4). Recommended Na/PO_4 ratios are 2.6-2.85, depending on several factors such as operating pressure and impurities present. The desired ratio is maintained by controlling the proportions of monosodium, disodium and trisodium phosphates in the boiler water.

Chelants and other synthetic polymers are boiler water treatment chemicals which disperse precipitated particles, distort crystalline deposits and keep scale forming minerals in solution to inhibit scale formation. These however have only limited applications in boilers operating at pressure above 8270 kPa gage. The residual concentrations of these chemicals should be maintained properly in order to achieve good treatment.

With regards to silica, there are no known internal chemical treatment which can preclude the effects of silica scale. Silica scale deposition can be prevented only by keeping its concentration in the boiler water below the maximum limits by blowdown.

(2) Cooling Water Systems

For scale inhibition in cooling water systems, the treatment chemicals that can be utilized are the solubilizing chemicals and crystal modifiers.

Solubilizing chemicals are specialty chemicals which have the ability to keep scale-forming materials in solution at concentration levels substantially higher than might be expected. Most of these are used primarily to prevent calcium based scaling. The common solubilizing chemicals used in cooling water systems include chelants (e.g., EDTA and NTA), inorganic phosphates, synthetic polymers (e.g. polyacrylates), organo-phosphorus compounds (e.g. phosphonates and phosphate esters) and acids (e.g. H_2SO_4). Table 8.6 shows a comparison of the leading scale control agents.

Table 8.6 Leading Scale Control Agents

Chemicals	Features	Limitations
Polyacrylates	o Cost relatively less. Maintenance dosage is 3-5 ppm o Effective even at high temperatures (120°C) o Stable and soluble at high and low pH. Non-toxic o Excellent dispersant properties	o Reacts with strong cationic chemicals (e.g. biocides) o Chemicals from different suppliers may vary
Phosphonates (e.g. AMP* and HEDP*)	o Keep calcium salts in solution even at high pH and severe scaling condition o Maintenance dosage is 3-5 ppm	o AMP is readily destroyed by chlorine. Degradation of AMP creates the scale-forming orthophosphate ions o HEDP is stable with chlorine but degrades in the presence of iron and iron oxide deposit. o These are weak chelating agents which can attack steel and copper alloys
Phosphate Esters	o Same as phosphonates	o Less stable; degraded easily
Inorganic Phosphate	o Holds calcium scales in solution for a limited time o Can keep scale and iron oxide deposits from forming even at very low dosage levels	o Degrade to orthophosphate form
Chelants (e.g. EDTA*)	o Keeps calcium scales in solution (sequestration)	o Expensive, not cost effective
Acids (e.g. H_2SO_4)	o Good for scale solubilization and pH adjustment o	o Produce soluble salts of scaling materials o Fluctuation in acid feed can produce widely varying pH levels. May cause corrosion if overfed.

*AMP – Amino Methylene Phosphonic Acid
*HEDP – hydroxy-ethylidene-1, 1-diphosphonic acid
*EDTA – Ethylene Diamine Tetra Acetic Acid

Table 8.7 Common Oxygen Scavengers

1. *Catalyzed Sodium Sulfite*. This is the most effective and least expensive O_2 scavenger. However, its use is limited only to low pressure boilers (below 8270 kPa gage) since its reaction with O_2 produces sodium sulfate which adds to the solids content of the boiler water. Above 8270 kPa gage, it also decomposes to form H_2S and O_2 which are both corrosive.
2. *Hydrazine*. This is the O_2 scavenger used in high pressure boilers since it introduces no solids into the boiler water (reaction with O_2 produces N_2 gas and H_2O). Its reaction with O_2 at low temperature and pressure is very slow and it is carcinogenic.
3. *Carbohydrazide*. This reacts rapidly with O_2 even at low temperatures and pressures and is non-carcinogenic. It is not usually used since it is expensive.

Crystal modifiers are specialty chemicals which distort the resulting crystal structure of the scale in such a way that the scale that forms becomes a non-adherent sludge. These are very effective even at high temperatures and are generally more cost effective. The use of such chemicals often permits higher cycles of concentration in the cooling system than solubilizing chemicals. They come in two (2) different classes which are equally effective, polymaleic acids and sulfonated styrenes. The most common residual concentration in the cooling water is 0.˜-2 ppm but can be kept as high as 5 ppm in very severe scaling conditions. Crystal modifiers are compatible with chlorine but can be deactivated by strong cationic chemicals.

Natural compounds such as lignins, tannins, starches and alginates are also used for scale control. These are good dispersants and crystal modifiers. However dosages ranging from 50-200 ppm are required making their application too expensive. They react with iron salts, biocides and flocculants. Moreover, they serve as nutrients for biological organisms.

It should be noted that whenever specialty chemicals are used for solubilize calcium salts either in boiler water or cooling water systems, operators should be aware that severe scaling will occur rapidly almost instantaneously if these chemicals are lost in the water being treated. Continuous and uniform feeding of these chemicals is very necessary to obtain good treatment.

Unfortunately, as in boiler water systems, the above treatments cannot be applied to silica scale formation since there are no known silica solubilizing or silica crystal modifying chemicals. Silica can be prevented from depositing only by keeping its concentration below its solubility limit.

(b) Corrosion Inhibition

Corrosion control is extensively discussed in Chapter 6. The most important requirements in using corrosion inhibitors for industrial water treatment are the following:

- o Knowledge of the metals used in the system (particularly in cooling water systems);
- o Awareness of metal susceptibility to corrosion given the operating conditions of the system; and
- o Familiarity with the limitations of the chemicals used for corrosion control.

(1) Steam System

Corrosion in a steam system (boiler water feed, boiler water and condensate) will occur when alkalinity is too low, i.e. pH below 9 (general corrosion), when dissolved O_2, CO_2 or other corrosive gases are present (pitting corrosion) or when localized areas are exposed to excessive caustic concentration (embrittlement). Electrolytic action between dissimilar metals in the system (galvanic corrosion) or complex interaction of iron with free caustic (selective gouging) can also cause corrosion.

Preventive treatment includes neutralizing the acidity of the water (controlling pH within specific limits), removal of dissolved gases and neutralizing the effect of CO_2.

Neutralization is obtained with alkaline chemicals such as caustic soda, ammonia and phosphates. Caustic soda is advisable only for low pressure boilers. Ammonia, though excellent for steel can destroy the protective oxide layers formed on copper bea ing metal surfaces. The action of phosphates has already been discussed.

Internal O_2 removal is achieved with the use of chemicals called O_2 scavengers. This technique supplements the use of deaerators. Table 8.7 describes the commonly used O_2 Scavengers.

O_2 and CO_2 carried over from the boiler can produce corrosive conditions when condensing downstream with steam. For condensate line protection, both filming and neutralizing amines are used.

Filming amines, injected into the steam header, form a protective film over metal surfaces contacted. Octadecylamine is the most widely used filming amine. If maintained in a continuous coating, it provides excellent protection.

Neutralizing amines are used for CO_2 corrosion control. These volatile chemicals are injected into the boiler, carried over with the steam and reacts with any CO_2 molecule in the steam and/or condensate. Some of the commonly used amines are morpholine, cyclohexylamine (CHA), diethylamino-ethanol (DEAE), 2-amino-2-methylpropanol (AMP) and dimenthylisopropanolamine (DMIPA). The key property for these chemicals is the vapor/liquid distribution ratio which

Table 8.8 Common Anodic Inhibitors

1. *Chromate.* This is probably the best and most often used anodic inhibitor. It forms a hard passive oxide film on metal surfaces. Though extremely effective over a wide pH range (5-10), it can cause severe pitting if applied sparingly. It is often used in combination with other inhibitors to improve its effectiveness and to allow reduction of the quantity used.
2. *Orthophosphates.* These are currently gaining popularity because they are environmentally inofensive. They are used at high levels to be effective, hence may cause scaling with calcium and fouling with iron. They should be used at controlled pH levels.
3. *Nitrates.* These were the first anodic inhibitors introduced and have been used in conjunction with polyphosphates. They must be used at levels above 500 ppm at pH above 7.5. They are best suited in closed recirculating systems and not for open recirculating systems since they oxidize and provide a nutrient supply for bio-organisms.
4. *Orthosilicates.* These are proven to be successful in treating potable water. However, they are slow in film formation and can contribute to severe pitting if used sparingly.

Table 8.9 Common Cathodic Inhibitors

1. *Polyphosphates.* These chemicals include the phosphate forms such as pyro-, tripoly- and hexameta phosphate. They work by forming a film or a slight scale containing calcium, iron and phosphate over cathodic sites. They revert to orthophosphate and if the system pH fluctuates, the reversion product is a potential scale former with calcium and a foulant with iron. Polyphosphates are also nutrient for algae and may cause algal bloom in spray ponds and lagoons. They are commonly used in once-through open recirculating systems but not in closed systems.
2. *Zinc.* This is an effective cathodic inhibitor only for steel. At pH 6.5-7.0, Zinc levels of 3-5 ppm will stay in solution and will provide good corrosion control for steel. At pH above 8, it will contribute to fouling. It is a nutrient at concentrations above 3 ppm. Common uses are in once-through open recirculating systems in combination with other corrosion inhibitors.
3. *Molybdates.* These are used for protecting steel. They are most effective at pH levels above 7.5 but are adversely affected by dissolved solids exceeding 5000 ppm. They are considered cost effective only for closed systems. Concentration levels of 100-200 ppm are needed to inhibit corrosion adequately in closed systems.
4. *Polysilicates.* These chemicals perform well in protecting steel, copper and aluminum from corrosion. They do not perform well at pH levels below 7.5

governs the tendency of the amines to remain with the steam upon condensation. Usually, a blend is used for maximum overall effectiveness. High ratio amines (e.g. CHA and NH_3) tend to remain with the steam thus providing protection for equipment and piping located far from the boiler.

(2) Cooling Water System

Several chemicals are used as corrosion inhibitors for cooling water systems.

Anodic inhibitors, also called passivators, are very effective against corrosion but must be used with extreme care. If an insufficient amount is applied into the system, the entire corrosion potential will occur at the unprotected sites resulting in severe pitting. The common anodic inhibitors are described in Table 8.8.

Cathodic inhibitors are also called safe inhibitors or blocking agents. They reduce the corrosion rate by taking over the cathodic reaction with the excess dissolved oxygen in the water. Table 8.9 describes the common cathodic inhibitors.

The effectiveness, limitations, dosages and control requirements of the above corrosion inhibitors are summarized in Table 8.10.

For other metals such as aluminum and copper alloys, some of the above inhibitors can be used. Copper alloys can be protected by chromate, polysilicate and organic inhibitors called copper corrosion inhibitors. These include mercaptobenzotriazole (MBT), benzotiazole (BZT) and tolytriazole (TT). About 10 ppm MBT and 1ppm each of BZT and TT are most often used.

Other corrosion control techniques which can be applied for the protection of steel in a cooling water system are the use of cathodic protection and application of protective coatings. Both can be used either as the total corrosion control program or in conjunction with chemical corrosion inhibitors. Cathodic protection using sacrificial anodes is preferred over impressed currents. Anode materials are either zinc or magnesium with the former having the advantage of contributing zinc ions to the cooling water which act as cathodic inhibitor. Coatings teamed with cathodic protection can prove both effective and economical. The coatings used most often are coal tar or asphalt based materials, alkyds and epoxy types. Epoxies are often preferred over the others because of their greater resistance to temperature and excellent flexibility and bonding properties.

Table 8.11 summarizes the typical chemical treatment programs for corrosion inhibition in cooling water systems.

Table 8.10
Corrosion Inhibitors Selection Guide for Industrial Water Treatment

INHIBITOR	METAL[3]			LIMITATIONS			DOSAGES (ppm)		Film Formation	Reducing[1] Conditions		
	STEEL	COPPER	ALUMINUM	Ca,ppm	pH	TDS,ppm	Initial	Maintenance	Days	H_2	SO_2	HC
Chromate	E	E	E	0-1200	5.5-10.0	0-20000	30-50	5-20	3-4	No	No	
Polyphosphate	E	A	A	100-600	5.5- 7.5	0-20000	40-60	10-30	5-6	Yes	Yes	
Zinc	G	N	N	0-1200	6.5- 7.0	0-50000	10-20	3-5	5-6	No	Yes	
Polysilicate	E	E	E	0-1200	7.5-10.0	0-50000	40-50	10-20	10-12	Yes	Yes	
Molybdate	G	F	F	0-1200	7.5-10.0	0-50000	40-60	5-20	10-12	No	Yes	
Copper Inhibitor[2]	E	E	G	0-1200	6.0-10.0	0-20000	–	1-10				

Notes: 1. Indicates treatment suitability under specified reducing condition
2. Benzotiazole (BZT) or Tolytriazole (TT)
3. E = Excellent A = Attacks
G = Good N = None
F = Fair

Table 8.11 Typical Cooling Water Treatment Programs

A. Closed Recirculating Systems

System pH	8.5-9.5
Choice of Inhibitors	
Chromate	200 ppm CrO_4
Boron Nitrate	200-2000 ppm plus 200-500 ppm borax ($Na_2B_4O_2$) as buffering agent
Molybdate	100-200 ppm plus copper corrosion inhibitors (10 ppm MBT, 1 ppm BZT, 1 ppm TT)

B. Once-Through Systems

Inhibitors	Concentrations
Orthophosphate	1-10 ppm PO_4 plus 0.1-1.0 ppm Zinc
Polyphosphate	1-10 ppm PO_4 plus 0.1-1.0 ppm Zinc
Silicate	10 ppm Silica (min.) pH 7.5
Copper Inhibitors	1-5 ppm slug fed for 15-20 mins once or twice a week
Fatty Amine Salts	5-10 ppm

C. Open Recirculating Systems
Typical Chromate Based Corrosion Inhibitor Programs

Chemicals	Concentrations
Chromate/zinc	5-10 ppm CrO_4/5-10 ppm Zn
Chromate/Phosphate/Zinc	10-30 ppm CrO_4/3-5 ppm SiO_2 3-5 ppm Zn
Chromate/Polysilicate	5-10 ppm CrO_4/5-10 ppm SiO_2
Chromate/Molybdate	10-30 ppm CrO_4/1-5 ppm MoO_4

Chemicals	Concentrations
Chromate/Phosphate	5-10 ppm CrO_4/3-5 ppm Phosphate
Typical Non-Chromate-Based	Corrosion Inhibitor Programs

Chemicals	Concentrations
Polyphosphate	10-30 ppm PO_4
Ortho/Polyphosphate (50/50)	10-30 ppm PO_4
Polyphosphate/Zinc	10-20 ppm PO_4/1-3 ppm Zn
Zinc/Tannin/Lignin	3-5 ppm Zn/50-100 ppm Tannin + Lignin
Polysilicate	10-15 ppm SiO_2
Molybdate/Phosphate	5-20 ppm MoO_4/3-5 ppm Phosphonate
Polysilicate/Molybdate	10-20 ppm SiO_2/1-3 ppm MoO_4
Phosphonate/Polyacrylate	5-20 ppm Phosphonate 10-20 ppm Polyacrylate

(c) Fouling Control

The control of fouling both in cooling water and steam systems is very important since foulants are primary sources of the ills in both systems. Foulants do occur, and the degree of fouling always increases since both systems are operated for longer periods of time between cleaning, and sometimes due to the increased use of poor quality water. They degrade the heat transfer efficiency of heat exchange equipment, plug passages of water and also degrade the effectiveness of scale and corrosion inhibitors. Foulant control is very necessary in implementing internal chemical treatment methods both in steam and cooling water systems.

Fouling can be controlled by mechanical and chemical means. A combination of mechanical and chemical prevention plus chemical clean-up methods can be used with great success. Chemical treatments are effective if properly applied and maintained. But all have limitations and require proper matching to the particular foulant and fouling conditions. Insufficient levels of treatment should be avoided since this may result in little or no fouling control. On the other hand, overdose can be detrimental as well as wasteful.

(1) Steam Systems

Fouling in steam systems is predominant in the boiler water inside the boiler. This is usually caused by corrosion products and sludges formed in the system. The chemicals used for controlling these foulants are the dispersants and sludge conditioners. The dispersants break up the foulants into smaller particles and keep them suspended in the water, making them more easily removed from the system via blowdown. Synthetic water soluble polymers are the most common dispersing agents. The sludge conditioners currently used are synthetic polymers with high molecular weights which agglomerate suspended solids into large non-adhering particles that are easily removed by blowdown. Polyacrylamides are the commonly used sludge conditioners.

(2) Cooling Water Systems

Fouling in cooling water systems is classified into two categories: general fouling and biological fouling. General fouling relates to the fouling caused by artificial and natural foulants that can be found in a cooling water system while biological fouling relates to that caused by biological organisms. The latter is of two types: microbiological fouling, which is caused by microscopic organisms such as algae and bacteria; and macrobiological fouling, which is caused primarily by invertebrate life such as mussels, clams, etc.

The typical chemicals used for general fouling control are the dispersants, sludge fluidizers and surfactants. These are described in Table 8.12.

For biological fouling control, two types of chemicals (biocides) are used: oxidizing and non-oxidizing agents. The effectiveness of these chemicals is well-established. However, proper care is required to avoid possible adverse environmental effects of effluents containing the chemicals. The choice between oxidizing and non-oxidizing microbiocides depends on various factors such as environmental effect, system temperature, pH and design. Table 8.13 shows a description of the oxidizing chemicals. The non-oxidizing chemicals are described in Table 8.14.

Non-oxidizing chemicals sometimes prove to be more effective than oxidizing chemicals. Hence, it is now common practice to blend these two types of chemicals for broader control.

The effectiveness and characteristics of leading biocides against fouling organisms are summarized in Table 8.15. The following are guidelines in the selection and application of microbiocides:

i. Combined application of microbiocide and an antifoulant provides superior control.
ii. The essential element determining the capability of a microbiocide is the resistance offered by the microbe. The first line of microbial resistance is membrane impermeability. The second is the ability of the microbe to develop immunity to the microbiocide.
iii. Temperature and pH have strong effect on microbiocides.

Table 8.12 Types of Chemicals Used for General Fouling Control

1.	*Dispersants.* These are synthetic water soluble polymers and the most prominent are the polyacrylates. Polyacrylates with molecular weights of about 1000 are the most effective dispersants for mud/silt, airborne dust/dirt, iron oxide and biological slime. In recirculating systems 4-5 ppm levels are maintained for proper control. They are not degraded by biological organisms, chlorine or iron salts but are deactivated by strong cationic biocides. They cost less than natural dispersants (e.g., lignin, tannin) for the same performance.
2.	*Sludge Fluidizers.* The most common sludge fluidizers are the polyacrylamides, although polyamines, polyacrylates and various copolymers can also be used. For once-through systems, a dosage of 1 ppm or less for 1 hour feeding each day is typical. For recirculating systems, levels of 0.2-0.5 ppm are usually maintained.
3.	*Surfactants.* These are also called wetting agents and are commonly used for removing oil or gelatinous foulants. Dosages range from 10-20 ppm depending on the amount of oily foulant.

Table 8.13 Oxidizing Chemicals for Biofouling Control

1.	*Chlorine.* This is considered the most familiar and effective industrial biocide. It diffuses easily through the cell walls of microorganisms reacting with the protein bodies in the cell which are essential for life support. At pH levels of 9.5 or greater, chlorine is less effective. Generally, pH levels of 6.5-7.5 are considered practical for chlorine based microbiological control program.
2.	*Chlorine Dioxide.* This is an alternative for chlorine but is relatively costly (up to 5 times more costly than chlorine). It is pH insensitive and is produced by reacting chlorine with sodium chlorite at the point of use.
3.	*Brominated Propionamides.* These are the new oxidizing toxicants for microbial control in cooling waters. A specific example is 2, 3-bidromo-3-nitrilo propionamide (DBNPA). The DBNPA molecule is an extremely potent, broad spectrum microbiocide.

Table 8.14 Non-Oxidizing Chemicals for Biofouling Control

1.	*Organo Tin Compounds.* These are known for their toxicity to algae, molds and wood rotting organisms. They function best in the alkaline pH ranges and are often formulated with quanternary ammonium compounds or complex amines to improve their biocide and dispersant capabilities.
2.	*Quaternary Ammonium Salts.* These are generally most effective against algae and bacteria in alkaline pH ranges. They are deactivated in systems heavily fouled with dirt, oil and debris. Due to their surface activity, they tend to emulsify oils and produce extensive foaming if overfed.
3.	*Organo Sulfur Compounds.* These are highly effective against fungi and slime-forming bacteria. These less toxic, water soluble compounds function best in pH ranges 7 and above with the exemption of Methylene-bis-thiocyanate which is not recommended for highly alkaline recirculating water system.
4.	*Copper Salts.* These have long been used for controlling algae and bacterial growth.
5.	*Isothiazolinone.* This is considered the best algicide in the market. It has been used effectively to combat not only algae but also a broad spectrum of microorganisms over a fairly wi[illegible] [illegible] range.

iv. Microbiocides are usually slug-fed to a system to incur rapid, effective population reductions from which the organisms cannot easily recover.

v. It is better to combine a highly effective, though expensive, biocide with a less expensive type for broad control at reasonable cost.

vi. Microbiological fouling control programs must provide an optimum period between successive dosings. It would be costly to carry out a program which gives adequate control but allows rapid organism build-up to the tolerance level because this would require more biocide to be added to maintain fouling control.

Table 8.15 Microbiocide Selection Guide

Microbiocide	Bacteria				Fungi	Algae	Comments
	Spore Former	Non-Spore Former	Iron Depositing	Corrosive			
Chlorine	S	E	E	O	S	S	Oxidizing, dangerous to handle, corrosive to metals, powder, gas or liquid, delignifies tower wood, less effective at higher pH.
Quarternary Amonium Salts	E	E	E	VG	S	VG	Foams; Cationic
Organo-Tin plus Quarternaries	E	E	E	E	VG	E	Foams; Cationic
Methylene Bis-Thiocyanate	E	E	VG	VG	S	S	Not effective at pH >7.5; Cationic
Isothiasolinones	E	E	VG	VG	VG	E	Dangerous to handle, not effective at pH> 7.5 nonionic
Copper Salts	S	S	S	O	S	S	May cause copper plating
Bromine Organics	E	E	E	VG	O	S	Hydrolyzes, must be fed directly from drum
Organo-Sulfur Compounds	VG	E	VG	VG	VG	S	Toxic effluent, reduces CrO_4; Anionic

E = Excellent VG = Very Good S = Slight O = None

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PART III

EQUIPMENT APPLICATIONS

Preventive Maintenance of Boilers, Kilns and Furnaces

PREVENTIVE MAINTENANCE OF BOILERS, KILNS AND FURNACES

9.1 INTRODUCTION

Boilers, kilns and furnaces are major energy consuming equipment found in almost all industrial plants. Good preventive maintenance in these equipment reduces fuel consumption dramatically, improves performance and reduces costs.

Correct operating procedures, such as proper pre-start-up checks, start-up procedures, on-stream monitoring, emergency procedures and shut-down procedures are intimately related to maintenance. The best source of information on these are the manufacturer's manual. This chapter will only present some general preventive maintenance guides. It is not intended to duplicate the manufacturer's manual.

9.2 DIAGNOSTICS

This section presents some important guides for determining the need for maintenance. These include monitoring of operating conditions and parameters, tests, and inspections.

Accurate records are invaluable in evaluating equipment performance and determining the need for maintenance. Ideally, such records must be started when the boiler or furnace is new in order to provide high but realistic standards of maintenance.

9.2.1 On-Stream Indicators

Superheat Steam Temperature. The superheat steam temperature normally varies with the load. Abnormal superheat steam temperature, readily apparent from the examination of accurate records, indicates a number of possible problems, such as:

(a) too much excess air
(b) too low feedwater temperature
(c) improper operation of steam temperature indicating and/or control equipment
(d) secondary combustion
(e) heavily slagged furnace
(f) below normal steam pressure
(g) too low temperature setting
(h) warped and leaking superheater by-pass damper

If the superheat temperature is below normal it may be due to;

(a) too little excess air
(b) too high feedwater temperature
(c) too much carry-over

(d) excessive external deposits on superheater
(e) improper operation of indicating/control equipment.

If the superheat steam temperature suddenly drops and then recovers, the boiler in priming. This is undesirable since the resulting carryover can seriously corrode superheater metal or cause deposits to form. The temperature fluctuations are proportional to the boiler water total solids or alkalinity.

Boiler Water Level. The proper boiler water level must be carefully maintained. If the water level cannot be seen in the sight glass, shut off the burner. Too high water level can be checked by blowing down until it appears in the sight glass.

A constant reduction of the drum water level could be due to:

(a) Defective feed pump
(b) Malfunctioning feed pump recirculating control
(c) Faulty boiler feedwater valve control
(d) Tube leak

The problem may be identified by quickly comparing current system pressures and valve positions with recorded data at similar loads. Abnormalities will pinpoint the fault.

If the feed water flow is increasing with respect to steam flow but the water level continues to decrease, there is a tube leak. Emergency shut-down procedures must be implemented at once.

Stack Gas Temperature. The stack gas temperature will vary with the load, increasing when the load increases and decreasing when the load decreases. An abnormally high stack gas temperature could be due to:

(a) high excess air
(b) fouled/dirty firesides
(c) secondary combustion
(d) leaky baffles
(e) a fire in the air heater

Abnormally low stack gas temperature could be due to any of the following:

(a) excess air too low
(b) very high CO_2
(c) some CO
(d) smoke

Flue Gas Analysis. Aside from temperature, the quality and composition of flue gases also provide valuable information on maintenance requirements. In addition to providing data for the computation of efficiency and specific fuel consumption, the composition of flue gases also determine the necessary burner adjustments for optimum combustion. One of the most popular measuring devices is the Orsat gas analyzer.

Incomplete combustion not only wastes fuel but also forms carbon deposits which greatly reduce the heat transfer coefficient of metals. Some sources report that a one-eighth inch of soot is equivalent to two inches of insulation. Burner adjustments with flue gas analysis are thus one of the most important tools of maintenance.

In many cases, flameouts or burner failures are caused by faulty safety devices such as flame scanners, and limit, temperature, or pressure switches. Burner settings should not be modified to suit the peculiarities or faults of instrumentation. Accurate pressure, temperature, and O_2 data are needed in fine-tuning burners. These data should be methodically kept and periodically consulted to maintain system efficiency. Burner or unit safety interlocks should never be bypassed by mechanical blocking or electrical jumpering. Such safety devices should be periodically tested and promptly replaced when found to be defective.

In oil burners, the most important factors that control atomization are geometry and cleanliness. Geometry refers to physical aspects such as internal and external mating surfaces of nozzles, rotary cups and diffusers. The maintenance of concentricity is critical; even only slight eccentricity may cause uneven fuel-droplet distribution in the air stream. Unburned droplets may even be flung out of the combustion zone. Sharp cut-off surfaces, flared contours lands and grooves, and ports and orifices should be free from distortion caused by bending, warping, fatigue, crystallization (burning), nicking, clipping, or encrustation.

Table 9.1 shows oil burner problems, their possible causes (in order of likelihood) and some suggested solutions.

9.2.2 Steam/Water Tests and Impurities

Boiler water impurities are the cause of corrosion, scale and sludge. Each water supply is unique, and water treatment specialists should be consulted.

The following are some general discussions on boiler water tests and contaminants. Refer to Chapter 8 for a more detailed and complete discussion.

(a) *Boiler Water and Contaminant Tests*

Routine chemical analyses or control tests vary, depending on the type of chemical treatment used. Such analyses include tests for alkalinity, phosphate, chelate, hydrazine, sulfide, organic color, pH, and total dissolved solids.

Table 9.1: Common Oil Burner Problems and their Solutions

Source- References 1 & 3

Note: Some items may not be applicable to certain burners

Problem/Symptom	Possible Causes	Solutions
1. Black smoke, dull orange fire	a) rich F/A mixture b) improper vane and damper settings c) cold oil or cold furnace d) improperly assembled nozzle components	1. Reduce F/A ratio Measure O_2 Check for proper tip atomizing medium 2. If O_2 is abnormally high, check and adjust oil temperature, primary and secondary air spinner vanes and dampers
2. Flame impingement (carbon buildup on wall, hard direct flame on tubes)	a) incorrect secondary air damper or spinner b) incorrect spray tip angle c) deteriorated throat tile and refractory, incorrect throat selection	1. Reduce spin of secondary vanes Increase spin of primary vanes 2. Use narrower spray angle tip 3. Replace if necessary, consult manufacturer

Cont. (Table 9.1)

Problem/Symptom	Possible Causes	Solutions
3. Flame lazy & dark excess air cannot be lowered to design w/o smoking, flame carry-over into superheater	a) too narrow spray tip angle b) incorrect spin and damper settings c) cold oil	1. Change to wider spray angle tip 2. Increase primary and secondary spin 3. Close secondary air damper incrementally 4. Check oil pressure and temperature and atomizing steam/air pressure 5. Check oil gun and tip assembly
4. Burnup of burner parts	a) too much primary air spin causing an excessive vortex; b) in multiple burners, too little cooling air through idle burners	1. Reduce primary air spin 2. Increase cooling air
5. Sparklers in flame	wet steam or water in atomizing air	remove moisture by appropriate means
6. Repeated flame outs due to scanner not detecting flame	a) improper aiming of scanner b) dirty scanner bulb or lens c) wrong scanner type selected	1. Make adjustments 2. Clean 3. Replace UV scanner with infrared type or visible light type
7. Severe furnace pulsation (1-3 per sec.)	instability and low excess air	1. No flameout-increase A/F ratio 2. Flameout-shut off fuel wait for 5 mins. before purging or relighting
8. Dense white smoke when burning no. 2 oil	poor atomization or too much excess air, resulting in incomplete combustion	Caution: if unit has a regenerative air heater an air heater fire is possible 1. Shut off unit, cool, purge, inspect air heater and clean 2. On restart, check quality of oil temperature
9. Fireballs or fireflies (form hard carbon deposits on impact)	improper air and fuel mixing caused by damaged or encrusted atomizer	Clean or replace if necessary
10. High CO (greater than 0.03%)	rich F/A mixture improper atomization and mixing	1. Adjust as necessary 2. Inspect burner, damper, throat tiles, etc. reduce excess air.
11. High O_2 (greater than 4%)	too much excess air	Reduce excess air

Contaminant tests vary with the suspected contaminants. Some of the more common are for detecting oil, iron and silica. Oil tests usually require laboratory facilities; however, gross oil contamination may be detected by visual inspection. Raw water should be tested for such contaminating agents as; a) mud, clay and salt; b) oxygen, carbon dioxide and hydrogen sulfide; c) sewage, bacteria and algae; d) scale-forming compounds of calcium, magnesium and silica; e) oil; f) iron compounds; g) sulfuric, hydrochloric and other acids; h) normally soluble sodium compounds.

Very high concentrations of soluble or insoluble solids in boiler water will cause foaming. Specific substances such as alkalies, oils, fats, greases, and certain types of organic matter and suspended solids are known to cause foaming.

Table 9.2 a shows the recommended tolerable levels of impurities for given boiler pressures. Table 9.2b shows some common deposits found in raw water.

(b) *Measurement of Corrosion*

Corrosion in boilers may be detected by some impurities revealed in the water analysis, such as iron.

Table 9.2 a: Limits of Impurities for Boiler Water
Source: Reference 5

MAXIMUM LIMITS OF IMPURITIES FOR BOILER WATER

Boiler Pressure (kPa)	Total Solids (ppm)	Alkalinity (ppm)	Suspended Solids (ppm)	Silica* (ppm)
0 - 2074	3500	700	300	125
2075 - 3108	3000	600	250	90
3109 - 4143	2500	500	150	50
4144 - 5177	2000	400	100	35
5178 - 6210	1500	300	60	20
6211 - 6900	1250	250	40	8
6901 - 10348	1000	200	20	2.5
10349 - 13789	750	150	10	1.0
Over 13789	500	100	5	0.5

*Silica limits based on limiting silica in steam to 0.02-0.03 ppm.

BOILER FEEDWATER

Drum Pressure kPa	Iron (ppm Fe)	Copper (ppm Cu)	Total Hardness (ppm $CaCo_3$)
0 - 2074	0.100	0.050	0.300
2075 - 3108	0.050	0.025	0.300
3109 - 4143	0.030	0.020	0.200
4144 - 5177	0.025	0.020	0.200
5178 - 6210	0.020	0.015	0.100
6211 - 6900	0.020	0.015	0.050
6901 - 10348	0.010	0.010	
10349 - 13789	0.010	0.010	

Table 9.2 b: Common Impurities Found in Water
Source: Reference 6

Constituent	Difficulties Caused	Means of Treatment
Turbidity	Imparts unsightly appearance to water. Deposits in water lines, process equipment, etc. Interferes with most process uses.	Coagulation, settling and filtration
Color	May cause foaming in boilers. Hinders precipitation methods such as iron removal and softening. Can stain product in process use.	Coagulation and filtration. Chlorination. Adsorption by activated carbon.
Hardness	Chief source of scale in heat exchange equipment, boilers, pipelines, etc. Forms curds with soap, interferes with dyeing, etc.	Softening. Demineralization International boiler-water Surface-active agents.
Alkalinity	Foaming and carryover of solids with steam. Embrittlement of boiler steel. Bicarbonate and carbonate produce CO_2 in steam, source of corrosion in condensate lines	Lime and lime-soda softening. Acid treatment. Hydrogen zeolite softening. Demineralization. Dealkalization by anion exchange.
Free Mineral Acid	Corrosion	Neutralization with alkalies.
Carbon Dioxide	Corrosion in waterlines and particularly steam and condensate lines. pH varies according to acidic or alkaline solids in water. Most natural waters have a ph of 6.0-8.0	Aeration. Deaeration. Neutralization with a alkalies. pH can be increased alkalies and decreased by acids.
Sulfate	Adds to solids content of water, but in itself, is not usually significant. Combines with calcium to form calcium sulfate scale.	Demineralization
Chloride	Adds to solids content and increases corrosive character of water.	Demineralization
Nitrate	Adds to solids content, but is not usually significant industrially. Useful for control of boiler metal embrittlement	Demineralization
Silica	Scale in boilers and cooling water system. Insoluble turbine blade deposits because of silica vaporization	Hot process removal with magnesium salts. Adsorption by highly basic anion exchange resins, in conjunction with demineralization.

Constituent	Difficulties Caused	Means of Treatment
Iron	Discolors water on precipitation. Source of deposits in waterlines, boilers, etc. Interferes with dyeing, tanning, papermaking, etc.	Aeration. Coagulation and filtration. Lime softening. Cation exchange. Contact filtration. Surface-active agents for iron retention
Manganese	Same as iron	same as iron
Oxygen	Corrosion of waterlines, heat exchange equipment, boilers, return lines, etc.	Deaeration. Sodium sulfite. Corrosion inhibitors.
Hydrogen Sulfide	Cause of "rotten egg" odor. Corrosion	Aeration. Chlorination. Highly basic anion exchange.
Ammonia	Corrosion of copper and zinc alloys by formation of complex soluble iron.	Cation exchange with hydrogen. zeolite. Chlorination. Deaeration.
Dissolved solids	"Dissolved Solids" is measure of total amount of dissolved matter, determined by evaporation. High concentrations of solids are objectionable because of process interference and foaming in boilers.	Various softening process, such as lime softening and cation exchange by hydrogen zeolite, will reduce dissolved solids. Demineralization.
Suspended Solids	"Suspended Solids" is the measure of undissolved matter, determined gravimetrically. Suspended solids cause deposits in heat-exchange equipment, boilers, waterlines, etc.	Subsidence, Filtration, usually preceded by coaqulation and settling.
Total Solids	"Total Solids" is the sum of dissolved and suspended solids, determined gravimetrically	See "Dissolved Solids" and "Suspended Solids"

One important test for corrosion is hydrogen gas sampling of steam. This test is based on the release of hydrogen when iron corrodes. Measuring the amount of hydrogen gas released can indicate immediate fluctuations in load, boiler water changes or fuel changes. This information recorded over a period of time, when interpreted by an experienced, well-trained engineer, will indicate corrosive boiler conditions.

(c) *Blowdown Regulation*

Since there are no simple, routine tests for determining suspended solids, blowdown is usually controlled through the use of a simple instrument which measure the electrical conductivity of boiler water. This test gives an estimate of the dissolved solids on the water. Chloride tests may also be used. By checking the feedwater and boiler water dissolved solids, the operator can estimate the number of feedwater concentrations and then be able to determine the amount and schedule of blowdowns. In high pressure boilers, silica, iron and alkalinity tests may also be used.

(d) *Embrittling Water*

Caustic cracking or embrittlement is the cracking of boiler steel due to concentrations of caustic solution attacking the stressed metal. Embrittling tendency of boiler water may be determined with the use of special equipment. The test involves circulating a representative sample of boiler water through highly stressed steel specimens for about 30 days. Cracking of the specimen occurs if the sample has embrittling tendencies.

(e) *Measurement of Carryover*

Boiler carryover can be measured with the use of a sodium ion analyzer. This instrument measures the sodium ion content in a cooled steam sample that will correspond to the amount of boiler water solids contaminating the steam. The sodium ion analyzer will detect carryover down to 1 ppb sodium in condensed steam.

9.2.3 Inspection

Routine maintenance shut-down provide opportunities for complete water-side and fire-side inspection. This will reveal signs of deterioration, such as corrosion and erosion, sub-standard operation, and the need for maintenance and cleaning. Minor problems, such as partially clogged chemical feed lines, small tube blisters, refractory cracks and soot blower lance defects can be detected and corrected before major damage occurs. Properly conducted inspections, coupled with accurate records, can be the basis for the type and frequency of scheduled maintenance and cleaning.

Before inspection is done, the following safety precautions must be observed:

(a) Drums and breakers must be purged, if the boiler has been laid up under nitrogen.
(b) All vents, drains, and inlet and outlet lines must be closed, locked and tagged.
(c) There should always be a man stationed outside the vessel being entered.
(d) Bare light bulb or ordinary drop lights should not be used in enclosures; instead, use flashlights or specially protected bulb to avoid electrocution
(e) The area to be entered must be adequately ventilated.
(f) For furnaces sharing a common stock, isolation dampers must be closed, locked and tagged.
(g) Caution must be observed when toxic fuel oil additive ashes (i.e. manganese) are present. Silicon bearing insulations may produce fine dust which can cause silicosis. Proper breathing equipment should be used in such cases.
(h) All overhead slag must be removed.

Tables 9.3a and 9.3b contain some pointers for inspecting both the fire-sides and water-sides of boilers. Due to the variety of boiler types, some items may not be applicable to a particular unit.

Minerals in inadequately treated boiler water tend to deposit onto heat transfer surfaces with the following detrimental effects:

(1) tube failures from overheating
(2) plugging and partial obstruction of tubes
(3) corrosion beneath the deposits
(4) greatly reduced heat transfer

Some of the common deposits and their characteristics are shown in Table 9.4. Deposits are seldom composed of one constituent alo[illegible] are generally a mixture of various types of minerals, corrosion products, and other contamin[illegible] as oil.

Table 9.3a: Items to be Checked on Water-Side of Boilers
Source: Reference 3

WATER-SIDE	CHECKED FOR:	COMMENTS
1. steam drum	pitting, deposit, corrosion	oxygen pitting usually occurs above normal water level
2. tubes	corrosion, thinning, scale, pitting	
3. mud drum	deposits	indicates adequacy of blowdown
4. overhead final screens	deposits	indicate carry-over
5. baffles and dryer screens	proper installation	there must be no gaps
6. threaded bolts and flares	thinning and corrosion	
7. all water inlet pipes, chemical feed pipes, gage glass pipes	deposits, proper orientation	

In addition to the above-mentioned parts, all plates, tubes, rivets, bolts, stags and internal fittings must be checked for corrosion, cracks, breakage or distortion. Cracked stags or rivets give off distinctly different ringing sounds when lightly tapped with a hammer as compared to undamaged ones.

9.3 PREVENTIVE MAINTENANCE PROCEDURES

Preventive maintenance procedures in boilers are aimed primarily at keeping heat transfer surfaces and auxilliary systems clean, optimizing combustion, ensuring the proper functioning of instrument, gages and devices, and making minor repairs, adjustments or replacements before serious damage occurs. The combustion systems of oil-fired boilers, furnaces and kilns are similar, and therefore so are their maintenance requirements.

9.3.1 Water-side Maintenance

(a) *Cleaning Operational Deposits*

Two general methods are available for determining the need for chemically cleaning operational deposits from boilers. The first relies on weekly measurements of iron and copper concentrations in the feedwater. From this, the total amount of iron deposited in the

Table 9.3b: Items to be Checked on Fire-Side of Boiler
Source: Reference 3

FIRE - SIDE	CHECK FOR:	COMMENTS
1. tubes, water - walls	corrosion, blistering, bulging, cracks corrosion, soot	
2. superheater	swelling	due to overheating from bringing pressure up too quickly, or scale on the waterside
3. refractory	major cracks, spalling, melt-outs	use feeler gages or hacksaw blades for detecting cracks
4. casing and doors	leaks	
5. economizer	plugging, fouling	
6. air heater, gas ducts	fouling, soot, corrosion	corrosion is most likely in the cooler portions and in accumulations of soot and dirt
7. view ports	damage	replace
8. seal and operating air systems	proper installation	
9. soot blower and nozzles	damage, erosion, aim	repair, adjust
10. tubes in area of soot blowers	erosion	impingement of soot blowers
11. draft taps, airflow taps, flue gas sampling taps	plugging, obstructions	
12. partial hydrostatic test	leaks	use boiler feed pump to generate pressure

Table 9.4 Common Boiler Deposits
Source: Reference 6

Deposit	Physical Description	Characteristics	Causes
1. Phosphate	soft brown or gray	easily removed	phosphate internal treatment program
2. Carbonate	granular and porous	dense and uniform, will effervesce in acid solution difficulty in removing	Carbonate in water/chemicals.
3. Sulfate	hard, brittle	dense, will not pulverise easily; will not effervesce in acid	Sulfate compounds in raw water, chemicals.
4. Silica	very hard, porcelain-like	very dense, very difficult to pulverize, not soluble in HCl	improperly treated raw water
5. Iron	very dark colored	usually magnetic, will dissolve in hot acid	corrosion products, contamination

boiler water may be determined. This amount will then be compared to a standard based on the maximum steaming capacity of the boiler. When the standard is equalled or exceeded, acid cleaning is necessary. In any case, the boiler must be acid-cleaned at least every six years. The other method involves the actual sampling of tube deposit thickness and analysis of the deposit.

These two methods complement each other and should both be used.

Acid Cleaning

An experienced chemical cleaning company must be consulted before acid cleaning is done. The following procedure should be modified to suit particular conditions and equipment.

In new units dilute HCl acid (approximately 5% by weight) solution is used to removed mill scale and rust. For units which have been in operation, additives are added, depending on the boiler water analysis. The following provisions must be made before acid-cleaning.

(1) Install the following:

Acid fill/drain line sized to empty the vessel in 60 minutes. In large units it is advisable to provide a number of acid fill lines at strategic points to ensure uniform acid concentration.

Atmospheric vent lines, nitrogen fill line (w/pressure gage 35kPa). Thermocouples on upper drums and lower heaters superheater backfill connection (for demineralized water or condensate). Temporary sight glass.

(2) Check all drain lines to make sure that they are clear. The boiler should be filled with clear water to normal levels and its temperature should be raised to about 82°C. The following should be checked before acid is introduced:

i. The superheater is full of treated water
ii. Furnace openings and dampers are closed
iii. Drum vent valves are open
iv. All blowdown, chemical valves and superheat drains are closed
v. Metal temperature is around 82°C

With the metal temperature constant, acid solution and 0.25% NH_4HF are added. In removing operational deposit, the following additives may be included, depending on the tube sampling and laboratory analysis:

Copper Removal

i. If copper is below 20% of iron content HCl solution and thiourea.
ii. For copper more than 20% of iron content, a two step ammonium bromate solvent is used.

Hardness Removal

i. For hardness scales caused by calcium sulfate or calcium silicate, alkaline boil-out must be done before acid cleaning.

ii. For organic deposits insoluble in conventional alkaline boil-out, substitute alkaline potassium permanganate solution, to be followed by inhibited HCl cleaning.

The solvent temperature should be kept between 70 to 80°C. Hourly samples are taken until the acid solution and the total iron concentration approach equilibrium. This usually takes less than 6 hours. After that, the boiler is rinsed twice with demineralized water (with 0.1% citric acid) at about 60°C and drained under 35kPa nitrogen. Neutralizing solution is then applied (1% soda ash) for 4 hours; for two hours, the boiler is slowly fired to 690 kPa gage and allowed to hold pressure for 2 more hours. Gradual cooling follows; intermittent blowdown vents are then opened to reduce pressure to 0.2 kPa. When the temperature drops below 95°C, the unit can be drained. Nitrogen should be purged before the boiler is entered for inspection. Sediments should be flushed out and gage glass connections, instrument leads, chemical feed and continuous blowdown piping should be blowdown. *No welding or open flames should be allowed when acid is in the boiler; hydrogen gas liberated in the cleaning process is highly flammable.*

For new boilers, the internal surface should be chemically cleaned to remove oil, grease and protective coatings through boil-out. The manufacturer's manual should be consulted. Before boil-out is started, the pre-boiler system should be alkaline flushed or cleaned. Oil and grease should be mechanically removed where possible.

Mechanical Cleaning

Soft-scale deposits may be removed from tubes and plates by hand-scrapers with special long-handled tools to reach inaccessible parts. For hard scale, chisels and hand hammers may be used. Compressed-air or steam driven hammers are available. Water-tubes are usually cleaned with cutting-tools driven by steam or compressed air.

(b) Blowdowns

Periodic blowdown is recommended to prevent the accumulation of deposits left behind by evaporation, particularly for feedwater of high solids contents. Blowdown schedules should be based on chemical analysis of the feedwater, steaming rates, and accepted limits of soluble solids in the boiler water. It is recommended that a water treatment expert be consulted. As a rule of thumb, mud drums should be blown down at least once every 24 hours.

Blowdowns should be sudden in order to create a thermal shock which will dislodge deposits that have accumulated in the tubes or drum.

Lay-ups

When the unit is shut down for stand-by purposes and draining of the boiler is not required for maintenance or repairs, the boiler metal must be protected against corrosion. The following procedures are recommended:

(1) Short Outage (2 days or longer)

If the boiler is to be shut down for a short period of time (such as a weekend outage) during which the drum pressure will drop to atmospheric pressure:

Introduce nitrogen at a superheater drain valve or boiler drum vent when the steam pressure drops below 5 psig. Maintain a total pressure of 5 psig (due to nitrogen) during the entire lay-up period.

(2) Long Outage (1 month or longer)

When the Boiler is to be shut down for a prolonged period of time (such as a seasonal outage), the following procedure is recommended;

Fill the superheater and reheater with a condensate containing 0.25 ppm of ammonia and 100 ppm of hydrazine. Add the condensate from the outlet ot the non-drainable sections of the boiler and fill the entire boiler. The treated condensate can be displaced with nitrogen or the entire unit can be laid up wet under nitrogen pressure depending upon the temperature of the surrounding area. Maintain a nitrogen pressure of 20-35 kPa. When top valves on the superheater outlets are not installed, steps should be taken to blank off the line so that boiler can be pressurized.

9.3.2 Fire-Side Cleaning and Maintenance

(a) *Soot Blowers*

Soot and slag deposits greatly reduce heat transfer, cause over-heating, and expedite corrosion by absorbing and retaining moisture and corrosive substances.

Soot blowers should be operated frequently enough to keep external heating surface clean.

One way of determining blowing frequency, aside from inspection, is by monitoring the stack gas temperature drop, draft loss and steam/air temperature increase when the soot blowers are being operated. From the analysis of the data, a pattern will emerge; if the pattern is broken, corresponding investigation and adjustments should be made, taking the following into consideration:

(1) The boiler bank and superheater are simultaneously blown to maintain heat pickup balance. It may be advantageous to reduce blowing frequency in the blower bank and increase blowing frequency in the superheater if steam temperature is too low.

(2) Superheater blowing frequency may be reduced while increasing frequency in other areas to reduce steam temperature and increase steam generation.

(3) Increased blowing in the economizer and air heater will increase heat recovery but this must be balanced against the cost of the blowing medium (steam or air) and metal erosion. Observation of rate of soot and slag deposition, cost of blowing, and blowing effectiveness should be used to detemine the optimum schedule.

Normally, soot blowers are used twice a day, although good practice may require more frequency. Soot and slag must not be allowed to accumulate since this will reduce soot blower effectiveness.

A new method of soot removal by acoustic means has been developed and has proven to be quite effective and economical. It was found that the operating cost of acoustic soot blowers is only about 10% of other methods.

(b) *Water-Washing the Fireside*

Ash deposit accumulating on the boiler and superheater surfaces plug the passes in the boiler and superheater. This is detrimental because:

(1) Full load may not be possible because of increased pressure losses which reduce fan capacities.

(2) Incomplete gas circulation or "laning" through the boiler and superheater can cause overheating.

(3) Soot-blowing effectiveness is reduced; plugging rate is increased.

(4) Smoking ensues.

(5) Boiler effectiveness is reduced due to heat transfer loss.

The need for water-washing is indicated by the following:

(1) increased pressure drop through the boiler
(2) reduced steam temperature
(3) increased exit gas temperature
(4) reduced boiler capacity/performance
(5) observed build-up during inspection

The requirements for water-washing are:

(1) outage of sufficient duration
(2) supply of water at desired temperature and pressure
(3) drainage from boiler
(4) lances or nozzles for directing the water

The boiler should be cooled to prevent spalling and stresses on the refractory. The refractory should be protected by plastic or other available material. Super 300 tartar slurry may be applied; this not only protects refractory from water but also prolongs its life. Rods or bars may be used to dislodge tough accumulation but extreme care must be exercised to avoid damaging the tubes. The surfaces should be cleaned to bare metal. Water at 38 to 43°C at a minimum pressure of 2060 kPa gage is preferrable. Wetting agents and corrosion inhibitors may be added. Caustic or soda ash can be used with care since the bonding qualities and melting points of acidic refractories may be reduced. It is advisable to blank-off burner openings, instrumentation or low pressure seal air inserts.

After washing, the boiler should be dried immediately to avoid corrosion in metal parts and restore the refractory to operating condition. This is done by firing the boiler at a very low rate.

Soot deposits inside fire-tubes may be removed by hand scrapers made to fit closely in the tube or by long-stemmed brushes.

(c) *Ammonia - Steam Fireside Cleaning*

This method involves the use of ammonia to clean the fireside of sulfate deposits which are difficult to remove. It has been successfully used many times in the Philippines and is applicable to both water-tube and fire-tube boilers. The steps are:

(1) Shut off burners

(2) Inject liquid ammonia after flame-out through the burners or fabricated injection nozzles. The ammonia will vaporize and go to every part of the fireside.

(3) Close dampers while injecting ammonia.

(4) Allow the boiler to cool down.

(5) Circulate water through the tubes to condense the ammonia vapor onto the fireside surfaces. The ammonia will react with the sulfate deposits to form ammonium sulfate, which is easy to remove. Reaction time is about 4 to 6 hours.

(6) Open dampers to find out if excess ammonia is present. If it is, stop ammonia injection. Another way of determining if enough ammonia has been injected is by collecting the fireside condensate drippings. If the pH of the drippings is equal to or over 8, stop ammonia injection.

(7) Dry the furnace by opening the dampers and operating the auxilliary fans or introducing steam.

(8) Blast the fireside surfaces with compressed air. The ammonium sulfate deposits should come off easily.

(d) *Lay-Ups*

Protection of boilers which are out of service for long periods of time is crucial. Moisture in air can cause serious corrosion to metal parts and degeneration of the refractory. However, short outages of up to 30 days do not require any special fireside protection, as long as the furnace has been dried properly after it was water-washed.

For outages of over one month, the aim of preservation is to keep the furnace cavity, boiler bank, and other areas dry through the following:

1. Seal all possible openings for in-leakage of rain with plastic sheets or plywood.
2. Keep the furnace cavity temperature above the atmospheric condensation temperature. For dry climates or indoor units, this can be done with a string of lightbulbs in the cavity. For high-humidity areas or outdoor units, electric space heaters must be used.
3. Trays of dessicant must be placed inside the boiler to absorb moisture; use 13 Newtons (1.4 kg) of dessicant per 2.8 cubic metre of furnace volume. The dessicant must be inspected and dried or replaced every two months.
4. Other areas of water entry into the furnace, such as seal air systems on view ports and oil guns, leaking soot blower valves, and instrument lines, must be properly sealed.

Table 9.5a: Daily Requirements
Source: References 1 & 2

Check	Comments/Potential Problems
Water level controls	Excessive solids or treatment, oil contamination, mechanical malfunction
Boiler water level	Operating level; pump-on, pump-off levels
Boiler blowdown	Blowdown valve leakage, excessive water blowdown; Water column blowdown analysis as prescribed by specialist
Burner operations and visual flame check	Cleanliness, properly working controls, correct atomizing pressure for any variance from normal setting
Pressure (burner ON and OFF)	
Oil burner pressure Oil supply pressure Oil supply temperature	Variations indicate dirty strainers, leaks, or fuel pump wear for proper oil viscosity
Gas pilot pressure Atomizing steam/air pressure Exhaust gas temperature controls	Variation from normal value
Pressure and temperature controls	Excessive steam pressure or water temperature may indicate excessive boiler loading
Motor operation	Excessive noise, vibration, defective seals bearings
Housekeeping	Look for leaks, noise, vibration, unusual conditions
Record updating	To include above observations, fuel and type, any maintenance, water analysis, pre-heater temperature observations.

Table 9.5b : Weekly Requirements
Source: References 1 & 2

Check	Comments/Potential Problems
Operation of water-level controls, low water cut-off	Bring down water level to test automatic shut-off; do not allow water to fall below recommended level
Blowdown water level control	Purge float valve of possible sediment accumulation
Feedwater pressure (temperature)	Abnormal values
Fuel supply	Low level
Oil supply vacuum	Variations indicate dirty strainers, accumulation of deposits, needs more frequent cleaning; Burner maintenance Follow manufacturer's recommendations
Gas analysis	CO_2, excessive smoke, temperature, stack draft and pressure drop through boiler
Flue gas leakage	Gasketing, etc.
Hotspots	Indicating by paint discoloration
Safety or relief valve	Leakage, working condition
Pilot and flame scanner	Spark gap, electrode condition, cleanliness
Lubricating oil assembly	Oil Level
Tight closing of fuel cut-off	Flame extinguishing characteristics
Flame safeguard	Per manufacturer's recommendation
Burner operation	Cut off fuel, observe flame failure, note reaction time, start boiler and observe light-off characteristics

9.3.3 Scheduled Maintenance Requirements

Periodic inspections and corrections/replacement prevent major failures and damage from occuring, improve efficiency, and reliability and reduce downtime. Thus, they cost less in the long run.

The following tables on periodic inspection and maintenance of boilers are general and may not apply to a specific unit. They are not substitutes for the manufacturer's manual; however, they provide useful insights and information.

Table 9.5c - Monthly Requirements
Source: References 1 & 2

Check	Comments/Potential Problems
Blowdown	Frequency, water treatment
Burner Operation	Flue gas analysis , stack temperature
Combustion air supply	Evaluate records, check air inlet, clean filters, check oil level
Fuel system	Check pressure gages,pumps, filters and transfer lines, clean replace filters as required
Water pump, circulating pump	Packing glands, bearings, couplings
Duration of run	Longer run is an indication of wear
Water strainer	Fouling, clogging, sediments
Indicating lights, alarms	
Operating and limit controls	Test for function
Low water cut-off	
Safety and interlock	Function
Belts	Tension

Table 9.5d: Semi-Annual Requirements
Source: References 1 & 2

Check	Comments / Potential Problems
Item	
Clean low water cut-off	
Remove all plugs in LWCO and piping	Or as required by insurance company
Remove and clean oil preheater	Or as usage indicates
Refractory	Spalling, damage, cracks, deterioration
Fireside surfaces Waterside surfaces Safety/relief valves	Soot and slag accumulation, blistering and swelling scale, and sitting

Table 9.5e: Annual Requirements
Source: References 1 & 2

Check	Comments/Potential Problems
Breeching, bolts foundations, brickwork	Damage, cracking
Refractory	Repair as necessary
Fireside surfaces	Clean with brush, water wash, vacuum clean
Waterside surfaces	Follow recommended procedures, consult water treatment specialist, hose-down sludge, scale, etc.
Relief valves	Recondition/replace
Fuel system	Fuel storage tanks - sludge and water, corrosion Fuel oil pre-heater - sludge/scale build-up Fuel pump wear and tear
Control system	Check electronic controls, electrical terminals, necessary switches
Chemical feed system	Empty, flush, recondition

9.3.4 Specific Maintenance Suggestions

a. By-pass air-heaters and economizers at start-up, shut-down or low loads when the flue gas temperature falls below 430°C to prevent corrosion due to condensation. Always provide by-passes for air-heaters and superheater.

b. In multiple burner systems, provide cooling air for idle or non-firing burners during operation to protect them from over-heating.

c. Isolate non-operating boilers in multiple boiler systems.

d. Check fuel-oil thermostats to insure proper viscosity for good atomization.

e. Use proper oil filters to assure good atomization

f. Use non-greased bearings in dampers. Grease in bearings collects dust and dirt, resulting in bearing seizure.

g. Use fuel additives to prevent the deposition of sodium and salts when firing oils which have them.

h. Prevent air in-leakage into the combustion space and stack. Leakage may be detected by taking oxygen readings at two points; an increase in oxygen downstream indicates that air is seeping in through cracks between the two points.

9.4 APPLICATION CASE

The following is an actual weekly maintenance schedule for the boilers of a textile plant in Metro Manila.

1st Shift:

1. Clean the atomizing cups of steam boilers.
2. Push-on carbon debris inside the furnace of steam boiler
3. Regenerate the two cochrane units
4. Fill-up the emergency water elevated tank.

2nd Shift:

1. Clean the deaerator tank, especially the cone type strainer.
2. Check/align the belt tension of individual burner, steam boiler.
3. Replenish oil and grease on all bearings; pumps, compressors, and induced draft fan.
4. Clean the fuel strainers near storage tank.
5. Refill with salt the emergency hooper tank and the salt dissolving tank.
6. Clean the dirty plastic trays, sampling bottles, panel boards and others.
7. Clean the entire boiler/Infilco house vicinity,
8. To prepare rolled cloth in preparation for the starting of boiler.

3rd Shift:

1. Clean the fuel strainers of steam boiler.
2. Purge condensate from steam main.
3. Pump-in the accumulated oil in our receptacle.
4. Start-up steam boiler operations.

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Preventive Maintenance of Air-Conditioning and Refrigeration Equipment

10.1 INTRODUCTION

Refrigeration systems have four basic parts, which are the evaporator, the condenser, the expansion device, and the compressor. In absorption systems, an absorber and generator apparatus takes the place of the compressor. The evaporator and condenser are heat exchangers, and their maintenance requirement consists of keeping the heat exchange surfaces clean. Compressors have mechanical components such as bearings, valves, etc. which are subject to wear. Lubricants for compressors may be contaminated with water, refrigerant, and rust. Other devices such as filters, gages, etc. could become clogged. The refrigerant circuit is usually infiltrated by air and non-condensable gases, which reduce the effectiveness of the condenser and other heat exchangers, and unnecessarily increases the work of the compressor. Moisture in the air causes corrosion of internal surfaces and contamination of the oil. These factors are the concerns of maintenance in air-conditioning and refrigeration systems.

Cleanliness is very important during fabrication, installation, and servicing. Since the refrigerant loop is closed, any dirt or contamination left in it will remain and cause serious maintenance problems.

Since each air-conditioning and refrigeration system is unique, it is recommended that the manufacturer's manual and the installing company be consulted. What will be presented are some general maintenance guides; some may not be applicable to a particular equipment or installation. Electric motors, which are the most commonly used prime movers, are discussed in Chapter 11.

10.2 DIAGNOSTICS

10.2.1 On-Stream Indicators

The refrigeration or air-conditioning system has certain operating characteristics which if properly recorded and correctly interpreted will indicate the need for maintenance. Action or investigation is usually needed when there are any deviations from normal temperatures, presures, vibration levels, etc. it is recommended that operators develop a "feel" for the system so that maintenance signals can be detected at once. The following are some important parameters to be observed during operation.

(a) Refrigerant Pressure.

The critical points of measurement of refrigerant pressure are before and after the compressor. Table 10.1 contains ways of interpreting abnormal suction or discharge pressure.

(b) Condition of Lubricant

Operating Oil Pressure. The operating oil pressure will gradually decrease due to clogging of oil filters and loosening of the wearing parts of the system. Some manufacturers recommend that the oil filter be changed when the operating oil pressure has decreased to

Table 10.1: Possible Causes of Abnormal Refrigerant Pressure
Source: References 2 & 3

Problem	Indications	Cause	Suggested Action
1. Too high discharge pressure	a. Too warm water from condenser	Insufficient or too warm cooling water	1. Increase cooling water flow 2. Lower cooling tower thermostat
	b. Hot condenser	Air or noncondensable gas in system	Purge
		Excessive refrigerant	Trim regrigerant
	c. Cooling tower functions properly but discharge pressure is still high	Cooling tower too low	1. Recheck refrigerators 2. Change cooling tower if required.
2. Too low discharge pressure	a. Too cold water from condenser	Excessive condenser water	Adjust valve or selting
		Cooling tower thermostat set too low	Raise selting of thermostat
	b. Cooling tower works but discharge pressure low	Cooling tower too large	1. Recheck specifications 2. Replace cooling tower if necessary
3. Too high suction pressure	a. Compressor runs continuously	Excessive evaporator load due to infiltration	Prevent infiltration (e.g. real cracks, close windows etc.)
	b. Too cold suction line	Liquid refrigerant flooding back to compressor due to overfeeding of expansion valve	Reset expansion valve and check probe attachment
4. Too low suction pressure	a. Bubbles in sight glass	Lack of refrigerant	Repair leak, if any and recharge refrigerant
	b. Loss of capacity	Blocked expansion valve	Clean or repair valve
	c. Too low temperature in conditioned space	Thermostat contacts stuck close	Repair or replace thermostat
	d. Too high superheat	Too much pressure drop through evaporator	Check for plugged external equalizer, if any

70%. Experienced technicians can tell by feeling the casing of the oil filter if it is clogged. The possibility of extreme bearing wear should be investigated. If there is severe oil pressure fluctuation, it is possible that there is a leak on the vacuum side of the lubrication piping or the oil pump seal.

Oil Contamination. Contamination is a serious lubrication problem. The most common oil contaminants are rust, water from leaks, and the refrigerant. If the oil has become dark or black, it is a sure sign of contamination. Several laboratory tests are helpful in determining the cause and extent of oil contamination (Refer to Chapters 4 and 5). Used oil filters should be dissected and the deposits trapped in them examined. Aluminum fragments indicate sericus aluminum bearing wear.

Oil Carried by the Refrigerant. Serious losses in capacity of the condenser and evaporator could be due to oil carried by the refrigerant and deposited on the heat exchange surfaces. This reduces the heat transfer coefficient of the metal. Operational characteristics can indicate oil deposition. For example, oil can be detected by the absence of condensation in the lower portions of cooling coils. Higher condensing temperatures could be due to oil in the condenser surfaces.

(c) Non-Condensable Gases in System

Air or leaks will generally cause a reduction of capacity. In high-pressure systems, the result is one or more of the following:

(1) Lowering of evaporator pressure and temperature
(2) Icing in parts of exposed liquid line
(3) Higher chilled water temperatures
(4) Lower condenser discharge temperatures
(5) Lower motor load (determined by taking current and voltage readings)

Low pressure systems using R-11 are particularly susceptible to air infiltration. Leaks are difficult to detect because the direction of flow is into the system. If automatic purging becomes too frequent, or the compressor cuts out due to high pressure without any other apparent cause, air in-leakages are probable. Leak testing should be done as soon as practicable.

10.2.2 Leak and Vacuum Testing

(a) Leak Testing

Hissing sounds, particularly at joints and gaskets, indicate leaks. The exact location of the leak can be determined through the soap test. Continuous bubbling will show where the leak is.

A halide torch or electronic halide leak detector can be used to locate leaks at joints. welds, flanges, and other connections, particularly in high-pressure components. R-12 can be readily detected using these instruments, but in a low pressure unit which uses R-11, it is necessary to transfer the R-11 and fill the system with a mixture of dry nitrogen and R-12. As an example, in York Turbopaks R-12 is introduced in the evacuated system up to about 14 kPa; then the pressure is built up to 70 kPa with dry nitrogen. Care and thoroughness are very important in testing for leaks.

(b) Vacuum Testing

In vacuum testing, the system is isolated from the atmosphere and emptied of gas or air using a vacuum pump. It is then allowed to stand for some time. If the internal pressure increases, there is a leak which must be found and repaired. For example, in

York turbopak units, the pressure to be maintained is around 5 mm Hg corresponding to about 0.06 °C wet bulb temperature. If after 4 hours the wet bulb temperature is still below 4 °C, the Turbopak unit is considered leak-free.

Vacuum testing may not be effective in large units because small but significant leaks will produce virtually no increase in pressure.

10.2.3 Valve and Filter Temparature

Operation of valves and solenoids or clogging of filters can usually be checked by touch. This is one reason why it is important for the operators to develop a "feel" for the system. Some ways of checking for clogging or malfunction through touch follow.

(a) Clogged Strainer

The outlet piping of a clogged strainer will feel cooler than the inlet piping. Severe clogging will cause dew or frost to appear at the outlet piping.

(b) Thermostatic Expansion Valve (TEV)

If the suction line is abnormally cold, the TEV power unit may have lost its charge. To test this, the following is suggested.

(1) Cut off power to compressor
(2) Remove sensor from line and place in ice water.
(3) Start the compressor
(4) Remove the sensor from the water and warm it in the hand; if the suction line immediately becomes cold (indicating a flood of liquid refrigerant), the power unit is operating properly. **Warning: Do not allow flooding to continue longer than is necessary to determine that refrigerant flooding has occured. Liquid refrigerant can seriously damage the compressor.**

An abnormally cold suction line indicates refrigerant flooding which could also be due to an improperly set TEV

(c) Solenoid Valve leakage

A leaking solenoid valve in the closed position may be detected by feeling its outlet and inlet piping. The outlet will be colder than the inlet if the valve leaks. Serious leakage may impair the compressor's low suction pressure cut out.

(d) Refrigerant Charge

Bubbles in the sight glass, coupled with a warm, low pressure suction line indicate lack of refrigerant.

Too much refrigerant may be the cause of high head pressure. In extreme cases, high-pressure cut-out or thermal overloads in the starter may shut the motor off.

10.2.4 Megging the Motor

Hermetic compressors are vulnerable to moisture from outside air or leaks collecting inside their shell. Testing the motor winding resistance with a megaohmeter will show if there is a need to drive off moisture in the windings through heating. Decreased resistance generally indicates moisture; the lesser the resistance, the more moisture is present. Graphs are usually used to determine if the motor needs to be heat-dried. An example of this is shown in Figure 10.1.

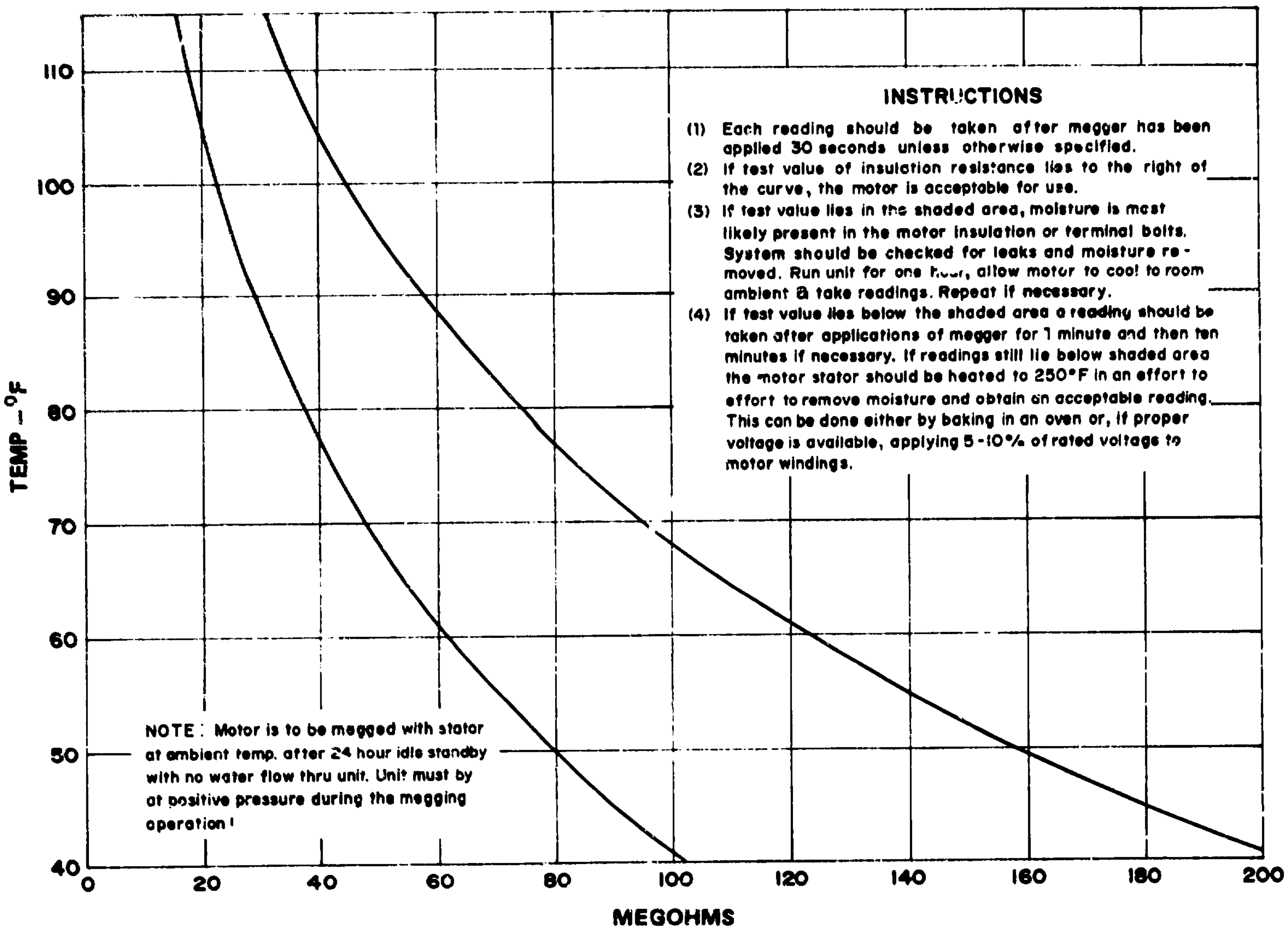

Table 10.1: Possible Causes of Abnornal Refrigerant Pressure
Source: References 2 & 3

10.3 PREVENTIVE MAINTENANCE PROCEDURES

10.3.1 Water Treatment and Internal Cleaning

Maintenance of heat exchange surfaces, particularly the condenser and cooler tubes, primarily involves keeping them clean and free of scale, fouling, oil, and corrosion. These deposits reduce the heat transfer coefficient of metal and generally contribute to its deterioration.

(a) *Water Treatment*

Most scale and deposition problems are water-related, and it is advisable to at least consult a competent water treatment authority. A chemical analysis should be done on representative water samples to determine the proper water treatment program. Chapter 8 tackles internal and external water treatment.

(b) *Cleaning*

Tube deposits can be generally classified into two types as follows:

(1) *Rust or sludge.* These deposits usually accumulate inside tubes but do not build up on the internal tube surfaces as scale. They can usually be removed by thorough mechanical brushing.

(2) *Scale.* These deposits are due to mineral and other contaminants in water. They are quite thin, and are not readily seen during inspection, but they are highly resistant to heat transfer. Acid cleaning is necessary to remove them.

Soft bristle bronze brushes may be used to clean tubes of rust or sludge. It is recommended that water be admitted into the tubes during brushing to improve cleaning. To do this, the brush may be mounted on a tube with some holes in it, with the other end of the tube supplied with water through a hose. Brush cleaning should precede any acid cleaning.

It is recommended that samples of scale or dirt from tubes be chemically analyzed to determine the best cleaning solution for acid cleaning. If this is not possible, however, commercial hydrochloric (muriatic) acid can be used. If the services of a competent cleaning authority cannot be acquired, the following general cleaning procedure may be adopted:

(1) Brush-clean the heat exchanger

(2) Make the system watertight

(3) Provide for inlet and outlet piping, an acid mixing tank, and a suitable pump as in Figure 10.2. The capacity of this tank should be more than the anticipated maximum volume of acid solution that the system will hold, plus a certain amount in the tank for recirculation.

(4) Place the necessary amount of water in the acid mixing tank, and add the appropriate amount of inhibited acid cleaner. **Caution: Always pour acid into water. Never add water to acid.** If the scale is coated with an oily film, use a good grease cutting detergent first before the acid, rinse, and then use the acid solution.

(5) Operate the pump to recirculate the solution through the system. The open mixing tank allows any gases which may have been liberated (like hydrogen) to escape. **Do not allow any open flame or spark in the area, as this may cause the hydrogen to explode.** Recirculation should go on for a few hours. Some suppliers recommend one hour for the grease cutting solution and four hours for the acid solution. Cleaning should be repeated if subsequent inspection reveals the presence of scale.

(6) Rinse the system with water. Then, neutralize the acid by soaking the system with a suitable alkali solution for about an hour. Some companies use 0.5% $NaOH$ solution by weight. Drain the neutralizing solution and rinse the system with fresh water.

10.3.2. Purging

Non-condensable gases and moisture laden air should be kept out of the system. Air and non-condensables usually gather in the condenser, covering some condensing surface, and increasing internal pressure, extra work done to compress the air mixed with the refrigerant, and moisture in the system causes acid formation and corrosion.

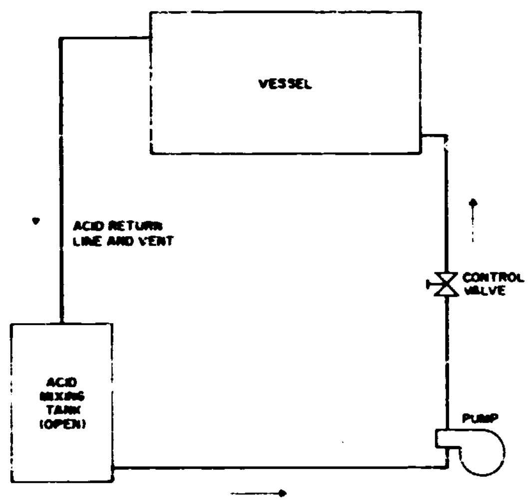

Figure 10.2 Acid Cleaning Auxiliaries and Connections

Since it is virtually impossible to completely isolate the system from the atmosphere, air and non-condensable gases must be periodically purged out of the system.

Most systems are equiped with automatic purging units which separate the air from the refrigerant by condensing the latter. After a pre-set time, non-condensed gas is vented to the atmosphere. Since there is a great possibility that some refrigerant may be purged out with air, the setting of the purge unit should be periodically checked. Excess automatic purging should be investigated. It may be necessary to replace float or pressure switches and/or solenoid valves to correct faulty purge operation. Periodic maintenance of purge units is needed to ensure reliable performance. An example of a purge unit preventive maintenance schedule is shown in Table 10.2.

Table 10.2: Typical Preventive Maintenance Schedule for Purge Units
Source: Reference 2

Period	Maintanance Procedure
1. Quarterly (more often if conditions warrant)	Change the purge unit filter drier
2. Annually	a. Clean and inspect all valves which are part of the purge unit system b. Drain and flush oil and refrigerant from the purge unit shell c. Clean all orifices d. Inspect the foul gas inlet of check valve

10.3.3 Vacuum Dehydration

Before refrigerant is charged into the system, air moisture must be removed. One practical method involves the removal of air from the system with a vacuum pump. As the pressure decreases, moisture flashes to vapor and is carried out with the air. The limiting vacuum pressure is around 0.7 kPa (abs). At this pressure, most of the air has been drawn out of the system but there is still some moisture left. To provide a medium for extracting this remaining moisture, dry nitrogen is usually introduced into the system. Then, the vacuum pump is again operated to draw out the nitrogen and moisture up to the pressure of 0.7 kPa (abs).

10.3.4 Scheduled Maintenance

According to some sources, refrigeration and air-conditioning systems are designed for a theoretical life of 20 years. Scheduled maintenance requirements vary, depending on the system.

Compressors should be inspected at least weekly for proper oil level. The oil should be visible in the sight glass when the compressor is running. Oil should be added whenever the oil falls below the recommended level. In open-type compressors, the shaft seal should be inspected and replaced if it leaks.

Other system components also need to be checked and serviced periodically depending on the manufacturers recommendation. Generally, this consists of replacing the oil filter, draining the purge drum of water, checking drive-belt tension on components, and lubricating linkages.

Annual requirements may include changing the oil, checking the electrical control systems, and general compressor overhauls.

An example of a scheduled maintenance program follows;

(a) *Daily*

(1) If the compressor is in operation, check the bearing oil pressure.

(2) Check the entering and leaving condenser water pressures and temperature.

(3) Check the entering and leaving chilled water temperatures and pressures.

(4) Check the liquid refrigerant temperature leaving the condenser. A thermometer well is located in the flow control chamber for this purpose.

(5) Check the compressor discharge temperature. A well is provided in the compressor discharge connection for a thermometer. During normal operation discharge temperature should not exceed 121 °C.

(6) Check the compressor motor amperes.

(7) Check for any signs of dirty or foul condenser water. (The temperature difference between water leaving condenser and liquid refrigerant leaving the condenser should not exceed the difference recorded for a new unit by more than 2.2 °C

(b) *Weekly*

Check the refrigerant charge

(c) *Quarterly*

Change the purge unit filter-drier at least quarterly, or more often if required.

(d) *Annually (more often if necessary)*

(1) Drain and replace the oil in the compressor oil reservoir

(2) Replace the oil filter element.

(3) Replace motor cooling liquid filter element

(4) Clean the condenser tubes

(5) Replace oil eductor filter

(6) Inspect and service electrical components as necessary.

Maintenance of absorption systems consists primarily of keeping moist air and non-condensables out by repairing all leaks and purging. Table 10.3 is a summary of manufacturers' recommendations for scheduled maintenance in absorption systems.

10.3.5 Ventilation Systems

Regular maintenance in air-conditioning ventilation systems reduces fan power requirements and eliminates overventilation and uncontrolled infiltration. The following are some maintenance guides for duct, damper and coil systems.

(a) Check ductwork for any obstructions, loose or damaged insulation and air leaks. Adjust turning vanes and accessories. Tape or caulking may be used to seal leaks.

(b) Regularly clean or replace air filters. If possible, use low pressure-drop filters (consult contractor or manufacturer). Check electronic air cleaners for accumulations and replace filter media if necessary.

(c) Periodically clean air heating, cooling and dehumidification coils with a mixture of detergent and hot water. A portable high-pressure cleaning unit may be used. Check and correct leakage around coils and casing.

(d) Regularly clean all dampers, fan parts, spray chambers, diffusers, controls, strainers and eliminators to keep them free from dirt, lint. etc. Use high-pressure water to clean eliminator wheel blades. Inspect mixing dampers and linkages and clean, adjust VAV boxes to stop overcooling or overheating. Check tightness of automatic dampers and improve seals with felt weatherstrip.

(e) Recalibrate all sensors, controlling louvers, and dampers regularly.

(f) Check all air inlets, outlet-diffusers, registers, and grilles for dirt and obstructions. Clean if required.

Uncontrolled infiltration unnecessarily increases the cooling load. It may be prevented by the following;

(a) Check interior and exterior surfaces for cracks and faulty seals; caulk where needed.

(b) Inspect sections of dampers, louvers, ducts and pipes that enter the building for leaks. Caulk may be applied to seal sources of infiltration.

(c) Check all window and door seals for tightness and repair if necessary.

(d) Keep window and door latches or locks in good condition and repair all cracked and broken window glass.

(e) Window air-conditioners, louvers and dampers should be sealed with plastic covers if idle for long periods of time.

(f) Inspect automatic door opening and closing devices to assure quick action and tight sealing.

Table 10.3: Summary of Absorption Manufacturers' Maintenance Recommendations

Source: Reference 3

Frequency	Manufacturer 1	Manufacturer 2	Manufacturer 3	Manufacturer 4
Daily				Check purge indicator and oil level Purge unit or timer Pressure-check prior to each start-up
Weekly	Purge unit	If down over 3 days vacuum purge unit and test prior to start-up	Check purge oil level	Check, pump-seal water level throughout year and before each start-up
Monthly ...	Check purge alignment and belt tension Check purge oil	Check purge metering rate Check leak rate by vacuum test Reclaim solution Add octyl alcohol	Check purge belt tension	Check purge belt tension
Semi-Annually		Lubricate solution motor linkage	Check corrosion inhibitor content Change purge oil	
Annually ...	Change purge oil Lubricate purge motor Add octyl alcohol Adjust controls	Replace vacuum tubes in control motor	Replace purge discharge-valve rubber and oil-distributor rubber	Change water-pump seal Lubricate pump motor Check controls Change purge oil and belt
Biannually		Remove alcohol from purge Clean or replace purge sight glass Replace upper and lower bail check-valve seat Replace valve diaphragm Clean or replace absorber sight glass	Replace valve diaphragm	
Others	Clean pump coolant and lubricate strainers	Inspect pumps and motors after 20,000 hr	Reclaim solution leak check Clean pump strainers, float	Reclaim solution per test

10.3 APPLICATION CASE

This case study indicates that good preventive maintenance can result in substantial savings through increased efficiency, lesser material requirements, and reduced cleaning frequency. The savings generated are not necessarily entirely due to preventive maintenance. Other factors such as amount and type of material being refrigerated could have affected the power consumption of the compressor.

The Food Terminal Inc. main cold storage facility in Bicutan, Taguig, Metro Manila has a number of NH_3 compressors. Regular monitoring, cleaning, adjustments and annual overhauls were done on a particular high-stage screw compressor. The following comparison was obtained.

1. **Before Preventive Maintenance**

   a. Higher consumption of lubricating oil
   Cost = 9.33 drums/year/compressor at ₱5241.36/drum
   equivalent to ₱48,901.89/compressor /year

   b. Overheating of Ammonia Compressor as a result of dirty oil cooler, requiring cleaning of carbonized oil. Cost = ₱1,384.62/compressor/year

   c. Oil separator filters were clogged/damaged by accumulated carbon. Filter life was reduced by one half.
   Cost = ₱265 x 14 pcs. = ₱3710/compressor/year

   d. Oil pressure filter clogged/damaged by accumulated carbon. Filter life was reduced by one half.

   Cost = P1,700/compressor/year

   e. Frequent cleaning of suction oil filter, pressure oil filter, capacity control unit results in the purging of approximately 5 kg of NH3.

   $$\text{Cost} = \frac{5\text{ kg NH3}}{\text{compressor}} \times \frac{2}{\text{month}} \times \frac{12\text{ months}}{\text{year}} \times \frac{₱18}{\text{kg NH3}}$$

   = ₱2160/compressor/year

   f. Worn out oil pump bearings

   $$\text{Cost} = ₱310 \times \frac{2\text{ times}}{\text{year}} = ₱620/\text{compressor/year}$$

   g. Reduced equipment efficiency and increased power consumption

   $$\text{Cost} = \frac{\sqrt{3}\,(460V)\ (555\text{ amp.})\ (0.95)}{1000} \times \frac{24\text{ hrs}}{\text{day}} \times \frac{365\text{ days}}{\text{year}} \times \frac{₱2.50}{\text{kWh}}$$

   = ₱9,199,816.43/year

   h. Total Operating and Maintenance
   Cost = ₱9,257,292.94/compressor/year

2. **Preventive Maintenance Work Done :**

Maintenance in compressor as required in the general maintenance schedule

a. Continuous monitoring and checking of compressor operating status and condition.

b. Lubrication of electric motor drive.

c. Cleaning of filters and purifiers and condensers.

d. Adjusting compressor controls as required.

e. Overhauling of compressor and motor ₱17,155.71

3. **Experience and Results with Preventive Maintenance:**

Applying preventive maintenance in the operation of the ammonia compressor, the following results were observed:

a. Consumption of lubricating oil decreased.
Cost = 8.66 drums/year/compressor at ₱5241.36/drum
= ₱45,390.18/compressor/year

b. Lesser accumulation of carbonized oil

c. Oil separator filters clogged/damaged were reduced
Cost = ₱265 x 14 (1/2)
= ₱1855/compressor/year

d. Oil pressure filters clogged/damaged were reduced
Cost = ₱850/compressor/year

e. Cleaning frequency of suction oil filter, pressure oil filter and capacity control unit was reduced by one-half.

$$\text{Cost} = \frac{5\text{ kg NH3}}{\text{comp.}} \times \frac{1}{\text{month}} \times \frac{12\text{months}}{\text{year}} \times \frac{₱18}{\text{kg NH3}}$$

= ₱1080/compressor/year

f. Less worn out oil pump bearings
Cost = ₱310/compressor/year

g. Increased equipment efficiency with a reduction in operating current by approximately 10 amp. average at same load.

$$\text{cost} = \frac{\sqrt{3}\ (460V)\ (545)\ (0.95)}{1000} \times \frac{24\text{ hrs.}}{\text{day}} \times \frac{365\text{ days}}{\text{year}} \times \frac{₱2.50}{\text{kw-hr}}$$

= ₱9,034,063.98/compressor/year

Total Maintenance and Operating Cost with Ammonia Compressor Overhauling:
Cost = ₱9,100,694.87/compressor/year

Total Maintenance and Operating Cost Without Preventive Maintenance;
Cost = ₱9,257,292.94/compressor/year

Net Savings = ₱156,598.07/compressor/year

NOTE: Labor Cost Not Considered.

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Preventive Maintenance of Electrical Equipment

11.1 INTRODUCTION

The preventive maintenance programs involving electrical equipment should be aimed towards eliminating the conditions that contribute to failure before it occurs within the life expectancy of the equipment. This should accomplish two objectives: 1) It should maintain the equipment in good condition and 2) It should provide warning against impending breakdown. Energy conservation is also an important result.

It is essential that the maintenance engineers and technicians be completely aware of the operating sequence and purpose of each part. It is not the purpose of this chapter, however, to discuss the many types and uses of various electrical equipment but rather to describe general preventive maintenance diagnostics and procedures applicable to most electrical equipment.

11.2 DIAGNOSTICS

Diagnostic procedures are means of gathering information concerning the condition of electrical equipment. The information normally coming monthly from machinery history files and other sources, such as equipment brochures and manuals, are analyzed and gathered for use in decision making. Diagnostics consist of a variety of electrical tests, visual examinations and knowledge of equipment operation. These are utilized to look for a weakness in the equipment so that it can be removed or repaired before it causes trouble.

A complete record for each piece of electrical equipment should be maintained. The records should show nameplate data, ratings, date of installation, etc. The manufacturer's drawings, recommendations, instructions, and spare parts data should be recorded. The dates of each inspection should be recorded and a record of all tests and maintenance should be kept.

Properly recorded data will be extremely helpful in emergencies to identify parts quickly and to procure replacements needed to make repairs. In many cases they will indicate when repairs can be anticipated.

The basic considerations for determining preventive maintenance diagnostics are as follows:

a. The type of electrical apparatus
b. The application of the apparatus
c. The environmental conditions under which it must operate
d. Its age and condition

Table 11.1 gives the common causes of failure of electrical equipment.

Table 11.1 Common Causes of Failure of Electrical Equipment

Source: Reference 1

1. Environment	Dirt and dust Chemical Moisture Excessive heat
2. Application in terms of	Overloading Improper selection enclosure Voltage and/or power factor problems
3. Installation	Poor or loose mountings Improper electrical connections Improper protection
3. Condition	Age Wear or damage

11.2.1 Periodic Tests

These are tests used to establish the condition of the equipment. They are conducted at varying intervals of time depending upon the type of equipment.

The following is a list of periodic tests that can be performed on electrical equipment·

(a) *Insulating Resistance Test.* This test is performed to verify the integrity of the insulation used in all types of electrical equipment. This includes transformers, circuit breakers, cables, motors, switches, etc.

(b) *Power Factor Test.* This test is used to measure the power factor of the insulation in all types of electrical equipment and cables. The test is conducted at temperatures above 0°C since ice is a relatively good conductor. This test provides an indication of the quality of the insulation. Values obtained during the acceptance tests are compared with expected ranges of values determined from similar equipment. After the initial tests a comparison is made between values obtained at different times so as to establish a trend and thus anticipate potential troubles. Whenever possible, power factor tests are incorporated into the routine factory tests for equipment. The acceptance test values may then be directly compared with the factory values.

(c) *DC High Potential Test.* This is a test of the dielectric strength of insulation. It is utilized to determine the quality of the insulation in electrical equipment particularly items with solid dielectrics such as porcelain, rubber, PVC, PE, Micarta, etc. It is not generally used for on site testing of equipment windings with the exception of motor generator windings or on oil filled equipment. Extreme care is exercised when applying the test voltage so as to avoid equipment damage. Successful withstanding of the voltage indicates satisfactory dielectric strength. In addition a comparison of the charging current between tests over a a period of time will indicate the degree of deterioration of the insulation as well as an examination of the plot of the leakage current vs. time during the "soak" portion of the test.

(d) *Dielectric Absorption Test.* This test is again a test of the quality of the insulation. It is applicable to transformers, regulators and other similar devices as well as shielded high voltage power cables. Its primary function is to provide an indication of deterioration prior to complete failure.

This test is performed by charging the insulation under test with an insulation resistance test set, The test is applied for a period of time sufficient to fully charge the cable. Resistance readings are taken every 15 seconds during the first 3 minutes and at 1 minute intervals thereafter. The test shall continue until 3 equal readings are obtained. This final reading shall be recorded. All windings or other conductors (in the case of a cable) not being tested are grounded. The tank (or shield) are grounded also.

(e) *AC Over Potential Test.* This test is performed to verify the integrity of the insulation in low voltage devices (600 volt and below) and associated wiring. Specific manufacturer's recommendations are observed before applying this test to solid state components. The test consists of applying an AC voltage to the device for 1 minute and verifying the successful withstand of this voltage.

(f) *Contact Resistance Test.* This test is used to measure the resistance of the main contacts of a circuit breaker. A rise in resistance is an indication of the need for maintenance or replacement of the contacts.

(g) *Winding Resistance Test.* The winding resistance in motor, transformer, regulator, etc. is not subject to change unless turns are open or short circuited. An accurate measurement of the resistance at the time of acceptance will thus permit future assessment of winding faults. Periodic checks will disclose shorted turns before further problems occur.

(h) *Insulating Oil Test.* Neutralization number, interfacial tension, dielectric strength, color, and visual examination tests are performed as described in IEEE No. 64 "Guide for Acceptance and Maintenance of Insulating Oil in Equipment". A comparison of the values obtained for each test over a period of time will indicate the gradual deterioration of the oil unless oil treatment has been performed.

(i) *Combustible Gas Analysis.* A combustible gas analysis is performed to determine the amount if any of various types of combustible gases in the transformer gas cushion. These combustible gases are produced over a period of time by small magnitude turn-to-turn or other internal arcing faults. Internal arcing involving the core or other steel parts may result in particles of carbon in suspension also. Upon detection of combustibles testing should be repeated at shorter intervals of time so as to assure removal of the unit from service before major trouble occurs.

(j) *SF_6 Gas Analysis.* SF_6 gas used in circuit breakers is subject to contamination due to the products released during the interruption of current. This contamination increases with the severity of the fault and with the deterioration of the breaker contacts. Specific tests are not normally performed, since the gas should be reconditioned on a regular basis in accordance with the manufacturer's recommendations.

(k) *Timing Test.* A timing test is performed at the time of acceptance and again after all adjustments or replacements of contacts in circuit breakers. The test is used to verify that all poles of the circuit breaker and all series contacts in each pole are opening simultaneously. The circuit breakers are timed as closely as possible to the tolerances provided by the manufacturer.

(l) *Motion Analyzer Test.* The motion analyzer test is conducted to verify the good condition and proper adjustment of the mechanical operating linkages of a circuit breaker. A graphical representation of the elapsed time versus distance travelled is plotted. Any wear or poor adjustment will result in a non-uniform curve. This test should be conducted in conjunction with the timing test.

(m) *Series Overcurrent Test.* All re-closer and low voltage power circuit breakers having series trip devices should be tested periodically to verify the calibration and proper operation of the device. The test is performed at a number of current level so as to verify the current versus time operating characteristics and the minimum instantaneous trip current level, if applicable.

(n) *Turns Ratio Test.* A turns ratio test is performed periodically as an aid in detecting turn-to-turn short circuits in power and instrument transformers.

(o) *Polarity Test.* Polarity tests should be performed on all power and instrument transformers after installation and again after any removal and replacement of a unit.

(p) *Protective Relay System Tests.* All protective relays and each protective relaying scheme as a whole should be subjected to operational tests at least once per year. The test will vary depending upon the particular scheme and component relays. The test, however, should in all cases be of the type where actual abnormal operating conditions are simulated and the proper operation of all components are checked. Multi phase current and potential sources are used where applicable rather than attempting to test multiphase devices with single phase sources.

(q) *Meter Calibration Tests.* Indicating instruments are tested by comparison with a portable standard instrument which is connected into the same circuit as the instrument being tested. Test switches are usually provided for this purpose on the front of the panel.

(r) *Capacitance Test.* The capacitance coupling capacitors, the condenser section of bushings and other similar capacitive devices should be verified at time of installation. Periodic measurements are usually not made unless a specific reason is incurred.

(s) *Ground Grid Resistance Measurement.* The ground grid resistance are measured periodically to verify that significant changes have not occured due to changes in ground water levels or other similar natural phenomenon. The value obtained are compared with previously measured values or with design criteria values in the case of a new installation.

(t) *Vibration Test.* Several models of instruments are available which detect and electronically measure vibration in rotating equipment. The use of vibration testing equipment provides a means of yardstick determintation of equipment condition by the establishment of norms. Preventive maintenance programs include equipment sheets indicating points of measurement for the application of a probe connected to a portable hand-held instrument indicating a reading in vibrations. Variation from established norms activates scheduling of a particular piece of equipment for further examination before a failure occurs. Complete analyzers are available to pinpoint problems.

11.2.2 Electrical Equipment and Facilities

Electrical equipment from the facilities point of view will include the main substation, all distribution circuit breakers, transformers, and all other devices which may be directly affecting any of the above items and lighting system.

Table 11.2 gives common electrical and recommended diagnostics used in preventive maintenance programs.

Table 11.2 Recommended Tests for Common Electrical Equipment
Source: Reference 1

Item and Description	Recommended Tests
Service Entrance Overhead supply or an underground cable	Insulation resistance test Power factor test DC high potential test Dielectric absorption test AC over potential test
Electrical Distribution systems	Insulation resistance test Power factor test DC high potential test Dielectric absorption test AC over potential test
Protective Devices Relays - Induction-disk - Pick-up induction disk unit - Induction disk unit - Instantaneous element pick up	Protective relay system test Insulation resistance test Minimum current test for main contact Time characteristics Minimum current test for relay to operate
Fuses	Continuity test Fuse element characteristic test
Enclosed switches	Contact test Series overcurrent test
Molded case circuit breaker	Series overcurrent test Timing test Contact resistance test Insulation resistance test
Low voltage power circuit breaker	Series overcurrent test Timing test Contact resistance test Insulation resistance test
Oil circuit breakers	Timing test Insulation oil test Insulation resistance test Contact resistance test
Transformers	Insulation resistance test Dielectric absorption test Winding resistance test Insulating oil test Combustible gas analysis test

Cont. (Table 11.2)

	SF_6 gas analyses Turns ratio test Polarity test
Motors	Insulation resistance test Vibration test Winding resistance test Power factor test
Regulators	Insulation resistance test Ground test

11.3 MAINTENANCE PROCEDURES

The factors that must be considered in establishing sound maintenance procedure applied to electrical equipment are complex. The variety of types of equipment, the uses to which they are applied, and budget considerations for a specific situation must all be evaluated. It is the responsibility of the plant engineer or the maintenance manager to set up schedules that will eliminate unexpected equipment failure.

Machinery history files if available are consulted to obtain information as to what and how maintenance procedures should be accomplished.

Manufacturer's instruction manuals as well as text publications are also used as guides in determining standards of maintenance procedures for performing an electrical preventive maintenance program. Two typical detailed inspection maintenance procedures are outlined in this chapter. One maintenance procedure inspection detail applies to motors and the other applies to transformers. Motors and transformers are taken as samples on assumption that they constitute the majority of the electrical equipment. Planned preventive maintenance procedures can identify weaknesses in electrical equipment (See Table 11.3).

11.3.1 Electrical Facilities

Most of the facility electrical equipment is of a nature that will not require frequent maintenance activity. Except where questions of age, condition and environment modify the procedures it can be expected that most activity will occur quarterly or yearly.

Preventive maintenance procedures will be mainly on:

- o Testing the condition of the insulation on periodic basis
- o Inspecting the cable installation's physical condition
- o Ensuring the tightness and good condition of mechanical connections.

(a) Minimum Preventive Maintenance Procedures for Electrical Protective Devices:

(1) *Clean.* Motor overload relays should be cleaned periodically. Remove dirt or dust created by the operating conditions in the plant packed around the moving parts and actually preventing their operation.

Table 11.3: Electrical Equipment Weaknesses, Causes, and Effects

Source: Reference 1

Weaknesses	Cause	Effect on Systems Equipment
Loose Connections	Heat build up Erosion of conductor part	Collapse of electrical conductors and fixtures due to their own weight Phase to phase fault
Improper Contact	Arcing fault condition	Protective devices fail to operate
Dust and dirt	Lack of equipment protection to physical environment	Improper functioning of protective relays Failure to work of other devices
	Build-up of dirt in an electrical equipment	Flashover
	If accumulated on electrical devices, becomes a good heat insulator	Prevents proper dissipation of heat Speeds up deterioration of insulation Provides a path for leakage currents and cause flashover
Dust and Moisture	Hindrance of movement of breaker mechanisms	Failure to open all three phases of the breaker at the same time
	Provide leakage paths	Cause short circuit
Deterioration in oil	Arcing between contact surfaces	Cracking of some oil in the contact area turning to gas and sludge, lowering the dielectric quality of the insulating medium
	Varying load conditions and changes in atmospheric temperature and pressure	

Cont. (Table 11.3)

	When oil is used as dash-pot in circuit breakers, contamination by impurities entering the shaft and plunger	Time current tripping of the switch is completely upset
Improper settings	Arbitrarily increasing the rating of fuses and molded cricuit breakers	Failure to respond to different amounts of faults currents
	Changing the setting on protective relays and low voltage power circuit breakers	Inadequate or improper protection

(2) *Tighten Connections.* Connections should be tightened with appropriate tools to prevent chatter and unnecessary movement.

Loose connections could create extra heat and cause a false operation of the thermal element of the relay.

(3) *Inspect Heater Size.* Determine that the specified heater is being used in the relay. Heaters' cross section becomes smaller when oxidized over a period of time.

Heat required to operate the relay is provided with a smaller amount of current causing unnecessary tripping of the motor.

(4) *Electrical Test.* The motor overload heater and relay should be subjected to a current three or four times its rating and the tripping time measured.

Compare this time with the relay manufacturer's curves or specifications to make certain that the relay is operating properly.

Underwriters' Laboratories specifications indicate that the relay should ultimately trip in an ambient temperature of 40°C within 8 minutes at 200 percent of its rated current and within 30 seconds at 600 percent of its rated current.

(b) **Preventive Maintenance Procedures on Fuses**

It is recommended that fuses be inspected at 1 year intervals except where experience indicates that shorter intervals are required. The required frequency of inspection varies between industries and with varying local conditions.

The following steps are recommended:

(1) Check the fuse ratings to be sure that the required rating is installed. All fuses at any one point in a circuit should have similar characteristics. If renewable fuses are used, the renewal links should be checked to be sure that the correct size and number are installed. Check link connections to be sure they are tight.

(2) Look for evidence of overheating. Replace fuses that have discolored or weakened casings. Determine and correct the cause of any overheating. Check fuse clips to assure good contact. Where the ferrules or knife blades of cartridge fuses are oxidized or corroded, they should be cleaned and polished. Silver plated contact surfaces should not be abraded.

(3) Look for installations where the fuse has been bridged with a solid conductor. The correct size of fuse should be installed and the necessary action to prevent the bridging should be taken

(4) Check wiring terminals to assure that all connections are tight. Where there is evidence of heating, the connecting surfaces should be cleaned and polished. Silver plated surfaces should not be abraded. Aluminum connections that show deterioration should be replaced.

(5) Check enclosures to assure that fuses are protected and that readily ignitable materials are excluded. Ensure that covers are in place and fastened. In hazardous locations, assure that fuses are installed in appropriate explosionproof enclosures.

Table 11.4 shows the maintenance requirements of fuse components.

Table 11.4: Maintenance Guides for Fuses

Source: Reference 2

Component	Procedure
1. Ferrule	Make sure that the ferrule is tight in the fuse clip.
2. Connectors	Tighten circuit connections to fuse block.
3. Fuse Assembly	Keep the entire assembly fuse block and fuse clean so that the heat generated by current flow through the fuse link may be properly dissipated.
4. Spare Fuses	Make sure that the spare fuses of the proper types and sizes are available.

(c) **Preventive Maintenance Procedures for Enclosed Switches.**

It is recommended that these be inspected at 1 year intervals except where experience indicates that shorter intervals are required. The required frequency of inspection will vary between industries and with varying local conditions. The following steps are recommended:

(1) Thoroughly clean all parts and lubricate the operating mechanism where required.

(2) Checked the contacts for alignment and adjustment. Clean and dress the contact surfaces where required. If contact clips have lost their tension, they should be replaced.

(3) Check connections of blades to the insulating connecting bar to be sure they are tight. Check to be sure that the external operating mechanism is attached to the insulating connecting bar. Check that the spring for snap action is operating correctly. Where there are damaged parts they should be replaced or a new switch should be installed.

(4) Check terminals to assure that all connections are tight. When there is evidence of heating, the connecting surfaces should be cleaned and polished. Silver plated surfaces should not be abraded. Aluminum connections that show deterioration should be replaced.

(5) Check enclosure to assure that they are clean and that the switch is protected and that readily ignitable materials are excluded. Check that covers are in place and fastened. In hazardous locations ensure that switches are installed in appropriate explosionproof enclosures.

(d) **Preventive Maintenance Procedures for Molded-case Circuit Breakers:**

(1) *Clean.* External cleaning is necessary so that the heat can be dissipated properly. Do not break any seal.

(2) *Tighten.* Electrical connections should be tightened so that heat is not introduced to the thermal overload element.

(3) *Test.* Test the magnetic thermal and mechanical elements of the breakers.

Test the mechanical movement of contacts and mechanical linkages by manual operation and actuation.

Pass an electric current through the overload sensing element of a sufficient magnitude to actuate mechanisms current value to be equivalent to 300 percent of the breaker rating.

Measure the tripping time and then compare with specified values or curves.

It is recommended that a visual inspection be made at 1 year intervals except where experience indicates that shorter intervals are required. The required frequency of inspection varies between industries and with varying local conditions. For circuit breakers rated above 50 amperes it is recommended that a routine test be made at 2 year intervals unless the annual inspection indicates that more frequent tests be made. Since most molded case circuit breakers are factory calibrated and sealed, this seal should not be broken.

For visual inspection at annual intervals, the following steps are recommended:

(1) Examine for evidence of damage or overheating and, if found, replace the device involved and correct the source of damage.

(2) Examine the terminals to be sure that all connections are tight. Where there is evidence of heating the connecting surfaces should be cleaned and polished. Silver plated surfaced should not be abraded. Aluminum parts that show deterioration should be replaced.

(3) When installed in enclosures be sure that enclosures are clean and provide the necessary protection. Check that covers are in place and fastened. In hazardous locations be sure that circuit breakers are installed in appropriate explosionproof enclosures.

The procedure for the routine test at 2 year intervals are those listed above for the 1 year inspection plus the following:

(1) With the circuit breaker completely disconnected measure the insulation resistance between phases and between phase and ground with a megger. Also measure that resistance between the line and load terminals of each pole with the circuit breaker open. If the resistance values are below 1 megohm, the circuit breaker should be considered unsafe and should be returned to the manufacturer for repair.

(2) With the circuit breaker completely disconnected make a dc millivolt drop test from the line to load terminals of each pole. The manufacturer can supply the acceptable voltage ranges for the millivolt drop tests.

(3) With an ammeter in the circuit, apply an overload of approximately 300 percent of the circuit breaker rating to each pole to assure that the circuit breaker will trip automatically. Should the circuit breaker fail to trip it should be returned to the manufacturer for repair.

(4) With an ammeter in the circuit, apply a current of approximately 200 percent of the instantaneous magnetic trip pickup value to assure that the instantaneous trip device is operating

(5) Mechanical operation should be checked by moving the operating handle to the on and off position several times.

(e) **Minimum Preventive Maintenance Procedure for Low Voltage Power Circuit Breakers**

Low voltage power circuit breakers normally contain two separate elements:

(1) Set of contacts with required mechanical linkage for its operation as switch

(2) Overload sensing device

The mechanical or visual inspection of overhaul of this type of breaker are shown in Table 11.5.

Table 11.5 : Maintenance Guides for Low Voltage Power Circuit Breakers

Source: Reference 2

Device/Component	Maintenance Procedure	
Entire breaker overload trips	CLEAN	the entire breaker and all overload trips.
Primary bus con-tractors	EXAMINE	the primary fingers on the bus and the copper or spring for discoloration or other evidence of overheating.
	REMOVE EXAMINE AND CLEAN	the arc chutes. Look for cracks, missing or broken snuffers, splashed copper, dirt, and moisture.
Racking mechanism and the mechanical linkages	LUBRICATE	the racking-in mechanisms and the mechanical linkage which is used to open and close the breaker. Make sure that none of this lubricant gets on the electrical contacts.
Armature of the overload devices and trip bar	DETERMINE	that the armature of the overload device will strike the trip bar on the breaker with sufficient force to open the breaker.
Connections	TIGHTEN	all bolted and screwed connections
Trip devices	EXAMINE	the trip devices to make sure that they are all the same type and that the settings are approximately the same.
The whole breaker	TEST	the electrical operation of the breaker. The time delay trip is tested by subjecting the breaker to 2-1/2 to 3 times the time delay setting. Measure tripping time and compare to specified value. Determine minimum current required for instantaneous trip.

A visual inspection at 1 year intervals is recommended unless it is indicated by experience that shorter intervals are desirable. The required frequency of inspections will vary between industries and with varying load conditions. A complete inspection is recommended at 2 year intervals.

For the annual inspection the following steps are recommended:

(1) Examine for damage or evidence of overheating and if found, replace or repair the parts involved and determine and correct the source of the damage.

(2) Examine the terminals and be sure that all connections are tight . Where there is evidence of heating, the connecting surfaces should be cleaned and polished. Silver plated surfaces should not be abraded. Aluminum connections that show deterioration should be replaced.

(3) Examine the enclosure to be sure that it is clean and that the necessary degree of protection is provided.

For the 2 year inspection, the following additional steps are recommended following the manufacturer's instructions:

(1) Thoroughly clean all parts.

(2) Check the contact alignment and pressure. Adjust if required to the manufacturer's recommendations.

(3) Check the settings of the direct acting trip devices and check their operations by moving the armatures by hand to trip the circuit breaker. (Exercise care to avoid injury).

(4) Where circuit breakers are electrically operated check the reliability of the control power source.

(5) Examine latches and triggers for proper adjustment and to make sure that they are in accordance with manufacturer's recommendations.

(6) If there are flexible shunts, see that they are in good condition and that their connections are tight.

(7) Check pins, bolts, nuts, and other hardware and tighten if required.

(8) Examine auxiliary switches to assure that contacts are in good condition and that operating links are correctly adjusted.

(9) Check control wiring for loose connections.

(10) Remove arc chutes and examine for burning. Remove any deposits

It is recommended that the calibration of the direct acting trip devices be tested at 5 year intervals and adjusted if required. These tests should be made only by personnel experienced in this work and who have the necessary equipment and training in its use. Arrangements may be made with testing laboratories equipped for this type of testing. In very large facilities, the necessary trained personnel and the test equipment may be justified as a part of the plant maintenance organization.

(f) Preventive Maintenance Procedures for Oil Circuit Breakers.

After every short circuit interruption, the contacts should be examined and oils should be tested. It is recommended that a complete inspection be made at 2 year intervals. Where operation of the circuit breaker is frequent, inspections at more frequent intervals should be made. The following steps are recommended:

(1) Test the oil. If the oil breaks down below 22 kV in a standard tester, it should be filtered or replaced. Usually, arrangements for filtering oil may be made with the circuit breaker manufacturer or with the supplying utility.

(2) Thoroughly clean all parts and lubricate parts where required.

(3) Check contact alignment and adjust if required.

(4) If contacts show evidence of roughness, dress with sandpaper or a fine file.

(5) Examine lift rods to be sure they are not warped or cracked.

(6) Examine latches and triggers and ensure that they are in accordance with manufacturer's recommended adjustment.

(7) If flexible shunts are used, be sure they are in good condition.

(8) Examine main current carrying parts for evidence of heating.

(9) Check pins, bolts, nuts, and other hardware. Tighten where necessary.

(10) Examine auxiliary switches to assure that contacts are in good condition and that operating links are correctly adjusted.

(11) Examine control and secondary wiring for loose connections.

(12) Check adequacy and reliability of control power source.

(13) Lubricate bearings, gears etc. in accordance with manufacturer's instructions.

11.3.2 Preventive Maintenance Procedures for Transformers

In modern plants, the facilities aspect of preventive maintenance includes a large variety of transformers.

Because of the nature of a transformer, the primary concern of a preventive maintenance program is to maintain the life and condition of insulation on the windings. This means that all the conditions that could contribute to insulation failure must be guarded against and a means of periodically testing for detrimental conditions be set up. In transformers the temperature surrounding the windings is one of the most important concerns. There are basically two type of tranformers:

(a) Dry Transformers
   (1) Fan forced
   (2) Natural circulation

(b) Liquid filled
   (1) Self cooled
   (2) Mechanical system

It is evidenced by the very basic transformer classification that the emphasis is on cooling of the transformer. The first requirement is one of setting up regular schedules and of keeping all portions of the transformer clean and the effectiveness of the cooling system in top condition.

The dry type transformer requires less maintenance than do liquid filled types. The preventive maintenance of transformers of this type will include the following:

(a) A method of daily recording the ambient temperature surrounding the transformer installation.

(b) A method of daily checking the peak load to which the transformer is being subjected.

(c) A method of determining the proper operation of supporting or auxiliary cooling apparatus such as fans.

(d) A periodic schedule of testing the value of insulation resistance.

(e) A regular shcedule of cleaning. This includes the windings casings and all ventilating air passages.

(f) A regular schedule of tightening connections, bolts and other fastenings.

Liquid-filled transformers require the same general maintenance as dry types with the added maintenance of the liquid cooling system. The liquid cooling systems vary considerably in the arrangement of the heat dissipating equipment. The type of arrangment and the coolant must be determined and in general include the following:

(a) Regular checking for leakage and the level of the coolant.

(b) Periodic filtering and tests for acidity and interfacial tension of oil. This would include the addition of an inhibitor to the oil to slow oxidation and deterioration.

(c) Regular schedules of checking the nitrogen or gas seals on conservator types.

(d) Regular schedule of filter maintenance on types including natural circulation filters.

The manufacturer's instruction manual should be used as a guide in setting up regular and/or periodic preventive maintenance procedures.

Tables 11.6 and 11.7a refer to maintenance procedures applied to transformers and other transformer-related equipment. A specific guide of maintenance procedure includes inspection, washing, cleaning, testing, sampling oil, filtering oil, acidity neutralization, transformer, drying. vacuum filling of oil, etc. The manufacturer's manual should be consulted where specific data on a particular transformer can be availed of.

11.3.3 Preventive Maintenance Procedures for Motors

Emphasis for the program has been in the direction of developing yardsticks while equipment is in operation to determine its operating condition. In general what has been indicated is that if the motor application is proper and if the insulation and bearings are in good order, the motor will operate successfully for a long period of time. Table 11.8 contains some good maintenance practices in electric motor maintenance.

While the motor is in operation:

(a) Visual examination
(b) Audible examination
(c) Ammeter reading
(d) Temperature readings
9e) Voltmeter reading
(f) Check and add to lubricant
(g) PM (check for past comparison)

Table 11.6 Maintenance Guide for All Transformers
Source: Reference 1

Item	Check for:	Frequency/Comments
Liquid level gauge	Proper level	Every shift
Ambient, liquids and winding temperature indicators	Recommended temperature	Every shift
Switchboard instruments	Load	Every shift
Voitage	Excessive values (indication of improper top connection)	Every shift
Relays	Proper function	Quarterly
Overvoltage Protective equipment	Proper function	Semi-annualy
Ground connections ground resistance	Good condition Low value	Semi-annually

Table 11.7a Maintenance Guides for Open-Type Power Transformers

Source: Reference 1

Item	Check for:	Frequency/Comments
Weather proof ventilators	Free passage of air	Remove obstructions (Quarterly)
Oil	Dielectric voltage of 25 kV	Filter oil if dielectric test drops to 20 kV (Quarterly)
Under main cover, man-hole cover, and bushing supports	Moisture caused by: 1. leaky gaskets 2. cracked or damaged bushings 3. restricted breathing	Semi-annually
Above the core	Oil sludge deposits and evidence of moisture	Drain oil to the top of core to fa-[illegible]litate injection [illegible] annually)
Entire unit	Small sludge deposits (due to high operating temperature	Raise interior and wash with oil. Clean tank. Filter oil if possible (every 5 years)
Fans Core and coils	Proper operation Proper lubrication Dust and corrosion (Horizontal surfaces)	Every shift Annually Quarterly
Temperature alarm	Proper operation (trip annually)	Quarterly
Contact surfaces	Cleanliness	When charging taps

Table 11.7b Maintenance Guides for Pyranol Transformers
Source: Reference 1

Item	Check for:	Frequency/Comments
Relief diaphragm	Evidence of cracks	Replace cracked diaphragms (Quarterly)
Gas absorbers	Dump of caked compund	Replace compound (Quarterly)
Pyranol	Lower than 25 kV di electric	Use filter press (every 6-12 months)
Tanks and connections	Leaks	Pressure-test for 12 hours at 34.5 k Pa; use soap suds to pinpoint leaks (every 6-12 months)
Under main cover, manhole lower and bushing supports	Condensation	every 5 years
Entire unit (interval parts)	Proper condition	Every 7 to 10 years

Table 11.7c Maintenance Guides for Gas-Seal, Gas-Oil Seal, and Sealed Transformers
Source: Reference 1

Item	Check for:	Frequency/Comments
Gas-pressure relief diaphragm	Damage	Replace Every shift
Pressure-vacuum gauge	Leaks (indicated by failure of pressure to change with temperature	Every shift
Insulating liquid	Moisture	Every 6 to 12 mos.
Oil level (in idle spare transformers)	Correctness	Every 6 to 12 mos.
Above core	Moisture, parts displacement Deposits	Every 7 to 10 years Every 5 years
Entire unit	Leaks	Pressure-test (Annually)

Table 11.7d Maintenance Guides for Gas-Seal Equipment
Source: Reference 1

Item	Check for:	Frequency/Comments
Gas-pressure	Proper value	Every shift
Oxygen content	Oxygen in excess of 5%	During first month and every 6 month thereafter
Gas cylinder	Amount of contents (Allow time for purchase of replacement	Monthly
Pressure relief valve Minimum-pressure alarm circuit	Proper operation	Trip and observe action (Quarterly)
Gas regulator	Proper settings	Quarterly

Table 11.7e Maintenance Guides for Air-Pressure Cooled Transformers
Source: Reference 1

Item	Check for:	Frequency/Comments
Oil	Too high temperature, indicating the need to operate fans	Every shift
Fans and control	Proper operation	Monthly

Table 11.7f Maintenance Guides for Water-Cooled Transformers
Source: Reference 1

Item	Check for:	Frequency/Comments
Cooling water	Abnormal increasing and outgoing temperature	Weekly
Cooling coil	Leaks	Inspection interval varies; it depends on age, corrosiveness of water, operating experience, etc.
Water pressure and flow	Gradual decrease indicating clogging	Semi-annually

Table 11.7g Maintenance Guides for Force-Oil-Cooled Transformers

Source: Reference 1

Item	Check for:	Frequency/Comments
Pump glands	Proper condition and oil level	Every shift
Incoming and out-going oil tempera-ture	Abnormal values indica-ting inefficient opera-tion	Weekly
Cooler screens	Fouling or clogging	Weekly
Oil strainer	Too large oil pressure drop through strainer indicating clogging	Weekly

Table 11.7h Maintenance Guides for Air-Blast Transformers (Indoor)

Source: Reference 1

Item	Check for:	Frequency/Comments
Air temperature	Too high value	Hourly
All air passage, filters, etc.	Dirt, fouling, etc.	Monthly

Table 11.8 Good Maintenance Practices for Electric Motors

Source: Reference 4

Keep motor off line when not needed	Saves unnecessary wear of brushes, commutator and bearings, saves lubrication
Do not leave field circuit unless motor has been especially designed for this type of duty	Check temperature of shunt fields with ther-mometer to see that it does not exceed 90°C When field must be excited, caution mainte-nance men to be sure field circuit is opened before working on the motor. On AC check stator windings
Keep motor clear of metal dust or cuttings that can be drawn into win-dings and pole pieces	Magnetic attraction will draw metal parts into the air gap and damage windings. Cast-iron dust particularly damaging
Reassembling of motor	Be sure to retain proper air gaps in motor by checking bore of pole faces before removing poles from the frame. Mark shims and poles. Reassemble, replacing poles and liners in original position on DC motors
Note wearing parts and parts fre-quently replaced to determine anti-cipated repairs	Carry in proper storeroom stock of replace-ment parts. Make survey of standard repair parts to avoid duplication of parts to be carried

Table 11.9 Electric Motor Relubrication Guide
Source: Reference 4

Service	Motor horsepower				
	1/4-10	15-40	50-150	200-250	Over 250
Easy infrequent operation, valve operators, door openers, portable tools	7 years	5 years	3 years	2 years	9 months
Standard: one or two shifts, machine tools-airconditioning conveyors, compressor refrigeration, laundry, textile macinery, woodworking, water pumping, generally class B insulation	5 years	3 years	1 year	9 months	6 months
Severe: continuous running. Fans, pumps, motors generator sets, coal and mining machinery, steel mills, some Class F insulation	3 years	1 1/4 years	6 months	4 months	3 months
Very severe: dirty and vibrating applications hot pumps and fans, high ambient Class H insulation	9 months	4 months	3 months	2 months	1 1/2 months

*Some manufacturers recommend longer periods and some recommend shorter periods, based on open and shielded bearings with grease reservoirs adjacent to bearings.

Table 11.10a Monthly Maintenance Guides for Electronic Motors
Source: Reference 4

Components	Inspection or maintenance operation
BEARINGS	Make sure that grease or oil is not leaking out of the bearing housing. If any leakage is present, correct the condition before continuing to operate
Ball and roller	Listen to a few bearings on a sampling basis. Bearings that get progressively noisier will need replacement at next shut-down
Sleeve	Check the oil level. Check the oil color through the slight gauge. Slightly cloudy oil is all right. Black oil is a danger sign
BRUSHES	Check the brush length. Replace when rivet or clip will rub commutator before next inspection. Inspect for worn or shiny brush clips, frayed or loose pigtails, and clipped or broken brushes. However, many DC brushes have no clips. Pigtails are tamped. There is danger that the pigtail of a worn-out brushed will cut the commutator. Such brushes have a wear marker on the pigtail. When it gets below the top of the box the brush should be discarded. Remove a few brushes to check the brush-commutator contact face in the case of DC motors and the brush-collector contact face in the case of AC motors and generators. Burned areas indicate commutation or sliding contact troubles. **Warning: High voltage. Electronic shock and rotating parts can cause serious or fatal injury. Avoid contact with live electronic parts and moving mechanical parts. (It is well to note that silicon-controlled rectifier drives may have high voltages at the brushes even with armature stationary. Lines switches should be open.)**
COMMUTATORS	Check the commutator for roughness by carefully feeling the brushes with a fiber stick. Also occasional wiping is recommended using a piece of coarse or nonlinting cloth. Jumping brushes give advance warning that a commutator is going rough . Observe the commutator for signs of threading. If threading is getting worse-take action. Healed over threading is acceptable. Check for excessive commutator wear rate, streaking, copper drag, pitch bar marking and heavy slot bar marking. Commutator should have not more than 0.0025 in total indicator runout or 0.0002 bar-to-bar steps. For high-speed commutators surfacing should meet 0.0010. and 0.0001 limits respectively.

Table 11.10b Semi-annual Maintenance Guides for Electric Motors
Source: Reference 4

Components	Semi-annual Inspection or maintenance operations
BEARINGS Ball and roller	Listen to all bearings. Pull back bearing cap to inspect grease condition on a few representative machines
Sleeve	Take samples of oil from representative bearings for acidity (neutralization number) test. See manufacturer's sleeve-bearing relubrication recommendations. (Oil acidity is affected most by atmospheric contaminants and temperature; take one sample in each different area.) Change oil if required.
COMMUTATORS	Check risers for cracks. If there are cracks, check end of shaft keyway and shaft fan. (Cracks here mean extreme torsional vibration in system.)
INSULATION	Measure 1-and 10-min insulation resistance and calculate the polarization index. Compare with records. Wipe deposits from brush-holder stud insulation and commutator creepage path or collector creepage path. Remove deposits from around field-coil connections on DC machines where grounding might occur. Blow deposits out of the commutator rise area or the collector area with clean dry air. Blow out any blocked ventilation openings in windings. Make visual inspection for signs of overheating (dry, cracked, "roasted-out" insulation and varnish)
MECHANICAL Bolts	Check all electrical connections for tightness. Look for signs of poor connection (arcing, discoloration, heat). Adjust inspection period to suit experience. Inspect foundation for signs of cracking, displaced foot shims, check foot bolts for tightness. Check frame split bolts, brush holders, brush holder stubs, bracket bolts, etc., on sampling basis. check corners all coupling bolts.
Shaft	Check corners of exposed end of shaft keyway for cracks (due to extreme torsional vibration). If there are cracks, check fan commutator risers and DC machines and the fan and character of the applied load on AC machines
Ventilation	Check for clogged screens, louvers, filters, etc.
Vibration	Check for excessive vibration (more than .005 to .0075 mm that will indicate change in balance or alignment. If actual operation cannot be seen, check for other signs of vibration (loose parts, chafing, shiny spots, rust deposits)

Cont. (Table 11.10b)

COLLECTORS	Check the collector for roughness, dust, and wear. Ordinarily the rings will require only occasional wiping using a piece of coarse or nonlinting cloth. If the brushes are bouncing up and down on a cycle basis, check for collector-ring concentricity
MECHANICAL	
Air filters	Replace when necessary. Clogged filters cause overheating and lead to premature insulation failure
Bolts	Perform visual observation for loose bolts, loose parts, or loose electrical connections
Noise and vibration	Check for any unusual noise, vibration, or change from previous observations. Loose pole bolts often are the source of magnetic noise when motors are fed from rectifiers

Table 11.10c Annual Maintenance Guide for Electric Motors
Source: Reference 4

BEARINGS Sleeve bearings	Drain housing. Remove top half of housing. Lift top half of bearing. Inspect bearing surface and rings for wear. If excessive wear or sludge is found in bottom of housing roll out the bottom half of bearing for inspection. Clean if necessary and refill.

Table 11.11 General Troubleshooting Chart for Electric Rotating Equipment
Source: Reference 4

Trouble	Cause	Action
Hot bearings-general	Bent or sprung shaft	Straighten or replace shaft
	Excessive belt pull	Decrease belt tension
	Pulley too far away	Move pulley closer to bearing
	Pulley diameter too small	Use larger pulleys
	Misalignment	Correct by realignment of drive
Hot bearings-sleeve	Oil grooving in bearing obstructed by dirt	Remove bracket or pedestal with bearing and clean oil grooves and bearing housing, renew oil
	Bent or damaged oil rings	Repair or replace oil rings
	Oil too heavy	Use a recommended lighter oil
	Oil too light	Use a recommended heavier oil

Cont. (Table 11.11)

	Insufficient oil	Fill reservoir to proper level in overflow plug with motor at rest
	Too much end thrust	Reduce thrust induced by driven machine or supply external means to carry thrust
	Badly worn bearing	Replace bearing
Hot bearings-ball	Insufficient grease	Maintain proper quantity of grease in bearing
	Deterioration of grease or lubricant contaminated	Remove old grease; wash bearings thoroughly in kerosene and replace with new grease
	Excess lubricant	Reduce quantity of grease. Bearing should not be more than half filled
	Heat from hot motor or external source	Protect bearing by reducing motor temperature
	Overloaded bearing	Check alignment, side thrust, and end thrust
	Broken ball or rough races	Replace bearing; first clean housing thoroughly
Oil leakage from overflow plugs	Stem of overflow plug not tight	Remove; recement threads, replace and tighten
	Cracked or broken overflow plug	
	Plug cover not tight	Requires cork gasket, or if screw type, may be tightened

Table 11.12 Troubleshooting Guide for Electric Motors
Source: Reference 4

Trouble	Cause	Action
1. Fails to start	Circuit not complete	Check if switch open, leads broken
	Brushes not down on commutator	Check if brush springs need to be replaced or if brushes are worn out.
	Brushes stuck in holders	Remove and sand; clean up brush boxes
	Armature locked by frozen bearings in motor or main drive	Remove brackets and replace bearings or recondition old bearings if inspection makes possible
	Power may be off	Check line connections to starter with light. Check contacts in starter.
	Motor may be overloaded	Reduce load.

Cont. (Table 11.12)

	One phase open	See that no phase is open.
	Poor stator-coil connection	Remove end bells, locate with test lamps, and repair.
2. Motor stalls	Wrong application	Change type or size of motor. Consult manufacturer of driven equipment
	Overloaded voltage	Reduce load
	Low motor voltage	See that nameplate voltage is maintained within standard tolerances
	Open circuit	Fuses blown, check overload relay, starter, and push button
	Incorrect control resistance of wound rotor.	Check control sequence. Replace broken resistors. Repair open circuits
3. Motor starts, then stops and reverses direction of rotation	Reverse polarity of generator that supplies power	Check generating unit for cause of changing polarity
	Shunt and series fields are bucking each other	Reconnect either the shunt or series field so as to correct the polarity. Then connect armature leads for desired direction of rotation. The fields can be tried separately to determine the direction of rotation individually and connected so both give same rotation
4. Motor runs and then dies down	Power failure	Check for loose connections to line, to fuses and to control
5. Wrong rotation	Wrong sequence of phases	Reverse connections of motor or at switchboard
6. Motor does not come up to rated speed	Overload	Check bearing to see if in first-class condition with correct lubrication. Check driven load for excessive load of friction
	Starting resistance not all out Voltage low	Check starter to see if mechanically and electrically in correct condition Measure voltage with meter and check with motor nameplate
	Short circuit in armature windings or between bars	For shorted armature inspect commutator for blackened bars and burned adjacent bars. Inspect windings for burned coils or wedges

Cont. (Table 11.12)

	Starting heavy load with very weak field	Check full field relay and possibilities of full field setting of the field rheostat
	Motor off neutral	Check for factory setting of brush rigging or test motor for true neutral setting
	Motor cold	Increase load on motor so as to increase its temperature, or add field rheostat to set speed
	Not applied properly	Consult supplier for proper type and size
	Voltage too low at motor terminals because of line drop If wound rotor, improper control operation of secondary resistance	Use higher voltage on transformer terminals or reduce load. Correct secondary control
	Starting load too high	Check load motor is supposed to carry at start
	Low pull-in torque of synchronous motor	Change rotor starting resistance or change rotor design. Consult manufacturer
	Check that all brushes are riding on ring	Check secondary connections. Leave no leads poorly connected
	Broken rotor bars	Look for cracks near the rings. A new rotor may be required, as repairs are usually temporary
	Open primary circuit	Locate fault with testing device and repair
7. Motor takes too long to accelerate	High WK^2 Excess loading	Reduce load. Check moment of inertia with equipment manufacturer
	Poor circuit Defective squirrel-cage rotor	Check for high resistance Replace with new rotor
	Applied voltage too low	Get power company to increase voltage tap
8. Motor runs too fast	Voltage above rated	Correct voltage or get recommended change in air gap from manufacturer
	Load too light	Increase load or install fixed resistance in armature circuit

Cont. (Table 11.12)

	Shunt field coil shorted	Install new coil
	Shunt field coil reversed	Reconnect coil leads in reverse
	Series coil reversed	Reconnect coil leads in reverse
	Series field coil shorted	Install new or repaired coil
	Neutral setting shifted off neutral	Reset by checking factory setting mark or testing for neutral
	Part of shunt field rheostat or unnecessary resistance in field circuit	Measure voltage across field and check with nameplate rating
	Motor ventilation restricted, causing hot shunt field	Hot fields is high in resistance, check causes for hot field, in order to restor normal shunt field current. Restor ventilation
9. Motor gaining speed steadily and increasing load does not slow it down	Unstable speed load regulation	Inspect motor to see if off neutral. Check series field to determine shorted turns If series field has a shunt around the series circuit, that can be removed
	Reverse field coil shunt or series	Test with compass and reconnect coil
	Too strong a commutating pole or commutating pole air gap too small	Check with factory for recommended change in coils or air gap
10. Motor runs too slow continuously	Voltage below rated	Measure voltage and try to correct to value on motor nameplate
	Overload	Check bearings of motors and the drive to see if in first-class condition. Check for excessive friction in drive
	Motor operated cold	Motor may run 20 percent slow owing to light load. Install smaller motor, increase load, or install partial covers to increase heating
	Neutral setting shifted	Check for a factory setting of brush rigging or test for true neutral setting
	Armature has shorted coils or commutator bars	Remove armature to repair shop and put in first-class condition
11. Unbalanced line current on polyphase motors during normal operation	Unequal terminal volts	Check leads and connections

Cont. (Table 11.12)

	Single-phase operation	Check for open contacts
	Poor rotor contacts to control wound-rotor resistance	Check control devices
	Brushes not in proper position in wound rotor	See that brushes are properly seated and shunts in good condition
12. Motor overheats or runs hot	Overloaded and draws 25 to 50 percent more current than rated	Reduce load by reducing speed or gearing in the drive or loading in the drive
	Motor may have one phase open	Check to make sure that all leads are well connected
	Grounded coil	Locate and repair
	Unbalanced terminal voltage	Check for faulty leads, connections, and transformers
	Shorted stator coil	Repair and then check wattmeter reading (form coils)
	Faulty connection	Indicated by high resistance
	High voltage, low voltage	Check terminals of motor with voltmeter
	Rotor rubs stator bore	If not poor machining, replace worn bearings (sleeve bearings)
	Voltage above rated	Motor runs drive above rated speed requiring excessive horsepower. Reduce voltage to nameplate rating
	Inadequately ventilated	Location of motor should be changed, or restricted surroundings removed. Covers used for protection are too restricting of ventilating air and should be modified or removed. Open motors cannot be totally enclosed for continuous operation. Check air shields for clogging. Check suitability of blowers in use.

Cont. (Table 11.12)

	Draws excessive current owing to shorted coil	Repair armature coils or install new coil
	Grounds in armature such as two grounds which constitute a short	Locate grounds and repair or rewind with new set of coils
	Armature rubs pole faces owing to off-center rotor causing friction and excessive current	Check brackets or pedestals to center rotor, and determine condition of bearing wear for bearing replacement. Check pole bolts
13. Hot armature	Core hot in one spot, indicating shorted punchings and high iron loss	Sometimes full slot metal wedges have been used for balancing. These should be removed and other means of balancing be investigated
	Punchings uninsulated Punchings have been turned or band grooves machined in the core, Machined slots	No-load running of motor will indicate hot core and drawing high no-load armature current. Replace core and rewind armature. If necessary to add band grooves , grind into core. However, treated glass roving properly varnished and properly processed is the more common method of banding windings in the small and medium sizes. Check temperature on core with thermometer not to exceed 90°C
14. Hot commutator	Brush tension too high	Limit pressure to 34.5 kPa . Check brush density and limit to density recommended by the brush manufacturer
	High brush friction caused by atmosphere contaminants	Remove cause
	Brushes off neutral	Reset neutral
	Brush grade too abrasive	Get recommendation from manufacturer
	Shorted bars	Investigate commutator mica and undercutting, and repair

Cont. (Table 11.12)

	Hot core and coils that trnsmit heat to commutator	Check temperature of commutator with thermometer to see that total temperature does not exceed ambient plus 55°C rise, total not to exceed 105°C Class F and H will be hotter
	Inadequate ventilation	Check as for hot moto·
15. Hot fields	Voltage too high	Check with meter and thermometer and correct voltage to nameplate value
	Shorted turns or grounded turns	Repair, or replace with new coil
	Resistance of each coil not the same	Check each individual coil for equal resistance within 10 percent, and i f one coil is too low, replace coil
	Inadequate ventilation	Check as for hot motor
	Coil not large enough to radiate its lost wattage	New coils should replace all coils if room is available in motor
16. Motor vibrates and indicates unbalance	Armature out of balance	Remove and statically balance, or balance in dynamic balancing machine
	Misalignment	Realign. Alignment of flexible couplings generally must be closer than coupling manufacturer recommends
	Loose or eccentric pulley	Tighten pulley on shaft or correct eccentric pulley
	Belt or chain whip	Adjust belt tension
	Mismating of gear and pinion	Recut, realign, or repair parts
	Unbalance in coupling	Rebalance coupling
	Bent shaft	Replace or straighten shaft
	Foundation inadequate	Stiffen mounting place members
	Motor loosely mounted	Tighten holding-down bolts

Cont. (Table 11.12)

	Motor feet uneven	Add shims under foot pads to mount each foot tight
17. Motor vibrates after corrections have been made	Motor misaligned	Realign
	Weak foundations	Strengthen base
	Coupling out of balance	Balancing coupling
	Driven equipment unbalanced	Balance driven equipment
	Defective ball bearing	Replace bearing
	Bearings not in line	Line up properly
	Balancing weights shifted	Rebalance rotor. Securely fasten balancing means
	Wound rotor coils replaced	Rebalance rotor
	Polyphase motor running single-phase	Check for open circuit in one line or phase
	Excessive end play	Adjust bearing or add washer
18. Motor sparks at brushes or does not commutate well	Brush setting not true neutral	Check and set on factory setting or test for true neutral
	Commutator rough	Grind and roll edge of each bar
	Commutator eccentric	Turn and grind commutator
	Mica high-hot undercut	Undercut mica
	Commutating pole strength too great, causing overcompensation, or too weak, indicating undercompensation	Check with manufacturer for correct change in air gap or new coils for the commutating coils

Cont. (Table 11.12)

	Shorted commutating pole turns	Repair coils or install new coils
	Shorted armature coils on commutator bars	Repair armature by putting into first-class condition
	Open-circuited coils	Same as above
	Poor soldered connection to commutator bars	Resolder with proper alloy of tin solder. Current motors used mostly TIG welded
	High bar or loose bar in commutator at high speeds	Inspect commutator nut or bolts and retighten and grind commutator face
	Brush grade wrong type. Brush pressure too light, current density excessive, brushes stuck in holders. Brush shunts loose	See brushes
	Brushes chatter owing to dirty film on commutator	Resurface commutator face and check for change in brushes
	Vibration	Eliminate cause of vibration by checking mounting and balance of rotor
19. Brush wear excessive	Brushes too soft	Blow dust from motor and replace brushes with a changed grade as recommended by manufacturer
	Commutator rough	Grind commutator face
	Abrasive dust in ventilating air	Reface brushes and correct condition by protecting motor
	Off-neutral setting	Recheck factory neutral test for true neutral
	Bad commutation	See corrections for commutation
	High, low, or loose bar	Retighten commutator motor bolts and resurface commutator

Cont. (Table 11.12)

	Excessive brush tension	Adjust spring pressure not to exceed 13.8 to 17.2 KPa
	Electrical wear due to loss of film on commutator face	Resurface brush faces and commutator face
	Threading and grooving	Same as above
	Oil or grease from atmosphere on bearing	Correct oil condition and surface brush faces and commutator
	Weak acid and moisture laden atmosphere	Protect motor by changing ventilating air, or change to enclosed motor
20. Motor noisy	Brush singing	Check brush angle and commutator coating: resurface commutator
	Brush chatter	Resurface commutator and brush face
	Motor loosely mounted	Tighten foundation bolts
	Foundation hollow and acts as sounding board	Coat underside with soundproofing material
	Strained frame	Shim motor feet for equal mounting
	Armature punching loose	Raplace core on armature
	Armature rubs pole faces	Recenter by replacing bearings or relocating brackets or pedestals
21. Scraping noise	Fan rubbing air shield	Remove interference
	Fan striking insulation	Clear fan
	Loose on bedplate	Tighten holding bolts
22. Magnetic noise	Air gap not uniform	Check and correct bracket fits or bearing
	Loose bearings	Correct or renew

Cont. (Table 11.12)

	Rotor unbalance	Rebalance
	Magnetic hum	Refer to manufacturer
	Belt slap or pounding	Check condition of belt and change belt tension
	Excessive current load	May not cause overheating, but check chart for correction of shorted or grounded coils
	Mechanical vibration	Check chart for causes of vibration
	Noisy bearings	Check alignment, loading of bearing, lubrication, and get recommendation of manufacturer
	Magnetic noise	Tighten pole bolts. Motors supplied with power from an SCR source will generally have more noise caused by SCR ripple in armature current usually 120 180, and 360 Hz with harmonics
23. Motor dirty	Ventilation blocked, end windings filled with fine dust or lint	Clean motor will run 10 or 30°C cooler. Dust may be cement, saw-dust, rock dust, grain dust, coal dust, and the like. Dismantle entire motor and clean all windings and parts.
	Rotor winding clogged	Clean, grind and undercut commutator, or clean and polish collector. Clean and treat windings with good insulating varnish
	Bearing and brackets coated inside	Dusts and wash with cleaning solvent
24. Motor wet	Subject to dripping	Wipe motor and dry by circulating heated air through motor. Install drip or canopy type covers over motor for protection
	Drenched condition	Motors should be covered to retain heat and the rotor position shifted frequently
	Submerged in flood waters	Dismantle and clean parts. Bake windings in over at 105°C for 24 hr or until resistance to ground is sufficient. First make sure commutator brushing is drained of water and completely dry

Table 11.13 Troubleshooting Guide for Induction Motors
Source: Reference 5

Trouble	Cause	Action
1. Motor will not start	Overload control trip	Wait for overload to cool. Try starting again. If motor still does not start, check all the causes as outlined below
	Faulty (open) fuses	Test fuses
	Low voltage	Check motor-nameplate values with power supply. Also check voltage at motor terminals with motor under load to be sure wire size is adequate
	Wrong control connections	Check connections with control wiring diagram
	Loose terminal-lead connection	Tighten connections
	Driven machine locked	Disconnect motor from load. If motor starts satisfactorily, check driven machine
	Open circuit in stator or rotor winding	Check for open circuits
	Short circuit in stator winding	Check for shorted coil
	Winding grounded	Test for grounded winding
	Bearings stiff	Free bearing or replace
	Grease too stiff	Use special lubricant for special conditions
	Overload	Reduce load
2. Motor noisy	Motor running single-phase	Stop motor, then try to start. It will not start on single phase. Check for "open" in one of the lines or circuits
	Electrical load unbalanced	Check current balance

Cont. (Table 11.13)

	Shaft bumping (sleeve bearing motors)	Check alignment, and condition of belt. On pedestal-mounted bearing, check cord play and axial centering of rotor
	Air gap not uniform	Center the rotor and if necessary replace bearings
	Rotor rubbing on stator	Center the rotor and replace bearing if necessary
	Coupling loose	Insert feelers at four places in coupling joint before pulling up bolts to check alignment. Tighten coupling bolts securely
3. At higher than normal temperature or smoking	Electrical load unbalance (fuse blown, faulty control, etc.)	Check for voltage unbalance or single phasing. Check for "open" in one of the line or circuits
	Incorrect voltage and frequency	Check motor-nameplate values with power supply. Also check voltage at motor terminals with motor under full load
	Motor stalled by driven machine or by tight bearings	Remove power from motor. Check machine for cause of stalling
	Stator winding shorted	Cut out coil or rewind
	Stator winding grounded	Test and locate ground
	Rotor winding with loose connections	Tighten, if possible, or replace with another rotor
	Belt too tight	Remove excessive pressure on bearings
	Motor used for rapid reversing service	Replace with motor designed for this service

Table 11.14 Troubleshooting Guide for Wound-Rotor Motors
Source: Reference 5

Trouble	Cause	Action
Rotor runs at low speed with external resistance cut out	Wire to control too small	Use larger cable to control
	Control too far from motor	Bring control nearer motor
	Open circuit in rotor circuit (including cable to control)	Test by ringing out circuit and repair
	Brushes sparking	Adjust commutation
	Dirt between brush and rings	Clean rings and insulation assembly
	Brushes stuck in holders	Use right size brush
	Incorrect brush tension	Check brush tension and correct
	Rough collector rings	File, sand, and polish
	Eccentric rings	Turn in lathe or use portable tool to true up rings, without disassembling motor
	Excessive vibration	Balance motor
	Current density of brushes too high (overload)	Reduce load (if brushes have been replaced, make sure they are of the same grade as originally furnished) Check shaft for straightness

While the motor is shut down:

(a) Condition of insulation
(b) Cleaning
(c) Visual .This includes commutators, brushes, slip rings, and other motor parts; clearances on bearings and air gaps should be measured.
(d) Repacking and bearing inspection

Table 11.15 Troubleshooting Guide for Synchronous Motors
Source: Reference 1

Trouble	Cause	Action
1. Motor will not start	Faulty connection	Inspect for open or poor connection
	Open circuit one phase	Test, locate, and repair
	Short circuit one phase	Open and repair
	Voltage falls too low	Reduce the impedance of the external circuit
	Friction high	Make sure bearings are properly lubricated. Check bearing tightness. Check belt tension. Check load friction. Check alignment.
	Field excited	Be sure field-applying contactor is open and field-discharge contactor is closed through discharge resistance
	Load too great	Remove part of load
	Automatic field relay not working	Check power supply to solenoid. Check contactor tip. Check connections
	Wrong direction of rotation	Reverse any two main leads
2. Fails to pull into step	No field excitation	Check circuit connections. Be sure field applying contactor is operating. Check for open circuit in field or exciter. Check exciter output. Check rheostat. Set rheostat to give rated field current when field is applied. Check contacts of switches

Lubrication is one of the most important aspects of maintenance in electric motors. Table 11.9 shows some recommended relubrication intervals based on motor horsepower and type of service. Tables 11.10a to 11.10c are scheduled maintenance guides for electric motors. Tables 11.11 to 11.15 contain troubleshooting guides for specific motor types.

11.3.4 General Maintenance Procedure of Motor Bearings

Most bearing troubles are caused by sufficient or no lubrication, poor lubricant, dirty lubricant, failure of oil rings to revolve, clogged oil grooves or improper grade or waste in the waste-packed types of bearing. Every effort should be made to ensure obtaining the proper grade and type of lubricant. The temperature in the space surrounding the motor should also be considered when selecting the lubricant. It is useless, for example, to obtain a class H motor for use in a high-temperature condition and then have it fail from a lubricant that would not perform at that temperature.

Periodically, the lubricant should be replaced in bearings whether it be a sleeve bearing that is oil lubricated or a roller bearing that is packed for a prolonged period of operation.

The maintenance procedure should be divided into two basic considerations:

(a) Periodic schedules of those maintenance tasks performed while the equipment is in operation.
(b) Maintenance tasks for which the equipment must be shut down.

A maintenance timetable for electric motors is in Table 11.8. For a further discussion of bearing maintenance, refer to Appendix V. Guides to fault diagnosis of electric motors are in Tables 11.9 to 11.12. Tables 11.10, 11.11 and 11.12 are guides to troubleshooting of induction motors, wound-rotor motors and synchronous motors, respectively.

11.3.5 Motor Control Equipment

It is recommended that motor controllers be inspected and cleaned at 6 month intervals. Where motors are started and stopped frequently it may be necessary to clean and inspect at shorter intervals. The frequency of inspection will depend upon the rate of motor starts and on local environment. It is recommended that a complete inspection be made annually.

At the 6 month inspection the following steps are recommended:

(a) Thoroughly clean all parts. Tighten all connections and lubricate bearings as required.
(b) Examine the arcing tips and if rough, dress them with sandpaper or with a fine file.
(c) Examine terminals to be sure that all connections are tight. Where there is evidence of heating, the connecting surfaces should be cleaned and polished. Silver plate surfaces should not be abraded. Aluminum connections that show deterioration should be replaced.
(d) For oil-immersed equipment, check the level and condition of the oil. Add or replace oil where required.
(e) Examine the enclosure to be sure that the necessary degree of protection is provided.

Check that enclosure covers are in place and fastened. When installed in hazardous locations, be sure that controllers are mounted in appropriate explosionproof enclosures.

11.3.6 Relays

It is recommended that the calibration and time current characteristics of relays be tested at 2 year intervals. These tests should be made only by personnel experienced in this work and who have the necessary equipment and training in its use. Usually, arrangements for making relay tests may be made with the relay manufacturers, at supplying utilities, or with testing laboratories equipped for this type of testing.

11.3.7 Switchboards

It is recommended that switchboards be inspected and cleaned on annual intervals unless experience indicates that more frequent inspections are required. The required frequency of inspection will vary between industries and with different environment. The following steps are recommended:

(a) Be sure that all circuits in the swithboard are deenergized and that there is no chance of a circuit's being energized while the inspection is under way.
(b) Inspect the busses and connections and be sure that all connections are tight. Examine for abnormal conditions that indicate overheating or weakened insulation.
(c) Remove dust and dirt accumulations from bus supports and enclosure surfaces. A vacuum cleaner with a long nozzle will be found useful in this cleaning operation, wipe all bus supports clean with a cloth moistened in a cleaning solution. (refer to the manufacturer's instructions). Do not use abrasive material for cleaning plated surface.
(d) The switchboard devices should be maintained in accordance with instructions supplied for each device.
(e) Secondary and control wiring connections should be checked to ensure that they are tight.

11.3.8 Lighting

Facilities lighting systems constitute a major portion of maintenance expenditures depending upon the variety and types of fixtures and lamps supplied. The maintenance activity in conjunction with lighting is primarily geared toward maintaining the original designed quality and intensity of the light. Dust and dirt acted upon by the natural convection of air due to the heat of the lamps themselves. It is therefore necessary to have a program of periodically removing the accumulations. Lamp burnouts and replacement have created controversies as to how the burnouts should be replaced, either as they occur or on a group-replacement schedule based on life expectancy of the lamps. There are circumstances that do not warrant group replacement and other circumstances that demand such a program from the cost consideration.

Requirements used for circulating design criteria include the reflective capacities of walls and ceilings as part of the calculation. Any darkening of these surfaces must be regarded when maintaining light intensity. The lumen output of the lamps diminishes as they age. Hence, depending upon the critical requirements of a specific area, the age of the lamp must be considered.

Spot replacement of lamps is based on periodic inspections with burnouts replaced on daily or weekly schedules. It is evident that if the plan is carried out formally, periods in which there will be a number of burnouts present must be tolerated. In general spot relamping is costly from a labor standpoint. Mixing of new and old lamps is detrimental to appearance.

Group relamping is the systematic replacing of lamps based on a percentage of life expectancy. Group relamping result in more uniform and higher lighting instensities between schedules than with spot lamp replacement. There are a variety of methods of determining how often to group relamp. Of these it is preferable depending upon the facility to schedule the relamping on minimum acceptable light meter readings. The light meter readings should be taken at night so as to prevent outside daylight from affecting the reading. A standard for acceptable foot-candle readings should be established and periodic readings taken until a diminishing reading dictates a relamping. Fixtures should also be scheduled for washing and cleaning in conjunction with relamping schedules. Experience indicates that fixtures will require cleaning more frequently than the relamping schedule. It is practical to schedule washing on a yearly basis with relamping on a 2 year schedule if the light meter readings obtained by such practice are acceptable.

Another method of scheduling group relamping consists on counting the percentage of lamp failures for a given percentage of lamps and scheduling replacements based on the life cycle of the failed lamps. Statistics indicate that at approximately 80 percent of life expectancy 20 percent of failures are encountered. Relamping would replace all lamps and 20 percent of the best lamps removed would be retained for replacement purposes. When the replacements have been totally used up, another relamping should be scheduled. Group relamping depending upon individual situations can offer savings of approximately 25 to 30 percent over spot relamping procedures. Scheduling of relamping and washing should be tied in with the scheduling of other preventive maintenance activities.

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CHAPTER 12

Preventive Maintenance of Pumps and Compressors

12.1 INTRODUCTION

Electric power generated for industry is mostly consumed by compressors and pumps. A large number of industrial equipment, machines and systems use compressors and compressed air, while pumps are employed in distribution systems. The minimum amount of energy is consumed when the device is running at its peak condition and efficiency. To keep it in this condition will require a thorough preventive maintenance program.

Maintenance functions designed to keep pumps and compressors in their best condition or to restore them to this level are discussed in this chapter. The proper care and service of pumps and compressors will save on unneeded expenses, prolong equipment life and conserve energy.

12.2 DIAGNOSTICS

12.2.1 Pumps

(a) *Bearing Lubrication*

A regular ball-bearing grease with the following properties can provide lubrication for ball bearings:

(1) clean and neutral;

(2) neutral mineral soap base with no fillers or impurities;

(3) good film strength with a consistency of No. 1 to No. 2;

(4) chemically stable but does not oxidize in service or in storage;

(5) oil totally miscible in the soap base;

(6) operating temperature of 40°C to 93.3°C; and

(7) low internal friction; good adhesion; water resistant.

The intervals between lubrication changes will depend on the type of grease used; the type and size of the bearing and housing; the operating speed; and other service conditions. There are no rules as to when grease should be renewed because the grease loses its lubrication property gradually. A rough guide would be to renew grease after 3 months for severe service, and after 1 year for normal service. The exact length of the intervals can be determined through experience.

The bearing housing should be kept clean and only clean grease should be used. Over-lubrication can cause bearing overheating. When this happens, a detailed inspection is necessary before regreasing.

The higher quality automotive and aircraft engine oil should be used for oil-lubricated ball bearings. Mineral oil of SAE 30 will be satisfactory for most purposes.

Oil-lubricated bearing housings or oil pumps are equipped with oil gauges to monitor the oil level. Addition of oil is required when the level falls below the indicated lower level. The level of the oil in the housing should not exceed the center of the lowest bearing ball when the bearing is stationary.

The frequency of oil changes will depend on the operating conditions. For operating temperatures of 49 to 60 °C, an interval of one year is normal while for higher temperatures replacements every 2 to 3 months may be necessary.

Before applying the new oil, drain the housing and flush the bearing with low-viscosity oil.

(b) *Packings*

Packings used for the pumping of clear cold water are of long-fiber asbestos, square-braided and well impregnated with graphite and oil. For other fluids the manufacturer should be consulted in the selection of special packings.

The packing needs replacement before it gets hard enough to abrade the shaft. It pays to fully repack the pump instead of replacing one or two rings at a time. Remove the water seal cage to replace packing at the bottom of the stuffing box. The number of rings in the cage should be noted to be able to reinstall the rings in the proper order. When leakage cannot be controlled without excessive tightening of the glands, the shaft sleeves may have to be replaced.

(c) *Mecahnical Seals*

Mechanical seals provide absolute control of leakage. Lubrication of the seal faces with oil or grease is the only requirement, the pumped liquid itself providing lubrication.

The pump manufacturer's instructions in replacing seals should be followed They should be installed in their correct position; improper setting may cause too much load to be exerted on the seal faces, leading to rapid wear. Insufficient loading will make the seal ineffective, and leaking will result. When properly installed, seals require almost no service, with life of 2 to 3 months for severe service, and 2 years when handling clean fluids.

(d) *Protective equipment*

In the absence of a supply of clean cold water to protect seal faces, packings and shaft sleeves , and abrasive separator can be fitted to the discaharge side of a pump to remove dirt and abrasives from the fluid.

The clear fluid is then forced into the gland housing to prevent abrasive from getting to the seal faces or packing - ring seal area, An automatic shutdown device can be used to protect machanical seals, impellers, rings and other pump components from damage which can result from dry running The switches are connected to the process fluid passage and stop operation or give off a signal when there is a pressure drop.

Centrifugal pumps

The alignment of the driving unit and the pump is critical for efficient performance. For direct driven pumps this is usually taken care of during the installation of the unit. When the drive is transmitted through a V-belt drive, the belts should be in perfect alignment; misalignment will shorten the belt life. Belts should have the proper tension to prevent slip between the belt and pulley.

An increase in the wearing ring clearance will result in a decrease in the pump head and capacity. Monthly inspection is required when handling liquids which contain abrasive particles while an annual check is enough for pumping clean water. The rings should be replaced if the clearance is twice its original dimension or if there is a marked loss in head and capacity.

Screw pumps

Screw pumps are precision machines and extra care must be taken during servicing. The alignment of the male and female rotors should not be accidentally altered. The mechanical seals and the faces of the seals should always be maintained in good condition.

Improperly packed or tightened glands can lead to a host of pump problems. An overtightened gland will cause the following:

- Pump seizure
- Excessive gland/seal wear
- Excessive power absorbed
- Pump and/or motors overheating

An undertightened gland will result in product leakage, noisy operation, irregular discharge and a loss in capacity. Inadequate gland flushing can cause product leakage and excessive gland or seal wear.

Check pipes for alignment. To maintain the alignment, provide expansion fittings or support the pipework. The rotorcase can be strained by expansion or misalignment of the pipework.

Replace worn pumping elements to check capacity loss.

Relief valve leakage can lead to overheating of the pump, under-capacity or total absence of discharge. This leakage can be due to a wrong pressure setting or worn valve elements. The check valve will not set properly if the spring compression is poor. The valve should lift at about 10% above the duty pressure.

Pump diagnosis will benefit from on-stream pressure measurements at the inlet and outlet parts.

Reciprocating Pumps

Steam pumps require maintenance of gaskets and packings, inspection for mechanical wear and routine lubrication. At the steam end of the valve chest, check for rounding of the ends of the slide valve and "shouldering" or rounding of the valve chest face.

Excessive wear can cause irregular pump operation, piston short- or over-stroking, excessive noise and low discharge pressure. A faulty valve will also result in noisy operation.

Check valve adjustment with the piston at mid-stroke. Incorrect timing can result in short piston strokes.

At the liquid end, examine the valves for wear and pitting.

Inspect the piston, piston rod and cylinder liner for wear due to corrosion and pitting.

Rotary Pumps

Aside from the proper care of seals, rotary pump maintenance also requires inspection for wear. corrosion and material defects. Check individual parts for wear, and clearances for allowable tolerances. Maintaining the recommended clearances and proper timing is necessary for efficient operation.

For vane pumps, check the vanes and casing for wear. Usually excessive wear will be manifested in noisy pump operations or absence of discharge.

Check the setting of the relief valve; a high setting will result in excessive pressure and noise while a low setting will reduce the pump capacity.

12.2.2 Compressors

(a) *Air Delivery and Discharge*

Inlet lines may be needed to deliver a steady supply of clean, cool, dry air to the compressor unit. The filter is then positioned along the line where it may be easily checked from time to time. Metal inlet lines must be kept clean given an internal coating of water-and oil-proof sealer to counteract the formation of scale. These steps should be taken to provide a clean supply of air and to minimize the burden on the air filter.. The line must be checked for airtightness to prevent the entry of contaminants at the pipe, air filter and compressor connections.

The air filter screens out dirt which might get into the compressor and damage the rotors or bearings. The dry type air filter with renewable element is highly favored because of its ease of maintenance and high ability to screen out minute particles - above 10 microns in size. The manufacturer should be consulted in the selection of a filter for air laden with flour dust and cement times (less than 10 microns), fly ash (about 1 micron) and tobacco smoke (about 0.1 micron).

The interval between servicing, ranging from twice per shift to once a week, should be established after considering the service conditions and the quality of the air. A decrease in the compressor capacity or an excessively high motor current indicate a need to service the air filter. During servicing, the unit should be handled with care to prevent damage to the gaskets, canister or cup. Check the element for small breaks and see if it is properly installed in the canister. The presence of dirt on the discharge tube may mean breaks in the element, improper seating or worn gaskets. Too heavy dirt accumulation in the filter and too frequent servicing will require the installation of a centrifugal precleaner before the air filter or the transfer of the intake port to a cleaner environment.

Service indicators provide a cheap and accurate means of signalling the need for service of the air filter element. The indicator is a standard equipment on high capacity units and comes as an option for smaller compressors. The element needs servicing when the pressure differential across the element is 508 mm water column. Usually a marker becomes visible on the stem of the indicator when the pressure differential reaches this level. After servicing the marker can be reset manually to its original position. The service indicator will not function if there are leaks in the gaskets or breaks in the air filter element; a pressure differential will not exist.

(b) *Lubrication*

The manufacturer's recommendation on oil change intervals should be followed strictly. The recommendation is made only after the evaluation and testing of several lubricants. However, the time between changes will depend on the air quality, the maintenance of the air and oil-filter, the ability of the cooling system to control the oil temperature, the service conditions of the compressor and the oil quality. There may be a need for more frequent oil changes with intense humidity, high operating temperatures and dusty air.

An accurate way of determining the optimum oil change interval is to have the oil supplier analyze the oil drained at particular intervals, such as after 250. 500, 1000, and 1500 hours of operation, and so on. After getting the optimum interval, maintain the operating conditions at approximately the same level, a change in operation will mean a change in oil-change intervals.

Synthetic lubricants which claim less frequent changes are available on the market. Before switching to one, check if the synthetic fluid can meet the requirements of the original lubricant. To be on the safe side, consult the compressor manufacturer. Some synthetics may not be compatible with the gasket material on air line connections.

(c) *Oil Coolers*

Water-and air-cooled oil coolers are available for the cooling of the compressor system lubricant to maintain the optimum operating temperatures. The cooling efficiency of water-cooled oil coolers can be hindered by poor water quality. The use of unacceptable water will result in fouling, erosion, corrosion and eventually tube failure. The water can be tested for suitability and the appropriate treatment made: mechanical, chemical, or both. The preventive maintenance program should include regular inspection and service of the oil cooler tubes. The maintenance technicians should be alert for deterioration of the water quality which will be manifested as a change in the discharge water or tube condition.

The water flow control valve must be included in the maintenance checklist. Inspect the valve stem for corrosion or deposits. Remove any foreign material or oil on the stem. Use the fingers or gentle wrench tightening to secure the packing nut, do not over-tighten. Be careful not to bend or scratch the valve stem or bend or kink the capillary tubing connecting the valve head to the thermal element. The following can cause valve failure: overtightened packing nut, bent or corroded valve stem, clogged valve, faulty capillary system. A strainer at the water inlet line will safeguard the valve against foerign materials.

The accumulation of condensate in the oil system will minimize the lubricating properties of the oil and hinder control. To prevent moisture, maintain the oil system temperature above the pressure dew point of the system air.

(d) *Bearing and Seals*

The condition of these components is crucial to the operation of the compressor, particularly the screw compressor. Each rotor of the screw compressor is supported and maintained at close clearances by antifriction bearings. Abrasives in the lubricant and the effects of low viscosity oil subject the bearing to wear. Maintenance of the air- , oil- and cooling system will do a lot to prevent this. Excessive bearing wear will cause the rotors to move out of their correct position and may cause damage to the compressor.

The shaft oil seal is also adversely affected by abrasives, low-viscosity and high temperature lubricants. Minimal seepage is normal in all mechanical seals but excessive leakage is a signal that there are problems other than oil-seal wear.

12.3 PREVENTIVE MAINTENANCE PROCEDURES

Most pump and compressor breakdowns are due to seal and beering failure. The common source of process pump damage is seal failure. The present trend of very high rotational speeds increases the chances for damage of bearings and seals. Proper lubrication of these elements will minimize breakdowns and extend the life of the equipment. Maintenance of the cooling system will protect these parts from the effects of low viscosity lubrication.

The demand for high efficiency performance has made the use of smaller running clearances between elements imperative. Rotors, impellers or casings suffer from abrasive particles suspended in the medium being pumped or compressed. To minimize this danger, the use and maintenance of filter (air, and oil filters, strainers, etc.) is essential. Excessive wear on the pump or compressor elements will reduce the performance of the machine.

The integrity of the system is also dependent on the condition of the accessories and fittings attached to the pump or compressor. Clogged leaking or collapsed lines will cause difficulties in priming and faulty operation.

The maintenance of instrumentation which monitor temperature, pressure, etc. at key locations of the equipment is a must. These gauges serve as guides to correct performance, facilitate supervision and protect the operator by warning of impending failure. Maintenance requires regular inspection and periodic calibration against gauges of known accuracies.

12.3.1 Pumps

The maintenance requirements of a pump will depend on the type of pump and the kind of service it performs. This section will deal on the general guidelines for the maintenance of pumps. Usually the pump manufacturer will provide a maintenance manual with the pump. Any recommendation in this manual should be given priority for specific items.

Centrifugal Pumps

Centrifugal pumps require routine checks and maintenance at intervals specified by the pump builder.

Usually the preventive maintenance schedule is divided into monthly, three-monthly, six-monthly and annual checks, but the measures to be performed during these periods depend on the length and intensity of serivce. The maintenance program therefore should take into consideration the service conditions rather than just follow the routine specified in the maintenance manual.

Manufacturers recommend the frequency of bearing lubricant changes and specify the lubricant to be used. This frequency, however, may change depending in the bearing type, service conditions and various parameters. The monthly check of pump bearing temperature can be done weekly, with severe service, or if other factors dictate it. Likewise, the inspection of packings and seals, usually done twice a year to check for the possible replacement, may have to be performed more often or less frequently depending on the design of the pump, the pump installation and service conditions.

Generally the pump is disassembled annually to check for worn or damaged parts, and to replace these parts and other parts specified for replacement by the pump manufacturer. As already mentioned, this will vary according to the number of hours of operation and the kind of service. More frequent inspections of this kind may be necessary at longer intervals will save on downtime, replacement parts and maintenance service.

Table 12.1 Pump Maintenance Timetable

Frequency	Action
Monthly	Check the following items: 1. Priming 2. Speed 3. Noise 4. Seal Leakage 5. Gasket leaks Refer to motor or engine service manual for the maintenance of the driving unit.
Every Six Months	Remove impeller and do the following 1. Clean the casing and recirculation device 2. Remove seal grease and relubricate 3. Check clearances, replace if wear is excessive 4. Check the shaft seal, packing and shaft sleeve for wear and replace if necessary.
Every Twelve Months	Dismantle the pump and inspect and clean component parts

Source: Reference 7

Table 12.2 List common problems encountered with centrifugal pumps and offers some solutions.

Table 12.2 Fault Diagnosis for Centrifugal pumps

Condition	Possible Cause	Remedy
1. Pump does not turn	a. Drive belt slip	a. Check and adjust
	b. Coupling fault	b. Check if slipping or broken; replace if necessary
	c. Sheared shaft, gears or keys	c. Check; replace if necessary
2. Pump does not prime	a. Inlet clogged or restricted	a. Check
	b. Air leaks on suction side	b. Check line(s) and seals for leaks; replace if necessary
	c. Liquid drained from system	c. Fit foot valve
	d. Worn pump impeller	d. Inspect; try increasing pump speed or fitting foot valve
3. No discharge	a. Excessive suction lift	a. Check pump inlet for obstruction Check suction head
	b. Excessive discharge head	b. Check if valves are open check piping for obstrution Check total head
	c. Speed too low	c. Compare pump speed with manufacturer's recommendations
	d. Pump clogged	d. Check impeller for clogging
	e. Wrong direction of rotation	e. Check direction
	f. Vapor lock	f. Bleed suction pipe to clear air lock

Cont. (Table 12.2)

Condition	Possible Cause	Remedy
	g. Relief valve adjustment	g. Check setting, check for dirt on valve seat i. Check setting, check for dirt on valve seat
	h. Air leak	h. Check seals and line(s) for leaks
4. Low delivery	a. Air leaks	a. Check suction piping gaskets and pump for leaks
	b. Vapor lock	b. Verify if liquid in suc-line is not flashing by checking NPSH and fluid temperature
	c. Relief valve incorrectly set, or stuck	c. Check and adjust
	d. Worn impeller, wear rings	d. Inspect; replace if necessary
	e. Wrong direction of rotation	e. Check direction
	f. Constriction in suction line	f. Check if foot valve size is correct Check strainer for obstruction
	g. High fluid viscosity	g. Compare fluid viscosity with anticipated performance
	h. Excessive fluid temperature	h. Reduce speed and/or delivery; decrease suction head
	i. Speed too low	i. Compare with manufacturer's specification
5. Over-heating	a. Packings overheat	a. Check packings for fit and tightness Check packing lubrication or cooling flow, whichever

Cont. (Table 12.2)

Condition	Possible Cause	Remedy
		applies Compare packing with manufacturer's specification
	b. Bearings	d. Check oil level and lubricant condition Compare lubricant used with manufacturer's recommendation Check alignment and tightness Check oil seals Check if operating speed is not excessive
	c. Fluid too viscous	c. Adjust by heating, etc.
	d. Excessive pressure	d. Reduce pump speed use larger delivery lines
6. Vibration and noise	a. Cavitation	a. Check pump operating conditions
	b. Excessive fluid viscosity	b. Check product suitability
	c. Trapped air	c. Check for air leaks
	d. High vapor pressure fluid	d. Check product/pump compatibility
	e. Improper pump assembly	e. Check and correct
	f. Unbalanced impeller	f. Check impeller for damage or clogging
	g. Misalignment	g. Check alignment
	h. Mounting	h. Check rigidity
	i. Damaged shaft on bearings	i. Check; if necessary replace
	j. Pump wear	j. Disassemble and check
	k. Noisy relief valve	k. Adjust, repair or replace

Cont. (Table 12.2)

Condition	Possible Cause	Remedy
7. Excessive wear	a. Misalignment b. Out of balance c. Non-rigid mount d. Damaged shaft e. Insufficient lubrication f. Dirt in pump g. Corrosion h Speed too high i. Pressure too high j. Fluid laden with abrasives	a. See above b. See above c. See above d. See above e. Check type and amount of lubricant f. Supply filter g. Check product/pump compatibility h. Compare with manufacturer's recommendation i. Reduce speed or adjust system j. Check product/pump compatibility
8. Pumps requires excessive power	a. Speed too high b. Misalignment c. Internal friction d. Tight bearings e. Lack of lubrication f. High fluid viscosity	a. Compare with recommended speed b. Check c. Check for rubbing between parts d. Check bearings and packings (bearing temperature will be a clue). e. Check f. Check product/pump compatibility

Source: Reference 1

When the pump has provisions for easy inspection, disassembling and replacement of wear parts, usually true for pumps designed for severe service, it is wise to perform inspections at frequent intervals. Complete disassembly may be necessary if the pump displays a conspicuous loss of performance. But before this is done the pump should be tested for power, head and capacity to see of there is a need for shut-down and total dismantling.

Finally, a maintenance log should be kept for each pump, containing a checklist of maintenance requirements, the maintenance schedule, and the maintenance steps performed.

Reciprocating Pumps

Maintenance of reciprocating pumps is confined to regular inspection of valves, seals and packings. The number of hours of service before such maintenance is required will depend on the type of the design and operating conditions of the pumps. Procedures for such inspections will be illustrated in the manufacturer's instruction manual. With normal conditions the valves should be checked after three months from the break-in of a new pump. The succeeding inspections can then be based on experience. Other items which require maintenance are the piston and rod and cylinder liners.

Guide to correcting faults in pump operation are shown in Table 12.3 for steam pumps and Table 12.4 for power driven reciprocating pumps.

Fault diagnosis guides for rotary pumps and screw pumps are shown in Table 12.5 and 12.6 respectively.

12.3.3 Compressors

Lubrication

Use only the best mineral, hydraulic oil with corrosion and oxidation inhibitors, anti-foaming and anti-wear properties. Check if it is at the specified viscosity at ambient conditions. Do not combine different brands or kinds of lubricants.

The frequency of the oil change will vary according to the quality and temperature of the oil.

To change the oil, run the compressor until warm. After stopping, open the oil filler plug to allow the pressure in the system to escape through the vent hole.

(1) Remove the oil filter. Drain the oil into a pan.

(2) Clean the filter mounting. Do not allow any dirt to get into the system. Oil the gasket of the replacement filter and screw into place until it is properly seated.

(3) Open all drain plugs to drain the oil from the oil separator, oil cooler, oil stop valve and check valve. Retighten after draining.

(4) Fill the oil to the correct level in the filler pipe. Do not allow any oil to get into the system.

(5) Run the unit unloaded for a few minutes to circulate the oil. Stop the unit and check the oil level in the sight glass. Do not overfill.

Air Filter

Service air filter at the recommended intervals and/or when the indicator (if provided) signals for servicing.

(1) Remove the element only when the compressor is not running.

(2) Reset the service indicator.

(3) Inspect the element (either old or new) for tears and holes. Do not use a damaged element.

Do not reuse the element more than three times. To minimize down-time, always replace the old element with a new one.

After removing the element for servicing, clean the retaining cover and check the element sealing surfaces on the cover and pipe flange.

Table 12.3 Fault Diagnosis for Steam Pumps

Fault	Possible Cause	Remedy
1. No discharge	a. Pump is not primed	a. Prime Release trapped air on discharge side
	b. Excessive suction lift	b. Reduce friction by using larger diameter pipe or eliminating bends, etc.
	c. Air leaks	c. Check system for air leaks
	d. Vapor bound	d. Check fluid temperature, vapor pressure and suction lift
	e. Clogging	e. Check suction pipe, foot valve or strainer Check pump suction valves
	f. Deterioration	f. Dismantle and check suction valves, packings, valves or cylinder
2. Low discharge pressure	a. Low steam pressure	a. Check for clogging or leaks Inspect valves
	b. Tight packing	b. Loosen
	c. Excessive back-pressure	c. Check system head
	d. Deterioration	d. Inspect condition of piston packings, valves and cylinders
3. Pumps stops or hesitates	a. Steam supply unsteady	a. Check for obstructions, etc.
	b. Valve trouble	b. Check for valve wear and leakage Check valve timing
	c. Excessive back-pressure	c. Check system head
4. Variable delivery	a. Air leaks	a. Check system for air leaks
	b. Misalignment	b. Check alignment of pump, look for unsupported piping connected to pump
	c. Excessive suction lift	c. See above
	d. Vapor bound	d. See above
	e. Tight packing	e. See above
	f. Excessive speed	f. Compare with manufacturers specifications

Cont. (Table 12.3)

Fault	Possible Cause	Remedy
5. Pump short-strokes	a. Excessive cushioning b. Worn valve c. Entrained gas d. Incorrect valve e. Worn bore	a. Adjust cushioning valves to get correct strokes b. Check; re-face if necessary c. Modify suction intake d. Check and adjust e. Replace liner, re-bore and use larger piston
6. Pump over-strokes (hits head)	a. Cushion valves b. Piston leakage c. Valve leakage	a. Adjust to reduce stroke. b. Replace piston packing or worn liner; or re-bore cylinder c. Check valves on liquid head for leakage; if necessary re-grind or re-set
7. Excessive wear	a. Misalignment b. Bent piston rod c. Worn bore d. Fluid	a. See above b. Check trueness c. Replace liner or re-bore d. Check product/pump compatibility

Source: Reference 1

Table 12.4 Fault Diagnosis for Power Driven Reciprocating Pumps

Fault	Possible Cause	Remedy
1. Low discharge pressure	a. Air leaks b. Excessive wear c. Faulty valves	a. Check system for leaks b. Check cylinder bore for wear c. Check valve and valve seat condition
2. Excessive noise	a. Worn bearings b. Misalignment c. Excessive speed d. Excessive suction lift e. Trapped gas or air f. Faulty valve operation	a. Check condition; replace if necessary b. Check alignment; correct if necessary c. Compare with manufacturers specified rated speed d. Reduce suction lift if possible and/or reduce suction pipe friction e. Adjust suction pipe entry or position f. Check valves and springs
3. Variable delivery	Same as for steam pumps	Refer to Table 12.3
4. No discharge	Same as for steam	Refer to Table 12.3

Source: Reference 1

Table 12.5 Fault Diagnosis for Rotary Pumps

Fault	Possible Cause	Remedy
1. No discharge	a. Not primed	a. Prime
	b. High suction lift	b. Reduce suction lift or reduce friction in suction side
	c. Air leaks	c. Check system for leaks, particularly gaskets
	d. Blockage	d. Check and adjust
	e. Excessive wear	e. Compare wear against manufacturer's allowable tolerances
	f. Wrong direction of rotation	f. Check rotation
	g. Insufficient speed	g. Compare with rated speed
2. Low discharge pressure or reduced capacity	a. Insufficient speed	a. See above
	b. Wrong direction of rotation	b. See above
	c. High suction lift	c. See above
	d. Air leaks	d. See above
	e. Trapped air	e. Re-postition suction inlet
	f. Relief valve or bypass valve	f. Check and adjust
	g. Excessive wear	g. See above
3. Excessive noise	a. Misalignment	a. Check alignment of pump and motor/driven
	b. Internal damage	b. Check rotor
	c. Imbalance	c. Check rotor for static and dynamic balance
	d. Trapped air	d. See above
	e. Air leaks	e. See above
	f. Cavitation	f. Check operating conditions
	g. Excessive pressure	g. Check relief valve and adjust if necessary
	h. Deterioration	h. Check wear and clearances of components
4. High discharge pressure	a. High system pressure	a. Compare system pressure with pump rating, larger pump may have to be used
	b. Relief valve or bypass valve	b. Check and adjust
	c. System throttled	c. Inspect discharge valve opening; or check system for blocking

Cont. (Table 12.5)

Fault	Possible Cause	Remedy
5. Excessive wear	a. Abrasive liquid b. Misalignment c. High system pressure d. Excessive speed	a. Check pump/product compatibility; or check suitability of filter or strainer in use b. See above c. See above d. Compare with pump specification for viscosity of liquid handled
6. Excessive input power required	a. Damage b. High system pressure c. Excessive fluid viscosity d. Excessive speed	a. Check parts; shaft, bearings, etc. b. See above c. Check speed rating against actual viscosity of fluid; reduce speed for higher viscosities d. See above.
7. Pump overheats	a. Relief or bypass valves b. Excessive speed c. Excessive pressure d. Discharge throttle	a. See above b. See above c. See above d. Check flow through relief valves

Source: Reference 1

Table 12.6 Fault Diagnosis for Screw Pumps

Fault	Possible Cause	Remedy
1. No discharge	a. Wrong direction of rotation b. Clogged foot valve or filter c. Leaking front cover relief valve	a. Reverse motor b. Clear c. Check setting and readjust if necessary. Inspect and clean seating surfaces. Replace excessively worn parts
2. Undercapacity	a. Air leaks in supply line b. Clogged foot valve or filter	a. Inspect pipe joints and gland packings. Correct b. See above

Cont. (Table 12.6)

	Possible Cause	Remedy
	c. Excessive delivery pressure d. Loose gland packing e. Loose belt drive f. Worn rotors g. Leaking front cover relief valve h. Relief valve trouble	c. Clear obstructions d. Tighten e. Adjust to specified tension f. Replace g. See above h. Inspect wear on sealing surfaces and replace if excessive Check valve setting. Readjust spring compression to maker's specification
3. Irregular discharge	a. Air leaks in supply line b. Clogged foot valve c. Tight gland packing	a. See above b. See above c. Loosen
4. Pump hesitates; starts then stops	a. Air leaks in supply line b. Clogged foot valve or strainer c. Excessive delivery pressure d. Worn and/or unsynchronized timing gears e. Surface contact of pump rotors	a. See above b. See above c. See above d. Consult manufacturer e. Verify rated and duty pressures Consult manufacturer
5. Pump overheating	a. Excessive delivery pressure b. Tight gland packing c. Misalignment d. Shaft bearing wear or failure	a. See above b. See above c. Check pipework and support if necessary. Fit flexible connections. Check flexible couplings, particularly flange connections d. Consult manufacturer

Cont. (Table 12.6)

	e. Surface contact of pump rotors	e. See above
	f. Incorrect and/or inadequate lubricant	f. Verify with manufacturer's recommendation
	g. Worn and/or unsynchronized timing gears	g. See above
	h. Leaking front cover relief valve	h. See above
6. Excessive input power	a. Excessive delivery pressure	a. See above
	b. Tight gland packing	b. Locsen
	c. Misalignment	c. See above
	d. Shaft bearing wear or failure	d. See above
	e. Worn and/or unsynchronized timing gears.	e. See above
	f. Incorrect and/or inadequate lubricant	f. See above
	g. Surface contact of pump rotors	g. See above
7. Excessive noise and vibration	a. Air leaks in supply line	a. See above
	b. Clogged foot valve or filter	b. See above
	c. Product laden with contaminants	c. Clean the system. Fit filter to inlet
	d. Excessive delivery pressure	d. See above
	e. Loose gland packing	e. Tighten
	f. Misalignment	f. See above
	g. Non-rigid mounting	g. Fit lock-washers to slack fasteners and retighten
	h. Shaft bearing wear or failure	h. Consult manufacturer
	i. Worn and/or unsynchronized timing gears	i. See above
	j. Incorrect and/or inadequate lubricant	j. See above
	k. Surface contact or pump rotors	k. Consult manufacturer
	l. Relief valve trouble	l. See above

Cont. (Table 12.6)

8. Excessive wear on pump elements	a. product laden with contaminants b. Excessive delivery pressure c. Misalignment d. Shaft bearing wear or failure e. Worn and /or unsynchronized timing gears f. Surface contact of pump rotors	a. See above b. See above c. See above d. See above e. Consult manufacturer f. See above
9. Excessive gland and seal wear	a. Product laden with contaminants b. Tight gland packing c. Insufficient gland flushing	a. See above b. Loosen c. Check and adjust packing Adjust flow rate
10. Product leakage through gland	a. Product laden with contaminants b. Loose gland packing c. Inadequate gland flushing	a. See above b. Tighten c. See above
11. Pump seizure	a. Product laden with contaminants b. Excessive delivery pressure c. Tight gland packing d. Misalignment e. Shaft bearing wear or failure f. Worn and/or unsynchronized timing gears g. Incorrect and/or inadequate lubricant h. Surface contact of pump rotors	a. See above b. See above c. Loosen d. See above e. Consult manufacturer f. Consult manufacturer g. Verify with manufacturer's recommendation h. See above

Source: Reference 1

Intercooler

Keep the exterior of the cooler core tubes clean to maintain the cooling efficient. Clean these tubes at regular intervals; the time between cleaning depends on the service conditions.

Dismantle the intercooler protective guards to remove the intercooler core. Use compressed air to remove any dirt or foreign matter. Do not use a wire brush or metal scraper.

If provided, inspect and seat O-rings in the manifold flanges and replace if necessary.

Intercooler relief valve and safety valves

The intercooler relief valve, air receiver safety valve and compressor safety valve should be tested at least annually. Follow the manufacturer's instructions for testing. The valve should open at pressures specified in the maintenance manual. The necessary adjustments should be performed by qualified technicians.

Reciprocating Compressors

Valves

Valves must be dismantled and inspected at recommended intervals or when faulty valve operation is suspected. In the latter case, immediate action must be taken to prevent serious damage to the compressor. Never remove a valve without first releasing the pressure in the compressor.

A spare set of valves, damper springs and other valve accessories will reduce downtime of the compressor when servicing valves.

(1) Inspection and reconditioning.

Never remove a valve without first releasing the pressure in the compressor.

Do not interchange the parts of individual valves.

Follow the instructions of the manufacturer and use any special tool provided with the unit.

Check the valve plates for wear and damage. Replace any cracked or warped plates.

Check the following items for wear, compare the clearances with the allowable limits as specified by the manufacturer and replace if necessary.

- o Valve plate
- o Back plate shoulder
- o Valve seat
- o Back plate damper spring cavity

Replace all items if the anticipated wear at the next valve inspection will exceed the safe limits.

Damaged valve seats can be lapped or refaced on a grinder or lathe.

Follow the maintenance manual when reassembling the valves. Use appropriate tools and accessories, e.g., torque wrench, locating pin to ensure proper seating and alignment of the parts . After assembly, inspect the seating of the plates in the valves seats and check for free movement by depressing the valve plates.

(2) Installation

Check the following items for wear, stretching, or distortion and replace as needed.

- o O-rings
- o Steel thrust inserts in the valve retainers
- o Valve seat gaskets
- o Manifold washers
- o Intercooler setscrews

Follow instructions for the lubrication, if necessary, of all O-rings, gaskets, washers. etc. Seat or in their proper position. Install valve retainers in their proper positions.

Install the valve locking plates according to manufacturer's instructions. Tighten setscrews and central nuts just enough.

Regular valve

Perform the following during compressor overhauling:

Dismantle and clean the valve with white spirit or similar solvent at the recommended intervals. Dry the parts and oil before reassembly.

Remove and clean the filter for control air in the recommended solution. Worn valves or seats should be lapped on a smoothing block. Use only the finest grade of grinding paste.

Examples of preventive maintenance timetables for three types of compressors are in Tables 12.7 to 2.9. Trouble shooting guides for these compressors are in Tables 12.10 to 12.12

Table 12.7 Summary of Preventive Maintenance Schedule for Oil Free Screw Compressor

Operation	Daily	Weekly	Every 6 Months	Yearly
Drain condensate from intercooler, aftercooler and oir receiver	X			
Check flow and oulet temperatures of cooling water	X			
Check oil pressure	X			

Cont. (Table 12.7)

Operation	Daily	Weekly	Every 6 months	Yearly
Check intercooler pressure	X			
Check condition of air intake filter element (s)	X			
Check loading and unloading pressures	X			
Check for air, oil, water leaks	X			
Check oil level and condition of oil visually		X		
Inspect breather element (s); clean if necessary		X		
Test safety switches			X	
Have unit inspected by manufacturer's service representative			X	
Grease motor bearings *			X	
Clean oil filter(s)				X
Replace air intake filter element (s)				X
Change compressor oil				X
Test high pressure stage safety and intercooler relief valve (s) or intercooler safety valves				X
Test electrical interlockings and motor breakers				X
Clean float valves and unloader assembly				X
Clean unit and motor * air path				X
Have unit inspected by manufacturer's service representative				X

*See manufacturer's instructions. Clean and grease more frequently when compressor is operated in dusty surroundings.

Source: Reference 3

Table 12.8: Preventive Maintenance Schedule for Oil-flooded Screw Compressor

Period 1)	Running hours (1)	Operation	See note
Daily		Before Starting	
"	---	Check oil level	
	---	Check air intake vacuum indicator. Service filter element if indicator shows red	--
"	8	During operation Check air outlet temperature of compressor element	--
"	8	Check that condensate is discharged from moisture trap during loading	--
"	8	Check unloading and loading pressures	--
"	8	Check air intake vacuum indicator. If red is full out, service or renew filter element	--
"	8	Check that hourmeter is operative	
"	---	Check oil level	4
"		After stopping	
"	---	Drain condensate	--
Weekly		Check for oil leaks	--
"	---	Clean unit	--
"	---	Press oil separator pressure indicator during loaded operation to determine pressure drop over oil separator element	3
3 monthly	---	Operate safety valve	--
"	500	Inspect coolers; clean if necessary	--
"	500	Remove air filter element, clean by air jet and inspect	1
"	---	Remove, dismantle and clean float valve of moisture trap	--

Cont. (Table 12.8)

Period 1)	Running hours (1)	Operation	See note
Yearly	----	Test safety valve	--
"	---	Test temperature shut-down switch	--
"	--	Have operation of electrical interlockings motor breakers, etc. tested by an electrician	--
"	---	Replace air filter element	--
"	----	Check belt (s) for correct running	5
"	1000	Clean oil flow restrictors	--
"	1000	Change oil and oil filter	2
(1) Whichever interval comes first			

Notes:

1. More frequently when operating in a dusty atmosphere .
2. Use an oil filter as specified in the parts list. The part number is marked on the filter.
3. Replace element if pressure drop, i.e. the difference in reading on gauge exceeds manufacturer's specification.
4. Stop the unit and wait 10 minutes to allow the air bubbles to escape from the oil. The sight-glass should be filled with oil. Never overfill the tank. Before adding oil, ensure that the pressure is released.
5. if the belt (s) tend (s) to run off the pulleys, the position of the compressor element can be adjusted to keep the belt (s) centered on the pulleys when running. If necessary, slightly loosen the four bolts which secure support to the frame and adjust screws until the belt (s) run (s) correctly while running unloaded. Tighten the four bolts and nuts of screw. Load the unit and check belt (s) for correct running again Lock screw with its lock washer after adjustment.

Source; Reference 2

Table 12.9 Maintenance Schedule for Reciprocating Compressor

Twice every 8-hour shift
1. Check the lubricating oil pressure. 2. Check the intercooler pressure. 3. Drain any condensate which may have collected in the air receiver and aftercooler (if provided).
After every 50 hours of operation
1. Check the oil level in the crankcase. top up, if necessary, to the "Max" mark on the dipstick with the correct type of lubricating oil. Record the oil quantity added. . . . . 2. Clean the unit and its accessories externally
After every 100 to 500 hours of operation
Clean and inspect the air intake filter element for paper ruptures. Renew, if necessary Clean the element more frequently if the compressor is operated in dusty surroundings
After every 1500 hours of operation
1. Renew the air intake filter element (or more frequently, if necessary). 2. Dismantle, clean and inspect all the valves.
Once every six months
Test blow all the safety valves.
After every 3000 hours of operation
1. Dismantle, clean and inspect the lubricating oil pump and the compressor valves. 2. Dismantle and clean the regulating valve and its air filter. 3. Renew the oil in the crankcase. Clean the oil pump suction strainer and renew the oil filter. After the compressor has run for a few minutes it will be necessary to add lubricating oil to compensate for the filling of the oil filter. 4. Test blow all the high pressure safety valves and the intercooler relief valve.

Cont. (Table 12.9)

After every 6000 hours of operation
Have the compressor overhauled by an service outlet as instructed in the overhauling instruction manual.

Note: The above mentioned inspections are cumulative, i.e. items on the 50 hours inspection should be included on the 1500 hour inspection schedule. The 3000 hours inspection should always include the items on the 50 and 1500 hours inspection schedule

Source: Reference 4

Table 12.10 Troubleshooting Guide for Oil-free Screw Compressors

Condition	Possible Faults	Remedy
1. Compressor capacity or working pressure lower than normal	a. Air pressure switch incorrectly set (opens too soon)	a. Refer to maintenance manual for setting of air pressure switch.
	b. Throttle valve does not fully open or HP unloading valve in air inlet mainfold leaks	b. Inspect unloader assembly, pipes and connections; repir even slightest leak. Remove elbow pipe from between air outlet silencer and air inlet manifold; remove valve seat and valve cone, clean and inspect.
	c. HP safety valve, intercooler relief valve or intercooler safety valve leak	c. Consult manufacturer's service representative immediately
	d. Compressor elements(s) out of order.	
2. Compressor does not unload and causes HP safety valve to blow	a. Air pressure switch incorrectly set (opens too late)	a. Check setting. Refer to maintenance manual
	b. Air leak at connections of air pressure switch feed pipe	b. Inspect and tighten leaky connection (s)
	c. Throttle valve remains stuck in open position	c. Inspect unloader assembly.

Cont. (Table 12.10)

Condition	Possible Faults	Remedy
3. Motor cuts out immediately after starting (within approx. 20 sec.)	a. Motor incorrectly connected to the mains b. Oil pressure too low c. Oil pressure safety switch remains stuck in open position	a. Change over two wires of mains supply line b. See 8 c. Remove and test switch. Refer to maintenance manual
4. Motor cuts out during operation	a. Insufficient oil pressure b. Compressor over-heating c. Thermal overcurrent relay in starter box has tripped due to an overload	a. See 8 b. See 10 c. Investigate cause and reset relay
5. Wrong idling delay	Setting of time relay in correct	Change to correct setting. If correct setting cannot be obtained replace time relay
6. Unloading pressure or pressure drop cannot be adjusted	Air pressure switch out of order	Test pressure switch at various settings. Replace switch if it does not respond
7. Low compressor oil pressure	a. Oil level too low b. Oil filter element clogged c. By-pass valve in oil pump stuck in open position d. Oil pump failure	a. Top up level to upper mark on dipstick b. Dismantle filter, clean bowl and replace element c. Remove by-pass valve, clean and inspect d. Remove pump and inspect parts for wear
8. Discharge cooling water milky; leakage between air and water systems	O-ring or sealing ring between inter-cooler and moisture trap damaged or worn	Stop compressor immediately remove sealing ring and replace O-ring

Cont. (Table 12.10)

Condition	Possible Faults	Remedy
9. Air temperature switch trips, temperature fault indicator lamp lights up and motor stops	a. Insufficient cooling water flow through cooling system	a. Check and increase water flow. If thermostatic water valve installed, dismantle, clean and inspect, if necessary
	b. Cooling water inlet temperature too high	b. Decrease inlet water temperature, as required
	c. Air temperature switch incorrectly set	c. Set switch according to manufacturer's recommendation
	d. Restriction in cooling system due to formation of scale or settling down of dirt manual	d. Clean cooling system. Refer to maintenance manual
10. Excessive oil fumes or air flow coming from gear case breather(s)	Balancing piston diaphragm of compressor element crack	Remove balancing piston cover from timing gear covers and inspect diaphragms. Replace defective diaphragms.
11. Water droplets show on dipstick	O-ring or tube (s) of oil cooler leak	Remove and dismantle oil cooler. Pressure test core. Replace O-rings and change lubricating oil
12. Intercooler pressure below normal*	a. Choked air intake filter element(s)	a. Replace filter element(s)
	b. Intercooler relief valve (s) or intercooler safety valves leaking	b. Remove valve (s). Clean and inspect
	c. Air leak at gaskets in circuit between LP and HP compressor stages	c. Tighten screws of leaking connection. Replace gasket, if necessary
	d. LP compressor element not in order	d. Consult manufacturer
13. intercooler pressure above normal*	a. Insufficient cooling water flow through cooling system	a. Check and increase water flow

Cont. (Table 12.10)

Condition	Possible Faults	Remedy
	b. Cooling water inlet temperature too high c. Scale deposits on pipes and internal walls of intercooler d. HP compressor element not in order	b. Decrease inlet water temerature, if possible c. Clean cooling system as required. Refer to maintenance manual d. Consult manufacturer

*Note that the intercooler pressure varies in direct proportion with the barometric pressure.

Source: Reference 3

Table 12.11 Troubleshooting Guide for Oil-injected Screw Compressor

Condition	Possible faults	Suggested Remedy
Compressor does not load	a. Pressure in air net is above pre-set loading pressure and air pressure switch is open b. Solenoid valve out of order c. Air pressure switch out of order d. Toggle switch out of order or loose connection e. Unloading valve remains stuck in closed postion	a. Wait until pressure in air net is lower than pre-set loading pressure of air pressure switch b. Remove and check valve. Replace if necessary c. Remove and check switch. Replace if necessary d. Have switch and electrical installation checked by an electrician e. Remove and inspect unloader
2. Compressor does not unload; safety valve blows	a. Air pressure switch opens too late b. Air leak in unloading system c. Solenoid valve out of order d. Unloading valve does not close	a. Check setting. Refer to maintenance manual b. Inspect and tighten leaky connection(s) c. See 1b d. Remove and inspect unloader
3. Unloading pressure difference cannot be adjusted	Air pressure out of order	Test pressure switch at various settings. Replace switch if defective

Cont. (Table 12.11)

Condition	Possible Fault	Suggested Remedy
4. Condensate is not discharged from moisture trap during loading	a. Discharge pipe clogged or pinched b. Float valve malfunctioning	a. Check and correct, as necessary b. Remove float valve assembly, clean and inspect
5. Excessive oil consumption; oil carry-over through discharge Line	a. Oil level too high b. Restrictor in scavenging line clogged c. Incorrect oil causing foam d. Oil separator element defective	a. check receiver for overfilling. Release pressure and drain oil to correct level b. Clean restrictor c. Change to correct type of oil d. Have element remove and inspected by manufacturer's representative
6. Compressor capacity or pressure below normal	a. Air consumption exceeds capacity of compressor b. Choked air filter element c. Solenoid valve out or order d. Unloading valve does not fully open e. Safety valve leaking f. compressor element out of order g. Oil separator element clogged	a. Check equipment connected b. Remove and inspect element Clean or renew if necessary c. Remove and inspect element c. Replace, if necessary d. See 1e e. Remove and inspect. Replace if not airtight Replace if not airtight after reinstalling f. Consult manufacturer. g. See 5d
7. Excessive oil flow through air filter after stopping	Check valve leaking or oil stop valve jammed	Remove and inspect. Replace if necessary. Replace air filter element
8. Compressor overheating and/or unit shuts down through the air temperature switch	a. Insufficient compressor cooling b. Oil cooler clogged externally	a. Improve ventilation of compressor room b. Check and clean cooler, if necessary

Cont. (Table 12.11)

Condition	Possible Fault	Suggested Remedy
	c. Oil cooler clogged internally	c. Consult manufacturer
	d. Oil level too low	d. Check and correct, as necessary, Never overfill
	e. Compressor temperature shut-down switch incorrectly set	e. Set switch to trip at the specified temperature. Never set at a higher temperature without authorization from manufacturer
	f. Fan blade(s) broken	f. Check and correct as necessary
	g. Oil stop valve stuck in close position	g. Remove and inspect
	h. Oil separator element clogged	h. See 5d
9. Compressor is unloaded through air pressure switch, but discharge pressure continues rising slowly; safety valve blows	Vent-valve malfunctioning	Remove and inspect. Replace defective part(s)
10. Safety valve blows immediately after loading	a. Safety valve out of order	a. Remove and inspect. Replace if necessary
	b. Minimum pressure valve malfunctioning	b. Remove and inspect. Replace where necessary
11. Pressure between air outlet and receiver, which registers on working pressure gauge, slowly or rapidly decreases after stopping	a. Manual drain valve of air cooler not fully closed	a. Always close valve before starting. Replace leaking valve
	b. Float valve of moisture trap malfunctioning	b. Remove and inspect valve
with closed air outlet valve	c. Leaking pipe connection	c. Repair leakage
	d. Non-return valve of minimum pressure valve leaking	d. Remove and inspect minimum pressure valve. Replace defective part (s)

Cont. (Table 12.11)

Condition	Possible Fault	Suggested Remedy
	e. Air cooler leaking f. Air outlet valve not airtight (when air net is depressurized)	e. Replace cooler f. Repair or replace

Source: Reference 2

Table 12.12 Troubleshooting Guide for Reciprocating Compressor

Condition	Possible Cause	Remedy
1. Insufficient air receiver pressure	a. Air intake filter element choked. b. Valve of "Unloading device" sticking in open potion or its O-rings damaged or worn c. Damaged LP or HP valves. d. regulating valve incorrectly set (opens too soon). e. Air consumption exceeds capacity of compressor f. Air leaks.	a. Service or renew element. b. Remove plug from unloading device; check return spring and inspect O-rings Renew, if necessary. In assembling, always grease O-rings. c. Refer to maintenance manual. d. Check unloading pressure. Refer to maintenance manual. e. Check pneumatic plant and tools connected. f. Check and correct as necessary
2. Intercooler pressure deviates from normal range	Valve trouble.	Refer to maintenance manual
3. Pressure drop (difference between unloading and loading pressures) insufficient	Excessive lift of disk-valve of regulating valve.	Refer to maintenance manual

Cont. (Table 12.12)

Condition	Possible Cause	Remedy
4. Pressure in air receiver rises above maximum and causes HP safety valve to blow.	a. Regulating valve incorrectly set (opens too late). b. Valve of "Unloading device" sticking in close position.	a. Check unloading pressure. Refer to maintenance manual b. Remove plug from unloading device and check for dirt. Clean and inspect O-rings.
5. Oil pressure drops below minimum safe pressure motor cuts out.	a. Oil level in compressor sump too low. b. Oil strainer clogged. c. Oil filter clogged. d. By-pass valve of oil pump stuck in open e. Excessive clearance of big end bearings	a. Top up oil level as required. b. Clean strainer c. Install new filter. d. Dismantle valve, clean and inspect. e. Inspect bearings. Recondition them if necessary.
6. Oil pressure drops below minimum safe pressure, motor does not cut out.	Oil pressure gauge defective or gauge hose clogged.	Replace pressure gauge or disconnect hose while compressor is operating and allow oil to eject the dirt.
7. Motor cuts out immediately after starting.	a. Insufficient oil pressure. b.No oil pressure; reverse rotation of motor.	a. See no. 5 b. Change over two wires of mains supply cable.
8 Compressor overheating.	a. intercooler core tubes clogged by dirt and dust externally. b. Damaged LP or HP c. Oil level in compressor sump too low d. Low oil pressure.	a. Clean tubes with compressed air jet. b. See no 2 c. top up oil level as required d. See No. 5
9. Carbon deposit on valves.	a. inferior quality of lubricating oil used. b. Clogged air filter; not cleaned regularly	a. Clean valves. Change to a suitable quality oil. Refer to maintenance manual b. Clean valves. Service filter more often. Refer to maintenance manual.

12.4 APPLICATION CASE

The following describes the successful application of preventive maintenance on air and gas compressors in an oil refinery plant.

a. Equipment Specifications and Use:

Air and gas compressors for instrumentation and controls and for the process units, respect:vely.

b. Experience without PM:

These compressors are reciprocating compressors of the double acting, dry type, with channel valves operating 24 hours a day all year round.

The pistons are fitted with PTFE rider and piston rings and slides on press fit liners.

Without PM, scouring of the liners took place with a resultant downtime, material and labor cost of close to P1.5 million per year.

c. MM Work Done:

Eight (8) years ago the PTFE rings were upgraded to graphited teflon, with the width increased in size to twice the original specification at an approximate cost of ₱200,000.00. If the cost of using the original parts are deducted , the effective expenditures amount to only approximately ₱100,000.00.

Periodic bottom clearance checks were introduced, valve servicing and reconditioning performed a without any cost except normal utilization of the mechanics available.

d. Experience and Results with PM:

The total maintenance cost is now only ₱700,000.00/year corresponding to parts replacement for normal wear and tear. A clear savings of ₱800.000/year is being realized.

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CHAPTER 13

Preventive Maintenance of Forklifts, Cranes, Hoists and Conveyors

13.1 INTRODUCTION

Planned maintenance of materials handling equipment is a program in which inspections, adjustment, lubrication and replacement of parts are performed in a scheduled and systematic manner. A good program is based on a sound method of record keeping. Accurate records are the basis of maintenance and inspection schedules and the source of maintenance cost per machine data.

The specific objectives of a materials handling maintenance program are:

a. To reduce costly unscheduled downtime;
b. To reduce materials handling maintenance cost;
c. To increase vehicle productivity;
d. To preserve high trade-in value; and
e. To increase the personal safety of operators and other personnel.

There are numerous types of equipment which can be classified under materials handling, but only three will be discussed in this chapter, namely:

a. Forklifts
b. Cranes and Hoists
c. Conveyors

The best source of maintenance information is the manufacturer's manual issued with the equipment. Some general guidelines will be presented here. Due to the variety of equipment involved, the diagnostics and maintenance procedures for each equipment type will be presented mostly in tabular form.

13.2 FORKLIFTS

There are two types of forklift trucks based on their prime movers, which are: a) internal combustion engines and b) electric motors. However, some systems are common to both ICE and electric forklifts such as the hydraulic system, steering system, etc. Maintenance guides for these are shown in Table 13.1. Table 13.2 contains some trouble-shooting guides for internal combustion forklifts

Planned maintenance in industrial lift trucks involves the checking and adjustment or repair of specific parts at prescribed intervals, usually based on the hour meter readings of the equipment. The most frequently used hourly intervals are: 1) 40-50 operating hours (weekly), 2) 250-600 operating hours (monthly), 3) 1000-5000 operating hours (quarterly to annually).

Daily inspections by the driver or operator are usually conducted before each shift and are accomplished with the use of checklists. Figures 13.1a and 13.1b show examples of such checklists.

Tables 13.3a to 13.3c show scheduled maintenance guides for internal combustion engine forklift trucks under normal operating conditions. Some of these items also apply to electric forklifts. Please refer to Table 13.1 for more information on the common features of forklift trucks. Tables 13.4a and 13.4b contain scheduled maintenance guides for electric forklifts.

Table 13.1 Maintenance Guides for Features Common to ICE and Electric Forklift Trucks

Source: Reference 1

Item/Symptoms	Possible Faults	Suggested Remedies
a. *Drive Axle Assembly*		
Excessive noise in hypoid	Incorrect hypoid clearances	Adjust to specifications
	Loose bearing nut	Tighten
	Loose hypoid gear mounting bolts	Tighten to specified torque
	Damaged hypoid/ring gear	Replace
Excessive noise in differential gear while travelling	Loose belt retainers	Tighten
	Lack of differential gear oil	Top up to proper level
	Backlash due to improper clearances	Adjust clearances
Noise in front wheel	Defective front wheel bearings	Check, repack or replace
	Loose drive axle and wheel bolt	Tighten to specified torque
Oil leaks	Excessive oil	Remove plug and drain to proper level
	Loose axle bolts	Tighten to specified torque
	Damaged oil seals	Replace
b. *Brake System*		
Decreased braking capacity	Damaged, leaking cylinder/ fluid liner	Repair/replace
	Incorrect brake settings	Adjust
	Air in brake fluid system	Bleed air
	Defective automatic adjuster	Adjust, repair
	Worn brake lining	Replace
Incomplete brake release	Incorrect brake settings	Adjust
	Clogged master cylinder	Disassemble, clean and change fluid
	Faulty spring	Replace
Swerving to one side when brakes are applied	Worn lining on side opposite to the side swerved to	Replace worn lining
	Oil or grease in lining	Clean/remove oil or grease
	Incorrect tire air pressure	Inflate/deflate
	Incorrect brake clearances	Adjust

Items/Symptoms	Possible Faults	Suggested Remedies
Excessive noise	Metal fragments imbedded in brake lining	Clean lining
	Bent brake drums	Replace/repair if possible
c. *Steering System*		
Oil leaks	Worn or defective packing or "0" ring	Replace packing or "0" ring
Difficult steering	Defective oil pump	Repair or replace worn parts.
Excessive play on steering wheel	Incorrect oil level	Top-up/drain to level
	Bent linkage/cylinder rod	Repair/replace
	Defective steering control	Replace
Drecreased responsiveness	Leaks in cylinder	Replace seals
"Spongy" or erratic steering	Air in power steering fluid	Bleed air out
d. *Hydraulic System*		
Forks cannot be raised	Faulty control valves, linkages	Repair, replace
	Leakage in hydraulic pump and lines	Repair seals tighten lines
	Low oil level	Top-up sump tank oil level
	Deformation of mast assembly	Repair/replace
	Clogged hydraulic oil strainers	Clean/replace strainers
Forks cannot be lowered	Deformed mast assembly	Repair/replace
	Maladjusted rollers	Adjust/repair
Decreased lifting speed	Dirty/clogged hydraulic pump and lines	Clean
	Faulty lifting valve linkages	Repair/adjust
	Clogged hydraulic fluid strainer	Clean/replace
	Deformed mast assembly	Repair
Vibration of forks at a certain height	Incorrect oil level	Top-up to proper level
Excessive noise from fork operations	Defective rollers	Lubricate/replace
	Deformed mast assembly	Repair/replace
	Damaged bearings	Replace

Items/Symptoms	Possible Faults	Suggested Remedies
Erratic lifting speed	Dirty/clogged hydraulic sump tank strainers	Clean/replace
	Damaged load rollers	Replace
	Defective control valve linkages	Repair/replace
	Deformed mast assembly	Repair/replace
Uneven wear pattern on mast	Uneven chain tension	Adjust and balance chain tension

Table 13.2: Diagnostic Guides for ICE Forklifts

Source: Reference I

Item/Symptoms	Possible Faults	Suggested Remedies
a. *Engine*		
Hard-starting	Discharged/damaged battery	Recharge/replace
	Faulty starter	Repair/replace
	Improper connection of battery terminals	Clean and tighten terminals
	Excessively viscous engine oil	Change to specified viscosity
Faulty ignition	Damaged distributor point	Replace
	Improper point gap	Adjust
Air-Fuel mixture	Lean mixture	Adjust or clean carburetor
	Dirty carburetor	Clean
	Choked fuel pipe	Clean or replace
Unstable idling	Incorrect idling adjustment	Adjust
	Faulty intake manifold gasket	Replace gasket
Overheating	Low coolant level	Add coolant to proper level
	Loose V-belts	Tighten to specifications
	Faulty thermostat	Replace
	Faulty water pump function	Repair/replace
	Choked/leaking radiator	Clean/repair/replace
	Defective radiator cap	Replace
Excessive Noise	Improper valve clearance	Adjust
	Excessive clearance between valve stems and guides	Replace valves and valve guides

Cont. (Table 13.2)

Items/Symptoms	Possible Faults	Suggested Remedies
	Excessive piston-cylinder clearance Broken piston rings	Replace cylinder liners and pistons Replace
b. *Transmission System* 1) Manual Transmission Excessive noise when clutching Gears clash when shifting Reduced travel speed 2) Automatic transmission Decreased speed	 Defective release bearing Wrong clutch adjustment Damaged synchronizers Worn clutch lining Low transmission oil level Incorrect transmission oil viscosity	 Replace Adjust Replace Replace lining Check, top off Replace
Increased transmission oil temperature	Clogged lines, filters to transmission oil cooler	Clean lines, replace filters
Excessive transmission oil loss	Leaks due to Loose line connections Faulty transmission oil seal Faulty differential output shaft oil seal	Tighten Replace Replace
Truck moves even if shift lever is in "neutral"	Faulty neutral starting switch	Repair or replace switch

13.3 HOISTS AND CRANES

Cranes and hoists are used in lifting and transporting heavy loads. The most critical elements in these equipment are the lifting chains or cables. These parts, subjected to repeated tensile loads, stretch over a period of time and are work-hardened. Cables can be worn or frayed during use. Failure of chains or cables while in use is disastrous because of: damage to the load being carried, the surroundings, the lifting equipment, and most important, possible injuries or death to workers in the area. Good maintenance should prevent these from happening.

Aside from the lift chains or cables, the other important elements are the load hooks, trolleys and wheels, gears, bearings, sheaves, and sprockets. These elements are subject to wear and strain, and most of them require proper lubrication and cleaning.

Daily Operator Check Off List

Truck No.________________ Operator________________

Truck Model________________ Dept.________________

Date____________ Running Time________________Hours

Shift____________

Check	O. K.	adjust	Add (Amount)
1. Gas			
2. Water or Anti-Freeze			
3. Engine Oil			
4. Hydraulic Oil			
5. Steering and Horn			
6. Brakes			
7. Tires			
8. Hoist Cylinder			
9. Tilt Cylinders			
10. Air Cleaner			
11. Oil Pressure			
12. Forks			
13. Battery			
14. ________			
15. ________			

Operators Signature________________________

Figure 13.1a Suggested Daily Checklist for Gas Lift Truck

Source: Reference 3

Driver's Daily Checklist

Truck No._____ Operator:________ Date:____ Supervisor's OK _____

Meter Reading:

Start of day______________ Hrs. for day___________

End of day ______________

Check Before Start of Each Shift

Symbols: G-gasoline powered E-electric powered

VISUAL CHECKS indicate "√" if okay; "X" if defective. Explain all "X's" in "Remarks" area below:

- ☐ Engine air cleaner (G)
- ☐ Crankcase oil level (G)
- ☐ Radiator water level (G)
- ☐ Fuel level (G)
- ☐ Fan belt tension (G)
- ☐ Sump tank level (E & G)
- ☐ Tire condition (E & G)
- ☐ Battery cleanliness and Level (E & G)
- ☐ Battery cable connec - tions (E & G)
- ☐ Head and tail lights (E&G)
- ☐ Warning lights (E & G)
- ☐ Hour meter (E & G)
- ☐ Other gauges and instruments

OPERATIONAL CHECKS

- ☐ Horn (E & G)
- ☐ Steering (E & G)
- ☐ Service brakes (E & G)
- ☐ Parking brake (G)
- ☐ Seat brake (E)
- ☐ Seat safety switch (E)
- ☐ Brake interlock switch (E)
- ☐ Inching pedals (E & G)
- ☐ Clutch pedal (G)
- ☐ Hydraulic controls (E & G)

REMARKS: ______________________________

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____

Figure 13.1b Suggested Daily Checklist for Gas or Electric Forklifts

Source: Reference 3

Table 13.3a: Weekly or 40-50 Operating Hour Maintenance Guides for ICE Forklifts

Source: Reference 2

Item	Check for:	Suggested Action
1. Engine oil and oil filter cartridge	Contamination	Replace oil and cartridge
2. Crankcase breather	Dirt or fouling	Clean or replace
3. Fuel bowl and strainer	Sludge, fouling	Drain and Clean
4. Engine timing	Maladjustment	Adjust
5. Carburetor, idle speed, governor, degasser	Proper setting and operation	Adjust
6. Clutch	Proper operation/ maladjustment	Adjust clutch free play
7. Fan and accessory belt tension	Looseness or excessive tighteness	Tighten or reduce to recommended tension
8. Oil pressure	Deviation from normal	Find out cause (e.g. leaks, lack of oil, etc.) and remedy
9. Air cleaner	Dirt and fouling	Clean or replace
10. Battery		
Solution	Proper level and specific gravity	Top-up or replace solution
Terminals and connections	Dirt, looseness	Clean terminals and tighten connections
11. Main generator voltage	Normal value	Repair as needed
12. Spark plugs and distributor points	Oxides, arcing, dirt	Clean
13. Generator brushes and commutator	Deposits/wear	Clean or replace
14. Oil starter motor and generator	Proper operation	Repair as needed
15. Brake pedal	Travel, responsiveness	See Table 13.1, item b

Cont. (Table 13.3a)

16. Brake master cylinder, all hydraulic lines	Leaks, low fluid level	Repair seals, tighten connections, top-up fluid
17. Hoist and tilt cylinders	Leaks and wear	Replace seals Determine cause of uneven wear (see table 13.1 item d)
18. Hydraulic system	Oil level, leaks	Top-up, replace seals (see table 13.1 item d)
19. Hydraulic breather cap	Looseness, dirt, fouling	Clean, tighten
20. Water pump	Proper lubrication	Grease as required
21. Radiator and hoses	Leaks	Repair; tighten clamps, replace hoses
22. Radiator core	Deposits	Drain and clean
23. Over-all cleanliness		Steam-clean
24. Lift chains	Proper tension Lubrication	Adjust Grease as necessary
25. Inner slides and upright supports Piston head sprockets Tilt cylinder pins and lift brackets Steering axle Drive axle		Lubricate Lubricate Lubricate Lubricate Lubricate
26. Steering gear oil	Proper level	Top-up as necessary
27. Gas filler cap screen Sump filler cap	Dirt, fouling	Clean

Table 13.3b: Monthly or 250-600 Operating Hour Maintenance Guides for ICE Forklifts

Source: Reference 2

Item	Check for:	Suggested Action
1. Engine tune-up		
Cylinder	Loose compression	Overhaul
Tappets, governor		Adjust
Fuel pump screen	Deposits, fouling	Clean
Fan belts	Fraying, damage	Replace if necessary

Cont. (Table 13.3b)

Fan, water pump and generator bearings Cylinder head, manifold, and oil-pan bolts	Lubrication, vibrations, leaks Proper torque	Lubricate, repack/replace replace seals Use torque wrench to tighten to specified torque
2. Universal joint	Lubrication/wear	Lubricate/replace if necessary
3. Drive axle bolts	Looseness	Tighten
4. Lift chains	Balanced tension	Adjust/equalize tension
5. Mast	Uneven wear	Repair/replace
6. Lift bracket rollers	Wear/condition/lubrication	Replace/lubricate
7. Steering/rolling	Drift with capacity load	Adjust steering (see table 13.1 item C)
8. Gland packing	Leaks	Replace
9. Transmission, drive fluid	Proper level	Top-up
10. Brake lining drums and wheel cylinders	Wear Leaks	Replace if necessary Replace seals
11. Wheel bearings		Repair and adjust
12. Hub flange bolts		Tighten
13. Hydraulic pump Control value and lines	Proper operation Leaks	Repair as necessary Repair; tighten clamps
14. Muffler	Breaks, cracks	Repair/replace
15. Radiator	Deposits, contamination	Drain, flush, refill

Table 13.3c: Quarterly to Annual, or 1000-5000 Operating Hour Maintenance Guides for ICE Forklifts

Source: Reference 2

Item	Check for:	Suggested Action
1. Engine		Complete overhaul
2. Transmission and differential		Disassemble, inspect and replace worn parts
3. Hoist and tilt cylinders		Repack
4. Channels (disassembled) rollers wear strips	Wear, condition	Replace if required
5. Carriage, chain anchors, rollers	Distortion	Repair
6. Trailing assembly		Disassemble and check ff: a) ring pins b) steer knuckle pins c) bushings, etc. Replace worn parts
7. Hydraulic - brake system		Disassemble and check ff: a) wheel cylinder b) brake lines c) fittings d) linings e) master cylinder f) drums Replace worn parts
8. Steering gear		Disassemble and check; replace worn parts
9. Hydraulic tank		Drain, flush, refill
10. Lift chains		Remove, wash, inspect, repair broken/worn parts
11. Forks	Trueness	Adjust
12. Truck body	Dirt, deposits	Wash and paint as needed

Table 13.4a: Weekly to Monthly or 50-500 Operating Hour Maintenance Guides for Electric Forklifts

Source: Reference 2

Item	Check for:	Suggested Action
1. Controller	Freedom of movement	Adjust
	Burned control tips	Replace
Terminals	Looseness	Tighten
	Proper lubrication	Lubricate as necessary
2. Contractors	Burned contacts	Replace
Plunger	Freedom of movement, sufficient overtravel	Adjust as needed
Terminals	Looseness	Tighten
Spring	Proper tension	Adjust/replace
3. Resistors		Clean with compressed air
Coils	Signs of burning	Replace
Terminals	Looseness	Tighten
Coil insulators	Cracks and burns	Replace
4. Switches		
Terminals	Looseness	Tighten
Contacts	Excessive wear	Replace
5. Motors		
Commutator	Burning and pitting	Clean
Brushes	Excessive wear	Replace
Brush holders	Free clearance	Adjust
	Proper spring tension	Replace
Assembly	Foreign material, carbon dust	Clean with compressed air
Motor insulation	Cracks, breaks	Repair/replace
Terminal studs	Oxides, deposits	Clean
Coupling	Proper lubrication	Grease/oil as necessary

Table 13.4b: Annual or 5000 Operating Hour Maintenance Guides for Electric Forklifts

Source: Reference 2

Item	Check for:	Suggested Action
1. Motor	Dirt, deposits	Dismantle and clean all parts
2. Terminals	Deposits, oxides	Clean/tighten

Cont. (Table 13.4b)

3. Insulation	Fraying, charring	Repair/replace
4. Bushings	Wear	Replace
5. Brush holders	Tightness; proper radial position, angle, and spacing	Adjust as necessary
6. Brushes	Proper bearing Proper length	Adjust Replace/adjust
7. Armature	Shorts and grounds	Isolate/insulate
8. Commutator	Discoloration High or low bars	Adjust Adjust
9. Wire banding	Tightness	Reband if necessary
10. Shaft	Straightness	Repair
Bearings	Seals, lubrication, condition	Replace/repack, lubricate
11. Rotor	Dynamic balance	Balance
12. Field coils and connections	Condition, looseness	Repair, tighten
13. Motor couplings	Alignment, dirt	Clean, align
14. Assembly		Repack with proper lubricant Reseal as necessary

13.3.1 Chain Blocks

Chain blocks should be regularly cleaned and inspected. A critical indicator of the condition of the chain is the amount that the chain has stretched for a specified period of time.

The following monthly inspection procedure is suggested:

(a) Check the pitch or unit amount of strain by measuring at least 20 links of the chain. Maximum permissible stretch for lift chains is from 3 to 10 percent. On pocket wheel chains, the limit is about 1%. Consult the manufacturer's guide.

(b) Replace or repair overstrained chain, or decrease the loading on the chain, if the permissible limits are exceeded.

(c) Check for gouging, wear, marking and deformation. Any chain worn more than 10% of an area at any point should be returned to the manufacturer for repair.

(d) Check link joints for excessive wear, and lighten the loading if needed.

(e) Check iron and low carbon chain for work hardening. Anneal iron periodically, and normalize steel as required (usually less frequently). Heat treated steel and alloy chain should only be annealed or normalized by the manufacturer.

(f) If a chain running on load sheaves shows excessive wear, check the load sheaves for maladjustment or damage.

(g) Lubricate the chain thoroughly, particularly at the link juncture points. Graphite grease is recommended because it is waterproof and it stays in place. Chain used in gritty or dusty environments should never be lubricated, because dirt and grit will stick and accumulate in the lubricant.

(h) Check the deformation on load blocks by measuring their loaded dimensions and comparing them with previous values. Hooks which are slightly deformed may be straightened; however, those which are badly damaged should be replaced.

13.3.2 Hoists

Hand and power hoists have similar monthly maintenance requirements. These are presented in Table 13.5.

In addition, the following monthly lubrication guides are recommended for hand hoists:

(a) Lubricate more often in hot, moist or dustry places. Pay special attention to chain sprockets.

(b) Beware of lubricating the wrong parts. Some types of lever hoists should not be lubicated, while some differential types will not carry the load if too much lubricant is applied. In lubricating the sheaves of blocks and falls, be careful not to spill oil onto the ropes.

(c) Thoroughly clean the outside of the hoist and look for oil leakage which indicate faulty shields or bearings, or spillage from too much lubricant.

Power hoists have motors, switches and electrical connections which need additional care. The following monthly guides are suggested:

(a) Take care not to spill lubricants on electrical insulation.

(b) Inspect and service motors, electrical or air parts.

(c) Clean breathing holes or oil cases

(d) Clean the casing and all air passages

In addtion, it is recommended that limit switches be tripped daily to check their operation.

After servicing, hoists must be operated under full load and no load, using all functions. Noises may indicate worn gears, sheaves, sprockets, bearings, or looseness of parts. Any problems must be solved at once.

Table 13.5: Monthly Maintenance Guides for Hoists

Source: Reference 2

Item	Check for:	Comments/Suggested Action
1. Load hook	Signs of overloading and abuse (e.g. spreading, load applied to point instead of middle, etc.)	Reduce loading Brief operators on proper use and method of loading If damage is extensive, replace.
2. Chain	Damaged links	If only a few (1 or 2), are damaged have new ones welded in by manufacturer.
	Signs of abuse/misuse (e.g. non-use of slings, etc.)	Instruct operator on proper use
	Excess of 3% allowable strain (based on at least 20 links)	Reduce loading Replace if needed
		For hand hoists check annually Lubricate properly
3. Load brake (full load)	Irregularity of operation, drifting	Repair, adjust
4. Wheels and trolleys	Excessive wear Proper lubrication	Replace if necessary
Track	Levelness and true joints	Repair/adjust
Positioning apparatus	Accuracy	Adjust/repair

13.3.3 Cranes

Cranes, in addition to lifting, also transport heavy loads. There are basically two types: a) wall and floor cranes; and b) mobile cranes. The former are almost always powered by electricity, while the latter use diesel engines.

Wall and floor cranes move lifted loads on wheel's travelling on supported rails. Moving and loaded parts are subjected to wear, warping, misalignment, etc. Table 13.6 contains some monthly maintenance suggestions for wall and floor cranes.

The following should also be checked periodically, based on their respective recommended maintenance schedules.

(a) Service casters and wheels
(b) Grabs, slings, ropes, chains, and hoists.
(c) Electrical parts

Table 13.6: Monthly Maintenance Guides for Wall and Floor Cranes

Source: Reference 2

Item	Check for:	Suggested Action
1. Rails and supports	Parallelism/alignment Spread joints Deformation Gauge	Repair/adjust Repair/decrease loading Repair
2. Bearings, including: mast top thrusts, radials trolley wheels	Damage Proper lubrication	Replace Lubricate as required
3. Top and other braces	True alignment (brace and beam should swing together without any looseness or binding throughout arc of swing)	Adjust/repair Lubricate joints
4. Outriggers, removable-beam end column and other occasionally used devices	Proper operation	Repair as necessary
5. Batching, weighing, and other attached devices	Proper operation	Service as necessary
6. Wheels	Uneven wear between a driver pair	If difference is 3 mm or more, remachine or remate
7. Hoisting gear Hooks Load hook nut	 Spreading and marring Backing off	 Repair/reduce loading Tighten
8. Bolts, nuts, screws, gaskets and other parts	Looseness	Tighten
9. General		Lubricate and clean, especially electrical or other heat dissipating parts.

Table 13.7a: Daily or 8 Operating Hour Maintenance Guides for Mobiles Cranes

Source: Reference 2

Item	Check for:	Suggested Action
1. Controls, levers	Proper operation	Repair as necessary
2. Cables and clamps	Fraying Looseness Need for oil	Replace if necessary Tighten Lubricate
3. Tires	Proper inflation Equal pressure in all tires Stones, imbedded objects Cuts or damage	 Remove debris Repair/replace
4. Fuel supply	Low level Contaminants	Fill if necessary Exercise care in filling
5. Air reservoirs		Drain
6. Radiator	Low coolant level	Top-up
7. Compressor	Low oil level	Top-up
8. Tracks Center pin brushings, traction shaft, track roller, drive sprocket brushing, drive chains, etc.	Need for lubrication (Based on operating condition)	Lubricate as required
9. Crankcase, hydraulic reservoirs Engine chain case	Low oil level	Top-up
10. Sleeve bearings		Lubricate
11. Open gears; crowd, retreat, and propel chains		Lubricate as required
12. Dipper handle		Lubricate
13. Service air filters or fuel filters	Dirt, fouling (For dirty environment)	Clean/replace
14. Clutches	Grease Slipping	Clean Adjust
15. Reserve supplies of oil and lubricant, emergency equipment, tools, spare parts	Lack/absence	Provide
16. General Inspection	Signs of damage Tampering Leakage of water, fuel, oil	Investigate and correct

Table 13.7b: Weekly or 40 to 100 Operating Hour Maintenance Guides for Mobiles Cranes

Source: Reference 2

Item	Check for:	Suggested Action
1. Oil filter	Excessive deposits, fouling	Clean/replace
2. Water pump		Lubricate/grease
3. Air compressor		Service
4. Steering gear Propeller shaft Brake shaft Boom hoist shaft Roller shaft Center post Emergency Brake Starter Generator Distributor Front spring leaves All bearings		Lubricate
5. All gear cases	Need for lubrication	Lubricate as necessary
6. Transmission and differential	Low oil level	Top-up
7. Crawler link pins	Proper placement Condition	Adjust
8. Cables and cable drums Boom angles and connections	Fraying, wear Proper operating condition	Replace/repair as necessary Note: Do not lubricate dragline or pull shovel drag cables
9. Conical rollers, turntable gear, control linkage		Lubricate
10. Clutch cover, clutch lining and adjustment, brake bonds	Wear Looseness	Replace if necessary Tighten/adjust
11. Turntable roller path	Dirt, deposits Damage	Clean Lubricate Repair if necessary
12. Motors	Dirt in controller contacts	Clean

Table 13.7c: Monthly or 200 to 250 Operating Hour Maintenance Guides for Mobiles Cranes

Source: Reference 2

Item	Check for:	Suggested Action
1. Oil filter	Dirt, fouling	Clean and change cartridge
2. Brakes	Proper setting	Adjust
3. Compressor		Service
4. Sheaves	Damage, wear	Repair/replace
5. Racks and pinions on dipper stick	Wear, damage	Replace if necessary Lubricate
6. Slew rack and pinion, center port, slew roller paths	Proper lubrication and working condition	Lubricate Replace if necessary
7. Limit switches Safe-load indicators	Proper operation	Repair/adjust Lubricate
8. Wheel bearings, clutch release bearing	Dirt, deposits Excessive wear	Clean Lubricate Replace if necessary

Power cranes require special attention, some of guidelines for maintaining their electrical systems are listed below:

(a) Regularly check and adjust all power brakes, especially when there are signs of damage or maladjustment. If an AC brake has an increased humming sound, investigate at once. The coils may burn if the gap of the magnet is too wide.

(b) Keep the crane free of dirt, grease and other foreign matter.

(c) Check if the limit switches function properly.

(d) Check and maintain motors, brushes, contacts, etc.

(e) Replace kinked, severely worn cables

(f) Check and tighten all terminals.

Mobile cranes should be preiodically checked in specified time intervals. These intervals may be modified to suit the particular loads, operating conditions, or environment. Tables 13.7a to 13.7c show the recommended maintenance procedures for mobile cranes.

13.4 CONVEYORS

Conveyors are equipment which continuously transport material along their length. There are basically three types: roller, belt, and chain.

13.4.1 Roller Conveyors

These conveyors move loads over a series of rollers mounted in parallel. "Live" rollers, which are externally powered, impart motion to the loads, while "idle" rollers passively support the load along the length of the conveyor. Maintenance in roller conveyors consists primarily of keeping all rollers clean and free to turn. Table 13.8a shows some general monthly maintenance requirements of roller conveyors.

Table 13.8a: Maintenance Guides for Roller Conveyors (Monthly, unless otherwise indicated)

Source: Reference 2

Item	Check for:	Suggested Action
1. Entire unit (Particularly all line rolls, guides, tilt sections, and other velocity imparting devices)	Gravity or efficiency	a) Send standard test unit down the rolls. b) Note its travel speed (power on) or distance travelled (power off); decrease of these indicate need for service (e.g. lubrication, replacement of some bearings, alignment, etc.) c) Note its behavior on turns and make necessary adjustments.
2 Rolls Lubricated Non lubricated	 Lubricant in rolls	 Grease or oil Clean/remove lubricant and repair any damage due to it at least every 2 months a) Spin all rolls by hand b) Note signs of binding, looseness in bearings, and remedy.
3 Power transmission members		Service according to manufacturer's recommendation.

Cont. (Table 13.8a)

4. Automatic devices Switches Selector Counters Alarms Safety blocks Automatic control	Malfunction or need for	a) Trip devices b) Watch for expected result c) Investigate any trouble and repair/adjust
5. Hand control mechanisms Spur switches Switch locks Turntables Load-positioning brakes	Proper operation	Repair/adjust as necessary (pay special attention to those infrequently used)
6. Extra heavy sections	Damage due to dropping of heavy loads, production operations, etc.	Repair as needed. If damage is excessive, modify operating conditions if possible.
7. All sections	Signs of uneven wear indicating uneven loading Unequal frequency of operation	Reverse roller mounting (turn them end-to-end) Interchange rollers or whole sections between light and heavy traffic areas.

13.4.2 Belt Conveyors

These conveyors carry material on continuous belts usually made of a rubber or fiber or both. Belts are exposed to wear, erosion, and tearing due to abrasion of both the material being carried and the other parts of the conveyor, such as drums or rolls, guides, scrapers, etc. Table 13.8b shows some maintenance guides for belt conveyors.

On-stream cleaning is one of the most powerful tools in conveyor maintenance. The savings from effective belt cleaning are usually large. However, it is very important that the cleaning system be installed when the conveyor system is new, because to do so after the conveyor has been operating is difficult and expensive. In addition cleaning effectiveness may be reduced.

(a) Use a cleaning system composed of several units instead of only one for difficult application or for very effective cleaning.

(b) Consult manufacturers about the selection and installation of cleaning devices.

(c) Incorporate automatic adjusters to compensate for blade wear.

(d) Select simple devices to reduce maintenance requirements.

(e) Make provisions for regular inspection and maintenance. For example, chutes should be made easily accessible for regular checks.

(f) Select cleaning devices with versatile mounting systems for ease and flexibility of installation.

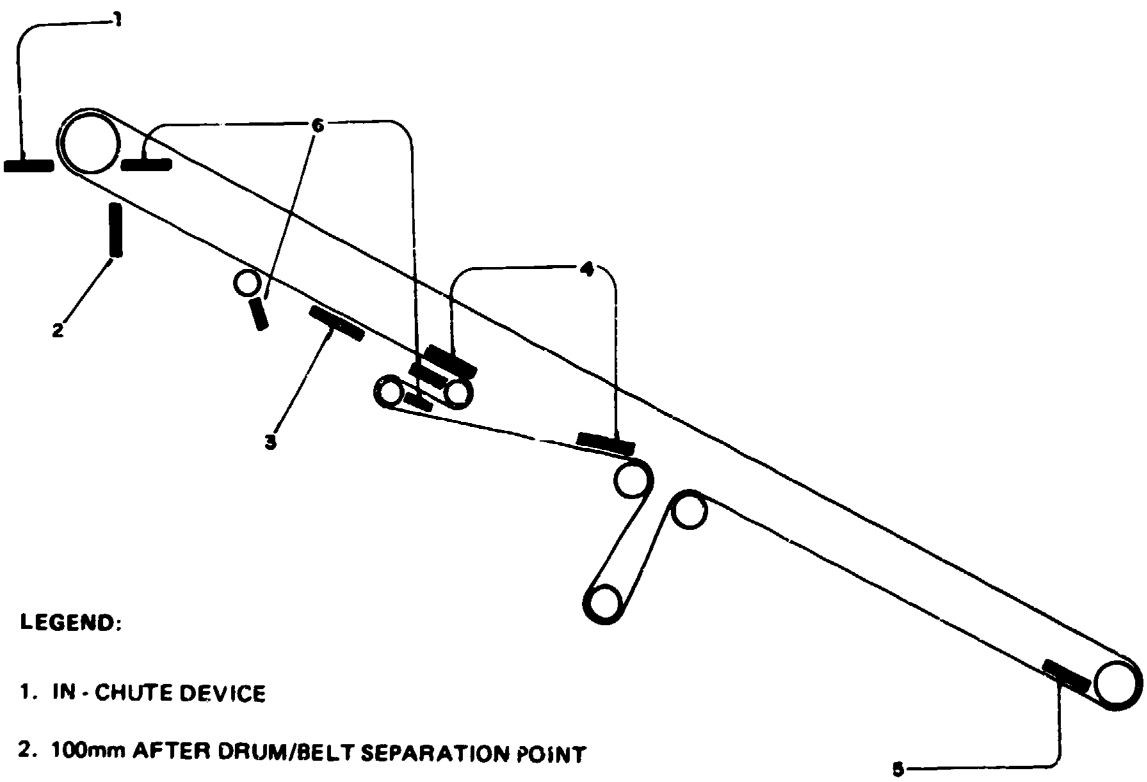
(g) Install belt cleaning devices according to the manufacturer's specifications.

(h) Use vulcanized joints on belts whenever possible to facilitate cleaning. If mechanical joints must be used, select a cleaning device that does not damage the joint.

(i) Obtain after-sales service from the manufacturer.

(j) Consider the cost of the cleaning device and spare parts (particularly the fequency of blade replacement).

An example of good cleaning system on a typical conveyor belt is shown in Figure 13.2.



LEGEND:

1. IN - CHUTE DEVICE
2. 100mm AFTER DRUM/BELT SEPARATION POINT
3. ACTING ON RETURN STRAND (DIRTY SIDE) BEFORE GTU OR DRIVE STATION
4. ACTING ON RETURN STRAND (CLEAN SIDE) BEFORE GTU OR DRIVE STATION
5. ACTING ON RETURN STRAND (CLEAN SIDE) BEFORE TAIL DRUM
6. DRUM SCRAPERS

Figure 13.2 Typical Cleaning System Layout for Conveyor Belts

Source: Reference 3

Table 13.8b: Maintenance Guides for Belt Conveyors

Source: Reference 2

Item	Check for:	Suggested Action
1. Belt	Cuts Worn surfaces	Repair immediately For rubber conveyors, vulcanize Repair with metal plates Use manufacturer's prepared repair products if available
	Slow elastic shrinking	Examine belt after overnight shut-down to see if belt needs to be slackened when resting
		Clean regularly by soaking dirt loose and washing with mild soap. Steam hoses or caustics should be avoided if possible.
Under or drive side of belt	Slipping (shiny areas) Lubricant contamination Dirt	Clean/tighten Clean Clean
2. Fastener	Cracking or breaking Tearing of fabric, rubber	Repair/replace fastener Repair/reinforce with thread
3. Cleats and other attached devices	Damage to area of belt where they are attached	Repair/reinforce belt
4. Power needed to run loaded belt	Increase with the same load	Check conveyor for: a) sticking rollers b) out of line pulleys c) eroded slides or guides d) over loading at take-up e) other belt-damaging factors Pronged meter may be used
5. Surroundings	a) Oil dripping for overhead machinery b) Weather leaks in housing c) Solvent fumes d) Sunlight on rubber belt e) Other hazards	Correct condition or isolate/protect the belt

13.4.3 Chain Conveyors

These conveyors have endless chains which function in much the same way as the belts in belts conveyors. However, unlike in belt conveyors where the primary concerns are abrasion and wear, maintenance in chain conveyors consists of keeping the links clean and properly lubricated. Table 13.8c shows some maintenance suggestions for chain conveyors.

Table 13.8c: Maintenance Guides for Chain Conveyors (Monthly unless indicated otherwise)

Source: Reference 2

Item	Check for:	Suggested Action
1. Drive motor	Proper operation and condition	a) Clean and service. b) Take power reading (Using a pronged meter) with the conveyor carrying a standard test. c) Compare reading with records; if considerably higher, investigate and remedy.
2. Remote controls, especially emergency stops	Proper operation/Setting	Service Adjust when needed
3. Automatic controls Warning signals Overload protection	Proper operation	a) Trip b) Wait for anticipated response; if none, investigate and remedy.
4. Lubrication		a) Refill automatic lubricators. b) Top up lubricant level in gear or motor reducers c) Lubricate whole system especially fittings and joints.
5. Sprockets Bearings Load-carrying devices Chains Take-ups, Similar parts	Mechanical condition Alignment	Repair if necessary Align

Cont. (Table 13.8c)

6. Governors, timers, speed-governing devices	Mechanical condition	a) Operate and time performance with stopwatch b) Investigate for sluggish operation.
7. Blowers, baffles, shields, other protective devices	Performance, Effectiveness in keeping fumes, abrasives, dust from chain	Repair/adjust if needed
8. Whole system	Noise indicating need for repair	a) Operate at no load with various speed. b) Listen for: 1. dragging rollers 2. chain rubbing due to misalignment 3. neglected bearings 4. looseness of parts c) Adjust/repair/replace as necessary
9. Supports	Plumbness, tightness, firmness	Repair as necessary
10. Structural alignment features (esp. sprocket and chain)	Trueness	Adjust/repair

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CHAPTER 14

Preventive Maintenance of Industrial Diesel Engines

14.1 INTRODUCTION

Diesel engines cover a wide range of applications and are extensively used in industry. They serve as prime-movers of stationary equipment such as stand-by and prime power generators, compressors and pumps. Most construction and materials handling equipment are also powered by diesel engines. They are exposed to long operating hours and rough conditions. Knowing this, the importance of a preventive maintenance program cannot be overemphasized.

A preventive maintenance system will preserve the engine in its working state and prolong its service life. Routine inspections and prompt response to minor complaints will cut costs in terms of time, replacement parts, and fuel.

14.2 DIAGNOSTICS

The manufacturer's recommendations regarding intervals between routine inspections are on the safe side and can be extended without jeopardizing the engine if proper operating practices are implemented. The engine should only be adjusted or dismantled when necessary.

The preventive maintenance schedule will depend on the following:

a. Type of engine
b. Work environment
c. Observed engine operating conditions
d. Work required for routine inspections and maintenance.

A record covering the operation and inspections done on the engine will prove to be very helpful. It can serve as a guide in planning, modifying and accomplishing the preventive maintenance program.

14.2.1 Fuel System

Diesel engines can burn several types of fuels but selection of the right kind is important, and the use of uncontaminated fuel is essential.

The following items must be periodically inspected and the appropriate measures made to correct any defect.

(a) *Fuel tank.* Fuel tanks must be kept clean. Filters prevent contaminants and water from getting into the engine but a supply of clean fuel is of utmost importance.

(b) *Filters.* Dirty fuel is a source of most diesel engine problems. All fuel filters and water traps should be checked frequently. Low fuel pressure is an indication of a clogged fuel filter.

(c) *Fuel lines.* Fuel leaks are a source of hazards and unnecessary waste. Inspect all fuel lines and connections at regular intervals.

(d) *Fuel transfer pump.* A continuous supply of fuel at the right pressure is necessary for smooth engine operation.

Analyzers are available to check the fuel transfer pump delivery and pressure.

(e) *Fuel injection nozzles.* High engine efficiency depends on the complete combustion of the fuel. The fuel injection nozzle must spray a fine mist of fuel at a pressure high enough to penetrate the compressed air charge in the combustion chamber.

Fuel injection nozzles can be tested with a nozzle tester. This is a high-pressure hand pump which delivers fuel through the nozzle. When testing, point the nozzle away from any person; fuel at high pressure can puncture skin and clothing.

(f) *Injection pump.* Injection pumps are precision instruments and are best left to qualified technicians. The service manual should be strictly adhered to when disassembling or servicing these instruments.

(g) *Governors.* Governors control the engine speed by working on the engine throttle They need minimal attention but should be kept clean and free from vibrations.

14.2.2 Cooling System

All internal combustion engines generate heat while running. The function of the cooling system is to remove the right amount of heat to keep the engine at the optimum operating temperature. In most designs the cooling system must also absorb heat from the engine oil cooler, aftercooler, torque converter and hydraulic oil cooler.

The most common cooling system, the radiator and fan, is shown in Figure 14.1. Its components include: the coolant water pump, the fan and radiator, and the water temperature regulator.

(a) *Coolant.* Ordinarily, the coolant used is water in combination with a corrosion inhibitor. Whether scale and deposit will form will depend on the composition of the water. Since water can cause corrosion, an inhibitor is necessary to prevent the formation of rust. The corrosion inhibitor also helps prevent pitting on metal surfaces caused by cavitation and corrosion. A coolant with the right proportion of water and corrosion inhibitor must be within the cooling system at all times.

Water can be tested to determine if it is suitable as a coolant. The coolant can also be tested to check the inhibitor concentration in the mixture.

(b) *Water Pump.* The water pump delivers the coolant from the radiator to the engine water jacket and oil cooler and back to the radiator. Pump failure will be readily manifested as overheating. Malfunction can be due to leaks in the pump housing and seals, damage in the bearing and shaft area, or broken impeller vanes.

The water pump pressure can be measured with a pressure probe at the pump outlet. With the radiator tank and regulator both open, it should read 70 to 140 kPa at high engine idle. A manometer installed at the inlet should then read 0 to 50 mm suction.

(c) *Radiator and Fan.* The hot coolant is cooled as it flows through the radiator. Air from the fan absorbs the heat from the coolant through the radiator fins and tubes. Maintain the correct level of coolant within the radiator, too little water can result in overheating, while an excess will cause spillage from the radiator. Bent fins and dirt in the radiator core minimize the rate of heat transfer. Avoid putting objects which can obstruct air flow in front of the radiator.

Positive contact must exist between fan belts and pulleys. Slip can cause wear on belt and pulley and slow turning of the fan.

Air velocity can be checked with an air velocity meter. Instruments which can help locate restrictions in the radiator core are also available. A potachometer can be used to check the fan speed.

A pressure gauge can be used to check the pressure the cooling system relief valve can hold. It should be able to hold a constant minimum pressure of 25 kPa and a maximum pressure of 95 kPa. Pressure can be applied to the system with a pressurizing pump or an air pressure regulating valve.

(d) *Water Temperature Regulator.* The temperature regulator prevents the flow of coolant to the radiator while the engine is cold. (Coolant is directed back to the water pump thru the by-pass line) As the engine heats up the regulator opens gradually to allow the flow of coolant. At the engine operating temperature the regulator is fully open and most of the coolant flows to the radiator.

The regulator can be tested with a hot water bath and thermometer. It should start opening at the opening temperature indicated in the service manual and attain its maximum position eventually. **CAUTION: Do not remove the regulator to solve an engine overheating problem.**

A complete check of the whole cooling system is possible with a multiple probe thermistor thermometer. The temperature at the following areas can be measured:

o Radiator tank top
o Water pump discharge
o Water temperature regulator unit
o Oil cooler inlet and outlet
o Engine oil

14.2.3 Lubrication System

Early engine failure can be traced to a faulty lubrication system. It can be caused by the following:

o Improper choice of lubricating oil
o Lack of appropriate oil additives
o Insufficient oil supply in crankcase
o Low oil pressure
o Contaminated oil

(a) *Lubricating Oil.* The choice of the lubricating oil should be based on the manufacturer's recommendation with due consideration to the observed engine operation and ambient temperature. The use of the wrong grade of oil can lead to excessive oil consumption and engine trouble. A too heavy oil will cause hard starting while low oil pressure can result from the use of too thin oil.

Table 14.1: Temperatures at Key Locations of the Cooling System

Source: Reference 2

Location		Approximate temperature reading
Radiator tank top	– –	Below coolant boiling point Must not be more than 61°C greater than ambient temperature. (water temperature regulator fully open)
Water pump discharge	–	4 to 8°C below radiator tank top temperature
Water temperature regulator unit	–	Must not be more than 1.1°C higher than radiator tank top temperature
Oil cooler unit	–	Oil inlet temperature must not be more than 132°C
Inlet	–	Must be 6 to 11°C higher than radiator tank top temperature (engine at full load)
Outlet	–	Must be 8 to 22°C lower than oil cooler inlet temperature (engine at full load)
Engine oil	–	17°C higher than temperature at water pump discharge (Measured in the oil manifold)

Protection of oil from contamination must start at the source. Only clean containers should be used. The right additives will extend the life of the oil and minimize oil contamination . The manufacturer's recommended oil contains the necessary additives. Oil must be changed because it eventually gets contaminated and the additives are used up.

The intervals between the oil changes specified by the engine manufacturer will not necessarily hold for all types of service conditions. One way of establishing the period between changes is to have the oil supplier analyze oil samples drained at different intervals to determine whether it needs replacement or is still qualified for use. This interval can be used as a basis for the fequency of oil replacement as long as service conditions remain the same.

Oil pressure gauges are available to test the engine oil pressure. The gauge is connected with an adaptor to the opening for the oil-pressure switch. Check the readings at engine idling and at normal engine operations. If the oil pressure cannot be maintained, the oil pump may require servicing or replacement.

(b) *Oil Filters.* Replace oil filters according to the manufacturer's instruction. Refer to manufacturer's specification as to when to replace.

(c) *Ventilation System.* The ventilation system carries the fuel and water vapor away to prevent the condensate from draining into the crankcase. Water vapor mixes with oxidized oil and carbon particles to form sludge, which clogs screens, filters and lines.

14.2.4 Air Supply and Exhaust

Incomplete combustion of the fuel will result if the air supply is inadequate. Dirt taken in with the air can damage the engine and lead to a premature overhaul. A faulty exhaust system will hinder the exit of combustion gases and prevent the entry of a full charge of fuel and air into the combustion chamber.

(a) *Intake System.* All air filters require regulation inspection. Follow the manufacturer's recommendations on service procedures and intervals. The service intervals will depend on the type of filter, the type of application and the contamination of the air. Inspect the whole air intake system for leaks, including all hoses, air filter fittings, filter-to-engine connections and intake manifolds.

Some air filters are equipped with indicator lights which signal when servicing is necessary.

Restriction of air flow into the engine can be checked with an auxiliary vacuum gauge from the engine builder or dealer. The gauge can be connected to the intake manifold or to the restriction indicator, if the air cleaner has one, with a tee fitting. Compare the gauge reading to the manufacturer's recommendation with the engine at fast idle. A high reading means restriction in the system.

The restriction indicator can be checked by gradually restricting the air-intake opening with a flat plate while watching the gauge. Replace defective indicators.

(b) *Exhaust System.* Maintenance includes checking and preventing leaks, removing carbon deposits from the exhaust manifold and replacing defective mufflers.

An Orsat Analyzer can be used to check the composition of the exhaust gases. This will indicate whether the engine is burning the correct fuel-air mixture.

(c) *Turbochargers.* Turbocharger mountings and connections should be checked for oil or air leaks. Make sure there is no air flow restriction at the crankcase vent. Abnormal turbocharger noise can mean imminent bearing failure or improper clearance between housing and turbine wheel.

14.2.5 Electrical System

Maintenance of the electrical system is focused on the battery, the generator or alternator, the starter motor and ancillary gauges.

(a) *Battery.* Battery care consists of maintaining the correct level of electrolyte inside the battery and cleaning the cable terminals and battery posts. Use distilled water to fill the battery. Minerals in hard water will form deposits on the plates and restrict chemical action. Be careful not to overfill. This will cause the electrolyte to escape through the vent holes and form deposits on the battery tops. Check vent holes for restriction.

Check the electrolyte specific gravity with a hydrometer before adding water. The reading should be between 1.215 and 1.270 at 27°C. To adjust for temperature changes add or subtract four gravity points (0.004) for every 5.5°C above or below 27°C

(b) *Alternator.* Common problems encountered with alternators are bearing failure and insufficient belt tension. Adjust tension according to the manufacturer's recommendation. Replace belts in poor condition and readjust tension after a few hours of operation to compensate for any stretch.

(c) *Generator and starter motor.* Starter motors and generators require minimal service. As with alternators, check the generator belt for condition and tension. Inspect generator brushes and replace worn brushes. Check the commutator for scoring or scratches.

14.3 PREVENTIVE MAINTENANCE PROCEDURES

Diesel engines are made by various manufacturers and no two employ the same design. This section covers the fundamental principles of diesel engine maintenance which apply to all kinds of diesel engines. The service manual provided by the engine builder is still the most reliable guide in setting up preventive maintenance program.

14.3.1 Fuel System

Perform the following checks on the components of the fuel system on a regular scheduled basis.

Maintenance of the fuel system consists of cleaning the tank, filters and fuel lines.

(a) *Fuel Tank*

Check:	Condition Prevented
1. Empty tank	engine does not start
2. Correct fuel	engine smokes or knocks
3. Dirty fuel	engine idles roughly
4. Condensate in fuel	engine misfires
5. Plugged fuel cap vent	engine does not start, starts hard or misfires

Partly filled fuel containers should be provided with drains to allow purging of water condensate.

Clean fuel-storage tanks regularly.

Screen out all scale , dirt, water and other contaminants from the fuel.

(b) *Fuel Lines*

Check:	Condition Prevented
1. Clogged fuel lines	engine does not start, starts hard or misfires
2. leaking fuel lines	waste of fuel, hazard, engine does not received the right amount of fuel
3. twisted, kinked, damaged, high pressure connectors	fuel is not delivered to the engine.

(c) *Injection Pump*

Only qualified technicians should service injection pumps. Follow the service manual and use the right tools.

Check:	Condition Prevented
1. faulty transfer pump	engine misfires, starts hard or does not start
2. stuck plungers or sticky pump rank or stuck control	engine idles roughly
3. air lock in unit	engine does not start, starts hard, or misfires
4. seized distributor	engine does not start, starts hard or misfires
5. Loose control sleeves	engine idles roughly
6. calibration of injection pump	engine idles roughly
7. worn distributor or pump plunger	low power output

CAUTION: Never steam clean an injection pump while the engine is running. Do not spray cold water on a warm pump. Pump seizure will occur.

(d) *Fuel-injection nozzles*

Check for stuck nozzle valves and plugged nozzle opening.
Check the nozzle-opening pressure.

(e) *Filter*

Inspect filter connections.

Check water separator daily and empty if the element is one-half full. When the water level cannot be seen, replace the element.

(f) *Governor*

Check	Condition Prevented
1. Poor idle adjustment	engine hunts, misfires, low-engine power output, rough idling
2. Loose or broken governor pump linkage	engine does not start, starts hard or misfires
3. Worn throttle linkage	engine idles roughly
4. Worn, broken or improperly adjusted spring	engine does not start, starts hard or misfires
5. Wrong, worn or broken control spring	erratic engine operation
6. Wrong governor spring	erratic idling, low power output

14.3.2 Cooling System

Frequent maintenance is necessary for the cooling system to work efficiently. The following steps will prolong the life of the cooling system and engine.

(a) *Loading the coolant*

(1) Use acceptable water with the right corrosion inhibitor.

(2) Close all drain plugs before filling the cooling system.

(3) If the capacity of the cooling system is unknown mix the correct proportion of water and inhibitor before filling.

If the capacity is known the inhibitor may be added while filling.

CAUTION: **The water and inhibitor should mix before the temperature rises and coolant is circulated in the radiator.**

(4) Filling should be done at a rate of 19 litres per minute or slower to prevent the formation of air pockets within the system.

(5) Run the engine for a few minutes before putting on the radiator cap. After putting the radiator cap, warm the coolant by idling the engine.

(6) Check the level of the coolant and add more if necessary. Replace the radiator cap.

(7) Check for leaks in the cooling system including hoses and connections.

CAUTION: All checks should be made while the engine is cool.

(b) *10 hour or daily inspection*

(1) Check the level of the coolant in the radiator and correct if necessary.

(2) Inspect the radiator core for bent or damaged fins and oil or dirt accumulation. Check for leaks.

(c) *250 hour or monthly inspection*

(1) Check fan belts for wear and tension. Adjust or replace if necessary.

CAUTION: Replace fan belts in sets. A new fan belt will carry most of the load when used with an old belt, causing excessive stress on the new belt.

(2) Refill the cooling system with corrosion inhibitor.

(d) 2000 hour or yearly inspection

(1) Inspect the radiator cap gasket.

(2) Clean the cooling system relief valve.

(3) Purge and clean the cooling system. Refill with new coolant mixture.

(4) Inspect the fan blades and guards for damage.

(5) Inspect all hoses and hose clamps. Retighten connections if necessary.

14.3.3 Lubrication System

Preventive maintenance of the lubrication system will center on the condition of the lubricants, the oil filters and the pressure regulating valves. The crankcase must be well ventilated to carry away fuel and water vapor which might condense into liquids in the crankcase and form sludge.

(a) *Oils*

(1) Use the right grade or weight of lubricating oil with the proper additives.

(2) Use clean containers.

(3) Use a dipstick to check the level of oil daily. Before checking the level, let the engine set for one minute to allow all the oil to drain back into the crankcase.

(4) Change at recommended intervals but take into consideration that service and plant conditions will dictate the frequency of oil change.

(b) *Filters*

(1) Most manufacturers recommend changing the oil filter for every oil change.

Filters are usually equipped with a bypass valve which opens when the filter gets clogged to prevent pressure build-up. When this happens oil goes directly to the engine to prevent oil starvation but this can cause serious damage. Change the filter before this can happen. Replace with the same type as the original.

Follow the instruction manual when servicing filters.

(2) Replace old gaskets and seal rings with new ones.

(3) After servicing, run the engine and check the oil pressure. Check for oil leaks.

(c) *Crankcase ventilation system.*

(1) Service air inlet according to suggestion in the service manual.

(2) If equipped with a regulating valve, clean or replace. Refer to service manual.

(3) If equipped with vent tube, remove and clean with solvent at regular intervals.

(4) Clean the vent tube filter if it has one.

14.3.4 Air Supply and Exhaust

The air intake and exhaust system require regular inspection of connections for leakage. The air requires frequent examination and servicing to function effectively.

(a) *Intake System*

(1) Check filter-to-engine connections for tightness.

(2) Check air cleaner unit for oil and air leakage.

(3) If the air filter has a rubber dust-unloading valve, check for obstruction by squeezing the rubber end.

(4) Service precleaners according to the manufacturer's recommendations. If the unit is exposed to dusty air, more fequent inspection is required.

Oil-Bath Cleaners

Stop the engine before removing the oil cup. Clean the cup if oil has thickened, contains water, or the sediment is more than 6 mm thick. Remove sediment from the bottom of the cup and rinse with clear fuel oil. Use the recommended oil to refill oil to the correct level.

CAUTION: Do not use highly volatile solvents to clean the oil cup. Overfilling the oil cup with oil can cause engine overspeeding and damage.

Dry-Type Cleaners

Empty dust cap daily.

If equipped with restruction indicator, service when the indicator signals clogging. The indicator may be faulty, so observe the length of operation and condition.

The element is cleaned in the following manner:

Remove dirt by tapping the element against the heel of the hand while rotating. For stubborn dirt, direct compressed air to the folds of the element. Blow up and down, inside and outside. For oily or sticky contaminants, dip and shake in a solution of lukewarm water and filter-element cleaner or comparable non-sudsing detergent. Rinse in clean water, shake to remove water and let dry thoroughly. Check for damage by putting light inside. Replace even slightly damaged element.

CAUTION: Use compressed air with a pressure of 210 kPa or less. Do not direct compressed air on wet element. This can rupture the material.

Change the element after its specified service life, if it is e[illegible]ely clogged with dust, or if the gasket is worn or lost.

(b) *Turbocharger*

(1) Check mounting and connections for oil or air leakage.

(2) Examine crankcase vent for restriction to air flow.

(3) Run engine at rated speed and listen for abnormal noise.

A high pitched whine could mean imminent bearing failure.

Peculiar noises could mean a wrong clearance between the turbine impeller and the housing.

(4) Run engine at rated speed and check for excessive smoke. Excessive smoke is sometimes caused by faulty turbocharger operation.

(c) *Exhaust System*

(1) Check the entire system for leaks.

(2) Clean carbon deposits from the inside of the exhaust manifold.

(3) Replace the muffler if necessary.

14.3.5 Electrical System

Attention is given to battery care and the drive belts for the alternator or generator and starter motor.

(a) *Battery*

(1) Every 50 hours.

Check electrolyte level. The level should be above the tops of the battery plates and below the bottom of the filter necks.

Before refilling, check if the electrolyte specific gravity is between 1.215 and 1.271 a reading that varies by more than 50 (0.050) specific gravity points means a poor battery condition. Replace battery.

Use distilled water to bring electrolyte to correct level. Add water only unless the electrolyte was spilled.

Check holes in caps for obstructions.

(2) Every 250 hours

Clean battery posts and cable terminals. If there are heavy deposits on the posts and terminals, clean at more frequent intervals.

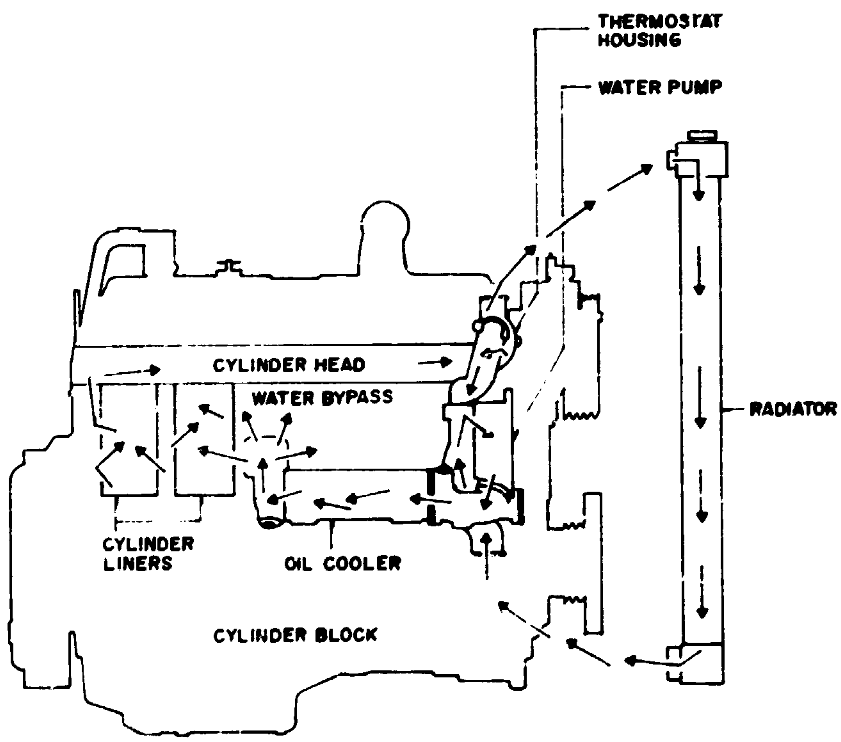

Figure 14.1 Typical Radiator and Fan Cooling System

Clean cable terminals by dipping in a solution of one part soda and sixteen parts water. Brush this same mixture on the battery posts and case until foaming stops. Wash with water and dry with a clean cloth. Connect terminals to the proper posts and coat with petroleum jelly or light grease for corrosion protection.

CAUTION: When cleaning the battery be careful not to allow the solution or water to get inside the battery. This can neutralize the electrolyte.

(b) *Alternator, generator and starter motor.*

The drive belts of the alternator or generator and the starter motor require periodic inspections.

(1) Every 250 hours.

If the generator and starter motor require lubrication, refill oil caps. Avoid over-lubrication; failure will result if the generator brushes get wet with oil.

Check the belt's tension and compare with the manufacturer's specification. Replace with an exact duplicate if necessary and readjust tension after a few hours of service.

(2) As required

Check generator brushes for wear. Brushes must be replaced if the tension arm rests on the brush holder instead of the brush or if the brush is corroded to one-half its former length. If the replacement brush binds in the holder, rub the holder with cloth or abrasive and remove dirt.

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Glossary of Maintenance Terms

Table A.1

Maintenance	A combination of actions carried out on an item to retain it in, or restore it to, an acceptable condition.
Emergency maintenance	Maintenance which is necessary to carry out immediately to avoid serious consequences.
Planned maintenance	Maintenance organized and carried out with forethought, control and records in accordance with a predetermined plan.
Breakdown	Failure resulting in the non-availability of an item.
Preventive maintenance	Maintenance carried out at predetermined intervals, or to other prescribed criteria, and intended to reduce the likelihood of an item not meeting an acceptable condition.
Running maintenance	Maintenance which can be carried out while the item is in service.
Shut-down maintenance	Maintenance which can only be carried out when the item is out of service.
Maintenance programme	A list allocating specific maintenance actions to a specific period.
Maintenance schedule	A comprehensive list of maintenance actions and their incidence.
History card	Record of usages, events and actions relating to a particular item.
Job report	A statement recording the work done and the condition of an item.
Overhaul	A comprehensive examination and restoration of an item, or a major part thereof, to an acceptable condition.
Downtime	The period of time during which an item is not in a condition to perform its intended function. (It is the time lost during scheduled production or service period due to the malfunction of the equipment).
Maintenance planning	Deciding in advance the jobs, methods, materials, tools, machines, labor , timing and time required.

Source: BS 3811: 1974 Maintenance Terms in Terotechnology, British Standards Institution.

Decision Guide for the Introduction of A Plant Preventive Maintenance Program

This section presents the steps which can be followed in introducing a PM program for a large plant. The steps can be simplified in the case of smaller plants. The materials to follow are taken from the article "Establishing an Effective PM Program" by Lee Anderson, published in the *Preventive Maintenance Guidelines*, Plant Engineering Library (1983).

Five specific phases are identified and decision flow charts corresponding to each phase are drawn to provide a quick guide through the sequence of activities.

Phase I – Suitability Study

The first phase is the "selling" portion of the program. The flow chart in Figure A.1 shows the basic steps for determining the need for a plant preventive maintenance program.

Step 1. A written statement must be prepared to define the preventive maintenance function for a particular firm. This must be communicated to all so that there will be a common understanding and recognition of PM work.

Step 2. Data must be gathered to determine the costs associated with operating a plant without a PM program for the past 2 years. These include downtime and maintenance costs to correct breakdowns, particularly on units that control production. An estimate of the costs of using a PM program for an equal period of time must be made and the cost figures compared to determine the minimum cost of optimum maintenance.

Step 3. The outline of a PM plan is formulated based on all information which have been gathered and is then presented to management. All phases of the project and all useful data must be included.

Step 4. If management decides to pursue the program, a planning committee involving key departments must be formed. This committee will serve throughout all the phases of the program although it may later be reduced to a smaller technical group.

Step 5. The committee should work out plans for the program and submit them for decision.

Step 6. If the decision is to proceed, the program must have the support of the majority. If the program is weakly supported, it should be stopped or postponed.

Step 7. If the majority "buys" the idea, then the first phase is completed, and detailed research can be carried out.

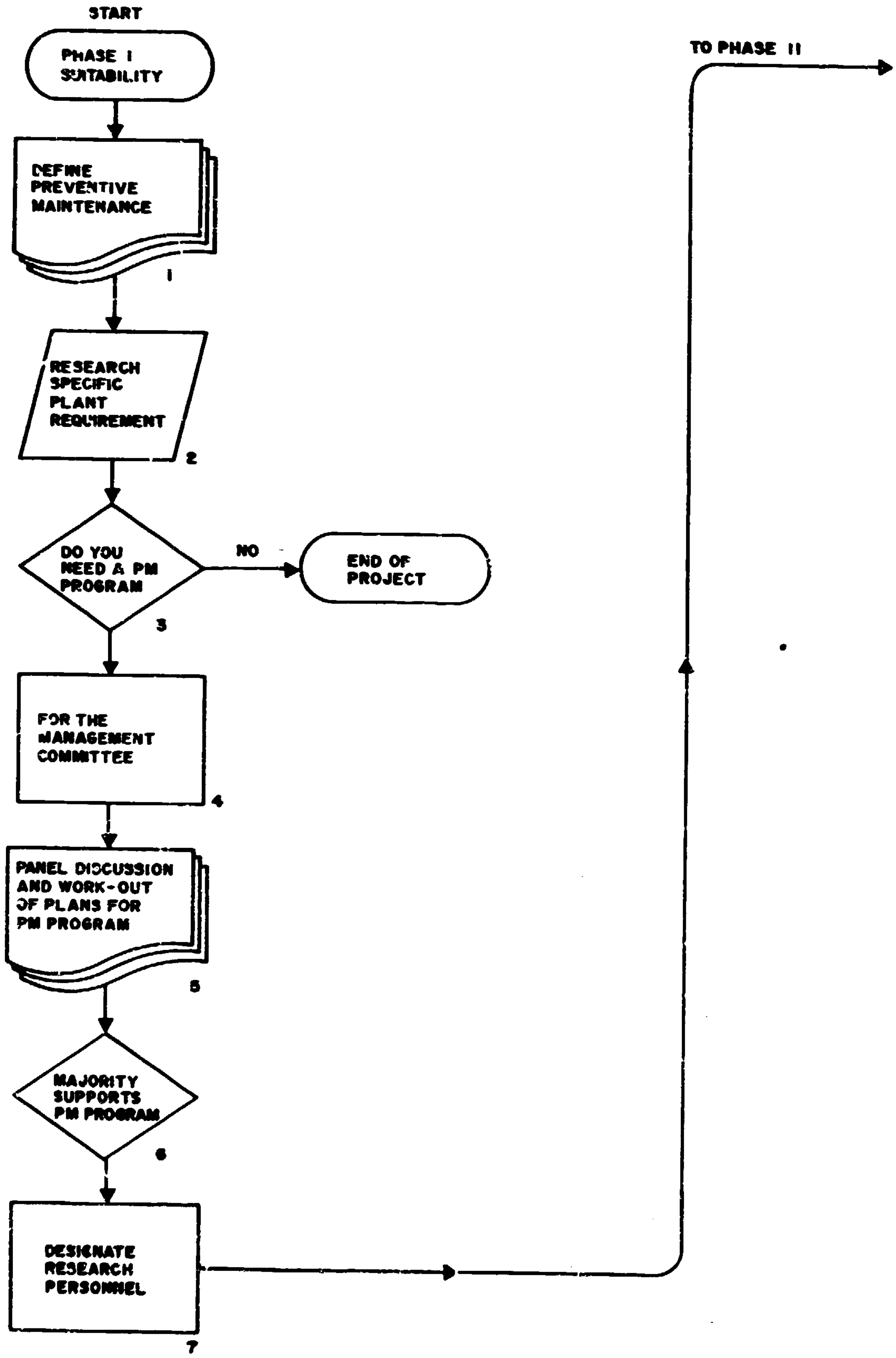


Figure A.1 Decision Flow Chart for Phase I (Suitability Study)

Phase II — Research

Research is an essential phase and requires a thorough and careful preparation because the results will become the foundation on which the PM program will be built. Figure A.2 shows the decision flow chart for this phase.

Step 1. The program committee selects the number of equipment/facilities to be included in a pilot PM program. Generally, no more than 5 percent of the plant equipment is considered. Maintenance manpower and scheduling of maintenance activities are considered.

Step 2. Next, a research group is designated to gather records and available historical repair and maintenance data of the selected equipment. A summary of the findings and recommendations is submitted to the program committee.

Step 3. The panel decides on the extent of the preventive maintenance work to be done on each of the pilot units. The application of PM could mean disassembly of the machine, or replacement of all parts, or replacement of just the worn-out and broken parts, or may consist of cleaning and lubrication only, or just inspection, with no disassembly. Two important factors in deciding the extent of PM application are the age of the machine and the severity of the service. "Middle of the road" decisions are usually found best in this case.

Step 4. With the extent of the work in the pilot PM program defined, the plant engineer may then be asked to assign qualified manpower for the program. If personnel are inadequate, recruitment must be done.

Step 4a. An alternative to hiring additional manpower is adjusting the program, like reducing the number of pilot equipment.

Step 5. The PM team for the pilot program is now formed and trained. They must be able to understand the PM program. They must also acquire the additional skills necessary, including the use of required tools and test instruments.

Step 6. All data previously gathered and pertinent records like manufacturers' instruction manuals are compiled. All parts, materials, tools and instruments are assembled for an orderly PM work.

Step 7. A thorough study of maintenance costs in the past is undertaken by the PM team.

Step 8. Next, a reliable estimate of the cost of the PM program must be done using, if possible, maintenance time standards.

Step 9. With costs determined, it can be seen whether the introduction of a PM program will provide substantial savings.

Step 10. If substantial savings cannot be realized, it must be determined whether the PM program could result in better product quality and/or greater output which could onset any losses.

Step 10a. If the PM program cannot be expected to provide savings nor improve product quality/quantity, the planning committee will have to decide whether to halt the project or to continue. A re-evaluation of the extent of coverage may result in an economically justified program.

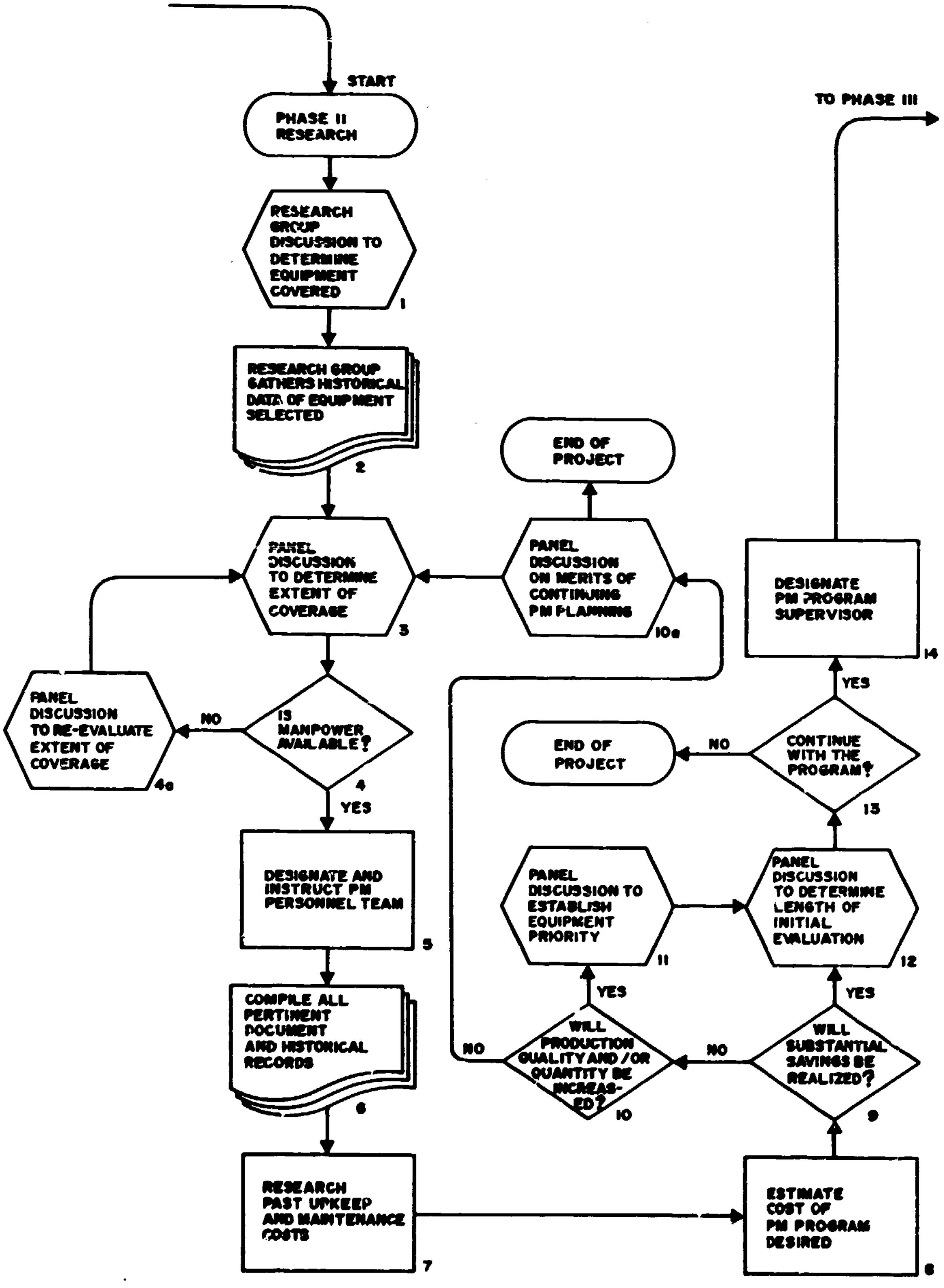


Figure A.2 Decision Flow Chart for Phase II (Research)

Step 11. If it is found that better product quality/quantity can be gained, the program committee must list down equipment priorities.

Step 12. At this stage, the program committee must set the time period that the program should be in effect. A full maintenance cycle must be completed in order to have a fair evaluation of the initial effort.

Step 13. At the end of the first maintenance cycle, the planning committee conducts the evaluation and decides if the program should continue. A unanimous decision among committee members is necessary for the continuation of a PM program to be effective.

Step 14. At this point, the research phase is completed. A decision to continue the PM program should mean a commitment to design the full-blown preventive maintenance system. A qualified PM program supervisor then has to be designated.

Phase III – Designing the PM Program

Once research has been completed and decision is made to proceed with designing the PM program for the plant, the management planning committee may be reduced to a smaller group comprising representatives from key departments.

Figure A.3 shows the decision flow chart for Phase III.

Step 1. The PM supervisor should now enlarge the team membership to include a subgroup which shall develop the overall PM program. It is essential to have a capable estimator/planner who is well-versed in the use of maintenance time standards and/or engineering performance standards. If no qualified estimator/planner is available, a consultant may be hired.

Step 2. Information/records on all equipment and facilities in the plant must now be collected and studied. The analysis of the equipment records should result in a determination of the extent of plant-wide PM work to be established.

Step 3. The planning panel determines (1) who will be responsible for scheduling units for PM and (2) how to schedule the units. This task can be done by the plant engineer, a maintenance planner/scheduler or a consultant. As to scheduling, it may be best to contact each department so as not to disturb production work.

Step 4. The panel should now draw up the record-keeping system for the PM plan. It is important to determine what records are to be kept, how and where to keep them and who will be responsible for compiling these records.

Step 5. If a computer is available, it may be used by the maintenance department. The other options are to buy, rent or lease a computer. Otherwise, the manual system of PM control must be used.

Step 6. If a computer is to be used, an EDP programmer must be assigned to the PM planning team.

Step 7. Property or accounting numbers should be assigned to all equipment. These identification numbers should be used in all references to the equipment to avoid confusion involving different units of the same type. Equipment locations should also be recorded. For mobile equipment, department or area assignments are given instead of location.

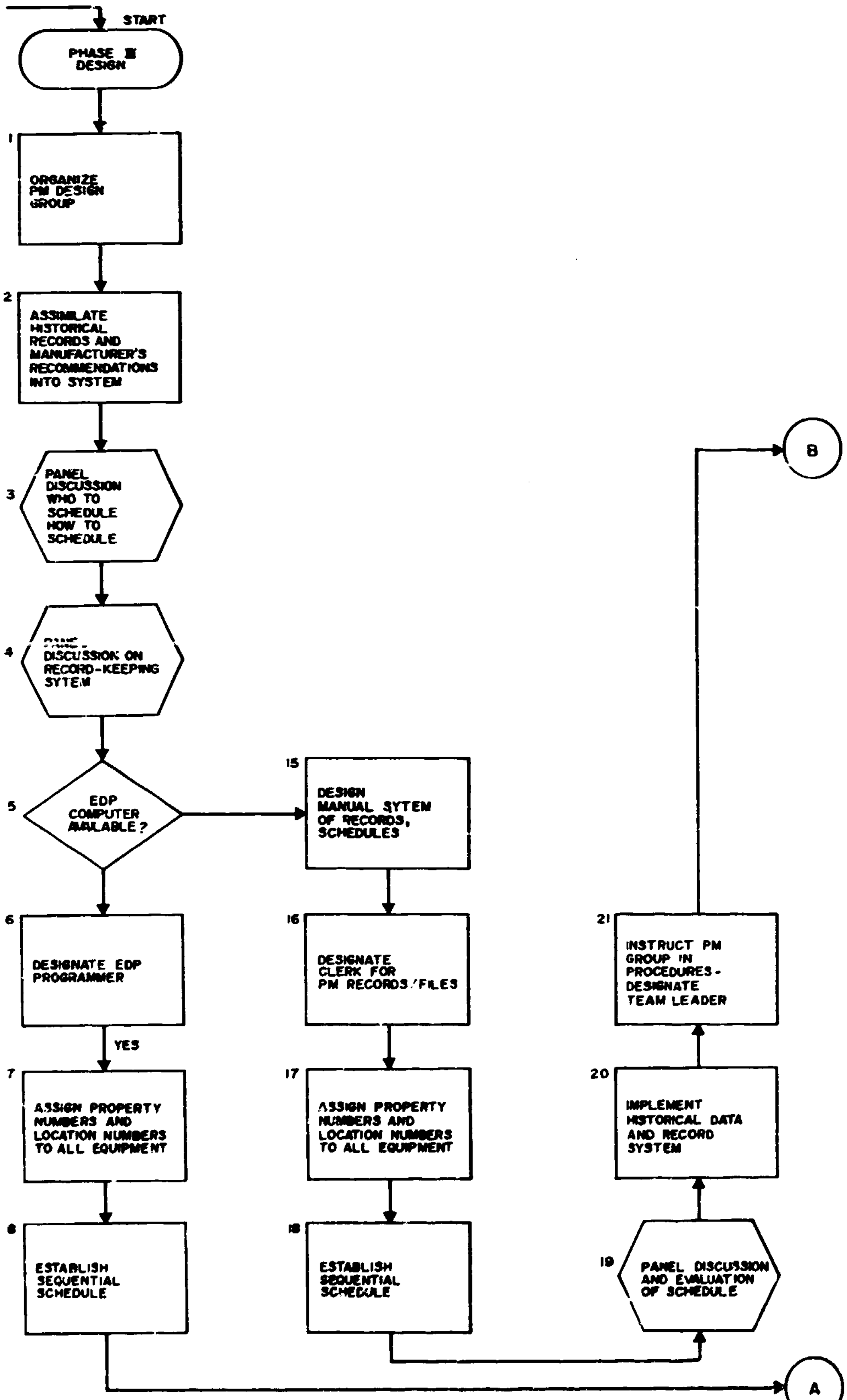
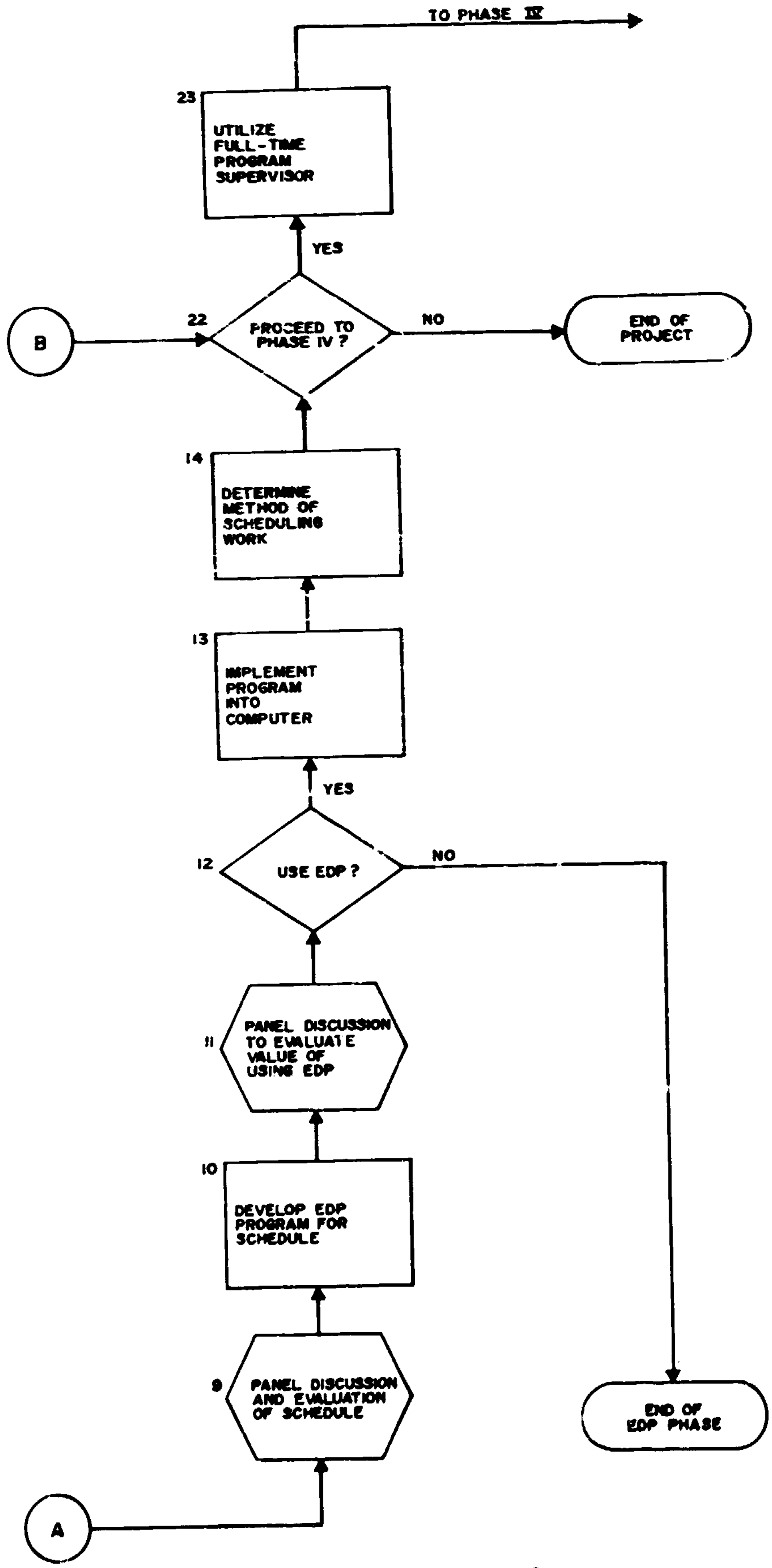


Figure A.3 Decision Flow Chart for Phase III (Designing the PM Program)

continued on next page



Continuation of Figure A.3

Step 8. The sequential schedule of PM activities is established. Here, several factors are considered, such as: number of units involved, extent of PM work required per unit, number of personnel available, loss of productive time per unit, etc. Manufacturers' instructions should be followed as much as possible, particularly for critical and expensive components.

Step 9. The panel should now meet to evaluate the schedule as to total cost and the effect on the plant. Needed changes can be made at this point.

Step 10. After the panel approves the schedule, a computer program can be prepared.

Step 11. Before proceeding further, the PM panel should now evaluate whether it is more advantageous to use EDP for the PM program.

Step 12. If the panel decides not to use EDP, then the option to computerize is abandoned.

Step 13. If the decision favors computerization, then the complete computer program must be prepared. Historical data are screened and step-by-step maintenance instructions should be detailed.

Step 14. The PM group works out a method of scheduling work assignments and recording cost/time data for the computer. At this point, the PM panel skips to Step 22. Steps 15 to 21 are for a manual PM system.

Step 15. If a computer is not available, the manual system is used. Schedules and record-keeping systems are prepared.

Step 16. The record/file clerk of the PM group should sit in on all panel meetings as discussion of details will be helpful to him in maintaining the filing system and preparing the summary report.

Step 17. Same as Step 7.

Step 18. Same as Step 8.

Step 19. Same as Step 9.

Step 20. The records/file clerk, should collect all the historical data and set up the files for the manual PM system.

Step 21. The plant engineer should now outline to the PM team the operating procedures for each equipment. A PM team leader (leadman or foreman) is appointed. The maintenance planner should closely work with the PM team leader to ensure that all needed logistics are ready before any PM project is started.

Step 22. The panel must now review the overall program and decide whether to continue on to Phase IV. Otherwise, the project is ended.

Step 23. If the decision is to proceed, the PM program supervisor designated in Step 14 of Phase II should now work on this job on a full-time basis.

Phase IV — Appraising the Planned Program

Phase IV consists of putting the plan into a test operation at a scaled-down basis in order to determine the workability of the entire program plan. Figure A.4 shows the flow chart for this phase.

Step 1. The PM team should now determine the most critical and troublesome equipment of the plant.

Step 2. The planning committee/panel selects from this list the equipment, comprising around 10 percent of the machines in the plant, to be included in the test phase of the program. The compiled historical data will serve as a basis for this selection.

Step 3. The equipment selected should be identified by account number and location. All maintenance/production personnel must be provided copies of this list.

Step 3a. If EDP is used, computer cards should be prepared for the designated units. In a manual system, the maintenance planner should prepare and submit the work orders to the PM team leader.

Step 4. The PM team leader, the maintenance planner and the program supervisor should now examine the historical data and determine any peculiar maintenance problems.

Step 5. The PM schedules for the selected machines should be established and strictly followed. The time evaluation cylce must also be set, allowing time for approximately half the machines to be given at least two periods of PM work. A maximum of 6 months is recommended for the cycle.

Step 6. The maintenance planner and PM team leader should ensure that the needed tools, spare parts and materials are available well ahead of the scheduled PM activity.

Step 7. The actual PM work for the test phase is now performed. Announcements are made prior to scheduled machine shutdowns and the actual maintenance activity is done with a minimum of delay.

Step 8. PM hours and cost data are recorded after each PM work, updating the historical data. A summary and analysis of the data are submitted to the PM program supervisor and the plant engineer.

Step 8a. In a computerized system, the equipment cards on which data have been recorded are returned to EDP.

Step 8b. A computerized data summary and analysis are issued for all the equipment in the test program. These data, which include downtime costs shall be used for the evaluation of the test program.

Step 9. The PM program supervisor should now present the results of the test program to the panel. The panel discussion should evaluate the program as to total cost and overall effect.

Step 10. If the results are satisfactory, the program may be continued. If not, it could spell the end of the project. However, every effort must be made to salvage the program, considering that much money would have already been spent.

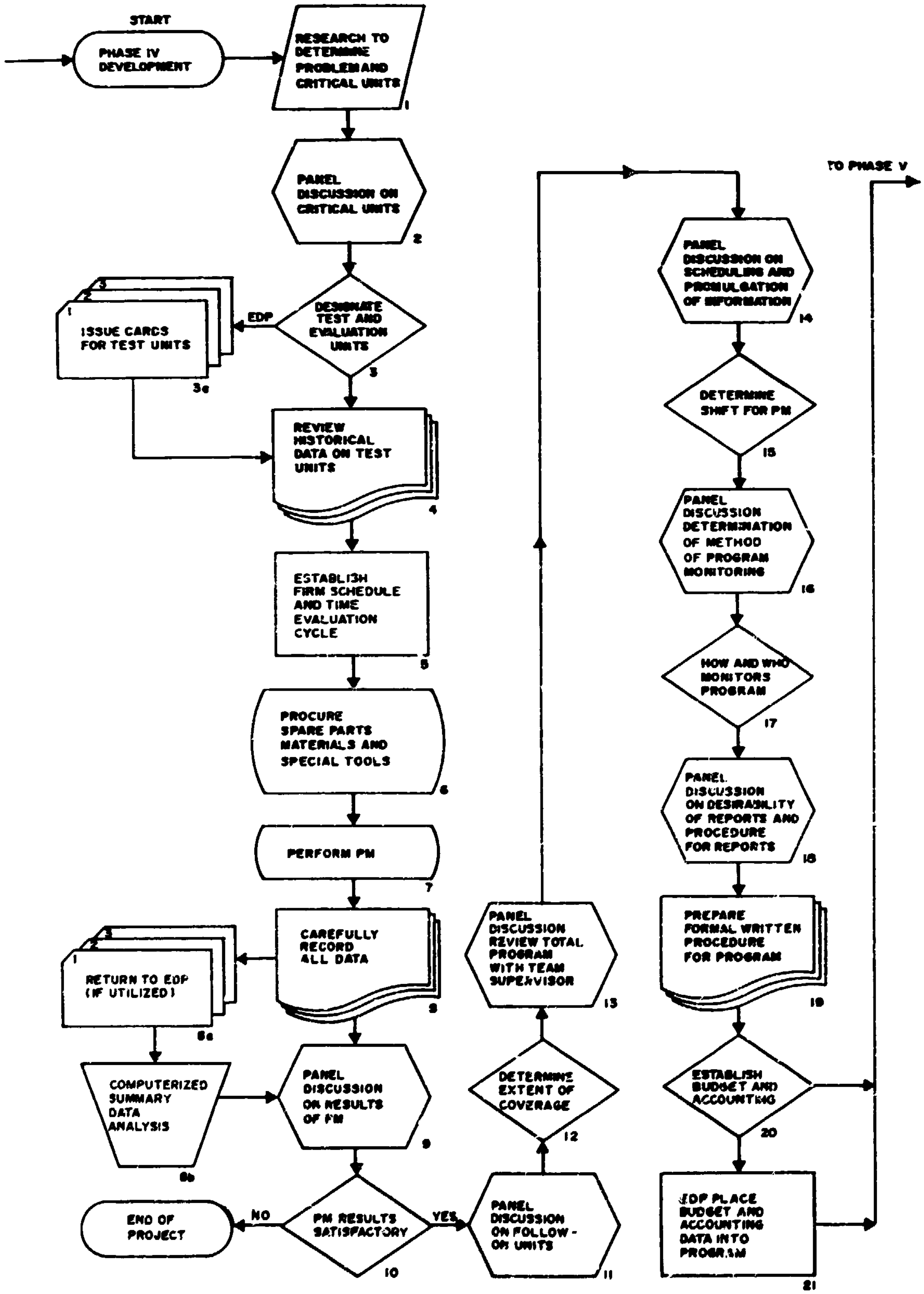


Figure A.4 Decision Flow Chart for Phase IV (Appraising the Planned Program)

Step 11. The panel should now discuss the expansion of the program to include approximately 50 percent of the equipment.

Step 12. The extent of equipment coverage is determined and announced to all departments concerned.

Step 13. The panel meets with the program supervisor to discuss anticipated problems for the expanded program. Additional manpower may be needed.

Step 14. The panel now discusses program scheduling and reporting. PM time allotments and cyclic intervals for each equipment are designated. Information and reports to be supplied to each department are determined.

Step 15. The plant engineer, PM program supervisor, maintenance engineer, and PM team leader must agree on the shift for PM work. Normally, the third shift is used because less interference is anticipated.

Step 16. The panel must provide for a system of monitoring the program. This includes inspection of equipment and PM work to ensure compliance with PM work orders and maintain quality workmanship.

Step 17. Qualified inspectors independent of the involved departments must be designated to do the system monitoring. In many plants, there is a quality control/inspection department. Inspection reports must be submitted to the program supervisor for evaluation or correction.

Step 18. The panel now reviews the reporting system to see whether paperwork can be minimized.

Step 19. The program supervisor should prepare a formal written procedure for the program. The final draft must be approved by the plant engineer and the facility manager.

Step 20. A budget for the total program should be prepared using the data from the test phase as basis. To ensure accurate cost data for analysis and control, PM funds should be kept separate from other maintenance budget accounts.

Step 21. If EDP is used, the budget and accounting data are put into the computer program.

Phase V — Operationalizing the PM Program

Phase V consists of putting the program into operation using 50 percent of the machines in a plant. This should provide results to be used as basis for final decision in establishing an effective full-scale preventive maintenance program. The decision flow chart is shown in Figure A.5.

Step 1. Copies of the completed PM schedule should be distributed to all departments involved. This schedule indicates the dates and time periods of downtime and PM activities for each equipment.

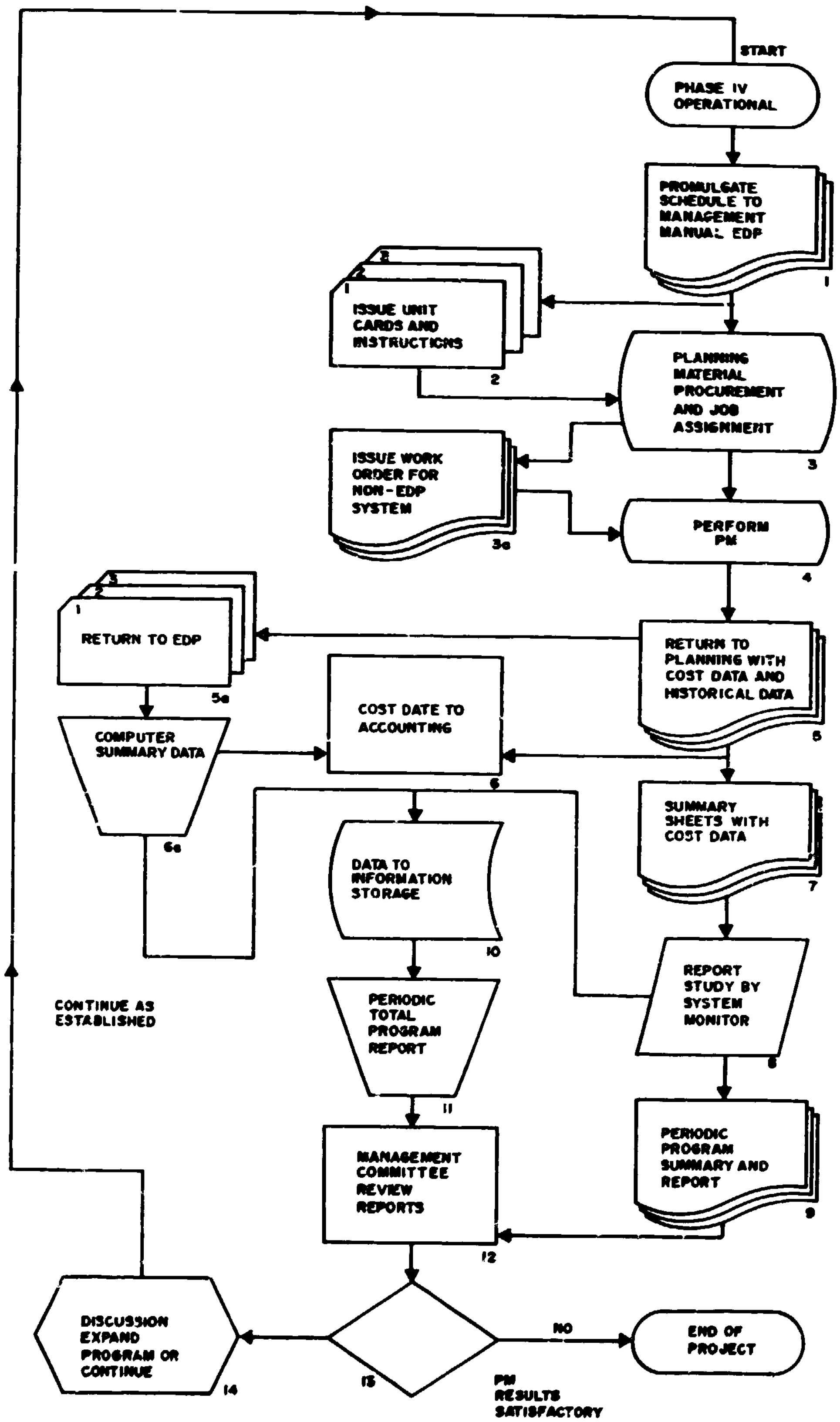


Figure A.5 Decision Flow Chart for Phase V (Operationalizing the Program)

Step 2. If a computerized system is used, EDP cards are issued for all units covered by PM work.

Step 3. The maintenance planner must ensure the availability of materials for PM work on each unit as per schedule. The program supervisor and PM team leader determine the manpower requirement and personnel assignments, based on the schedule.

Step 3a. If a manual system is used, the maintenance planner should prepare work order instructions. The team leader should ensure that actual PM work, time expenditures and material costs are recorded.

Step 4. Perform the preventive maintenance work.

Step 5. Completed work orders and recorded data should be immediately returned to the maintenance planner's office for review and recording.

Step 5a. In a computerized system, the unit cards are returned to EDP after review.

Step 6. For each PM activity, maintenance planning prepares an essential cost data report and submits it to accounting.

Step 6a. If a computerized system is used, EDP issues monthly or quarterly summary data reports.

Step 7. Maintenance planning should prepare summary reports weekly or monthly. The reports must contain pertinent historical information and total cost data for the reporting period.

Step 8. The program monitor studies the report and compares it with his own inspection findings.

Step 9. The program monitor should prepare quarterly data reports which he submits to management and to the other departments involved.

Step 10. If EDP is used, the cost and time data are put into the computer data file.

Step 11. Computerized data summary reports are issued.

Step 12. The management committee composed of the facility manager and the concerned department heads should meet to study possible improvements on the program, based on a review of the reports.

Step 13. At this point, the management committee studies the final report of the initial cycle of the PM program and makes the decision on whether or not to continue the implementation of the program plan. It should be understood that a higher total maintenance cost could be incurred during the first cycle, but production should increase because of reduced equipment failures. Greater total cost reduction should be anticipated for the second cycle.

Step 14. The management panel should now discuss the possibility of expanding the coverage of the program from the present 50 percent to include more equipment in the plant. The benefits as well as the costs of more PM work, like possible additional manpower should be taken into consideration, leading to a realistic assessment of attainable reduction of overall maintenance and operating cost.

Sample Mechanical Work Order System

A. INTRODUCTION

The mechanical work order (MWO) system is designed to meet two objectives: (1) to achieve a higher degree of maintenance cost control, and (2) to have an effective maintenance implementation and evaluation.

Since the maintenance program will derive its input data mostly from the work order, the mechanical work order form was designed to accommodate additional information.

This appendix serves as a reference and guide to effectively implement the mechanical work order system.

B. MECHANICAL WORK ORDER NUMBER

The mechanical work order form numbering has been so arranged that certain series of numbers have been specifically assigned to the different maintenance and construction areas, projects and services.

Maintenance Routine Jobs – MWO Series

1000 Series	–	Process Maintenance
2000 Series	–	Utilities Maintenance
3000 Series	–	OM&S/Terminal Maintenance
4000 Series	–	Mechanical Shop
5000 Series	–	Electrical and Instrument Shop

Other MWO Series

6000 Series	–	Billable Projects/Suspense Account
7000 Series	–	Capital Projects
8000 Series	–	Services

C. JOBS REQUIRING MECHANICAL WORK ORDER

All maintenance works, capital projects, damage, and billable jobs shall be covered by a mechanical work order with corresponding account code.

1. Routine jobs – monthly blanket mechanical work order.
   a. Rotary/equipment routine and PM
   b. Stationary/civil equipment routine and PM
   c. Electrical and instrument routine and PM
2. Major equipment maintenance and repair.

3. Shutdown or Turnaround Works — scheduled or unscheduled maintenance and repair of major equipment.
4. Capital Projects
5. Billable Projects/Suspense Account
6. Services

D. MECHANICAL WORK ORDER PREPARATION

1. The mechanical work order shall be prepared in quadruplicate. Figure A.6 shows a sample work order form. For routine repairs, a form such as that shown in Figure A.7 is used.

   a. Original (White) — Action Copy
   b. Duplicate (Blue) — Data Processing Copy
   c. Triplicate (White) — Originator Copy
   d. Quadruplicate (Yellow) — MWO Custodian

2. Originator (Engineering, Maintenance, and Operations)

   a. Prepares the mechanical work order.
   b. Fills in the description portion a detailed description or title of the project or job.
   c. Fills in the account code and writes date MWO was assigned or requested.
   d. Makes cost and manhour estimates.
   e. Writes the job details and location
   f. Determines job priority, inspects and determines job requirements including the safety aspects.
   g. Affixes signature and the date prepared.
   h. Sends MWO to proper approving authority.

3. Approving Authority

   a. Approves MWO with cost and manhour estimates not over ₱10M and whose manhour estimate is 150 or less.
   b. Department Manager — approves MWO with cost and manhour estimates over ₱10M or with manhour estimate over 150.
   c. Sends approved MWO to Maintenance Planning for record and distribution of copies.

4. Maintenance Planning (MWO Custodian)

   a. Assigns MWO number and records in MWO control file.
   b. Distributes copies as follows

      1. Original (White) — To maintenance superintendent/supervisor/project engineer for implementation.

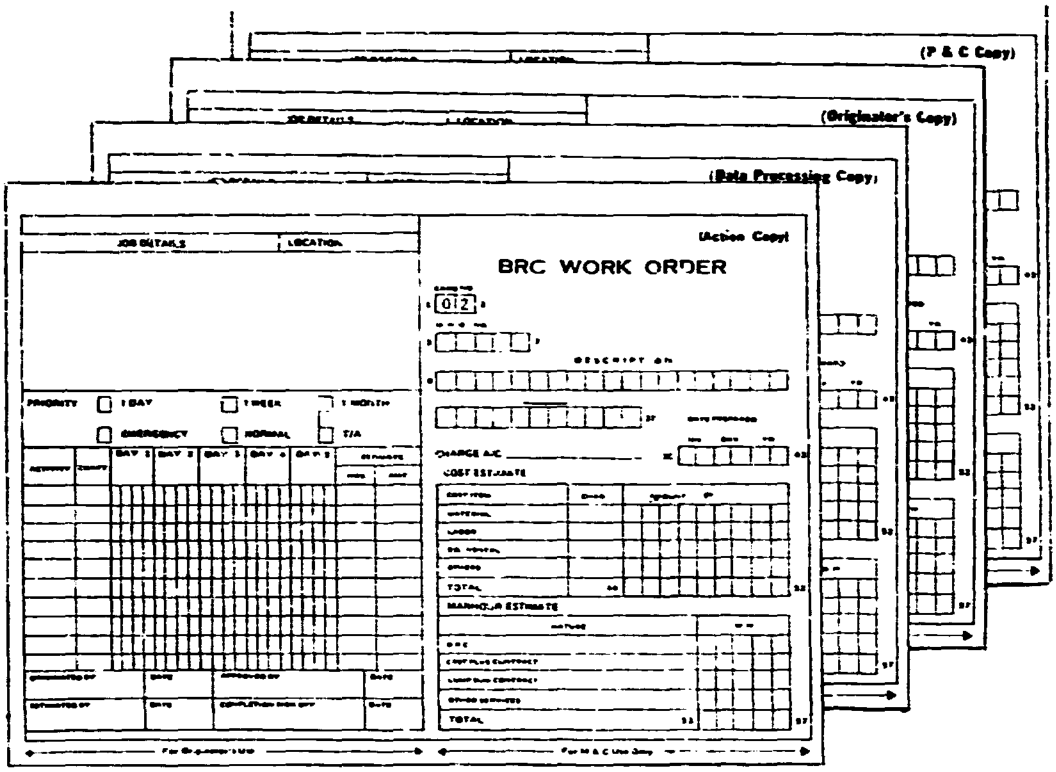


Figure A.6 Sample Work Order Form
COURTESY OF BATAAN REFINING CORPORATION

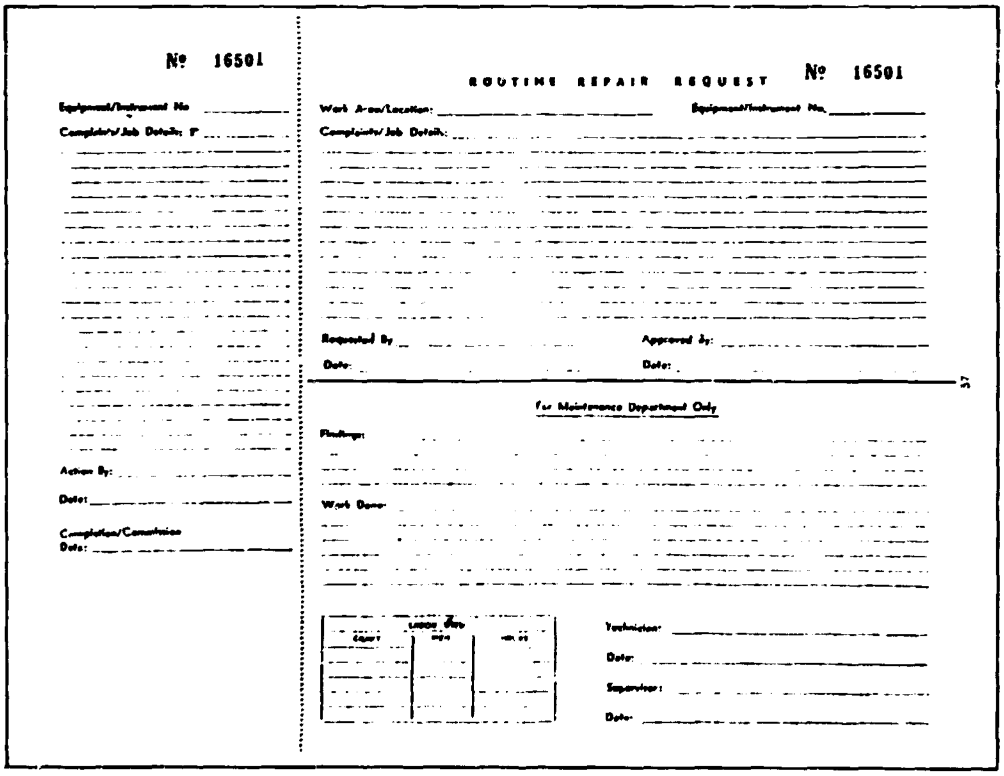


Figure A.7 Routine Repair Request Form

2. Duplicate (Blue) — To Data Processing through Accounting
3. Triplicate (Green) — To originator for implementation
4. Quadruplicate (Yellow) — Retain for MWO custodian file.

5. MWO for Lump Sum Contract

a. Contract Committee awards to deserving contractor for job implementation.

b. Department Manager approves MWO.

6. Maintenance Superintendent/Supervisor/Project Engineer

a. Implement mechanical work order, order material, requisition manpower, prepare bid specification, award, supervision and follow up to completion.

b. Signs completion sign-off portion after the job or project is finished.

c. Returns to Maintenance Planning all action copies (White) of all completed jobs.

7. Maintenance Planning

a. Records and marks "CLOSED" all completed Mechanical Work Order (White).

b. Sends to Data Processing through Accounting for updating the MWO analysis run and proper accounting work to be done.

8. Accounting

a. Implements all necessary recording and accounting works.

b. Sends to Maintenance Planning the Monthly MWO Analysis Run (original) and a duplicate), Listing of MWO Updates. Returns the original and duplicate copies of the MWO for Maintenance Planning record and file.

Maintainability Design Checklist

Table A.2

DESCRIPTION	RECOMMENDATIONS
Accessibility	1. Optimum accessibility should be provided in all equipment and components requiring maintenance, inspection, removal or replacement. 2. A transport window or quick-opening metal cover should be used for visual inspection accesses. 3. A hinged door should be used where physical access is required (instead of a cover plate held in place by screws or other fasteners). 4. If lack of available space for opening the access prevents use of a hinged opening, a cover plate with captive quick-opening fasteners should be used. 5. When a screw-fastened access plate is used, no more than four screws should be used. 6. On hinged access doors, the hinge should be placed on the bottom or a prop provided so that the door will stay open without being held if unfastened in a normal installation. 7. Parts should be located so that other large parts which are difficult to remove do not prevent access to them. 8. Components should be placed, so that there is sufficient space to use test probes, soldering irons, and other required tools without difficulty. 9. Units should be placed so that structural members do not prevent access to them. 10. Components should be placed so that all throwaway assemblies or parts are accessible without removal of other components. 11. Screwdriver-operated controls should be located so that when controls are adjusted, the handle will clear any obstruction.

Cont. (Table A.2)

Accessibility (Cont'd)	12. Enough access room should be provided for tasks which necessitate the insertion of two hands and two arms through the access. 13. The access opening should provide enough room for personnel's hands or arms and still provide for an adequate view of the work area. 14. Irregular extensions, such as bolts, tables, and hoses should be easy to remove before the unit is handled. 15. Access doors should be made in whatever shape it is necessary to permit passage of components and implements. 16. Units should be removable from the installation along a straight or moderately curved line. 17. Heavy units (more than about 12 kg) should be installed within normal reach of personnel for purposes of replacement. 18. Provisions should be made for support of units while they are being removed or installed. 19. Rests or stands should be provided on which units can be set to prevent damage to delicate parts. 20. Access points should be individually labeled so they can be easily identified with nomenclature in the Maintenance Requirement Cards (MRC) and maintenance manuals. 21. Access should be labeled to indicate what can be reached through this point (label on cover or close thereto). 22. Access openings should be freed of sharp edges or projections which could injure the personnel or snag clothing. 23. Parts which require access from two or more openings should be marked in order to avoid damage by trying to repair or remove through only one access. Double openings of this type should be avoided wherever possible. 24. Human strength limits should be considered in designing all devices which must be carried, lifted, pulled, pushed and turned. 25. Environmental factors (cold weather, darkness, etc.) should be considered in design and location of all manipulatible equipment items.

Cont. (Table A.2)

Accessibility (Cont'd)	26. The same type fasteners should be used for all access openings on a given equipment.
	27. Ventilation holes with screening of small enough mesh should be provided to prevent entry of probes or conductors that could inadvertently contact high voltages.
	28. A combination RFI and moisture proof gasket should be provided for each access opening in the enclosure.
	29. Accessibility of external test points should be assured under use conditions.
	30. Test points should be grouped for accessibility and convenient sequential arrangement of testing.
	31. Each test point should be labeled with name or symbol appropriate to that point.
	32. Test points should be located close to controls and displays with which they are associated.
	33. Test points should be located so as to reduce hunting time (near main access openings, in groups, properly labeled, near primary surface to be observed from working position)
	34. Test points which retain test probe should be provided so that personnel will not have to hold the probe.
identification	1. All units should be labeled – with full identifying data, if possible.
	2. Each terminal should be labeled with the same code symbol as the wire attached to it.
	3. On equipment utilizing color coding, meaning of colors should be given in manuals and on an equipment panel.
	4. Color coding should be consistent throughout system, equipment and maintenance supports.
	5. Display and control labels should clearly indicate their functional relationship. Display should be labeled by functional quantity rather than operational characteristics (i.e., volts, ohms, etc.).

Cont. (Table A.2)

Identification (Cont'd)	6. Schematics and instructions should be attached directly to, or adjacent to chassis for all units which may require troubleshooting. 7. When selector switches may have to be used with a cover panel off, a duplicate switch position label should be provided on the internal unit so that maintenance personnel do not have to refer to label on the case or cover panel. 8. Color codes for identifying test points or tracing wire or lines, should be easily identifiable under all conditions of illumination and should be resistant to damage or wear. 9. Functional organization of displays and controls should be emphasized by use of such techniques as color coding, marked outline, symmetry of grouping and/or differential plane of mounting.
Standardization	1. Functional interchangeability should exist where physical interchangeability is possible. 2. Sufficient information should be provided on identification plates and within related Maintenance Requirement Cards (MRC's) so the user can adequately judge whether two similar parts are interchangeable. 3. Parts, fasteners, connectors, lines and cables, etc., should be standardized throughout the system and, particularly, from unit to unit within the system. 4. Interchangeability should be provided for components having high mortality wherever practicable.
Safety	1. Edges of components and maintenance access openings should be rounded or protected by rubber, fiber or plastic protectors to prevent personnel injury. 2. Audible warning signals should be distinctive and unlikely to be obscured by other noises. 3. Critical warning lights should be isolated from other less important lights for best effectiveness. 4. When selecting warning lights, they should be compatible with ambient illumination levels expected. A dim light will not be seen in bright sunlight, and a bright light may be detrimental to dark adaptation.

Cont. (Table A.2)

Safety (Cont'd)	5. On-off fail-safe circuits should be utilized wherever possible to minimize failures without operator knowledge. 6. Bleeding devices should be provided for high-energy capacitors which must be removed during maintenance operations. 7. Struts and latches should be provided to secure hinged and sliding components against accidental movement which could cause injury to personnel during maintenance operations. 8. Limit stops should be provided on drawers or fold-out assemblies which could cause personnel injury if not restrained. 9. Safety interlocks should be used wherever necessary. 10. Components should be located and mounted so that access may be achieved without danger to personnel from electrical charge, heat, sharp edges and points, moving parts, and chemical contamination.
Cables and Wiring	1. Cables should be of sufficient length to provide movement of each functioning unit to convenient positions for checking and/or to allow free access to cable connectors during installation or removal. 2. All cables should be color coded and both ends tagged. Colors should be selected which cannot be confused because they are too nearly alike or may not be recognized because of poor illumination. 3. Cables and lines should be directly accessible to the personnel wherever possible (not under panels which are difficult to remove). 4. Cables should be routed so they need not be bent or unbent sharply when being connected or disconnected. 5. Cables should be routed so they cannot be pinched by doors, lids, etc., or so they will not be stepped on or used as handholds by maintenance personnel. 6. Cables or lines should be attached to units which can be partially removed (chassis on slide racks) and attached so the unit can be replaced conveniently without damaging the cable or interfering with the securing of the unit.

Cont. (Table A.2)

Cable and Wiring (Cont'd.)	7. The necessity for removal of connectors or splicing of lines should be avoided. 8. Cable entrances on the front of cabinets should be avoided where it is apparent they could be "bumped" by passing equipment or personnel.
Connectors	1. Adjacent solder connections should be far enough apart so work on one connection does not compromise integrity of adjacent connections. 2. Connector plugs should be designed so that pins cannot be damaged (aligning pins extended beyond electrical pins). 3. Self-locking safety catches should be provided on connector plugs rather than safety wire. 4. Connectors should be designed so that it is physically impossible to reverse connections or terminals in the same or adjacent circuits. 5. Quick-disconnect devices should be used wherever possible to save time and minimize human error which could occur in soldering, etc. (fractional-turn, quick-snap action, press-fit, etc.) 6. Marking on plugs, connectors, and receptacles should show proper position of keys for aligning pins for proper insertion position. 7. Connectors should be located for easy accessibility for replacement or repair.
Controls	1. All adjustments should be located on a single panel. 2. Controls should be located where they can be seen and operated without disassembly or removal of any part of the installation. 3. Controls should be placed on a panel in the order in which they will be normally used. 4. Controls when used in a fixed procedure should be numbered in operational sequence. 5. For concentric shaft vernier controls, larger diameter control should be used for the fine adjustment.

Cont. (Table A.2)

Controls (Cont'd)	6. Knobs, for precision settings should have a 50mm minimum diameter. 7. Controls should be labeled with functional statement. 8. Control position markings should be descriptive rather than coded or numbered. 9. Control scales should be only fine enough to permit accurate setting. 10. Except for detents or selector switches, controls should be used which have smooth, even resistance to movement. 11. Selector switches should be used which have sufficient spring loading to prevent indexing between detents. 12. Spring-loaded pushbuttons should be used which require no excessive finger pressure. 13. Tool-operated controls operable by screwdriver or other medium size standard tool should be used. 14. Coaxial knobs should be adequately coded to avoid confusion. 15. Calibration instructions should be placed as close to the calibrating controls as possible. 16. Adjustment controls should be easy to set and lock. 17. Visual, auditory, or tactile feedback should be provided for all physical adjustment procedures. 18. Some type of indexing should be provided for adjustment controls. (It is difficult to remember positional settings without some marking. Indexing can also show gradual deterioration in performance as settings change from time to time).
Display	1. All displays used in system checkout should be located so they can be observed from one position. 2. On units having operator displays, maintenance displays should be located behind access doors on operator's panel. 3. On units without operator panel, maintenance displays should be located on one face accessible in normal installation.

Cont. (Table A.2)

Display (Cont'd.)	4. Display scales should be limited to only that information needed to make decisions or to take some action.
	5. When center-null display are used, circuits should be designed so that if power fails the indicator will not rest in the in-tolerance position.
	6. Numerical scales should be used only when quantitative data is required.
	7. Scales should be provided with only enough graduation for required accuracy without interpolation.
	8. A special calibration point should be provided on scale or on a separate overlay if edges and midpoint of tolerance range are not sufficient for accurate calibration.
	9. Displays which provide tolerance ranges should be coded so both the correct reading and tolerance limits are identified.
	10. Critical warning lights should be isolated from other less important lights for best effectiveness.
	11. Counters should be used in which numbers snap rather than shift into place.
	12. Counters should be mounted close to the panel so that numbers are not obscured by bezel opening.
Handles	1. Handles should be used on units weighing over 4.5 kg.
	2. Handles should be provided on smaller units which are difficult to grasp, remove, or hold without using components or controls as hand holds.
	3. Handles should be placed above the center of gravity and positioned for balanced loads.
	4. Handles requiring firm grip, bale openings, should be provided at least 115 mm wide and 50 mm deep.
	5. Handles should be located to prevent accidental activation of controls.
Mounting	1. Wrong installation of unit should be prevented by virtue of size, shape, and configuration, etc.

Cont. (Table A.2)

Mounting (Cont'd)	2. Modules and mounting plates should be labeled. 3. Guides should be used for module installation. 4. Means should be provided for pulling out drawers and slide-out racks without breaking electrical connections when internal in-service adjustments are required. 5. Parts should be mounted on one side of a surface with associated wiring on the other side. 6. Easily damaged components should be mounted or guarded so they will be protected. 7. When fold-out construction is employed, parts and wiring should be positioned so as to prevent damage by opening and closing. 8. When screwdriver adjustments must be made by touch, screws should be mounted vertically so that the screwdriver will not fall out of the slot. 9. Internal controls (switches, adjustment screws) should be located away from dangerous voltages. 10. Screwdriver guides should be provided on adjustments which must be located near high voltage. 11. Parts should be located so that other large parts (such as indicator and magnetron tubes) that are difficult to remove do not block access to them. 12. Parts, assemblies, and components should be placed so there is sufficient space to use test probes, soldering irons, and other tools. 13. All throwaway items should be accessible without removal of other items. 14. All fuses should be located so that they can be seen and replaced without removal of any other item. 15. Fuse assemblies should be designed and placed so that tools are not required to replace fuses. 16. Fasteners for assemblies and subassemblies should be designed to operate with maximum of one complete turn.

Cont. (Table A.2)

Mounting (Cont'd.)	17. If bolts are used, they should require a minimal number of turns (less than 10). 18. When tool operated fasteners are required, only those operable with standard tools should be used. 19. Guide pins on units and assemblies should be provided for alignment during mounting. 20. When tool-driven screws must be used, types should by used which can be driven by several tools (screwdriver, wrench, or pliers, where possible. i.e., a new head with screwdriver slot). 21. Access cover fasteners of the captive type should be used.

Source: NAVYSHIPS 0967-312-8010 Maintainability Design Criteria Handook for Designers of Shipboard Electronic Equipment (Change 4), Department of the Navy, July 1972.

APPENDIX V

Preventive Maintenance of Rolling Bearings

1. INTRODUCTION

Rolling bearings are those type of bearings where the main load is transferred through elements in rolling contact. Ball bearings and roller bearings belong to this class of bearings. They can be designed to take radial loads, thrust loads or a combination of both. Different types of bearings are available as off-the-shelf items throughout the world. Bearings made by different manufacturers are interchangeable since their dimensions and tolerances are according to standards set by the ISO(International Standards Organization).

The proper use and maintenance of bearings can lead to reduced operating costs. It is necessary to follow the manufacturer's recommendations regarding their operation and maintenance. Also, they should be protected from contamination.

2. MOUNTING AND DISMOUNTING OF BEARINGS

The subsequent performance of a bearing will depend a lot on the way it is mounted. Appropriate tools should be used to prevent damage to the bearing while it is being installed or removed.

Some guidelines to bear in mind in mounting and dismounting bearings are:

a. The mounting force should be applied to the side face of the ring which is to have the tight fit. The transmission of this force to the other ring through the rolling elements should be avoided.

b. Use only appropriate tools. No force should be directly applied to the bearing with a hammer or similar striking instrument.

c. The bearing, shaft and housing must be free from dirt and abrasive particles.

Bearings are packed with rust preventive inside their wrappers. Most manufacturers employ rust preventives which are miscible with petroleum-base lubricants. This compound should only be removed if it is contaminated or has hardened inside lubrication holes and oil-mist lubrication is to be used. In this case the bearing must be cleaned with kerosene or similar solvent to remove the compound. It is also advisable to wipe away the compound from the surface of the ring which is to have the interference fit. All tools which will be used should be gathered prior to mounting or dismounting a bearing. The bearing should be taken out of its wrapper only as the last step.

2.1 COLD MOUNTINGS

The following procedure applies to the cold mounting of bearings of 100mm (4 in) bore and smaller, and for all shielded and sealed ball bearings.

(a) Put on a film of light oil on the surface of the ring to be force-fitted and on the seat of the shaft or housing.

(b) Use fixtures to spread the mounting force on the side face of the bearing and on the ring which will have the tight fit. Pipe tubing of suitable size and a flat plate will suffice as illustrated in Figure A.8.

(c) Apply the mounting force with a hammer or an arbor press to the fixture, not directly to the bearing. The force should be applied uniformly to avoid cocking the bearing on the shaft.

2.2 TEMPERATURE MOUNTINGS

Another method of mounting open straight-bore bearings of any size is to heat the bearing, slip it onto its seat and keep it in place until it cools enough to maintain a firm hold on the shaft. If it is impractical to heat the housing for outer ring fits, the bearing can be cooled with dry ice. This should not be practised in humid environments where condensation on the bearing might cause corrosion.

The important thing to consider in the hot mounting of bearings is to control the temperature to prevent overheating the bearing. Bearings can be heated with the following: a) hot plate, b) temperature controlled oven, c) induction heater and d) hot oil bath. For the hot plate and induction heater, a pyrometer should be used to monitor the temperature.

The use of a hot-oil bath is the simplest way of heating bearings. For easier control of the temperature to prevent overheating the bearing and fire hazards, a mixture of soluble oil and water can be used. A mixture of 10 to 15 per cent soluble oil will boil at 99 °C, which is adequate for most applications.

The solution is placed in a tank and heated. A grate is used to keep the bearing off the bottom of the vat and to allow contaminants to settle to the bottom.

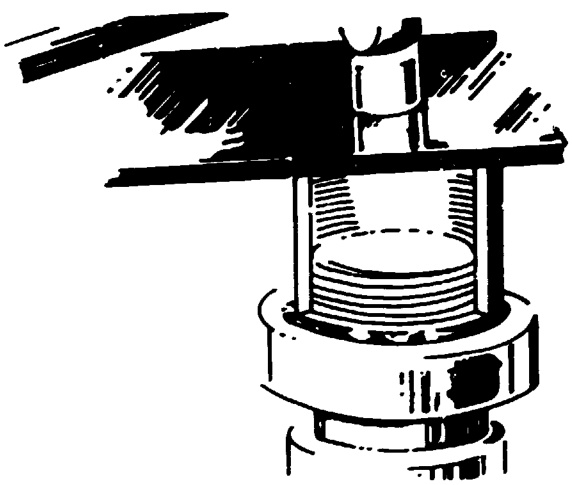


Figure A.8 Mounting Using Flat Plate and Hammer

Most bearings can be fitted at 99°C. Changes in metallurgical structure will occur at temperatures beyond 149°C while bearings of 50mm (2 in) bore and smaller should be kept below 121°C.

2.3 MOUNTING OF TAPERED-BORE BEARINGS

Tapered-bore bearings are forced up the taper of the shaft by tightening the locknut or clamping plate. Self aligning tapered ball bearings are set on the tapered seat and the locknut tightened manually until there is no play between parts. The nut is then tightened one-eight turn more with a spanner wrench. Finally, the lock-washer tab is bent into the nut slot closest to a washer tab in the tightened direction.

A tapered-bore spherical roller bearings can be fitted more accurately because of its characteristics. When the bearing is pushed up the taper of the shaft, the internal clearance (clearance between rollers and inner surface of the outer ring) is reduced by the expansion of the inner ring. The degree of fit between the cone and the seat is proportional to the reduction of this dimension. By knowing the internal clearance of the unmounted bearing and controlling the reduction of this clearance as the gearing is mounted, a very close fit can be attained.

Below is the procedure for mounting tapered-bore spherical bearings using the internal clearance as a guide to the closeness of fit between the shaft and bearing and referring to Table A.3:

(a) Place the unwrapped bearing on a table to allow for easy handling.

(b) Seat the lower rollers properly by swinging the inner ring back-and-forth along its circumference.

(c) Choose a feeler blade of 0.0762 or 0.1016mm (.003 or .004 in.) thickness. Use a thinner blade for smaller bearings. (The length of the blade should be longer than the length of a roller but less than the width of the inner ring).

(d) Push the uppermost roller against its guiding surface and insert the blade between two rollers and the outer ring.

Table A.3 Clearance for Driving a Spherical Roller Bearing on a Tapered Seat (Values in mm)

Bearing bore, mm		Reduction in radial internal clearance		Min permissible final clearance after mounting bearings with clearance		
Over	Incl.	Min	Max	Normal	C3	C4
40	50	0.0254	0.0305	0.0203	0.0305	0.0508
50	65	0.0305	0.0381	0.0254	0.0356	0.0635
65	80	0.0381	0.0508	0.0254	0.0406	0.0762
80	100	0.0457	0.0635	0.0356	0.0508	0.0762
100	120	0.0508	0.0711	0.0508	0.0635	0.1016
120	140	0.0635	0.0889	0.0559	0.0762	0.1143
140	160	0.0762	0.1016	0.00559	0.0889	0.1270
160	200	0.0889	0.1270	0.0711	0.1016	0.1651
200	225	0.1016	0.1397	0.0762	0.1143	0.1778
225	250	0.1143	0.1524	0.0889	0.1270	0.2032
250	280	0.1143	0.1651	0.1016	0.1397	0.2159
280	315	0.1270	0.1905	0.1092	0.1524	0.2413
315	355	0.1524	0.2159	0.1194	0.1651	0.2540
355	100	0.1651	0.2286	0.1270	0.1905	0.2921
400	450	0.2032	0.2667	0.1270	0.2032	0.3048
450	500	0.2159	0.2794	0.1651	0.2286	0.3429

Note: The axial displacement of the bearing is approximately 16 times the clearance reduction.
Source: Higgins, Lindley R. Handbook of Construction Equipment Maintenance, McGraw-Hill Inc., U.S.A., 1979.

(e) Slide the blade along the circumference of the outer ring toward the top bearing. The blade should pass between the top roller and the inner surface of the outer ring.

(f) Repeat this step with blades of increasing thickness until a blade cannot pass.

(g) Position the blade at the juncture of the top roller and the outer ring raceway. Grab the lower portion of the inner ring with the other hand and gently roll the top roller under the blade. Swivel the blade and pull it out.

(h) Repeat the above procedure with a blade .254 mm (.001 in) thicker and proceed until the blade cannot be pulled out.

The internal clearance of this roller and the outer ring is the thickness of the second to the last blade inserted.

(i) Rest the bearing on another position along its outer surface and using the same method, measure the clearance over different rollers.

(j) Do the same for the other set of rollers.

(k) Take note of the unmounted internal clearance and refer to Table A.3 for the recommended reduction in internal clearance.

(l) Position the bearing on its tapered seat and assemble the locknut.

(m) Force the bearing up the taper by tightening the locknut against the bearing with an impact type spanner wrench until the internal clearance is reduced to the value in Table A.3.

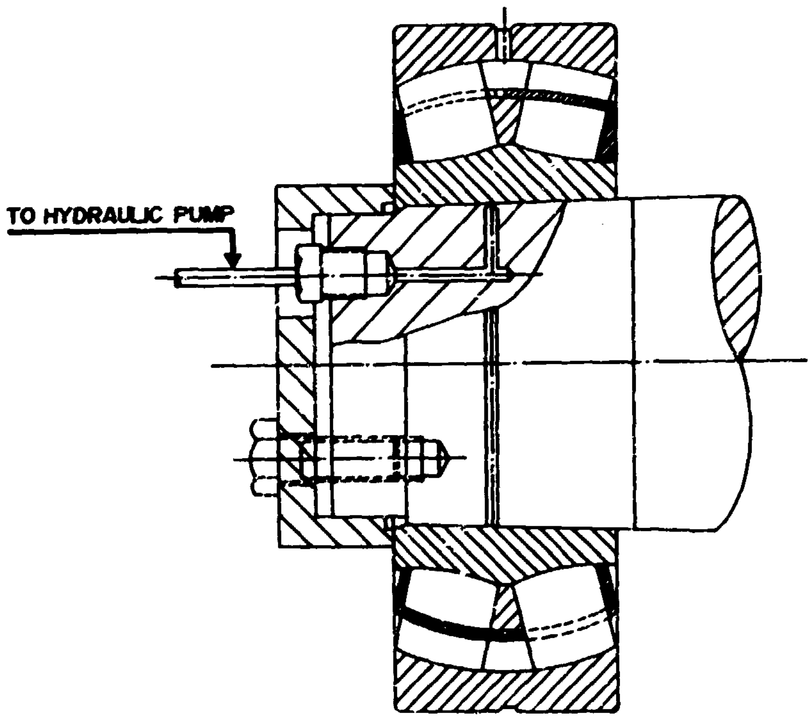


Figure A.9 Hydraulic Injection Through Shaft

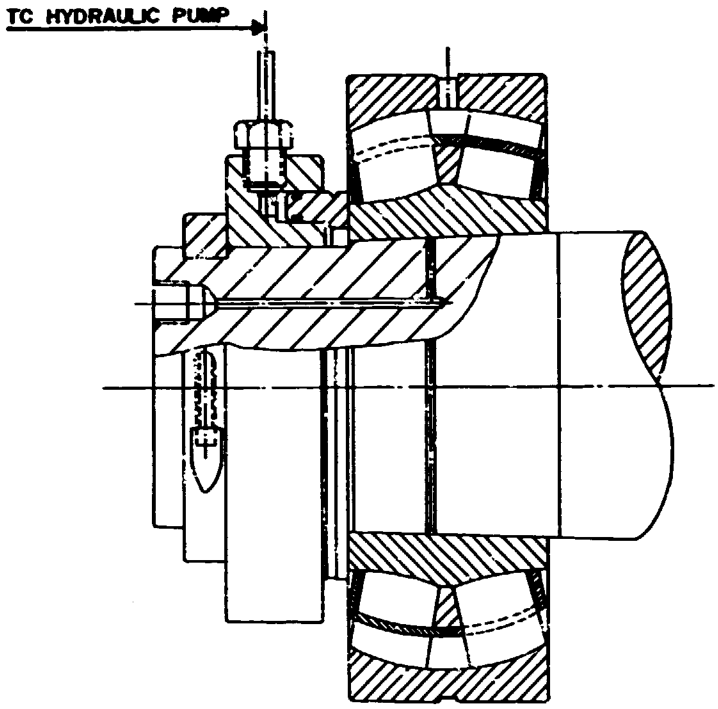


Figure A.10 Hydraulic Injection Through Hydraulic Nut

2.4 HYDRAULIC MOUNTING

The most efficient method of mounting tapered-bore bearings and which requires the least amount of driving force employs the injection of hydraulic fluid between the surface of the inner ring and the shaft seat. The hydraulic fluid can be pumped into the fit through a hole drilled into the end of the shaft (Fig. A.9), or through a hydraulic nut (Fig. A.10), for large sleeve mountings.

The bearing is driven up the taper just to provide some grip. The hydraulic pump is connected with the appropriate fittings and pressure is built up to 20,680-41,365 kPa (3000-6000 psi). This pressure will be sufficient to slide the bearing into place with minimal torque applied to the clamp plate or locknut.

Manufacturer's instructions should be followed when mounting cylindrical and tapered bore tapered roller bearings.

3. DISMOUNTING OF BEARINGS

Different types of tools and pullers can be used to remove a bearing from its seat. If necessary, pullers should be used with the appropriate fixtures to allow removal without damage to the bearing. Arbor presses used in mounting bearings can also be used in dismounting. As already mentioned, the thing to bear in mind is to apply the dismounting force to the ring with the interference fit.

Hydraulic removal can be employed to shafts with provisions for the introduction of fluid between the shaft and the bearing. To remove the bearing, the locking device is moved away by a distance of about 6 mm (1/4 in). The hydraulic pump is attached to the fitting (Fig. A.11) and pressure built up to the same amount 20,680-41,365 kPa used in the mounting. This pressure will cause the bearing to spring away from its seat but will be retained by the locking device.

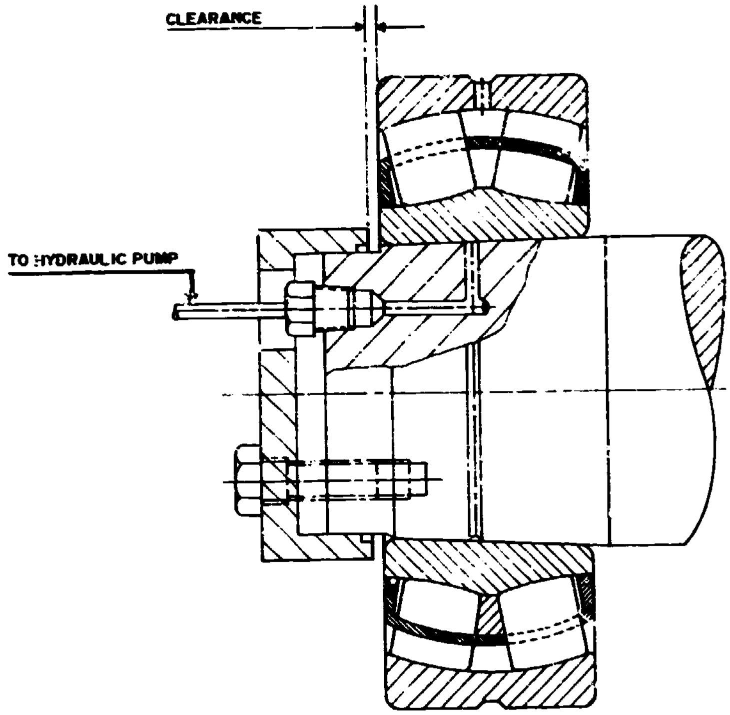


Figure A.11 Removal With Hydraulic Pump

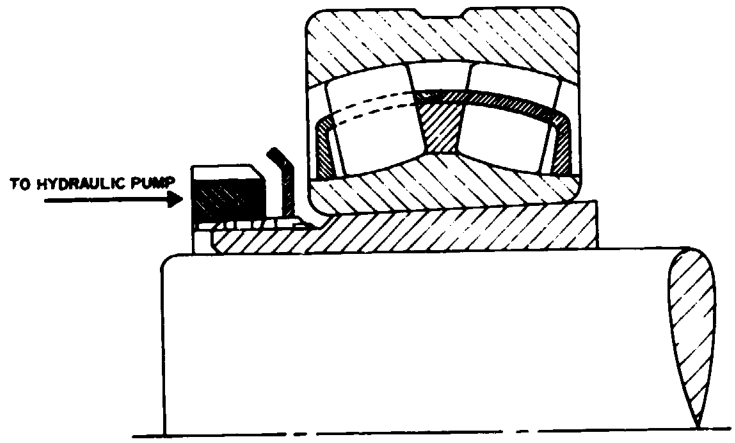


Figure A.12 Hydraulic Removal For Sleeve Mounting

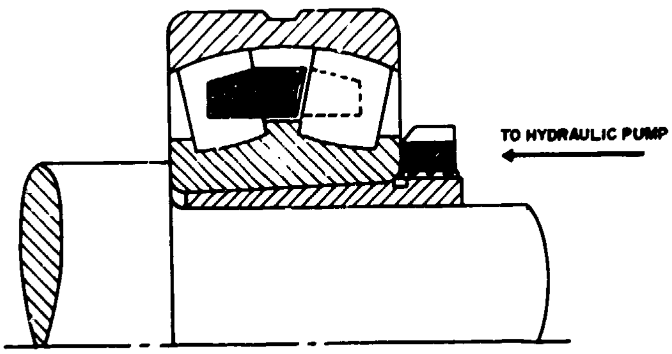


Figure A.13 Hydraulic Removal For Withdrawal Sleeve

A puller must be used together with a hydraulic pump when dismounting straight bore bearings. This pulier will provide the axial force needed to lift the bearing from the shaft.

Larger sleeve mountings can be provided with fixtures for hydraulic removal. For sleeve mountings on shafts with no holes for the pumping fluid, the technique illustrated on Fig. A.12 should be used. A special nut as shown in Fig. A.13 is required for withdrawal sleeves.

4. LUBRICATION OF BEARINGS

The most commonly used lubricants for rolling bearings are grease and liquid oil. Usually the bearing manufacturer specified whether grease or oil will be used and will recommend the specifications of the lubricant.

Below are guides to be used in choosing between oil or grease as lubricants.

Use oil for the following conditions:

a. High speeds.

b. High temperatures (over 93°C)

c. An oiltight seal can be fitted to the enclosure.

d. A central oil supply for the whole engine can be adopted.

e. Grease lubrication cannot be adopted for the bearing type.

Grease lubrication can meet the following demands:

a. Low speeds

b. Low temperatures (below 93°C)

c. Need for simple bearing enclosure.

d. Need for protection against the entry of dirt and other contaminants into the bearing.

e. Need for long intervals between relubrication.

4.1 OIL LUBRICATION

Table A.4 can be used as a general guide in selecting oil lubricants for rolling bearings.

Oil viscosities are usually specified by giving the viscosity rating at a temperature of 38°C (100°F) for light oils and 99°C (210°F) for heavy oils. Figure A.15 can be used to get the viscosity at another temperature.

Heavy oils with high viscosities at the operating temperature should be used for very low speeds, (less than 10 rpm). It is advisable to consult the bearing manufacturer for these conditions.

4.2 GREASE LUBRICATION

The recommendations of the National Lubricating Grease Institute (NLGI) for two types of rolling bearings are shown in Table A.5.

For grease lubrication, the supply of grease must be replenished at regular intervals. The spacing of these intervals will depend on the bearing size, operating speed and temperature. Table A.6 lists the recommended time between intervals for different bearing speeds and sizes. These intervals are to be used for temperatures below 71°C.

Table A.4 Oil-Lubrication Viscosity for Rolling Bearings

m^2/S (at 40°C)

Bearing bore, mm	Bearing speed, rpm				
	10,000	3,600	1,800	600	50
4-7	0.68	1.50	2.20		
10-20	0.32	0.68	1.50	2.20	4.60
25-45	0.10	0.68	0.32	1.50	3.20
50-70	0.07	0.22	0.68	1.50	3.20
75-90	0.03	0.10	0.22	0.68	2.20
100	0.03	0.07	0.22	0.68	2.20

Source: Mark's Standard Handbook for Mechanical Engineers. 8th ed.
Theodore Banmeister et. al. eds. McGraw-Hill Book Co., U.S.A. 1978

Table A.5 Recommended Grades of Greases for Different Types of Rolling Bearings

Bearing Type	Consistency (Grade)	Worked Penetration
Ball bearing	2	265-295
Roller bearing	0	355-380
	1	310-340

Source: Higgins, Lindley R. Handbook of Construction Equipment Maintenance, McGraw-Hill, Inc., U.S.A., 1979.

Below is the recommended procedure in relubricating bearing enclosures provided with grease nipples.

(a) Use the same lubricant as the original. The contamination of one grease with another will reduce its lubricating properties.

(b) Clean the grease nipple with the appropriate solvent. The solvent should not get into the cavity.

(c) Remove the lubrication fitting cover.

(d) If provided with drain plug, remove the plug and clean the drain cavity.

(e) Fill the grease gun with the required quantity or calibrate to get the delivery rate.

(f) Put the required quantity or until the grease comes out of the drain cavity.

(g) Run the mechanism until the excess grease comes out of the drain cavity.

Table A.6 Grease Relubrication Intervals for Ball Bearings (hours of operation)

Bearing bore, mm	Bearing speed, rpm				
	5,000	3,600	1,750	1,000	200
10	8,700	12,000	25,000	44,000	220,000
20	5,500	8,000	17,000	30,000	150,000
30	4,000	6,000	13,000	24,000	127,000
40	2,800	4,500	11,000	20,000	111,000
50		3,500	9,300	18,000	97,000
60		2,600	8,000	16,000	88,000
70			6,700	14,000	81,000
80			5,700	12,000	75,000
90			4,800	11,000	70,000
100			4,000	10,000	66,000

Note: Divide by 2 for cylindrical roller bearings.
Divide by 10 for spherical roller bearings.

Source: Marcks' Handbook for Mechanical Engineers. 8th ed.
Theodore Banmeister, et. al. eds. McGraw-Hill Book Co.
U.S.A. 1978

(h) Operate the mechanism and check if the temperature rise is within bounds.

Use the following procedure when replenishing grease in a hand-packed bearing.

(a) Dismantle the bearings assembly and wash in clean kerosene, degreasing agent or similar solvent.

For stubborn sludge or hard grease, use caustic solution to remove, or better still, soak the bearing in light mineral oil warmed to 54°C. **Do not use chlorinated fluids.**

(b) Wash in clean light mineral oil, preferably one with corrosion inhibitor. Do not spin the bearing before or during the oiling.

(c) Use fingers to force the grease into the spaces between the rolling elements. The bearing can be dismantled, if possible, for ease of refilling.

(d) After the cavities are completely filled with grease, spin the bearing by hand and wipe out any excess grease.

The spaces between the bearing should then be half filled with grease. Do not overlubricate.

5. TROUBLE SHOOTING OF ROLLING BEARINGS

A guide to bearing troubleshooting is contained in this section. The complaint, the probable cause of the problem and practical solutions are tabulated for easy reference.

Common bearing complaints are classified into five groups:

- Overheated Bearing
- Noisy Bearing/Excessive Vibration
- Loose Bearing
- Unlubricated Bearing
- Hard-turning Shaft

Each table is headed by a typical complaint which can lead to bearing failure. The first column lists the probable cause of the problem and the second provides a practical solution.

Table A.7 Overheated Bearing

Probable Cause	Practical Solution
1. Inadequate lubrication	Adjust oil-cup height maintaining oil level at center of lowest ball or roller. Fill grease housing 1/2 to 2/3 full. Clean oil holes, filters and vents. Use correct type of oil or grease.
2. Excessive churning of lubricant	Use lower-viscosity oil. Lower level of oil to center of bottom ball and roller. Fill grease housing 1/2 full. Use oil mist.
3. Inadequate internal clearance	Use bearing with additional looseness. Provide allowance for differential thermal expansion. Reduce interference of shaft and housing fits. Correct any housing out of roundness or warping.
4. High seal friction	Stretch felt or use reduced spring tension with leather or composition seals. Lubricate seals. Switch from rubbing seal to low-clearance shield.
5. Excessive preloading	Use shims or gaskets to relieve axial preload with opposed pair or with two held bearings on a shaft subjected to thermal expansion. Change design to use only one "held" bearing.
6. Spinning outer ring	Use closer housing fit. Use steel insert in soft aluminum housing. Use garter spring or rubber holding ring.
7. Misalignment	Get shafts and bearings in line by shimming pillow blocks, housing or machines. Realign bearing seats and shafts and housing shoulders.

Source: Basic Line – 5th ed., Petrophil Corporation Philippines, 1982.

Table A.8 Vibration or Noisy Bearing

Probable Cause	Practical Solution
1. Using wrong type of oil or grease	Check recommendation of lubricant supplier. A better-feeding grease or a higher viscosity oil may help.
2. Lack of lubrication	(Refer to Table A.7-1)
3. Defective bearing	Check bearing for brinelling, fatigue, wear, wobble or poor cage. Replace bearing if necessary.
4. Dirt and other foreign matter	Clean bearing housing. Replace worn seals and improve seal arrangement. Eliminate source of dirt, etc.
5. Corrosion	Improve sealing to keep out corrosive elements. Use corrosion-resistant lubricants.
6. Excessive internal clearance	Use bearing with smaller clearance.
7. Misalignment	(Refer to Table A.7-7)
8. Unbalance	Balance rotor
9. Housing fit or shaft	Build up shaft or bore through chrome plating or metallize and regrind.
10. Improper mounting	Avoid brinelling caused by pounding of bearing. Correct dirty or off-square shaft and housing shoulder and seals.
11. False brinelling	Isolate machine from platform during idle periods by using vibration mounts.
12. Seal rub	Check for metal bearing seal or shield rubbing on shaft, shoulder or housing.

Source: Basic Line – 5th ed. Petrophil Corporation Philippines, 1982.

Table A.9 Loose Bearing

Probable Cause	Practical Solution
1. Too large housing bore	Buildup bore with chrome plate. Metallize and regrind, bore out housing and press in sleeve to give proper bearing fit (a slip fit on outside diameter usually desirable to allow for different axial thermal expansion of a shaft between two bearings).
2. Too small shaft diameter	Turn down shaft chrome-plate or metalize and regrind for proper fit. Retighten adapter to get firm grip on shaft.

... asic Line – 5th ed., Petrophil Corporation Phillippines, 1982.

Table A.10 Loss of Lubricant

Probable Cause	Practical Solution
1. Leaking oil on seal	Correct oil level to center of lowest ball or roller. Replace seal; use double-seal arrangement with drain between. Eliminate any unfavorable air flow by proper baffles and balancing channels.
2. Leakage at housing split	Use thin layer of gasket cement. Replace housing if necessary.
3. Grease leakage	Fill grease housing 1/2 to 2/3 full only. Use channelling-type grease. Eliminate any pressure causing air flow through bearing. Keep solvents or water from entering and softening grease. Replace seals if necessary.
4. Dry or caked residue	Cool oil in external cooler. Cool bearing housing. Increase oil flow to promote cooling. Use silicone or other high temperature grease. If available, use oxidation-inhibited synthetic oil or grease.

Source: Basic Line – 5th ed., Petrophil Corporation Philippines, 1982.

Table A.11 Hard Turning of Shaft

Probable Cause	Practical Solution
1. Too much bearing preload	Reduce interference fit on shaft or in housing. Use bearing with greater internal clearance where heat conduction expands shaft and inner bearing ring. Relieve axial preloading by housing shims with either two opposed bearings or two "held" bearings on one shaft.
2. Severe seal rub	Stretch felt seals to reduce their friction. Use reduced spring tension on leather or composition seals. Scrape out inside diameter of rubber seals. Use shield with clearance on the shaft.
3. Corrosion	(Refer to Table A.8 - 5)
4. Dirt	(Refer to Table A.8 - 4)
5. Lack of lubrication	(Refer to Table A.7 - 1 and Table A.10)
6. Wrong type of lubricant	(Refer to Table A.8 - 1)
7. Bearing pinching or cocking	Scoop housing bore to relieve pinching. Replace or remachine warped housing. Check bearing seals for possible source of cocking

Source: Basic Line – 5th ed., Petrophil Corporation Philippines, 1982.

Lubrication and Corrosion Data

Table A.12 Types of Additives for Lubricating Oil

Main Type	Function and sub-types
Acid neutralisers	Neutralise contaminating strong acids formed, for example, by combustion of high sulphur fuels or, less often, by decomposition of active EP additives.
Anti-foam	Reduces surface foam
Anti-oxidants	Reduce xidation. Various types are: oxidation inhibitors, retarders, anti-catalyst metal deactivators, metal passivators
Anti-rust	Reduces rusting of ferrous surfaces swept by oil
Anti-wear agents	Reduce wear and prevent scuffing of rubbing surfaces under steady load operating conditions; the nature of the film is uncertain
Corrosion inhibitors	Type (a) reduces corrosion of lead; type (b) reduces corrosion of cuprous metals
Detergents	Reduce or prevent deposits formed at high temperatures, e.g. in ic engines
Dispersants	Prevent deposition of sludge by dispersing a finely divided suspension of the insoluble material formed at low temperature
Emulsifier	Forms emulsions; either water-in-oil or oil-in-water according to type
Extreme pressure	Prevents scuffing of rubbing surfaces under severe operating conditions, e.g. heavy shock load, by formation of a mainly inorganic surface film
Oiliness	Reduces friction under boundary lubrication conditions; increases load-carrying capacity where limited by temperature rise by formation of mainly organic surface films
Pour point depressant	Reduces pour point of paraffinic oils
Tackiness	Reduces loss of oil by gravity, e.g. from vertical sliding surfaces, or by centrifugal force
Viscosity index (VI) improvers	Reduce the decrease in viscosity due to increase of temperature

Source: Bailey, Charles A. and Aarons, J.F., *The Lubrication Engineer's Manual*, U.S. Steel, 1971.

Table A.13 Types of Additive Oil Required for Various Types of Machinery

Type of machinery	Usual base oil type	Usual additives	Special requirements
Food processing	Medicinal white oil	None	Safety in case of ingestion
Oil hydraulic	Paraffinic down to about −20°C, naphthenic below	Anti-oxidant Anti-rust Anti-wear Pour point depressant VI improver Anti-foam	Minimum viscosity change with temperature; minimum wear of steel/steel
Steam and gas turbines	Paraffinic or naphthenic distillates	Anti-oxidant Anti-rust	Ready separation from water, good oxidation stability
Steam engine cylinders	Unrefined or refined residual or high-viscosity distillates	None or fatty oil	Maintenance of oil film on hot surfaces; resistance to washing away by wet steam
Air compressor cylinders	Paraffinic or naphthenic distillates	Anti-oxidant Anti-rust	Low deposit formation tendency
Gears (steel/steel)	Paraffinic or naphthenic	Anti-wear, EP Anti-oxidant Anti-foam Pour point depressant	Protections against abrasion and scuffing
Gears (steel/bronze)	Paraffinic	Oiliness Anti-oxidant	Reduce friction, temperature rise, wear and oxidation
Machine tool slideways	Paraffinic or naphthenic	Oiliness; tackiness	Maintains smooth sliding at very low speeds. Keeps film on vertical surfaces
Hermetically sealed refrigerators	Naphthenic	None	Good thermal stability, miscibility with refrigerant, low flow point
Diesel engines	Paraffinic or naphthenic	Detergent Dispersant Anti-oxidant Acid neutralizer Anti-foam Anti-wear Corrosion inhibitor	Vary with type of engine thus affecting additive combination

Source: Bailey, Charles A. and Aarons, J.F., *The Lubrication Engineer's Manual*, U.S. Steel, 1971.

Table A.14 Some Materials Used as Solid Lubricants

Layer-lattice compounds	
Molybdenum disulphide	Graphite
Tungsten diselenide	Tungsten disulphide
Niobium diselenide	Tantalum disulphide
Calcium fluoride	Graphite fluoride
Polymers	
PTFE	Nylon
PTFCE	Acetal
PVF	Polyimide
FEP	Polyphenylene sulphide
Metals	
Lead	Tin
Gold	Silver
Indium	
Other inorganics	
Molybdic oxide	Boron trioxide
Lead monoxide	Boron nitride

Source: Landsdown, A.R., *Lubrication: A Practical Guide to Lubricant Selection*, Pergamon Press, Oxford, England, 1982.

Table A.15 Viscosity Ranges for Various Applications

Oil type	Viscosity range (m^2/S) at operating temperature
Clock or instrument oil	.05 – .20
Sewing-machine oil	.10 – .25
Motor oil	.10 – .50
Turbine oil	.10 – .50
"General Purpose" household oil	.20 – .50
Hydraulic oil	.20 – 1.00
Roller bearing oil	.10 – 3.00
Plain bearing oil	.20 – 15.00
Gear oils:	
Low-speed spur, helical, bevel	2.00 – 8.00
Medium-speed spur, helical, bevel	.50 – 1.50
High-speed gears	.15 – 1.00
Hypoid gears	.50 – 6.00
Worm gears	2.00 – 10.00
Open gear lubricants	1.00 – 500.00

Source: Landsdown, A.R., *Lubrication: A Practical Guide to Lubricant Selection*, Pergamon Press, Oxford, England, 1982.

Note: To convert m^2/S to cSt, multiply by 100

Table A. 16 1977 Table of SAE Oil Ratings

SAE no.	Viscosity at −18°C ($N\text{-}s/m^2$)	Viscosity at 100°C (m^2/s)	
	Max	Min.	Max
Engine oils			
5W	59,840	.038	–
10W	119,675	.041	–
20W[a]	478,700	.056	–
20		.056	less than .093
30		.093	less than .125
40		.125	less than .163
50		.163	less than .219
Gear oils			
75	155,580		
80	1,033,992		
90		.14	less than .25
140		.25	less than .43
250		.43	

[a]15W may be used to identify 20W oils which have a maximum viscosity of 239,350 $N\text{-}S/m^2$

Source: Landsdown, A.R., *Lubrication: A Practical Guide to Lubricant Selection,* Pergamon Press, Oxford, England, 1982.

Note: To convert Ns/m^2 to cP, divide by 47.87
To convert m^2/S to cSt, multiply by 100

Table A. 17 API (American Petroleum Institute) Automotive Engine Service Classification

"S" – SERVICE STATION ENGINE SERVICES CLASSIFICATION

Service Designation	API Engine Service Description	Related Military and Industry Designation
SA	FORMERLY FOR UTILITY GASOLINE AND DIESEL ENGINE SERVICE. Service typical of older engines under such mild conditions that the protection afforded by compounded oils is not required. This classification has no performance requirements and oils in this category should not be used in any engine unless specifically recommended by the equipment manufacturer.	Oil without additive except that it may contain pour and/or foam depressants.
SB	FOR MINIMUM DUTY GASOLINE ENGINE SERVICE Service typical of older gasoline engines operated under such mild conditions that only minimum protection afforded by compounding is desired. Oils designed for this service have been used since the 1930's and provided only anti-scuff capability and resistance to oil oxidation and bearing corrosion. They should not be used in any engine unless specifically recommended by the engine manufacturer.	Inhibited oil (non-detergent). Provides some anti-oxident and anti-scuff capabilities.

SC	FOR 1964 GASOLINE ENGINE WARRANTY MAINTENANCE SERVICE Service typical of gasoline engines in 1964 through 1967 Models of passenger cars and some trucks operating under engine manufacturers' warranties in effect during those model years. Oils designed for this service provide control of high and low-temperature deposits, wear, rust and corrosion in gasoline engines.	1964 Warranty approved MS Ford ESE-M2C101-A
SD	FOR 1968 GASOLINE ENGINE WARRANTY MAINTENANCE SERVICE Service typical of gasoline engines in 1968 through 1970 Models of passenger cars and some trucks operating under engine manufacturers' warranties in effect during those model years. Also may apply to certain 1971 and/or later models as specified (or recommended) in the owner's manuals. Oils designed for this service provide more protection against high and low-temperature engine deposits, wear, rust and corrosion in gasoline engines than oils which are satisfactory for API Engine Service Classification SC and may be used when API Engine Service Classification SC is recommended.	1968 Warranty Approved MS, Ford ESE-M2C-101-B, General Motors GM 6041-M
SE	FOR 1972 GASOLINE ENGINE WARRANTY MAINTENANCE SERVICE Service typical of gasoline engines in passenger cars and some trucks beginning with 1972 and certain 1971 models operating under engine manufacturer's warranties. Oils designed for this service provide more protection against oil oxidation, high temperature engine deposits, rust and corrosion in gasoline engines than oils which are satisfactory for API Engine Service Classifications SC and SD and may be used when either of these classifications is recommended.	1972 Warranty Approved, Ford ESE-M2C101-C, General Motors GM 6136-M, US MIL-L-46152A
SF	FOR 1980 GASOLINE ENGINE WARRANTY MAINTENANCE SERVICE Service typical of gasoline engines in passenger cars and some trucks beginning with the 1980 model operating under engine manufacturer's recommended maintenance procedures. Oils designed for this service provide increased oxidation stability and improved anti-wear performance relative to oils which meet the minimum requirements for API Service Category SE. These oils also provide protection against engine deposits, rust and corrosion. Oils meeting API Service Category SF may be used where API Service Categories SE, SD, or SC are recommended.	1980 Engine Manufacturer Maintenance Service, Ford ESE-M2C-153B, General Motors GM 60-48-M

Service Designation	API Engine Service Description	Related Military and Industrial Specification
CA	FOR LIGHT DUTY DIESEL ENGINE SERVICE Service typical of diesel engines operated in mild to moderate duty with high-quality fuels and occasionally has included gasoline engines in mild service. Oils designed for this service provide protection from bearing corrosion and from ring belt deposits in some naturally aspirated diesel engines when using fuels of such quality that they impose no unusual requirements for wear and deposit protection. They were widely used in the late 1940's in any engine unless specifically recommended by the equipment manufacturer.	US MIL-L-2104A
CB	FOR MODERATE DUTY DIESEL ENGINE SERVICE Service typical of diesel engines operated in mild to moderate duty, but with lower-quality fuels which necessitate more protection from wear and deposits. Occasionally has included gasoline engines in mild service. Oils designed for this service provide necessary protection from bearing corrosion and from ring belt deposits in some naturally aspirated diesel engines with higher sulfur fuels. Oils designed for this service were introduced in 1949.	US MIL-L-2104A Supplement 1 (1949)
CC	FOR MODERATELY DUTY DIESEL AND GASOLINE ENGINE SERVICE Service typical of certain naturally aspirated, turbocharged or supercharged diesel engines operated in moderate to severe-duty service and certain heavy-duty gasoline engines. Oils designed for this service provide protection from high-temperature deposits and bearing corrosion in these diesel engines and also from rust, corrosion and low-temperature deposits in gasoline engines. These oils were introduced in 1961.	US MIL-L-2104B, MIL-L-46152A Specs
CD	FOR SEVERE DUTY DIESEL ENGINE SERVICE Service typical of certain naturally aspirated, turbocharged or supercharged diesel engines where highly effective control of wear and deposits is vital, or when using fuels of a wide quality range including high sulfur fuels. Oils designed for this service were introduced in 1955 and provide protection from bearing corrosion and from high-temperature deposits in these diesel engines.	Caterpillar Superior Lubricants (Series 3), US MIL-L-2104C (1972), US MIL-L-45199B

Source: Caltex Product Reference Guide, Caltex (Phils.), Inc.

Table A. 18 API (American Petroleum Institute) Service Designations for Automotive Manual Transmissions and Axles

API – GL – 1	Spiral-bevel and worm gear axles and some manual transmissions under mild service.
API – GL – 2	Worm gear axles not satisfied by API – GL – 1.
API – GL – 3	Manual transmissions and spiral-bevel axles under moderately severe service.
API – GL – 4	Hypoid gears in normal severe service without severe shock loading.
API – GL – 5	Hypoid gears in severest service including shock loading.

Notes:

1. The ASTM D 2711-69 procedure should be modified per para. 3.2 when applied to EP lubricants.
2. Cleanliness: Must be free from grit and abrasives.
3. Additive Solubility: Must be filterable to 100 microns (wet or dry) without loss of EP additive.

Source: Caltex Product Reference Guide, Caltex (Phils.), Inc.

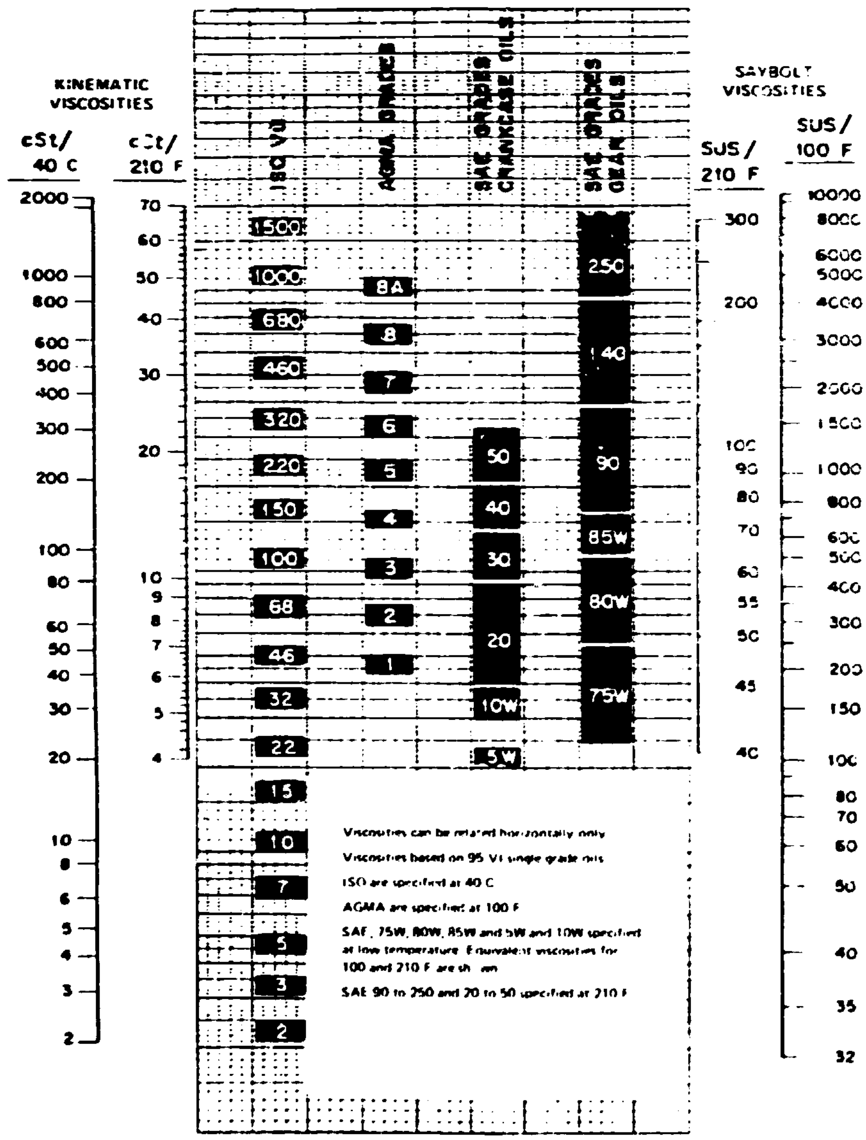


Figure A. 14 Viscosity Classification Equivalents

Note: To convert CST to m^2/S, multiply by 100.
To convert SUS to stokes, see table A.24, Appendix VII.

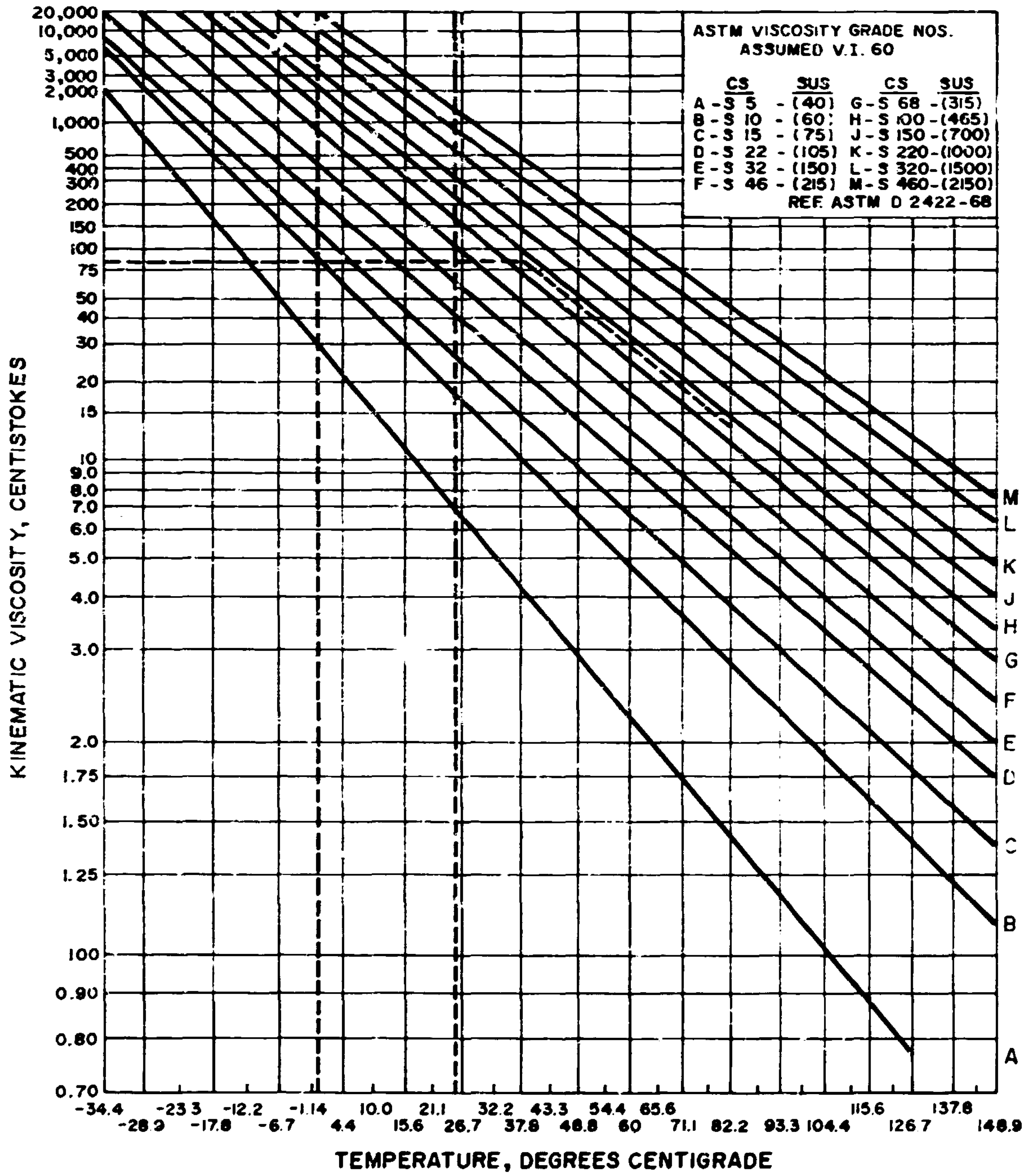


Figure A.15 Temperature-Viscosity Diagram

Table A. 19 Arrangement of Metals and Alloys in a Galvanic Series Based on Potential Measurements in Sea Water

Metal	Steady Potential Negative to Saturated Calomel, Half Cell Volts
Zinc	1.03
Aluminum 3 SH	0.94
Aluminum 61 ST	0.79
Aluminum 52 SH	0.76
Cast Iron	0.61
Low Carbon Steel	0.61
Stainless type 430 (active)	0.57
Ni-Resist (20 Percent Ni)	0.54
Stainless type 304 (active)	0.53
Stainless type 410 (active)	0.52
Ni-Resist (No. 0 Percent Ni plus Cu)	0.49
Naval Rolled Brass	0.46
Yellow Brass	0.40
Copper	0.36
Red Brass	0.36
Compositon G Bronze	0.33
Admiralty Brass	0.31
90:10 Cupro-Nickle, .8 Percent Fe	0.29
70:30 Cupro-Nickle, .06 Percent Fe	0.28
70:30 Cupro-Nickle, .47 Percent Fe	0.27
Stainless type 430 (passive)	0.25
Nickle	0.22
Stainless type 316 (active)	0.20
Inconel	0.18
Stainless type 410 (passive)	0.17
Titanium (commercial)	0.15
Silver	0.15
Titanium (high purity iodide)	0.13
Stainless type 304 (passive)	0.08
Hastelloy C	0.08
Monel Metal	0.08
Stainless type 316 (passive)	0.05

Table A.20 Electromotive Force Series (EMF)

Half cell potentials of metal under standard conditions. (Standard conditions are 1 – normal solutions of the metal ion at 25°C)

Metal	Std. Electrode Potential
Calcium	– 2.87 volts
Magnesium	– 2.40 "
Aluminum	– 1.70 "
Zinc	– 0.76 "
Chromium	– 0.56 "
Iron	– 0.44 "
Cadmium	– 0.40 "
Nickle	– 0.23 "
Tin	– 0.14 "
Lead	– 0.12 "
Hydrogen	– 0.00 "
Copper (1/2 Cu++)	– 0.34 "
Copper (Cu+)	– 0.47 "
Silver	– 0.80 "
Mercury	– 0.80 "
Gold	– 1.50 "

Saturated Copper – copper sulfate electrode, + 0.316 volts

• Saturated Calomel electrode, + 0.242 volts

Remarks:
1) Metals above hydrogen will liberate hydrogen from acids.
2) Metals are anodic to those below them (will corrode in preference to those below them when coupled).
3) The lower the position of a metal in this table, the more "noble" is the metal – i.e. the less susceptible it is to corrosion.

• Consists of mercury electrode covered by solution of 1 NKCl saturated with mercurous chloride.

System of Units

Table A.21 Symbols of Units

Symbol	Unit
m	metre
km	kilometre
L	litre
min	minute
h	hour
d	day
yr	year
a	annum
kg	kilogram
kg/h	kilogram per hour
t	tonne (= 1000 kg)
kPa	kilo Pascal (= 1000 N/m^2)
J	joule
kJ	kilojoule
GJ	gigajoule
W	watt
kW	kilowatt
MW	megawatt
kWh	kilowatt hour
MWh	megawatt hour
kV	kilovolt
kVA	kilovolt ampere
MVA	megavolt ampere
lm	lumen
lx	lux. (= 1 lm/m^2)
W/m°k	watts per metre kelvin
W/m^2	watts per square metre
W/sr	watts per steradian

Table A.22 SI Prefixes

Name	Symbol	Factor by which the unit is multiplied
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	u	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Table A.23 Selected Conversion Factors to SI Unit

US or metric Unit	Multiply by	To Obtain SI Unit
in	2.54	mm
slug	14.594	kg
lbm	0.4539	kg.
tonne (2204.6 lbm)	1,000	kg.
cu ft	0.028	m^3
U.S. gallon	3.785×10^{-3}	m^3
	3.785	L
barrel of oil (42 U.S. gallons)	159	L
Btu	1,055.1	J
kcal	4.187	J
hp–h	2.685	MJ
Btu/h	0.2931	W
hp	746	W
Btu/h – ft^2	3.1525	W/m^2
Btu/lbm	2.326	kJ/kg
kcal/kg.	4.187	kJ/kg
Btu/ft^3	37.26	kJ/m^3
cSt (centistoke)	0.01	m^2/s
cP (centipoise)	47 87	N–s/m^2
psi	6.8942	kPa

Table A.24 Conversion of SUS (Soybolt Universal Seconds) to stokes

32 < SUS < 100 sec	:	stokes = .00226 (SUS) – 1.95/SUS
SUS > 100 sec	:	stokes = .00220 (SUS) – 1.35/SUS

Directory of Technical Assistance Centers

National Engineering Center
University of the Philippines
Diliman, Quezon City
Telephone Nos. 922-47-14
97-60-61/81 Loc. 883
Contact Person:
Dr. Leopoldo V. Abis
Executive Director

Conservation Division
Bureau of Energy Utilization
Merritt Road, Fort Bonifacio
Makati, Metro Manila
Telephone No. 87-76-33
Contact Person:
Mr. Benjamin P. Lim
Division Chief

CONDITION MONITORING

Process Control Systems Contractors, Inc.
(CONSYSTEMS)
Rm. 605 Cardinal Building
999 P. Gil Cor. F. Agoncillo Street
Ermita, Manila
Telephone Nos. 58-65-84, 50-15-70
Telex: 65027 MBMIDC PN
Contact Person:
Macarthur B. Monsanto
Bus. Dev't. Director

Uptown Industrial Sales Corporation
56 Madison Street
Mandaluyong, Metro Manila
Contact Person:
Mr. Perfecto Tan
Exec. Vice President

LUBRICANTS AND LUBRICATION SERVICES

Caltex (Philippines), Inc.
540 Padre Faura Street
Ermita, Manila
Telephone No. 521-35-01
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Manager
Lubricant Sales and
Technical Services

Petrophil Corporation
7901 Makati Avenue, Makati, Metro Manila
Telephone Nos. 85-90-61, 85-90-88
Contact Person:
Mr. Floracito S. Navarro
Senior Engineer
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Pilipinas Shell Petroleum Corporation
1330 Roxas Boulevard, Ermita, Manila
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Marketing Technical Dept.

CORROSION PREVENTION AND CONTROL

Corrosion Engineering Services
Rm. 319, Carolina Choy Building
2276 Pasong Tamo Extension
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President

Asiatic Corrosion Control Corporation
14-A Tuayan Street
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Telephone Nos. 712-04-45 to 49
Contact Person:
Mr. Wenceslao F. Aquino
President

LEAK PREVENTION

Philippine Packings and Seals Corporation
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Salcedo St., Legaspi Village
Makati, Metro Manila
Telephone No. 86-36-55, 87-39-32
Contact Person:
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Vice President, Marketing

Hidromac-Dura Asia, Inc.
89 Buendia Avenue, Makati
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Telephone No. 87-69-78, 89-13-45
Contact Person:
Mr. Emmanuel Realica
President

INDUSTRIAL WATER TREATMENT

W. R. Grace (Philippines), Inc.
Dearborn Chemical Division
16 Cristobal Street
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Mr. Carlo S. Guanzon
Marketing Manager

Mer Chemical Laboratory and Services
7 Major Santos Dizon Street
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Chemperts Corporation
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Telephone No. 721-25-98
Contact Person:
Mr. Rafael Paguio, Jr.
Marketing Manager

Transworld Trading Co., Inc.
4th Floor, Don Pablo Building
114 Amorsolo St., Legaspi Village
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Telephone No. 88-13-26
Contact Person:
Mr. Gregorio D. Tiamzon

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89-94-68
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Technical Sales/Projects

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Telephone Nos. 947-92-75, 947-93-17
947-93-67, 47-12-35
Contact Person:
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President

Chester Industries, Inc.
1622-1626 Felix Huertas Street
Sta. Cruz, Manila
Telephone Nos. 711-40-11 to 14
Contact Person:
Mr. Ignacio S. Sam
President and General Manager

Atlantic Gulf and Pacific Co. of Manila
Honiron Division
Tacoma St., Port Area, Manila
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Contact Person:
Mr. Ruben Villanueva
Manager

MAINTENANCE SERVICES FOR REFRIGERATION AND AIR-CONDITIONING FACILITIES

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Koldwinds Systems, Inc.
1639 Dian St. Cor. Rockfeller Street
Makati, Metro Manila
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815-26-14
Contact Person:
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General Manager

MAINTENANCE SERVICES FOR ELECTRICAL EQUIPMENT

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827-44-17
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VP-Product Service Division

Cummins Diesel Sales & Service Corporation of the Philippines
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Mr. Leonardo C. Ulanday
Technical Services Manager

USIPHIL, Inc.
146 Pasig Boulevard
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Technical Services Manager

MAINTENANCE SERVICES FOR PUMPS AND COMPRESSORS

Pumps

Goulds Pumps (Phils.), Inc.
Natividad I Building
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Compressors

Atlas Copco (Philippines), Inc.
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J. P. Meneses
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Vice-President – Marketing

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