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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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IMPROVEMENT OF ENGINEERING DESIGN CAPABILITIES OF THE DEVELOPING COUNTRIES

(With Particular Reference to Automotive Components)[1]

by

Emil F. Gibian
Consultant
Cleveland, Ohio
United States of America

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SUMMARY

IMPROVEMENT OF ENGINEERING DESIGN CAPABILITIES OF THE DEVELOPING COUNTRIES [1]

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The object of this paper is the description and analysis of the factors which enter into the creation of new designs and which should be considered for the improvement of engineering design capabilities. This is done by describing in some detail case histories of actual engineering design projects involving new design developments of advanced automotive components. While the examples chosen are taken from the area of automotive engineering, the author believes that the principles deduced from these cases are generally applicable to design situations in most other branches of engineering. References cited in the paper offer further reading material on the subject.

The motives and reasons for undertaking engineering design activities are generated by personal desires of native engineers, by prestige considerations and most importantly by the advisability or necessity to adapt a design to the specific conditions of the country.

The international firms maintain large design engineering divisions and equip them with facilities to carry on research, development, design and testing of new products. Industrial plants in developing countries usually are smaller and cannot afford to maintain complete design engineering departments. Developing countries may resort to engineering design centers, where knowledge and facilities are pooled.

A new design, progressing from its conception to actual commercial application, affects most, if not all, departments of an industrial organization. The design engineering group, where the research, design and testing is performed, is not an isolated independent organization. Whether an engineering design center or a department of an industrial unit, the organization and function of such a group should be based on the concept of systems engineering. The personnel consists of design engineers, scientists, mathematicians, material specialists and technicians. It needs ready access to a library offering technical publications and patent literature. The use of a computer is indispensable for the solution of problems affected by many interrelated and variable factors. Computer programs are available also for "instant" design of components.

The tools of the design engineer are complex, sophisticated and costly. He must be backed up by research, development and testing laboratories, use mathematical models, statistical techniques and, as mentioned before, a computer.

Particular attention should be given to an early cooperation between the design engineer and the manufacturing engineer. This collaboration aims at incorporating in the design features which will facilitate manufacture of the product and possibly even improve its performance. Examples of such design considerations are enumerated.

Five case histories are then described, in which are illustrated many of the principles discussed in the paper.

A self-contained automatic tappet illustrates the development of a good design, which was still-born because certain technological advancements were not foreseen.

Exhaust valve made from 21-4N steel was perfected after a long development period, called for exhaustive testing and cooperation with various branches of engineering, particularly with metallurgists.

Molybdenum coated piston rings, their design, the development procedure, the laboratory and road testing equipment are described. The systems approach was used to arrive at optimum operating characteristics.

Designing a new steering linkage is explained step by step and the testing techniques for performance and safety are described.

Vehicle anti-skid brake control shows the use of mathematical models and computer analysis during the design stage and how costly prototype building can be avoided.

The concluding chapter attempts to give an answer to the question when and how should a developing country embark on an independent design engineering activity. It stresses the necessity for training competent engineers and to have adequate research, development and testing facilities. It is suggested that developed industrialized countries should lend a helping hand towards a successful start.

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I. THE OBJECT OF THIS PAPER

1. Today's automobile is a marvelous machine. It is a complex system, yet performs reliably, efficiently, safely and comfortably. To the average user, it appears to be a perfect piece of mechanism, the ultimate of perfection, where further improvements are neither possible nor desirable. Yet each year automotive engineers devise changes and improvements to better last year's product. What are the motives and the procedures that make these constant advances feasible? And when and how can the automotive industry of a developing country enter into an independent engineering design activity to fill the needs particular to its region's need and its conditions? The object of this paper is to analyze some of the factors to be considered in the development of an automotive engineering design center and to use actual case histories to illustrate the application of modern engineering techniques. While most cases will cover the successful development of new or improved automotive components, one or two actual case histories ending in failure will be used to illustrate factors responsible for a negative result. We learn from experience which embraces both success and failure.

II. DEFINITIONS OF OBJECTIVES

2. The automobile industry of a developing country starts--as a rule--with a strictly manufacturing operation, producing vehicles manufactured

to engineering specifications of a licensor from a developed country. No automotive design engineers are employed by the domestic enterprise in this initial phase, as there is no need for them and they could not perform any useful function. Design changes and improvements originate in the licensor's plant, are developed and tested there and passed onto the licens as a proven production item.

3. The desire to participate in the design of automotive vehicles and in the development of new ideas grows with the progress of the manufacturing activity. What are the motives for this urge and its final objectives? Firs is the emotional factor. Ambitious native automotive engineers need an outlet for their creative desire and generate ideas for new designs, but because of lack of research and development and testing facilities seldom can translate their ideas into reality nor do they find a receptive attitude in the engineering organization of the licensor. The second factor is also partly emotional and may be called a prestige consideration. Government authorities and the management of the automotive plant wish to enhance the prestige of its auto industry by incorporating original design features into the domestic product and thereby distinguishing it from the previous copy of a licensor's model as a truly domestic innovation and achievement. The third factor is a realistic objective: to adapt the home product to the specif needs and condition of the country. The terrain, climate, road conditions, servicing facilities, and economic conditions may call for new approaches to the design of the vehicle and its components, yet these changes will not

be accomplished by the licensor--be it because he has to give priority to the development of his home market or because he lacks the familiarity with the problems of his licensee. To illustrate this point, we may consider the modification of a highly successful car of U.S.A. make and made to exactly the same specifications in a developing country. Yet in this country of extreme sudden changes in altitude and the accompanying sudden transitions from low to high temperature, both the ignition timing and the cooling system adequate for United States conditions, proved inadequate for the mountainous terrain of the tropical country. The subsidiary in the developing country, by now provided with trained design engineering personnel, development and testing facilities, came up with redesigned ignition timing and cooling systems which perform successfully.

4. Large automotive manufacturing corporations in developed countries can afford to maintain large engineering departments with all the associated facilities necessary for design, research, development and testing of new vehicles or components. Manufacturers in developing countries will seldom be large enough to carry on such an activity but their desire to undertake independent design activities will lead to the establishment of Engineering Design Centers serving many plants and possibly performing this service for more than one country.

5. This paper concerns itself, as stated above, with the description of the requirements that have to be met to successfully enter into automotive design. To make this presentation of practical value, general principles

will be dealt with rather briefly and references cited will be drawn not only from the automotive area, but also from sources dealing with general design engineering. However, all these factors will be illustrated by rather detailed case histories to show how these principles have been actually applied.

III GENERAL CONSIDERATIONS

6. A new design originates in a broad sense in the engineering department, but before it can be translated into actual commercial application, the entire organization has to participate and contribute to the various phases in its conception, development, testing and manufacturing. Anyone concerned with the ramifications a new product development entails will find an excellent introduction to this subject in Victor Raviolo's SAE Paper No. 680509, "Planning a Product". A condensed version was published in the SAE JOURNAL (Ref. 1). Any new design whether a complete vehicle or a subsystem or a component, is created to fulfill an objective which should be clearly stated at the outset of the project. Research and development precede the actual design and is followed by testing of prototypes. However, at the same time the manufacturing organization enters into the picture, cost analysis is made, production steps are planned, the marketing situation is investigated and the financial analysis determines the investment necessary. The design engineering department is not an isolated and independent organization. Although it may be the originator of new ideas and concepts, it is dependent on other departments in the organization and needs their cooperation.

7. The functions and responsibilities of design engineering can be divided into four main areas: Research, Development, Design and Testing. Each one requires trained and specialized personnel, rather elaborate and expensive equipment, adequate technical library facilities and constant contact with the international automotive fraternity to keep up with the latest advances in automotive developments. Large international automotive manufacturers can afford to allocate substantial amounts to the design engineering function and do provide ample budgets for its activities in the above mentioned four areas. An automotive manufacturer in a developing country seldom will be in a position to pursue a complete independent design engineering activity because it lacks either the manpower or the necessary research and development equipment, yet feels competent to initiate new designs. Developing countries are seeking a solution to this dilemma by establishing automotive design engineering centers, to be financed partly by government funds and designed to serve all automotive manufacturers of the country or the region.

8. The concept of an engineering design center is not new, although those in existence have not been necessarily organized for any particular industry. Their function, services, procedures and funding vary from country to country, and they operate with a various degree of success. To the reader who is interested in a brief description of such centers, a few examples may be useful. In the Netherlands, Amsterdam's Institute for Industrial Design, subsidized jointly by industry and the Dutch

Ministry of Economics, is one of the oldest institutes (Ref. 2). In England, industry and the government's Board of Trade have long supplied jointly the funds for the operation of the Council of Industrial Design (COID); in addition, plans are afoot to bring engineering societies into the Council on a partnership basis (Ref. 2). Canada's design centers function as information distributors for designers, manufacturers, students and the general public (Ref. 3). The USSR has promoted numerous design centers whose goal is for industry to produce goods of quality up to the international level (Ref. 4). The All-Union Research Institute for Technical Excellence aims to function as a combination of an industrial design establishment and a consumer-product testing organization. From its headquarters in Moscow, it also directs subordinate institutes in nine cities across the Soviet Union. Industrial ministries also run design bureaus. One of the interesting products of the Research Institute was the design in 1965 of a "unique" taxi, the first significant all-Soviet contribution to automotive design. A further interesting development in the Soviet Union is a complex of design centers and "experimental" factories around Akademgorodok, the science center near Novosibirsk (Ref. 5). Such centers bring together related academic, engineering and manufacturing facilities; it is reported that more than half the engineering staff at each design bureau will be drawn from students and graduates of the nearby university, and promising students will be encouraged to follow projects into design and production.

IV. THE ENGINEERING ORGANIZATION

9. There are no rigid guide lines for the organization of an automotive design engineering organization, as so much depends upon the objectives, the local requirements, availability of manpower, availability of funds and so on. However, certain general principles may be established and they will apply, whether we deal with an engineering department of a single corporation or an engineering design center serving many plants. At an UNIDO Seminar on the establishment and development of automotive industries in developing countries held February and March 1968 in Czechoslovakia, Prof. F. Hooven submitted a paper entitled "Automotive Research and Development", which very clearly sets forth the structure and functions of a modern automotive design engineering organization (Ref. 6). A careful study of this seminar work is recommended before planning a design engineering department. A skeleton summary of Hooven's paper is used here to the extent it deals with the organization and function of a design engineering department. To attain its objective to create new and improved product designs, the design engineering department proceeds from basic research to applied research until the feasibility of the new concept is ascertained and then proceeds through advanced engineering and testing to a point where the best alternative is chosen and incorporated into a final design which is then subjected to rigid tests. During this phase, due regard must be given to past experience, possible use of new materials, manufacturing processes and the effect upon the function of the vehicle and all

its subsystems and components. This consideration leads to the concept of systems engineering, which directs research and engineering so as to make the most effective use of technological advances. Consideration of the future technical, economic and social environment is necessary. Design decisions must be made in the best interest of the complete system. Requirements for the creation of good designs include the availability of complete data on improved designs, records of the performance of materials and parts, services such as a technical library covering world wide developments and patent literature, qualified design and engineering personnel and accurate feedback of test results. Computer use is almost mandatory to solve complex problems encountered in systems approaches. Product development begins with the building of prototypes and their testing. Modern laboratory equipment should be available to simulate every aspect of operating conditions, durability and reliability. The redesigning of parts and use of different materials dictated by local conditions calls for local research and development. The organization of an automotive design engineering capability in developing countries should be seen as part of an overall program for developing a local technological capability.

10. This description of the role a design engineering department should play leads to deduction on how to organize, man and equip this institution. Four main groups compose the total activity: Research and Development, Design, Testing and Services. The Research and Development group may employ scientists, mathematicians, automotive engineers, metallurgists,

materials experts and laboratory technicians. Its equipment, besides the basic research instruments and devices will include special installations often designed by the research group itself. The design engineers certainly will include automotive engineers with wide practical experience, college graduates trained in computer operations, and--depending upon the objectives of the particular enterprise--some specialists working, for instance, in the field of combustion engines, power transmission, suspension, braking and steering. They will need access to a computer, preferably a machine shop for producing prototypes and making alterations. The testing group composed of engineers and technicians carries on tests of prototypes. Again the facilities will consist of standard items such as dynamometers and various special testing devices as will be illustrated in the case histories; even component manufacturers may need a test track to test their devices installed on complete vehicles as will be shown later. Finally the importance of services associated with design engineering cannot be underestimated. A technical library is essential and must be manned by trained librarians who can provide the engineering personnel with complete information on automotive subjects drawn from books, magazines, company bulletins, university publications; domestic and foreign patents are part of the material made available to keep up with the state of the art. It is evident from this description that a design engineering activity is a complex undertaking, requires high grade manpower and a relatively large investment which only large companies can afford. Developing countries therefore try to resort to one design engineering organization serving the entire national automotive industry. The national automotive design engineering center is to be of service to all plants that desire to use it and share in the cost of operating it. The future will tell how successfully this can be accomplished.

11. First of all, qualified and competent personnel has to be attracted to the design engineering center. The qualifications of such design engineers as well as the selection of proper and adequate research and development and testing equipment is touched upon in the concluding chapter. The direction of the design engineering activity has to be performed by a management versed not only in the technical aspects of the jobs, but also capable to appraise the importance or urgency of the ideas to be developed, the economic considerations for their development, the assignment of priorities and the scheduling of the work. Modern automotive engineering also requires that projects are not examined within the narrow limits of their individual function but be analyzed and carried out by applying the above mentioned concept of systems engineering. Case histories will illustrate these points better than general statements.

12. The design process progresses through many stages. The engineer possessing an inventive capability needs to train himself to always keep an open mind, accept criticism and suggestions of others, tc be willing to make changes, thus avoiding premature conclusions as to the excellence of his design or its economic feasibility. The usually high cost of development, pilot model production and testing should be a deterrent to rushing

into a new design project without a thorough previous design review and analysis. Of the various possible design stages, an interesting design process in twelve steps was described by Avery E. Coryell (Ref. 7). Without going into details, it proceeds from review requirements to brainstorm, preliminary analysis, analysis of approaches, refine the design, layout, design review of approach, detailed drawing, detailed analysis, hardware development, evaluation of hardware, manufacturing support and finally production. While Mr. Coryell touches only lightly on the research and development aspect of a new design, so important in automotive engineering, he concisely describes important elements in the twelve design steps. To start with, there is "the crucial need to understand fully the problem and requirements of the design before proceeding with the solution." When analyzing various approaches, it should be done on a function-cost basis. Many designs that are technically acceptable disregard economic or manufacturing capabilities. A separate chapter of this paper discusses the relation of the design engineer with the manufacturing engineer.

V. THE TOOLS OF THE DESIGN ENGINEER AND THE COMPUTER

13. At one time, many years ago, the tools of the designer were few and simple: a drafting board, a slide rule, an engineering handbook. In today's advanced and sophisticated automotive age, the automotive design engineer has to rely on many additional aids and his knowledge has to cover a much wider range of technical and scientific subjects. His modern tools are the

research and development laboratory, materials laboratory, the testing laboratory, electronic and optical instruments, mathematical models, statistical techniques, the technical literature embracing books, magazines, technical papers, engineering societies and their professional meetings, the patent literature of world wide coverage, and finally the almost indispensable modern tool, the computer.

14. The equipment of laboratories serving research, development and testing is of such a great variety that a description of facilities would exceed the space allotted to this paper. Suffice it to say that even the designer working in a relatively narrow field of automotive engineering will have need for elaborate, single purpose and costly equipment. This is particularly true in the area of testing, whether the tests are to aid in the development of a design during the design stage or whether the tests are devised to evaluate a completed design. A useful source of information on the instrumentation of testing laboratories is the November 22, 1967 issue of MACHINE DESIGN whose subjects are planning and implementing test programs (Ref. 8), data reduction techniques (Ref. 9), laboratory testing techniques (Ref. 10), environmental testing techniques (Ref. 11), field testing techniques (Ref. 12), and essentials of a measurement system (Ref. 13).

15. The numerous complex variables acting upon each other in the automotive systems and subsystems have made the use of computers in automotive engineering design indispensable, if exact solutions are to be

reached without tremendous waste of time and manpower. This use has become common in all phases of the creation of new designs and has contributed to the realization of many of the latest automotive improvements and innovations. Some of the references cited in this chapter may be a helpful introduction to the engineer not yet familiar with computer aided design techniques.

16. The electronic digital computer has been used by designers for quite a number of years in solving his problems; the gradual improvement of the equipment and the growth of computer technology has widened the computer's use and increased its versatility. The designer's creative potential was handicapped when he was depending on inefficient hand analysis or empirical data to perform his task of devising new designs or improving existing ones. The availability of computers and programming techniques can remove this handicap, give the designer the responsibility for creative thought and the computer the responsibility for the laborious computational aspects of the design procedure. There are several significant advantages in the analytical approach to the solution of a design problem. Evaluating a new design by experimental procedures often is complicated and time consuming, requires costly equipment, and may even result in approximation only.

17. The advantage of the computer is particularly valuable when the designer needs to examine how changing one or more parameters will affect the performance of the system. In empirical design, varying a

parameter may even require extensive structural changes in the system and very likely would necessitate changes of other parameters also. "Varying a system parameter in a computer simulation is a simple task that can be done without affecting other system parameters. These advantages plus computer speed, allow the evaluation of many more parameter variations than would be practical with the experimental design approach. Where the final design must be an optimum one in some respect--e.g., the lowest possible weight or cost within the design limits--computer-assisted design is often the only economically and technically feasible approach. Use of the computer enables a more extensive and thorough evaluation in much less time than would be possible with empirical techniques." (Ref. 14).

18. An example of computer aided design and of a relatively simple computer simulation has been recently published in the SAE JOURNAL. It describes computer programs, developed in the Design Center, Ford Motor Company, and used to design and evaluate rear view and side view mirrors (Ref. 15). Another example of interest to automotive designers concerns windshield design which must be evaluated for the amount of distortion it will cause in the driver's view. The usual practice consisted in the making of a prototype windshield and then photographing a reference grid with and without the prototype in place. The suitability of the design was then judged by visual comparison of the two photographs. Today a computer program performs the evalu tion by calculating the comparative grids based on the coordinates of the driver's eye and the grid, and the mathematical definition of the outer and inner windshield surfaces.

19. Many basic mechanical components incorporated in automotive design can now be designed "instantly" by computer. Programs for springs, gears, and other parts are available on punched cards or memory disks. If, for instance, a designer needs a spring, he "types the desired spring requirements into the machine in abbreviated English. The computer analyzes the input data and decides whether or not a given spring design is feasible. If so, it starts--in seconds--printing out all the necessary spring dimensions and computed loads. There is no need to call on a specialist to translate engineering terms into computer language." (Ref. 17). Thus, the designer leaves the drudgery to the computer and can devote most of his time to creative design.

20. We may also briefly mention a newer development, the use of graphical devices for communicating with the computer. This aspect of computer application may still be somewhat remote for a developing country, although the automotive industry in developed countries is already making use of computer graphics. A general introduction to this and related computer subjects will be found in Reference 17 and some examples are shown in Reference 18.

21. To summarize, it can be simply stated that the computer is becoming an indispensable tool of modern engineering practice. "We would go even further and say that computer techniques are the future environment of engineering design, as essential to its survival as oxygen is to the human body." (Ref. 19). The use of a computer will also be illustrated as actually applied in two of the case histories of Chapter VII.

VI. THE DESIGN ENGINEER VS. THE MANUFACTURING ENGINEER--FIGHT OR COOPERATION?

22. The designer cannot work in splendid isolation. His creative ideas should result in a product made from the most suitable materials and designed so it can be efficiently manufactured at an acceptable cost. There used to be a separation between design engineering and the manufacturing organization and their relations resembled those of two enemy camps constantly fighting each other. The designer insisted that his design was the only feasible one and any change would adversely affects its performance whereas the manufacturing engineer clamored that the materials specified could not be machined, the tolerances couldn't be held, entirely new equipment was needed to comply with the blueprint specifications, there was no way of holding the pieces in the fixture, and anyhow the cost would be so high that it was foolish to ask for the production of the new design. The result of these attitudes were prolonged disputes and fights, pride and stubbornness instead of reason prevailed and the proverbial enmity between designer and manufacturing engineer held up progress of many concerns and many projects.

23. The system concept has brought radical changes to this situation. It is now an accepted practice that the manufacturing engineer becomes involve in a new project even before the design engineer prepares drawings of a prototype. Correspondingly, the design engineer's responsibility doesn't end when his new product enters the manufacturing stage. "The designer who is responsible for the design of the product is often responsible for

following the product throughout the shop. Inevitably, problems arise and changes will be required. For example, a material option could relieve a procurement bottleneck or speed up a manufacturing operation." (Ref. 7).

24. The design engineer aims to develop a design to perform best its intended function. The manufacturing engineer cooperates with him from the start to incorporate in the design such features which will facilitate manufacturing the product and possibly even improve its performance. What are some of the features which may require the cooperation of design and manufacturing personnel during the design phase?

25. What material should be specified; what treatment is indicated to obtain required physical properties; is the surface finish desired to be obtained by machining, grinding, polishing; is the direction of grinding, polishing or honing marks important? Does the design provide means for locating parts in machine or fixture to the best advantage of the shop; is a basic reference point provided for insuring accuracy in the manufacturing process? When the part is to be machined on a numerical control machine tool, is the dimensioning and tolerance data suited for that manufacturing process? Can a design be changed to achieve lower cost, yet maintain its excellence; if certain design features would require new manufacturing equipment, can they be changed to allow utilization of available equipment; can a detail be made for parts joined by fasteners, welding, brazing or can it be made equally well from one piece or vice versa; shall a part be made from a forging, casting, bar stock, stamping; can an

assembly be modified to make use of standard parts or parts for which tooling is available instead of a new design? Can a design be modified to ease assembly, to use available tools? If the design cannot be produced on standard machine tools or equipment, the designer should furnish the manufacturing engineer blueprints and all other information needed to have the latter plan the acquisition of suitable new equipment and thus shorten the lead time which may be required to meet the production schedule. This list is far from complete but indicates the multitude of common problems to be resolved by the collaboration of the design and manufacturing engineers.

VII. CASE HISTORIES

26. To give the preceding chapters a meaningful implementation, several case histories will be described to serve as examples how new designs of automotive components actually have been developed. These examples will also illustrate the thoroughness which has to be applied by the design engineer to arrive at an acceptable and reliable new product.*

A. A Self-Contained Automatic Tappett

27. About twenty years ago, the need for a better tappet plagued the automotive industry. The solid non-automatic tappets required frequent adjustments, otherwise the valve clearance might become too small causing the

* The author is indebted to TRW Inc. for putting at his disposal the material used in these case histories. See also the acknowledgement at the back of this paper.

valve to burn, or too large, causing the valve to break. These tappets also were noisy and unacceptable in cars equipped with automatic transmissions. The industry turned to hydraulic tappets, but these were not satisfactory for two reasons. One, these tappets required a close fit of the plunger in the bore and there were no manufacturing facilities available to produce in quantity to the exacting tolerances; two, the engine oils deteriorated with service causing lacquer to develop and resulting in sticking tappets.

28. A large number of alternatives automatically adjusted tappet designs was studied and tried and the final selection was a self-contained silicone tappet, shown in Figure 1 in the form of a patent drawing. The tappet uses a self-contained charge of silicone oil (thus no sticking) and allows the use of relatively large tolerances (thus no production problems). It performed perfectly and yet it was never adopted by the engine builders. Why not? The answer to this question provides a good lesson to the design engineer. By the time the silicone tappet was developed, very sophisticated manufacturing methods and facilities had been perfected by the producers of conventional hydraulic tappets incorporating automated sizing and assembly equipment. But equally important, the oil industry improved engine oils by adding detergent and oxidation inhibitors, thus solving the problem of sticking tappets. So even through the silicone self-contained tappet is and was an improvement over the current hydraulic tappet, it was burdened with an unavoidably higher cost for the silicone oil charge (approximately three cents per tappet) and its adoption was no more justified in view of the

new oils and the consequent abolition of sticking. These developments were not foreseeable when the concept of a self-contained tappet was created in the designer's mind, but it shows how important it is to try to anticipate future technological advances.

B. 21-4N Valve Steel

29. Higher performance engines introduced after World War II with their higher compression ratios and hotter corrosive exhaust gases put a particularly heavy demand on exhaust valves made from heretofor satisfactory high chrome alloy steels. Valve life dropped in many areas below 20,000 miles. The valve maker entered into a project with a steel producer to develop a superior replacement for the XB and XCR valve steels. The first experimental steel was rolled three years later, in 1949, after intensive laboratory research and development. Valves from that steel underwent exhaustive dynamometer and other laboratory tests and showed excellent corrosion resistance, but the material proved to be too soft. Nitrogen was then added which improved the hardness but the steel could not be machined. Finally, sulphur was added to improve the machinability and the 21-4N production steel resulted. The development phase lasted seven years (from 1946 to 1953) during which period several hundred experimental analyses were cast and over a hundred engine tests were conducted. An excellent exhaust valve steel resulted from the joint efforts of the design engineers, metallurgists and chemists and manufacturing engineers, backed by ample research and development and testing facilities.

C. The Molybdenum Coated Piston Ring

30. To the layman, a piston ring looks like a simple cylindrical piece of metal, which should prove no particular problem to the design engineer nor for that matter, to the manufacturing engineer. This would be a very deceptive notion. As will be shown by this case of a molybdenum coated piston ring, complex problems had to be overcome, extensive research and development facilities were employed and a great amount of laboratory, simulated and actual road testing had to be performed to obtain the design engineer's objective. The designer had to be backed up by some unique and costly laboratory and testing devices, and he had to be an expert in combustion engine design to handle the project with a proper systems engineering approach.

31. Coating of piston rings had its origin in the North African war zone during World War II, when chrome plating was applied to fight the severe abrasive wear encountered in desert operations. Because chrome plating produces a dense layer, it has little oil bearing capacity and it was therefore necessary toemploy a coarse threaded cylinder bore surface in conjunction with chrome plated rings. When after the war, automobiles and trucks were operating on paved roads with engines of higher compression ratios equipped with better air filters, better carburetors and running long hours at high speeds, abrasive wear more or less disappeared, but the chrome plated rings produced a different wear characteristic, scuffing.

32. The piston ring designer needed to develop a better coating, but in attacking this problem he had to consider the entire system, the whole engine. Among other factors, he needed to study and to know the metallurgy of iron used in cylinder blocks or cylinder sleeves, the cooling system, he needed experts in the finishing of cylinder bores (what surface was best for wear and oil consumption), he had to become thoroughly familiar with the metalluargy of the coating material he intended to use, and he had to provide himself with a vast array of specially designed laboratory equipment (Ref. 20).

33. The coating material selected by the design engineer had to be more porous than chromium and nonweldable, to avoid scuffing and improve lubrication, it also had to withstand higher temperatures and pressures inherent in the new engines. Molybdenum appeared to have the desired characteristics, but manufacturing techniques had to be developed and various ring designs tried out and tested. The development of the Moly ring (Figure 2) started in 1959. Molybdenum was available in wire form at the high price of $15.00 per pound, and it was applied by means of a metallizing gun. By 1962, molybdenum coated piston rings were available for the replacement trade on heavy duty truck engines and considerable field experience was being gained. At this point, a program was initiated to make these rings available as original equipment for vehicle manufacturers. This was to be carried out in two steps. First, it was necessary to radically reduce the cost of molybdenum wire; several competitive

sources were engage in this endeavor, and the price was brought down to approximately $6.00 per pound. The second step consisted in radically new methods of applying molybdenum and controlling its characteristics; this involved a fresh approach to the design and entirely new manufacturing methods (Ref. 21). The application of the coating was first changed from metallizing to oxygen actylene sprayed molybdenum and, finally, to plasma sprayed molybdenum, not only improving the quality but also making an economic high production manufacturing process feasible.

34. The first automobile equipped with Moly coated piston rings was Chevrolet's Corvette, a sports car with a high performance, high speed engine which encountered scuffing problems with chrome plated rings. Before this first original equipment order was received, 11,000,000 miles of field testing were logged on heavy duty trucks, and the reliability and performance of molybdenum rings had been established. Yet, before the rings of the Corvette car could be manufactured, the design engineer had to know all of Corvette's engine problems. For instance, when flutter occurred, the flutter frequencies had to be calculated and vibration measured. The problem was solved by redesigning the piston grooves to accommodate rings of increased width.

35. The use of coated rings has spread to many engine manufacturers who have increased the performance requirements until they approach the acceptable limit of moly rings. Ring temperatures are reaching 700°C and firing pressures are up to 2000 psi. Molybdenum no longer has physical

properties to withstand higher temperatures and pressures, and the piston ring manufacturer has to look for other materials and more sophisticated processes. It was already indicated that new designs of piston rings, those simple looking cylindrical pieces of metal, are developed with the aid of sophisticated research and testing facilities and by a methodical procedure. The outline of such procedure is as follows:

1. Make samples and run screening tests in a small engine (for instance, a 4 cylinder Renault engine with cylinder sleeves), make comparative tests and measure for wear.
2. Examine rings and coatings for wear, deterioration and scuffing.
3. If deteriorated, conduct metallurgical examination to determine cause.
4. At this point, make decision whether to continue testing or abandon this design.
5. If results are satisfactory, run full scale test on heavy duty engine for approximately 1000 hours.
6. Conduct field tests.
7. If good results are achieved, submit samples to engine manufacturer for evaluation.

36. The type of research and testing facilities employed in the development of the molybdenum coated piston ring are illustrated by a few examples

Figure 3 is an overall view of the sample department showing some of the equipment required to produce experimental design rings, prototypes and rings for various test programs.

Figure 4, an important piece of equipment in the sample shop is the plasma unit used in conjunction with programs to develop economic wear resistant coatings.

Figure 5, to measure the size, distribution and amount of porosity in coatings and ring materials, a mercury intrusion porosimeter is available in the research and development department. It uses mercury at pressures of up to 15,000 pounds per square inch.

Figure 6. Accurate oil consumption measurements under various speed and load conditions are made by means of a radioactive cell. An isotope of bromine is mixed with the engine oil and the exhaust is passed through the extraction tower, and the amount of radioactivity, determined in a scintillation counter, is an accurate measure of the oil consumption.

Figure 7 shows the automatic control console for the radiometric cell.

Figures 8, 9 and 10 are very accurate instruments to measure characteristics of piston rings and piston ring grooves.

Figure 11 shows a step timer system being set up in the dynamometer laboratory. A series of speeds and loads is programmed and the engine will run through the prescribed cycle. The data are recorded on punched cards and fed to a computer.

Figure 12 shows a dynamometer tape control system. The tape has been produced on a test track or test course with the speeds and loads recorded on that tape as, for instance, on a trip from Chicago to St. Louis. By means of this arrangement, the test trip is exactly duplicated by the engine on the test stand, and it makes the trip over the test track as many times as desired without ever leaving the dynamometer laboratory. The advantage for comparative studies, always under the same conditions, is obvious.

D. Designing a New Steering Linkage

37. A new steering linkage has to be carefully designed and thoroughly tested as it must not only function properly, but also it must be absolutely fail proof. Therefore, research, development and testing are indispensable for steering linkage development. Today's most popular linkage designed for passenger cars with independent front wheel suspension is the parallelogram linkage system shown schematically in Figure 13. How does the design engineer proceed when designing a new linkage?

38. Each front wheel moves up and down independently of the other, therefore, a linkage system is required that will follow each wheel through its up and down motion without causing the wheel to change its direction during this movement. Eight basic data pertaining to the vehicle are required by the linkage engineer, namely, vehicle weight, wheel base, tread width, estimated height of center of gravity, path of the front wheels as they move from the bounce to rebound position, obstructions to be cleared as the

linkage system follows wheel movement up and down and through the full right and left turn, desired steering ratio and turning radius.

39. As the suspension system moves up and down, the tie rod must be located in such a position that it follows essentially the same arc as the wheel, and when the vehicle is steered from straight ahead to left or right, each wheel must turn at a proper angle so that their centerlines through any turn would intersect at a line drawn through the rear axle. In the past, this geometry of the linkage was worked out by a laborious trial and error process, but today, formulas which have been computerized are available so that all this preliminary work can be done fast and accurately by computer.

40. When the principal points of the steering linkage have been established, the required strength of the linkage components is calculated to withstand certain maximum load condition. The actual design then can be completed so as to have the required strength and to clear any obstructions in the system such as engine, frame, stabilizer bars, strut rods, etc.

41. At this point, engineering samples are made for both car tests on a test track and for laboratory tests. In the car test, actual loads are measured in the steering system by means of strain gages at all the critical points. The car is run at various prescribed speeds over test track lanes of varied surfaces. One lane duplicates a section of a neighboring highway, another lane contains corrugations and tar strips, another has a smooth concrete surface, another has a cobblestone surface, another two

lanes have each different grades of gravel surface and one lane has obstructions called Belgian blocks (Figure 14). The strain gage measurements give complete data of the compressive and tensile loads and the frequency of their occurrences per a predetermined number of trips over the above mentioned lanes for all components of the linkage being tested.

42. The next step takes us to the laboratory, where preliminary static strength tests are run on the engineering samples to determine whether they meet design requirements and whether they match the load data obtained from actual vehicle tests. If the design appears satisfactory at this point, then large volume samples are built and subjected to car and laboratory tests dealing with strength, environment, fatigue, wear, and other factors to insure the correct functioning, reliability and absolute safety of the linkage. The design engineer, therefore, needs to devise a great number of specialized tests and some unusual and elaborate test equipment.

43. A partial view of such a test laboratory is shown in Figure 15. A few examples of the tests performed will illustrate what care must be taken before a design can be considered acceptable. Tie rod strength test, tie rod fatigue test (Figure 16), centerlink strength and fatigue test (Figure 17), idler arm wear and fatigue test, tie rod end high load wear test, tie rod end wear test under environmental conditions (Figure 18), tie rod end seal tests, ball stud impact tests, complete front end tests (Figure 19). Tests are run to the equivalent of 100,000 miles.

Only after the linkage has passed all of these requirements is it considered ready for production tooling and release.

E. Vehicle Anti-Skid Brake Control

44. Automatic anti-skid brake control aims at achieving a minimum vehicle stopping distance while maintaining directional stability on various road surfaces and under all climatic conditions. The basic concept states that a braked wheel which is permitted no more than approximately 20% wheel slip will provide these conditions of safe braking performance. The system must stop the vehicles safely at the demand of the driver, including such demand as may be caused by emergencies or driver panic.

45. The functions of the control system, the dynamic interactions of the vehicle and its wheels and of the wheels with the road surface are of such complexity that an empirical solution is just not feasible; they are defined mathematically and the mathematical model can then be run as a computer problem to simulate the dynamics of the individual components and of the entire system.

46. One problem associated with the hydraulic pump design proposed to fit into the overall brake control system is hereby given as an example. This pump will be driven by the propeller shaft for the rear wheels of the vehicle. The pump, therefore, will always "know" the vehicle speed during the braking cycle and its associated controls must then modulate hydraulic brake pressure to maintain the optimum relationship between the wheel velocity and the linear velocity of the vehicle. The modulation

of the brake pressure is to be accomplished by a variable area discharge orifice and a computer program is employed to solve for this variable area; it is cited here as an example of one of many computer programs used in the design of this anti-skid system.

47. The problem is started with an initial estimate of the desired area. It then solves for the flow rate of this estimate and compares it to the desired flow rate. The resulting error or difference is used by the computer to adjust the initial area estimate and solve again and again until the error is within tolerable limits. The number of these repetitions or reiterations is recorded in the last column of the example, Figure 20.

48. This reiterative type of solution, feasible only in a computer program is run for a series of vehicle speeds in several steps from 6 miles per hour to 90 miles per hour and each step computed for a series of pressure increments through the desired pressure range. The example, Figur 20, is the computer output for a vehicle speed of 60 miles per hour or 88 feet per second (column marked XD). The orifice area (column AOR in square inches) for each road speed was then examined for similarity or possible fit within permissible tolerance, but the solutions obtained were not satisfactory and showed clearly that the required area was not only a function of system pressure (column P_p), but also a function of road speed. This proposed design had to be abandoned and a new one started based on the knowledge gained from the computer. The importance of this case lies in the fact that the computer furnished the complete data

in 34 minutes and a correct decision to produce a new design was made immediately. Without the services of a computer, it may have taken two or three months to build and test a prototype control at considerable expense of manpower and money only to find out that the design was unusable but without having gained a reliable indication of what was fundamentally wrong with the tested design.

VIII. CONCLUSIONS

49. When and how shall the automotive industry in a developing country embark on a course of independent engineering design? If the premises dealt with so far are accepted as valid, the answer to this question may be given in general terms in this concluding chapter.

50. The first consideration must be given to the industry itself. It should have developed to a point where it produces vehicles of close to 100% domestic content; it manufactures vehicles and components efficiently with minimum aid or supervision from the enterprises in the developed countries; it has also developed a large group of engineers employed in manufacturing, planning, quality control, product testing, materials knowledge; it has generated need for technical training and has promoted institutions of higher learning, universities and colleges, where engineering, scientific courses and research and development techniques are taught by capable authorities, thus creating a supply of future design engineers and automotive engineers. Some relatively simple redesign

tasks have already been performed with the help of the licensor to adapt parts of the vehicle to local conditions, and the local engineers who participated in these projects already have accumulated some experience in new product design procedures. To supplement this manpower source, arrangement should be made to send young engineers abroad to the manufacturer's design centers in developed countries for a period of at least two years to undergo thorough training in new design activities. Attractive assurances should be made to these young men to make sure that they will not hesitate to return to their native country as respected and needed members of the automotive engineering fraternity. The industry should also promote the forming of a professional society similar to the Society of Automotive Engineers and support its activities.

51. So much for the status of industry and the development of manpower proposed to carry on design engineering. The second consideration concerns the research and development and testing facilities which will be needed. This is primarily a question of funds, but the amount of money needed will largely depend upon the extent and nature of the proposed design activity. As has been explained in the previous chapters, the investment required to carry out even relatively simple design projects is fairly large. It is, therefore, likely that a design center will be organized as a joint undertaking. But let us remember that even the most grandiose design facilities won't create new designs; the ideas come from people who are trained and experienced. Research and development and testing

facilities are only tools of the design engineer, although admittedly indispensable tools.

52. So the answer to the question, when to start an automotive design activity, is rather simple. The automotive industry must have reached a high degree of manufacturing ability at a resonably large volume, the industry or the region has trained engineers available, the institutions of higher learning have good engineering courses to provide a source of manpower needed for a growing design engineering function, and there is a source for funds needed to equip the design engineering center with the research tools to be used.

53. The first design projects undertaken in a developing country may best be directed towards solving problems generated by conditions peculiar to the region such as climate, terrain configuration, dust, roads, usage of vehicles and so on. Start with simple projects and gradually build up knowledge and experience--avoid discouraging failures.

54. It also may be appropriate to direct a word of advice to the automotive manufacturers of developed countries. It is in their interest to aid their licensees in acquiring design engineering capabilities after they have reached the aforementioned degree of manufacturing proficiency. This can be done by accepting trainees from developing countries and by providing engineering help at the start of the first design efforts. Some very good ideas and developments may eventually come back as an unexpected remuneration.

55. This paper has attempted to describe design engineering activity in the field of automotive components from subsystems to individual parts. Both the description of general principles as well as the examples of actua case histories were intended to show the complexity of automotive design, the great care required to insure proper functioning and the safety of any new design, the need for trained and imaginative engineers and the vast amount of equipment needed to develop a new product. The purpose of suc a presentation was to guide and to encourage the undertaking of new design with the proper understanding of the task, the efforts needed and the risks taken. The words of caution were meant as an aid to the decision when to initiate a design activity and were not meant to discourage a young automotive industry to eventually stand entirely on its own feet.

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Emil F. Gibian

April 17, 1956 M. J. TAUSCHEK **2,742,031**

SELF-CONTAINED AUTOMATIC TAPPET

Filed June 25, 1953

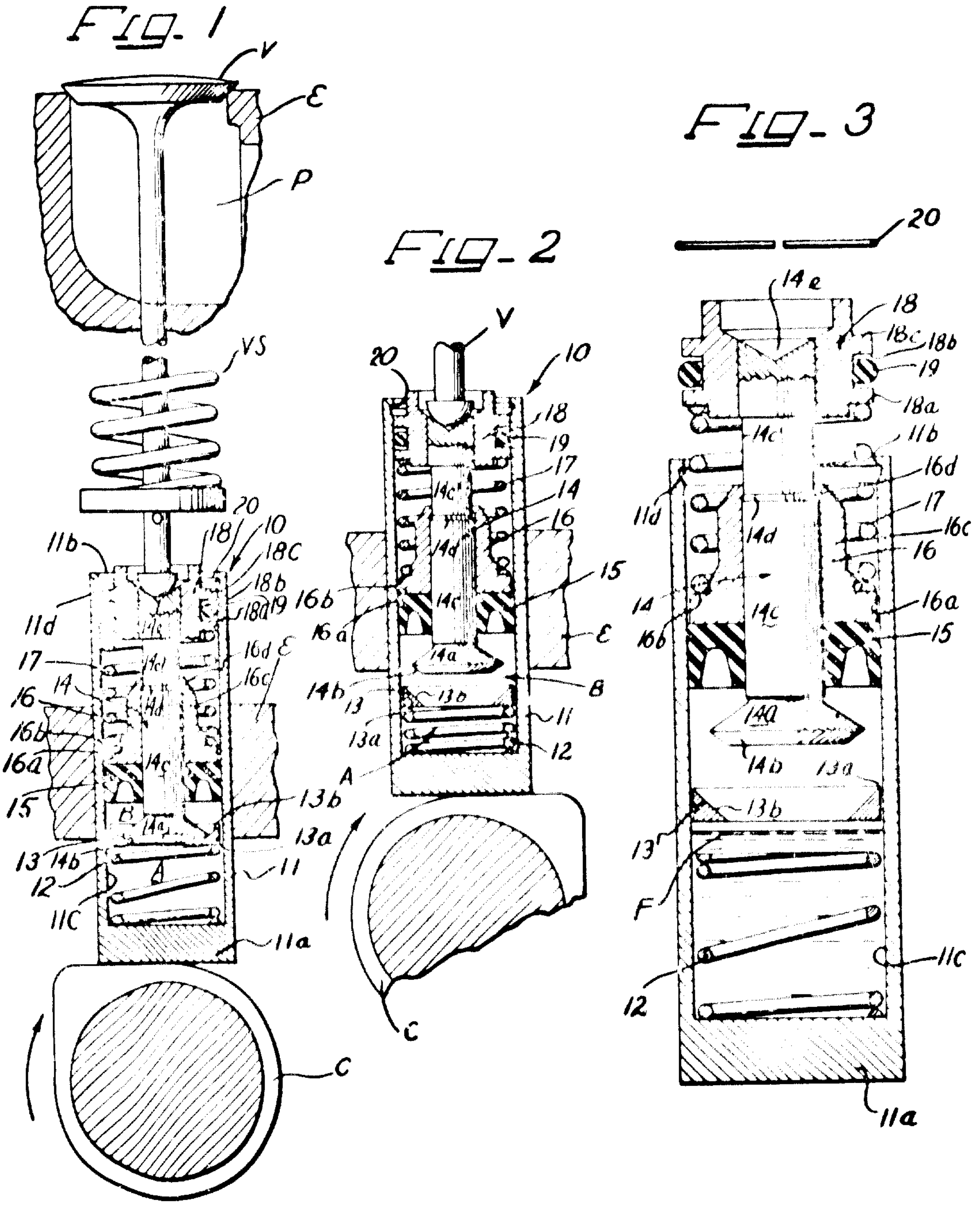

Figure 1.

Self-Contained Automatic Tappet

Figure 2.

Molybdenum Coated Ring with Insert Showing Porosity

Figure 3.

View of Piston Ring Sample Shop

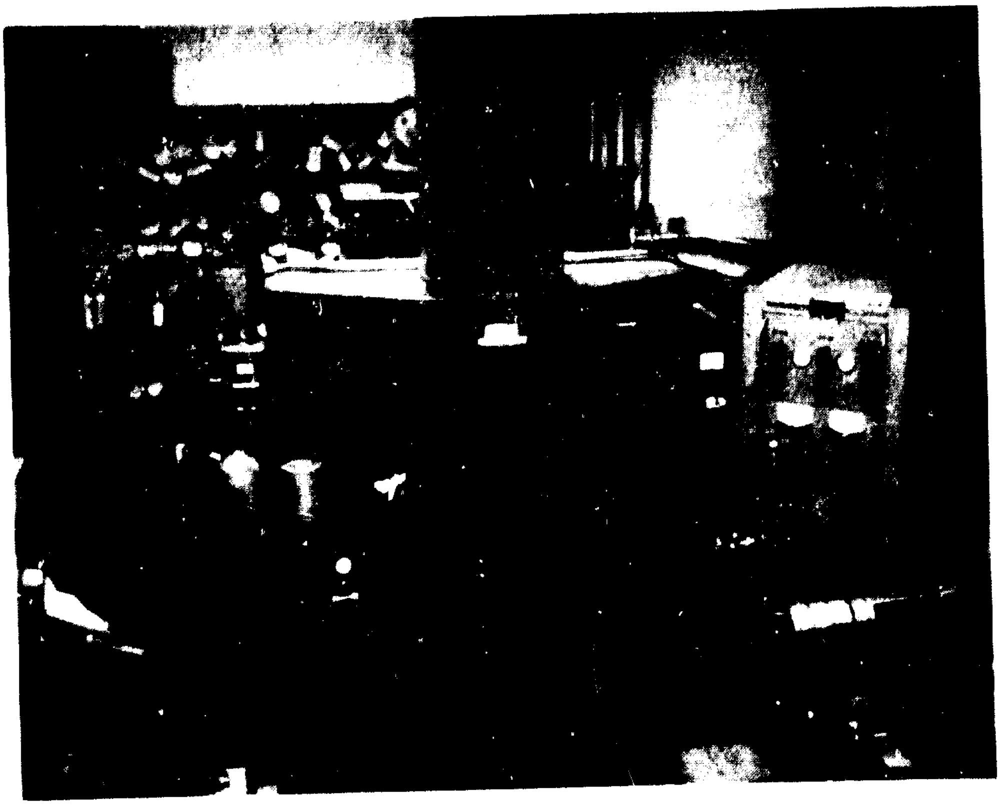

Figure 4.

Plasma Unit in Sample Shop

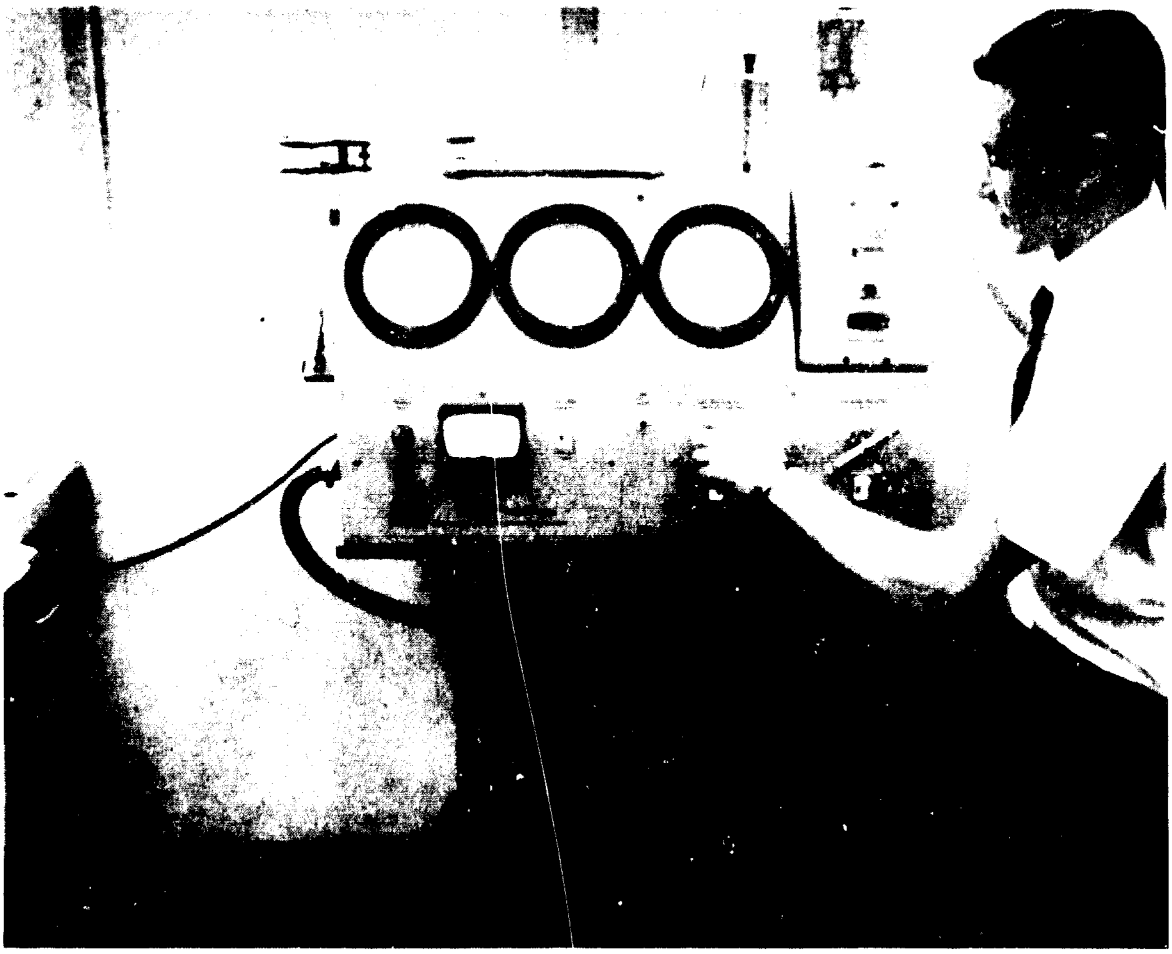

Figure 5.

Mercury Intrusion Porosimeter

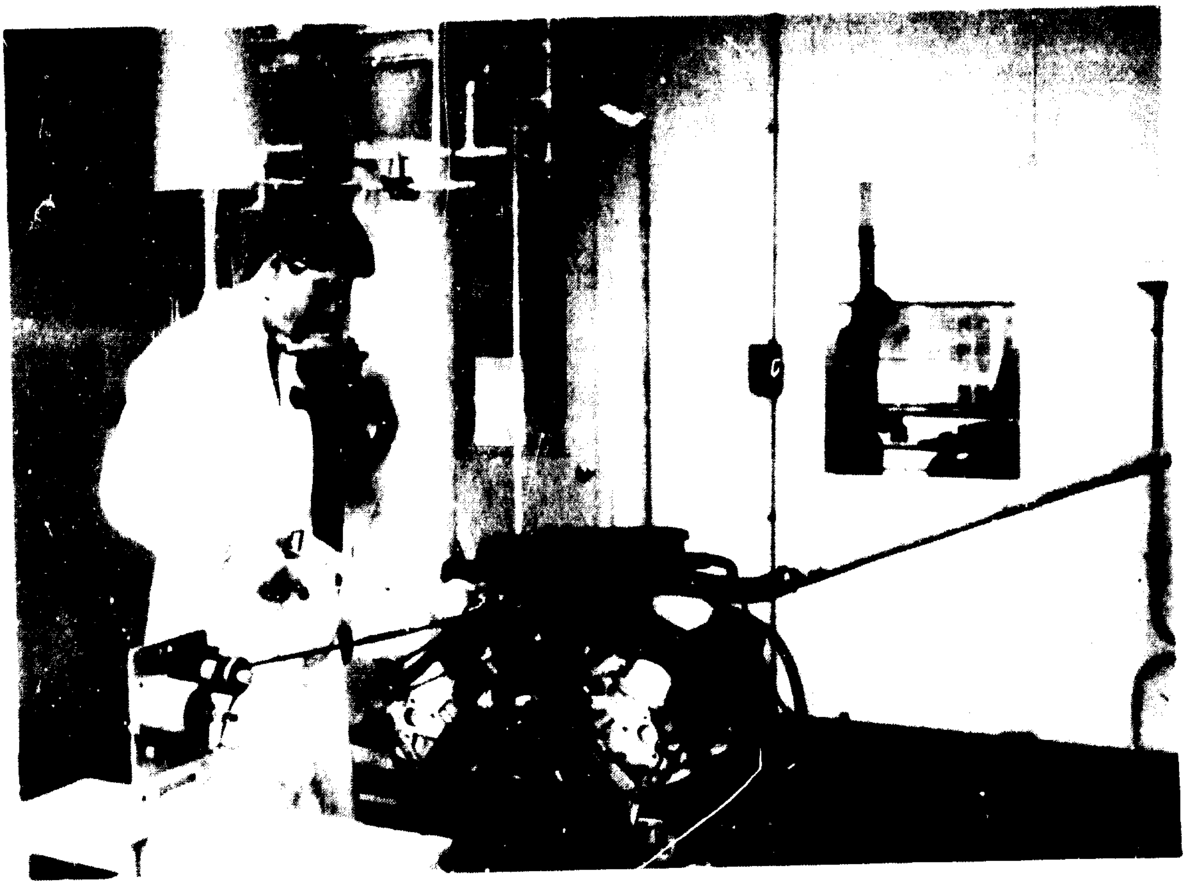

Figure 6.

Radioactive Cell With Extraction Tower in the Background

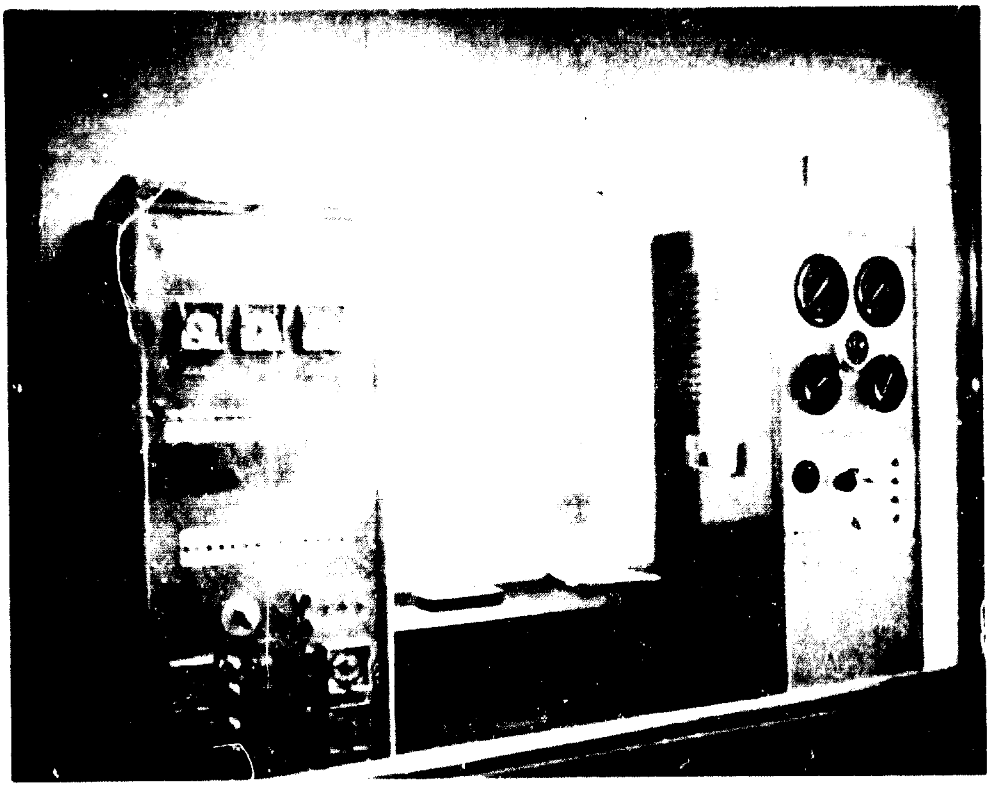

Figure 7.

Control Console for Radiometric Cell

Figure 8.

Special Gage to Measure Flatness of Piston Ring Grooves

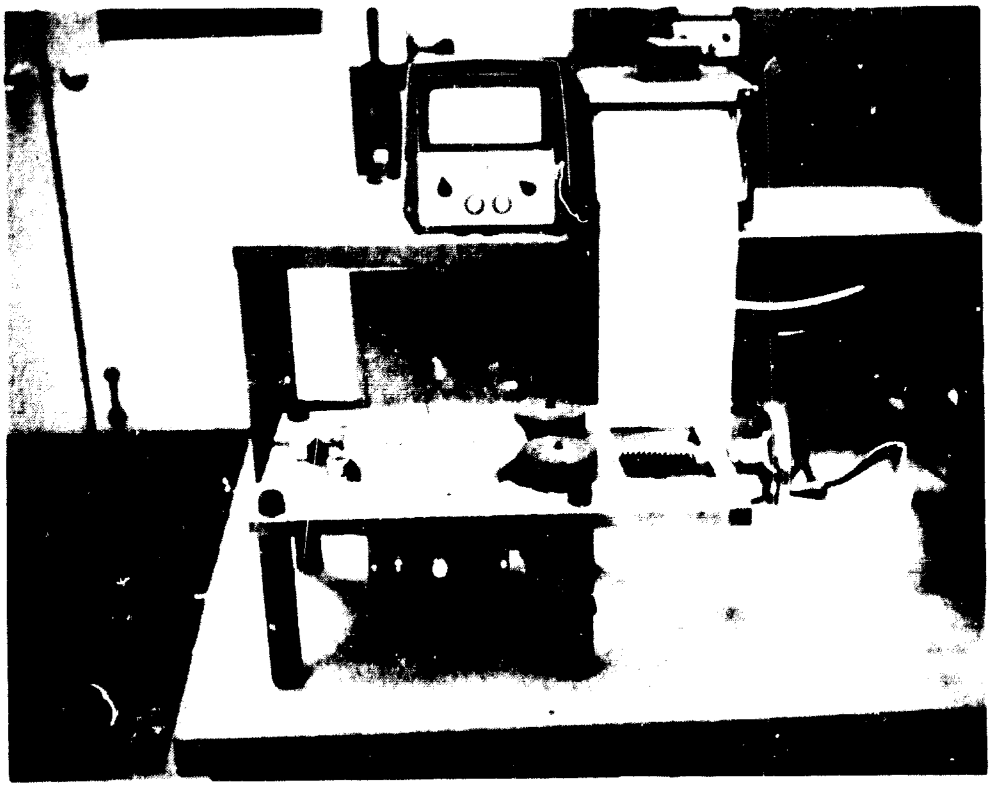

Figure 9.

Special Gage to Measure Flatness and Angle of Piston Ring Grooves

Figure 10.

Special Device for Measuring the Pressure Distribution of Compression Rings

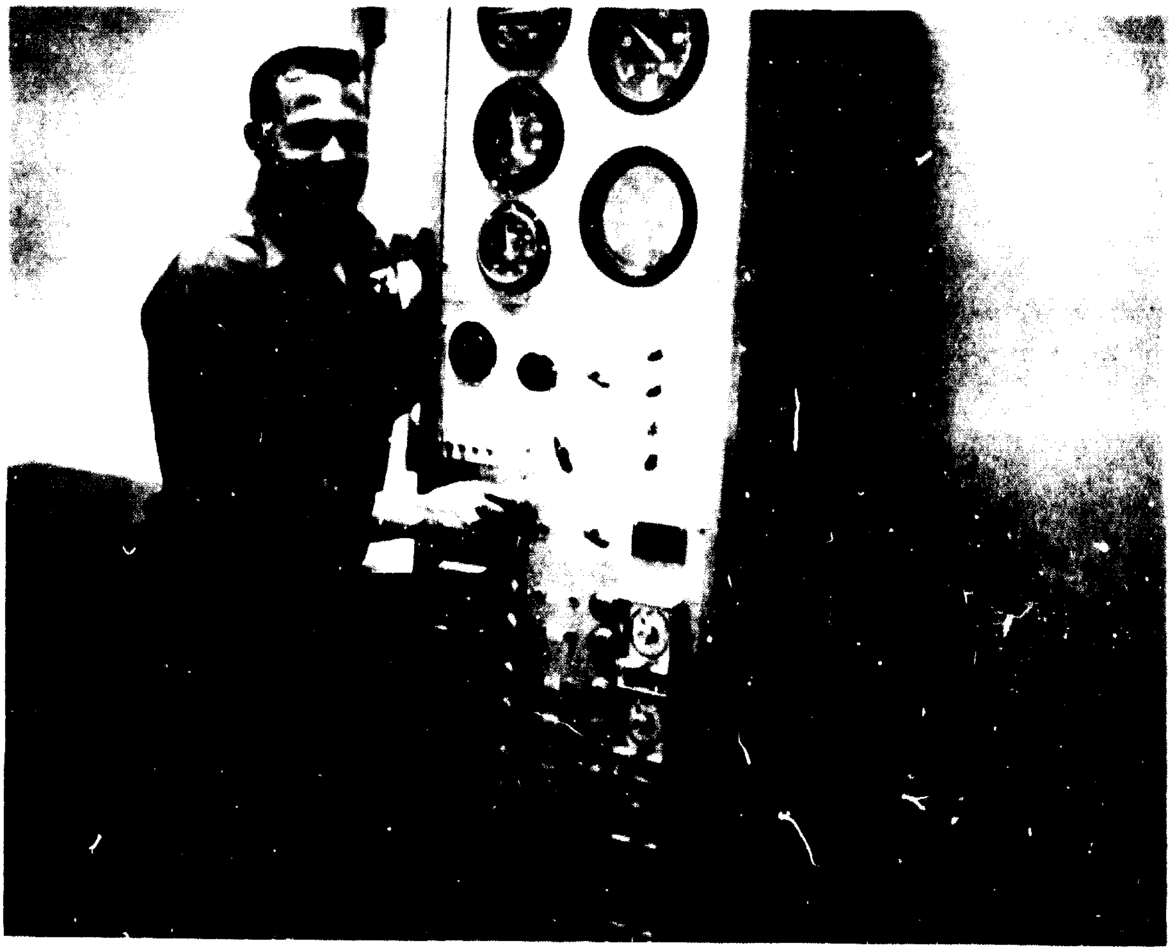

Figure 11.

Step Timer System for Programming Dynamometer Test

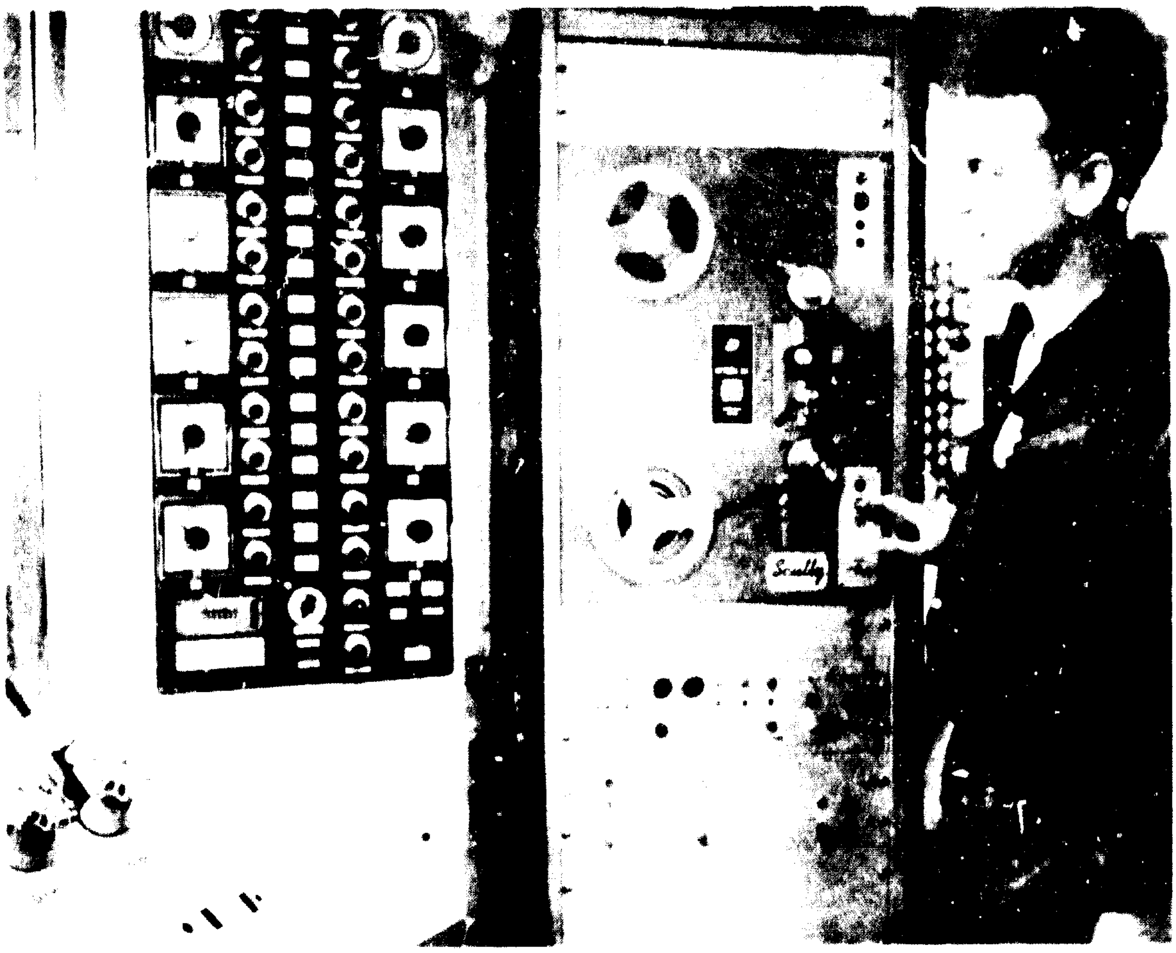

Figure 12.

Simulation of Field Testing by a Tape Control System

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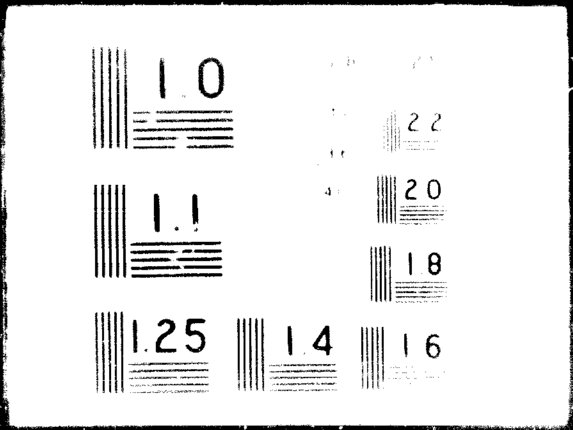


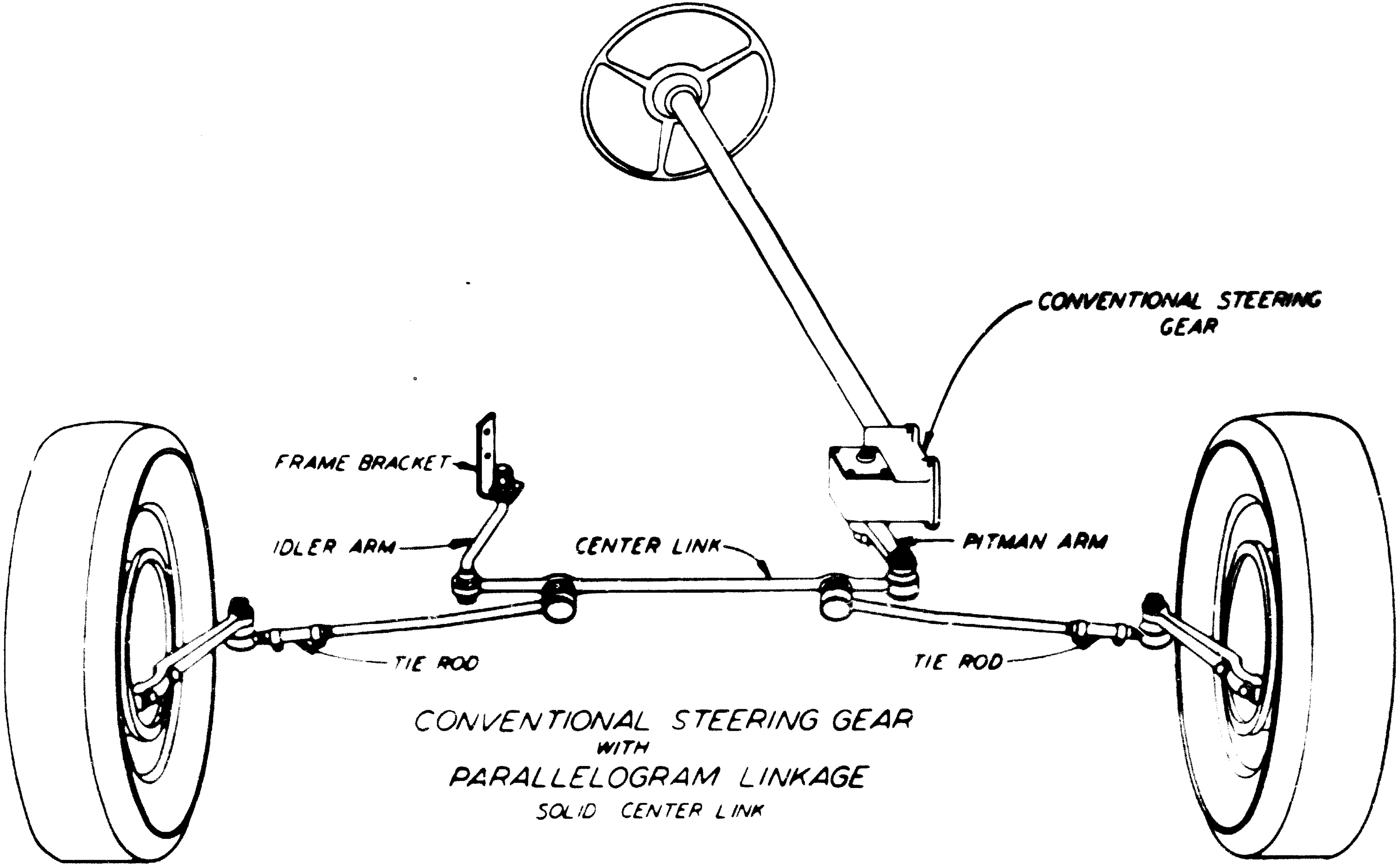
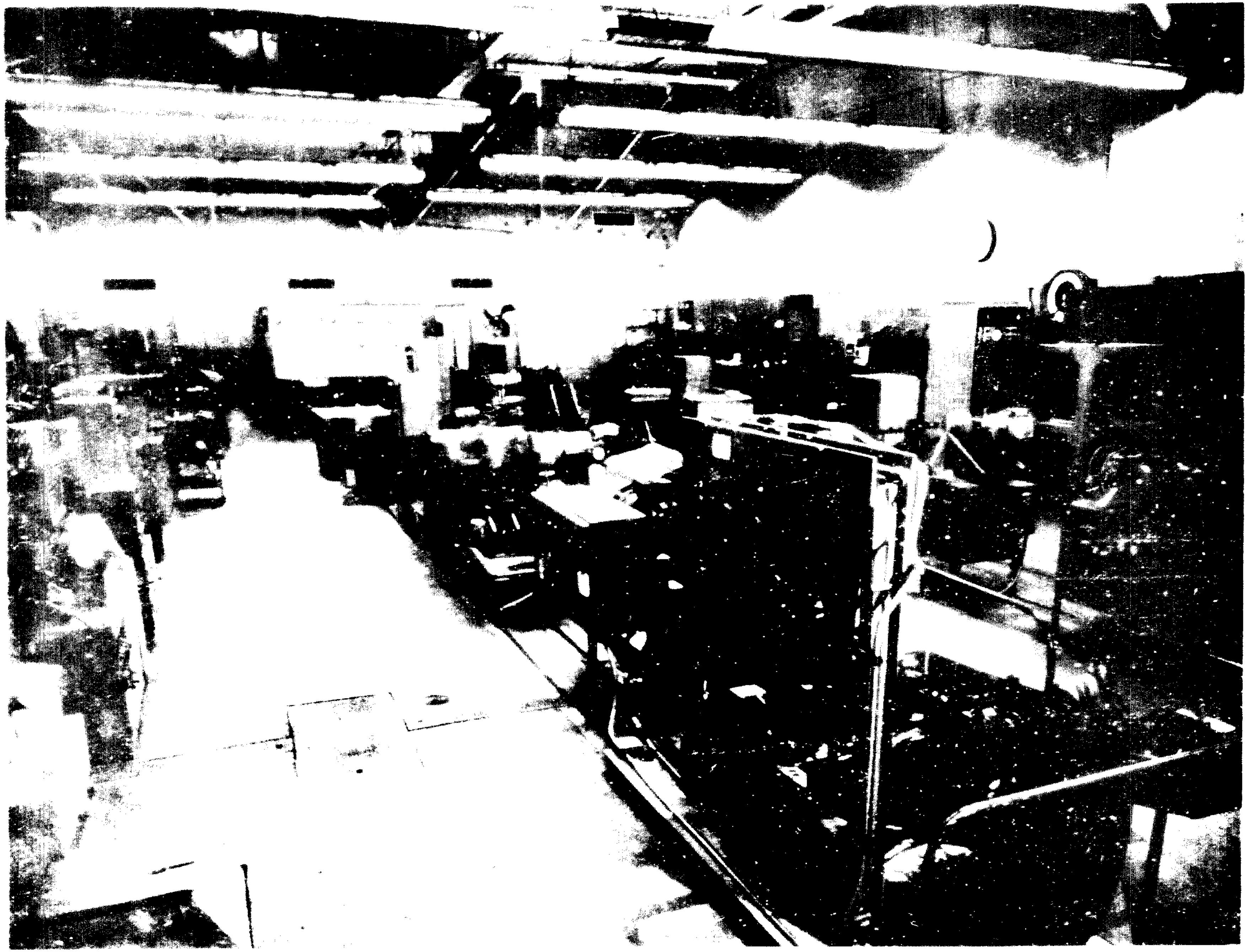


Figure 13.

Parallelogram Linkage

Figure 14.

Section of Test Track with Belgian Blocks for Testing Steering Linkages



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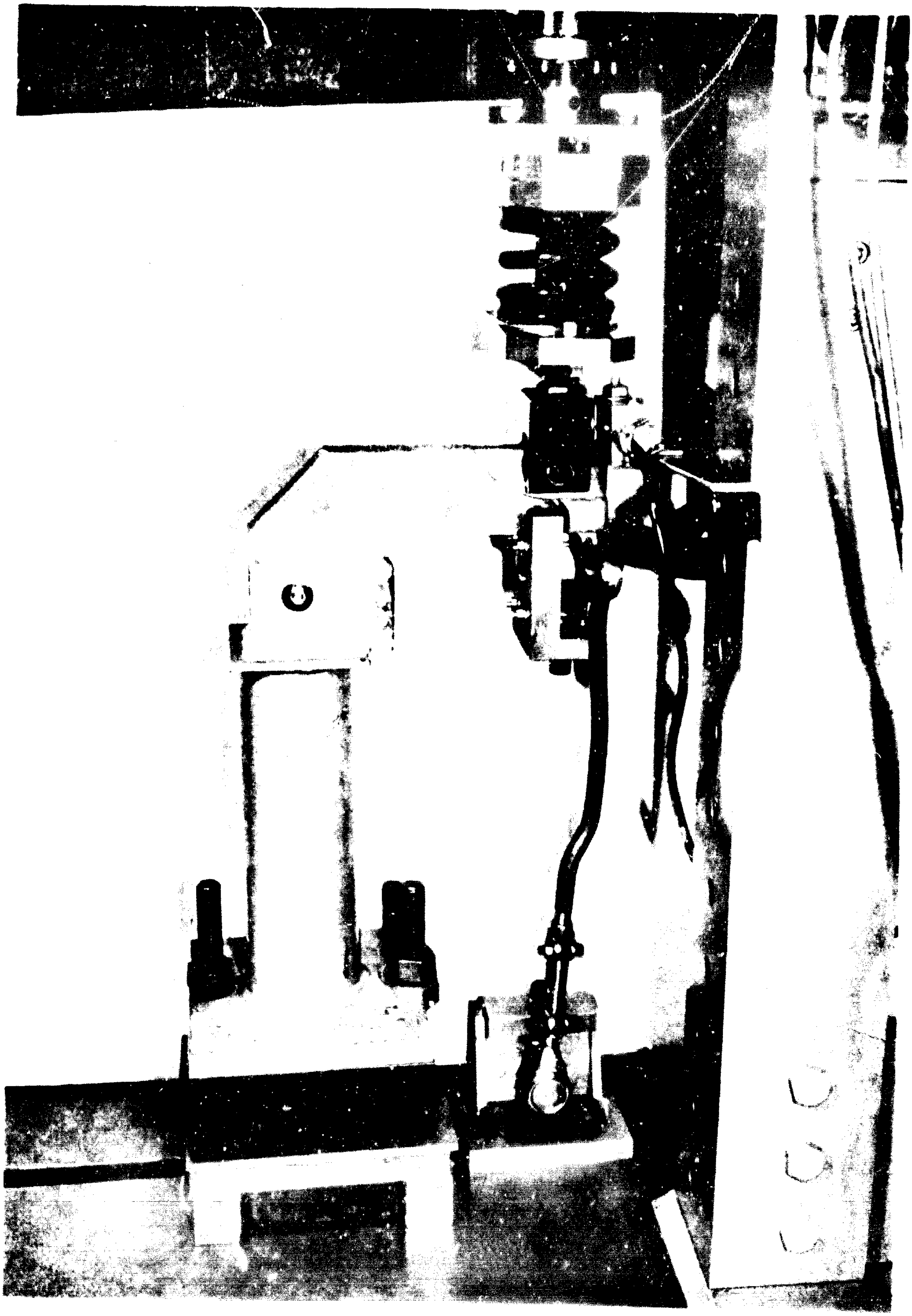


The [illegible] [illegible] Test

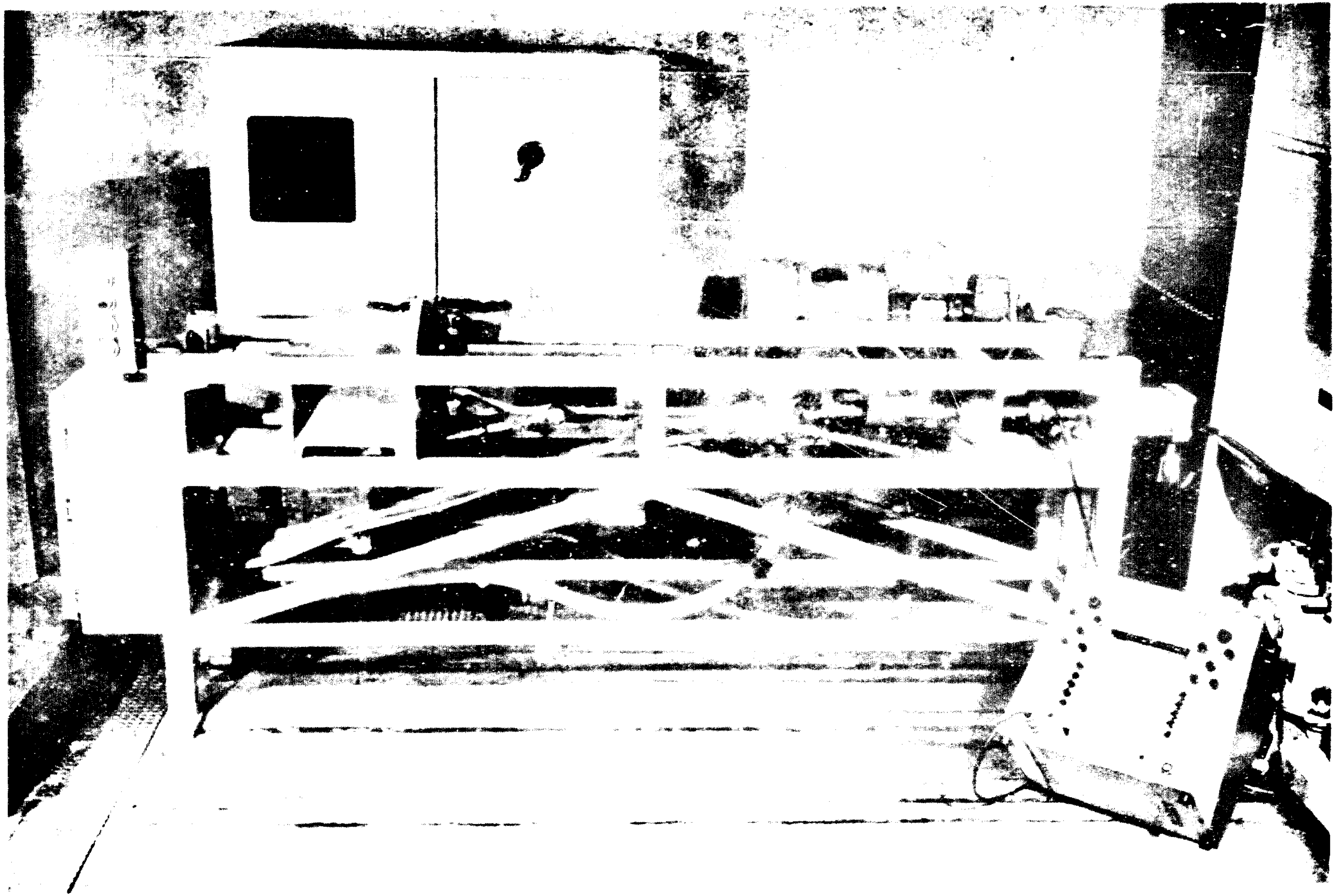


Figure 17 Centerlink Strength and Fatigue Test

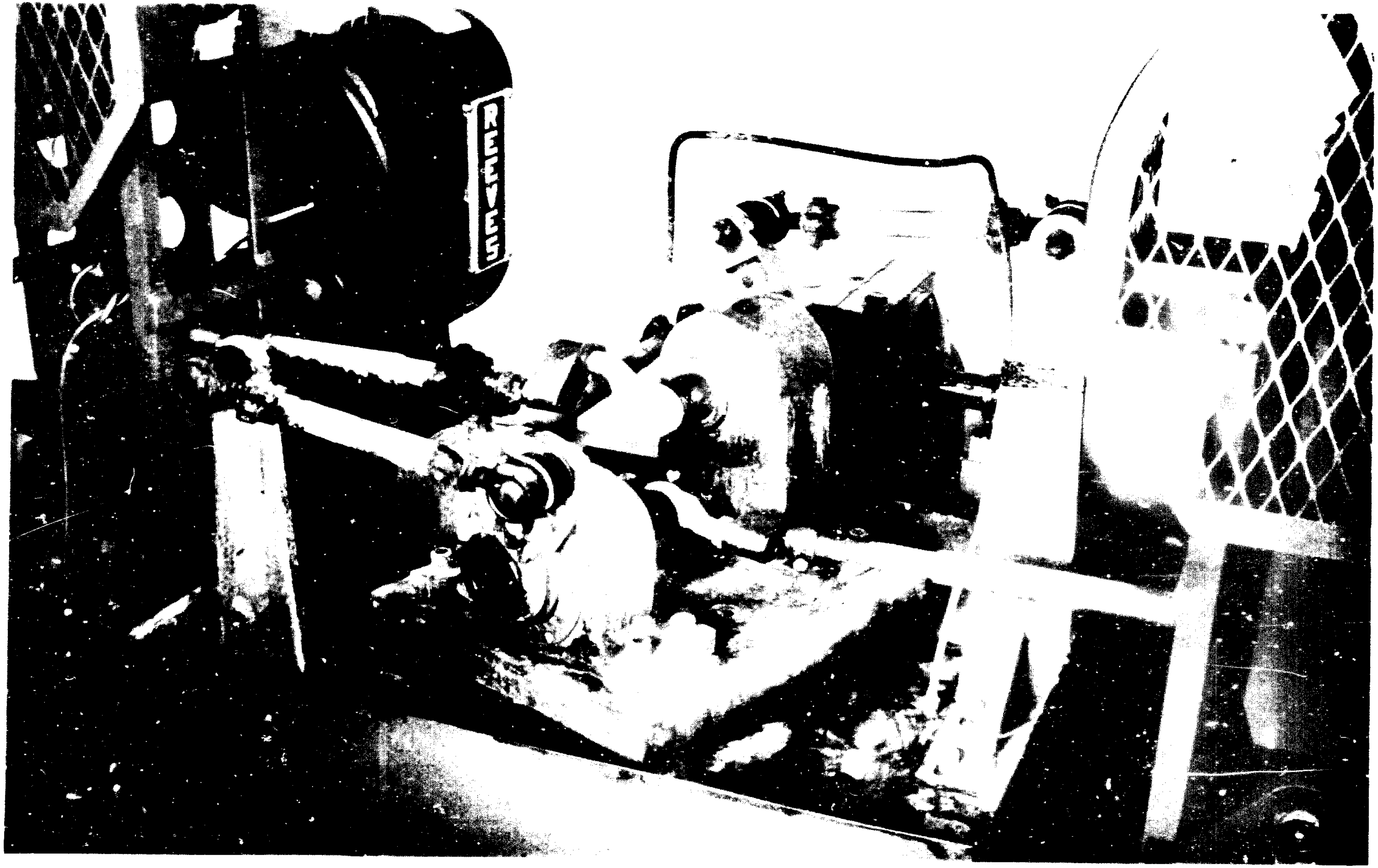
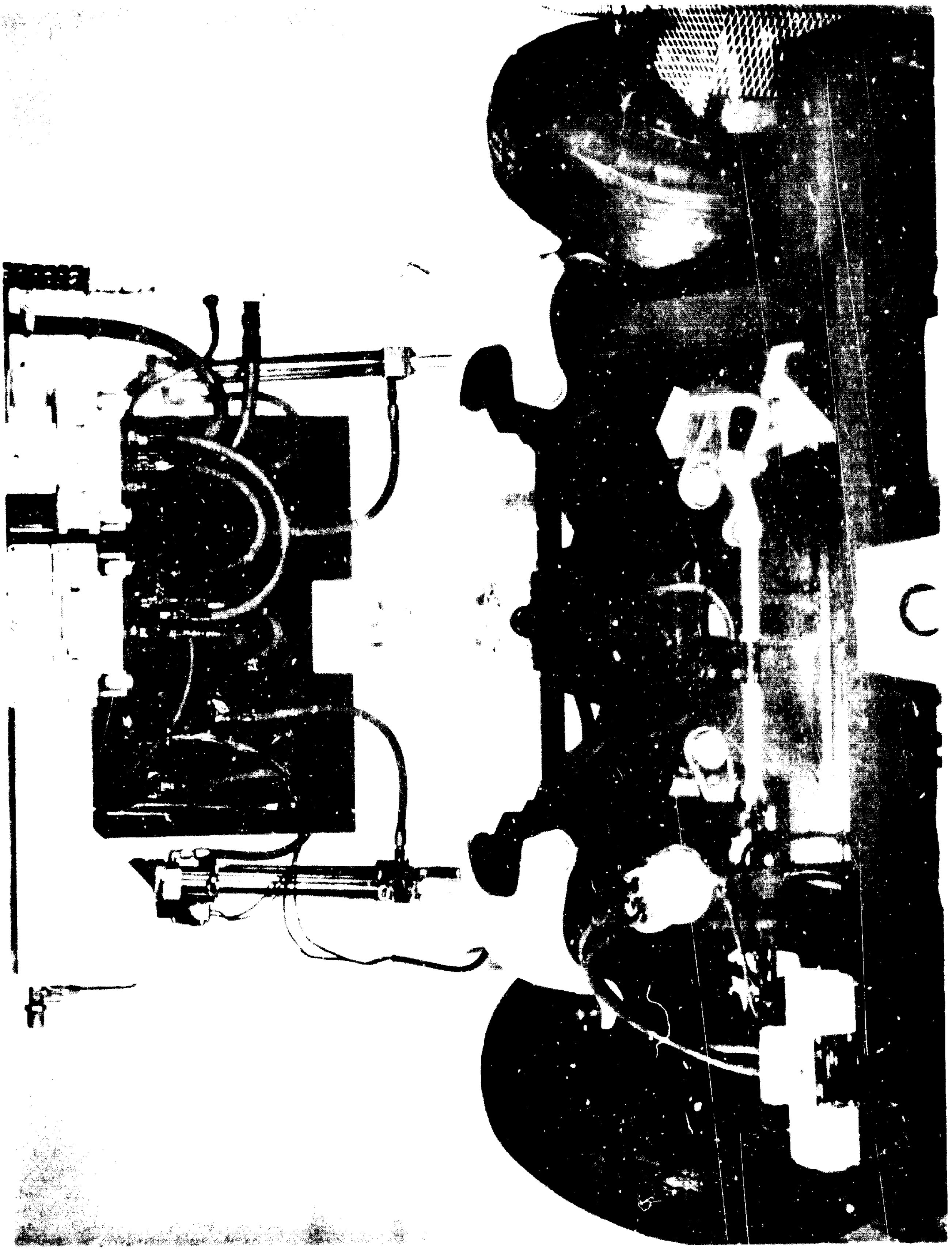


Figure 18.

Environmental Test of Tie Rod Ends



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INPUT XD ?88
  PFC      QP        YFC       AOR          PP      XD      DOR       ITER
   65     3.152     0.2777   0.002983        0      88    0.06162      6

   95     3.152     0.2293   0.003252       40      88    0.06435      5

  128     3.152     0.1967   0.003482       80      88    0.06658      5

  163     3.152     0.1734   0.003679      120      88    0.06844      5

  199     3.152     0.1561   0.003849      160      88    0.07001      5

  236     3.152     0.1425   0.004000      200      88    0.07137      5

  274     3.152     0.1317   0.004135      240      88    0.07256      5

  312     3.152     0.1227   0.004257      280      88    0.07362      5

  350     3.152     0.1152   0.004368      320      88    0.07458      5

  389     3.152     0.1088   0.004471      360      88    0.07545      5

  428     3.152     0.1031   0.004567      400      88    0.07626      5
```

Figure 20.

Computer Output of Solution for Variable Area Discharge

Orifice in Anti-Skid Brake System

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