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of
Our reference VAIS 52/He/Le/0127K
Extension 585/2316, 2209-206 va a
Linz, 1987 05 25
Subject UNIDO / AISU / Seminar on Electrical and Mechanical Maintenance in Rolling Mills Report on Seminar

Dear Sir,

We are pleased to submit three (3) copies of our report on the Seminar on Electrical and Mechanical Maintenance in Rolling Mills held April 25 - 29, 1987 in Hama.

This report has been prepared according to your request and we trust you will find it in order.

Yours faithfully
VOEST-ALPINE INDUSTRIAL SERVICES
Gesellschaft m.b.H.

(E. Reichel) (M. Helmy)
Vice President Senior Project Manager

Enclosure

606

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U N I D O / A I S U   S E M I N A R

Electrical and Mechanical Maintenance Rolling Mills

Duration:	25.04.87 - 29.04.87
Place:	GECO Steel, Hama
Lecturers:	Mr. Kunz / VA
	Mr. Neuburger / VA
Organisation:	Mr. Haider / AISU Damascus
	Mr. Sahouli / AISU Damascus
	Mr. Wusatowsky / UNIDO Vienna

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S E M I N A R R E P O R T

1. GENERAL

A seminar entitled "Electrical and Mechanical Maintenance in Rolling Mills" was held in Syria from 25th to 29th April, 1987. The seminar was organized by AISU and assisted by UNIDO.

Seminar programme: appendix 1
List of participants: appendix 2

2. SEMINAR PROCEEDINGS

Originally the seminar was planned to take place in Damascus for a period of 5 days.
The seminar was moved to Hama and the time reduced to 4 days only. On the fifth day, a final discussion was held with AISU in Damascus.

Only 7 of the designated countries took part in the seminar instead of the 9 originally planned.

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The reason for transferring the seminar was to allow the participation of 25 people from the Syrian iron and steel industries.

The proceedings were formally opened and closed by the mayor of Hama and the Managing Director of GECO-Steel.

3. REVIEW

Although the subject matter was generally of moderate difficulty, only a few of those attending took an active part in the lectures and discussions. For this reason, the more complex topics in the programme were not presented. Practical questions were discussed on site.

The start of knowledge of 80 % of the participants can be rated as average, while 20 % can be rated as above-agerage.

There were many questions on topics outside the main theme of "Rolling Mills".

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Appendix_1

SEMINAR PROGRAMME

1st Day (25.04.87)	Subject:	System of Preventive Electrical Maintenance o Minimum insulatin values o Thermal heating o Limiting temperatures o Commulation characteristics o Electrical machines
2nd Day: (26.04.87)	Subject:	DC Main Drive Motors o Transformers o Converter connections o Thyristors o Power control o Speed regulation o Step response of electrical machines
3rd Day: (27.04.87)	Subject:	Maintenance System of STAR, Algeria and GECO, Syria o Introduction o Aims, requirements and methods o Organisation and structure o Tasks, activities and allocation o Plant inspection o Qualification and classification of personnel

./2

4th Day: (28.04.87)

Subject: Failure Analyses of Anti-Friction Bearings; Lubrication

- o Introduction
- o Damage occurring before installation
- o Correct dimensioning and measures for design
- o Defective installation and dismounting
- o Installation errors
- o Maintenance and lubrication of bearings
- o Corrosion
- o Contamination
- o Vibration during standstill
- o Oscillation during opration
- o Damage due to current flow
- o Running hot
- o Working life and normal fatigue

5th Day: (29.04.87)

Final Discussion

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Appendix 2

LIST OF PARTICIPANTS

Name	Company	Position	Country
Ali Hussein Josef	Quattar Iron+Steel	Manager	Quattar
Adnan Rashaida	Arab. Engineering	Techn. Director	Jordan
Mahmud Alunif	Al Fouladh	Maint. Manager	Tunis
Al Bashir Alshitti	Al Fouladh	Maint. Manager	Tunis
Mohamed Ahemd Alamin	Ebisco	Software Eng.	Libya
Mohamed Du Abdusallam	Ebisco	Asst. Manager Mech. Maint.	Libya
Balladi Hussein	National Structure Metal+Copper Company	Director Work Preparation and Maintenance	Algerian
Burdia Ahmed	National Structure Metal+Copper Company	Director Projects	Algerian
Burderbala Ahmed Shkib	Metal+Copper Company	Maint.Dept.Manager	Algerian
Goula Said	Metal+Copper Company	Asst.Direct.Manager	Algerian
Bulmarkar Al Hussein	Sider Iron+Steel	Head of Dept.	Algerian
Mansur Mahluf	Sider Iron+Steel	Head of Dept.	Algerian
Ali Alkalai	Sider Iron+Steel	Head of Dept.	Algerian
Younis Heider	Arab.Union Iron+Steel	Direct.Bureau Damasc.	Syria
Falid Al Asfar	GECO-Steel	Gen.Director	Syria
Suher Al Sahm	GECO-Steel	Asst. Gen. Director	Syria
Isa Abud	GECO-Steel	Personal Director	Syria
Mohamed Cheil Masri	GECO-Steel	Techn. Director	Syria
Mohamed Sakar	GECO-Steel	Production Director	Syria
Saiad Kateni	GECO-Steel	Manager HRM	Syria
Asis Mahoul	GECO-Steel	Steel Plant Director	Syria
Beshar Adi	GECO-Steel	Manager	Syria
Hassan Saki	GECO-Steel	Manager	Syria
Abdilmunem Khalif	GECO-Steel	Manager Finishing HRM	Syria
Nage Ganama	GECO-Steel	Manager Mech. Maint.	Syria
Gassan Hamada	GECO-Steel	Manager Mech. Maint.	Syria
Amer Alsab	GECO-Steel	Dept.Manager Maint.	Syria
Bashir Halag	GECO-Steel	Dept.Manager Maint.	Syria
Maisa Algusi	GECO-Steel	Manager	Syria

About a further 34 participants from various Syian industries.

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Appendix 3

SEMINAR DOCUMENTATION

CONTENTS

0142K/Le

DC-MAIN DRIVE MOTORS AND CONTROLS

(Second Edition)

C O N T E N T S

1. INTRODUCTION

The standard motor for the drives of rolling mill stands is a DC motor with a separate feeding of armature and field by means of thyristor (SCR) converters. There are a few synchronous motors still driving rougher stands in continuous hot strip mills which are directly supplied by the AC network. A new design of feeding synchronous mill drive motors with a variable frequency is already available but there are not yet enough references at hand. These new 'direct converters' are controlled like DC motors but they need additional phase control units. We will only discuss DC rolling mill drives.

1.1 Lay-Out

- If a new plant is to be erected or an old one renewed, the first job is to set up a pass schedule and the tons per hour which are to be produced. The motors are dimensioned to do this at low investment cost, the economic factor is a balance of efficiency and investment costs.
  There are a few requirements to be taken into account.

- Efficiency:
  - DC motors are most efficient at base speed and in the subsequent field weakening area. Most of the passes should be rolled in this speed range. Avoid long passes with high motor current, as losses increase with the square of the current!

- Emergency operation:
  - Redundancy should allow emergency operation of the mill if one motor is out of operation. For economic reasons, only large plants may be equipped this way.

- Spares:
  - The established maximum down time allowance is most important for the selection of spares available, but the following must also be considered:
  - Repair in own repair shop, repair in another shop and spares ordering.

- It may take a few weeks to repair the armature of a DC main drive, this is usually too long a downtime. The costs of a spare armature are quite high, approx. 60 % of the motors cost. To equip all stands with the same type of motor, thus needing only one spare armature, is usually the cheapest solution. With this system, only a few motors are operated at full capacity, most of them being operated lower and the sum of losses is therefore also lower.

- The same voltage for all main drives in a hot strip mill allows the keeping of one spare transformer for all drives.

1.2 Basements

- There are no expansion joints between the basements of double motors.

- The dimensions of the basements take into account the weight of the motor and the peak torque.

- The foundation bolts are dimensioned for peak loads, as also for the stall torque of the armature under full field conditions. Axial pressure caused by breaks occurring in the drive elements of twin drives cause stresses in the foundation. Machines with pedestal bearings require base plates.

- Base plates are positioned exactly before the concrete is poured, as reassembling after motor repairs is much easier if the base plate is evenly flat.

- Usually the basement is a part of the cooling circuit and, as it is necessary to get a smooth surface of concrete, all air tunnels are varnished. Bare concrete parts in the cooling system may cause friction in the air circulation and thus damage the commutator.

- All cables within the basement are covered with fire resistant varnish. All cable trace entrances are sealed as well as doors, walls or any other openings, according to the respective pressure conditions.

- The draining system must not interfere with the cooling air system. Lighting of all the accessible spaces facilitates inspection and repair.

1.3 Bearings

- Slide bearings (Fig. 1)
  - . Large motors of 2 MW and more are equipped with pedestal bearings, the bearing being housed in a ball-shaped seat. Assembling of the motor is easy as the bearing is self-adjusting.
  - . Circulating oil systems lubricate the bearing; for emergency operation oil rings, pressure vessels or oil tanks situated in the roof are at hand.
  - . Oil lift pumps working at high pressure are necessary for reversing mill stands to avoid interruption of the lubrication near zero speed.
  - . The oil of all systems together must be sufficient to finish a pass without doing any harm to the bearing, if the power supply of the lubrication system fails.

- Roller bearing:
  - . Up to approx. 2 MW, main drive motors of rolling mills are equipped with roller bearings. The friction is lower, the oil supply is simpler and therefore no separate emergency system is necessary.

- Disadvantages are:
  - . Higher vibration sensitivity and complications when dismantling the motor. When changing the bearings, or for most other repairs, the couplings have to be withdrawn. Lifting the shrunk seat of couplings is usually done with high pressure oil. Control the seat carefully after dismantling, as small riffles may already prevent any further lifting of the coupling.

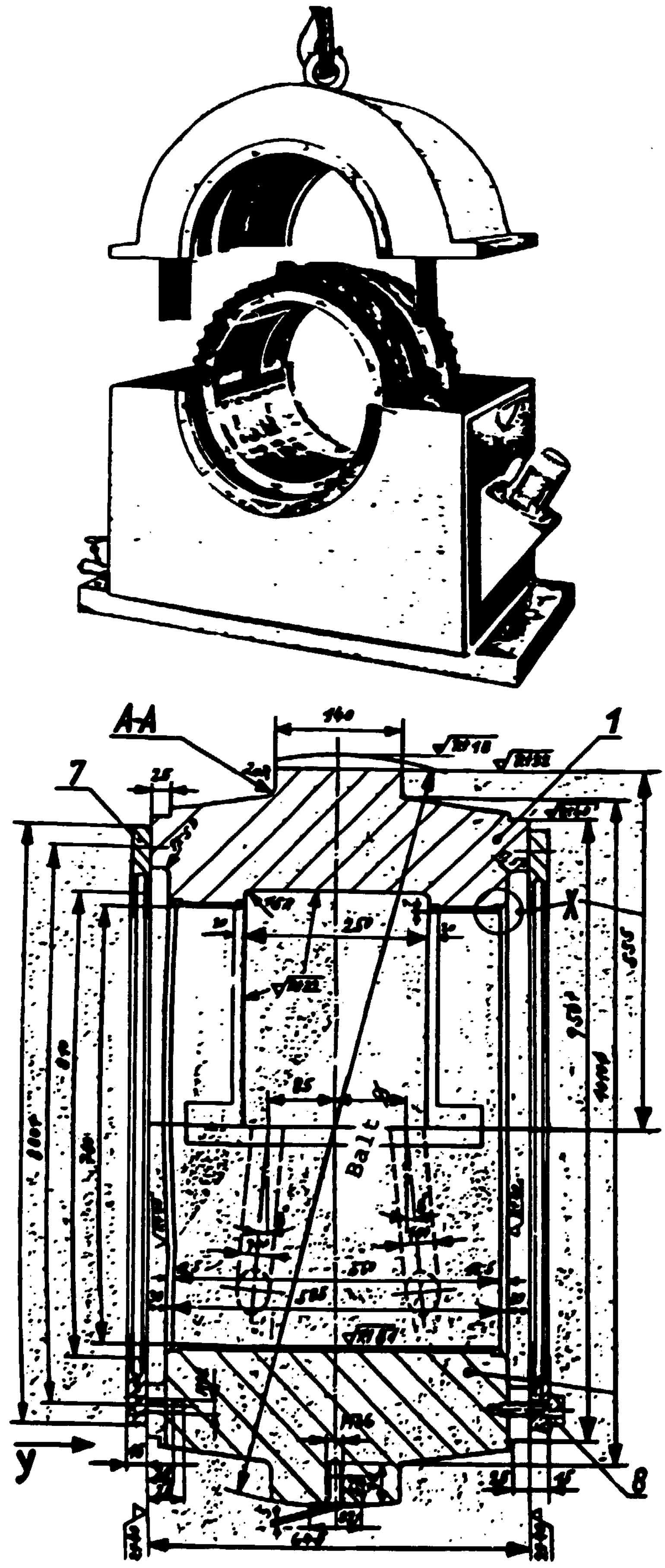


Fig. 1

- Bearings-general:
  - Circulating oil systems operating at low pressure are monitored by means of flow meters in the pipes leaving the bearing. Additional manometers are not necessary, but they allow additional control of the eccentricity of the motors equipped with slide bearings.
  - High pressure oil lifting pumps need only pressure switches and pressure indicator. Starting without pressure is not possible.
  - Central oil systems are fitted with adjustable valves and inspection windows for each bearing to ensure oil distribution. Temperature monitoring must have warning signals and switch off at critical temperatures. Slide bearings require a minimum temperature for starting and to achieve it, oil units and bearing pedestals are heated electrically. Vibration monitoring is not usual for rolling mill drives, but a nipple enabling exact testing with a portable instrument can be attached to the housing of roller bearings.

- Maintenance:
  - Slide bearings are inspected one year after their first test run and later, two-year intervals are standard. If there is a temperature rise, carry out an inspection as soon as possible. Oil distribution channels, the loading square of the bearings, and the surface condition of the shaft should be tested carefully.

. Roller bearings are inspected by 'vibration' tests each month. The first measuring of amplitude and frequency is carried out immediatly after starting the motor for the first time; record all values monthly. A rise in these values is a sign of wear.

1.4 The Shaft

- The shaft is dimensioned for repeated load shocks in rolling service and for peak torque, if there is a cobble in the mill stand. The torque amplification factor (TAF) can reach values up to 3 (Fig. 2)on double motors or twin drives. To hold the TAF low, the shaft torsional strength should be high.

- TAF is highest at the intermediate coupling of double motors and rolling torque is highest on the end of the shaft driving the mill stand. With the same diameter of the shaft in all bearings, only one spare armature and one spare bearing need to be held in stock.

- Mill stands not coupled by means of the rolled steel with a second stand of approx. the same size are limited in torque. The friction of roll to steel in the roll stand limits the peak torque.

- A shaft strong enough to take the shock at high speed, high roll force and high friction, if there is an incorrect setting of roll opening, is not possible. The factor, ultimate load to nominal load of 10, is a good value. The shrunk seat of the coupling slips before reaching 10 times nominal torque. Mill stands rolling together with other stands, such as hot strip mills or tandem mills, need mechanical protection. If there is a cobble in one stand, then all the following stands of the train are pulling and torque becomes excessively high.

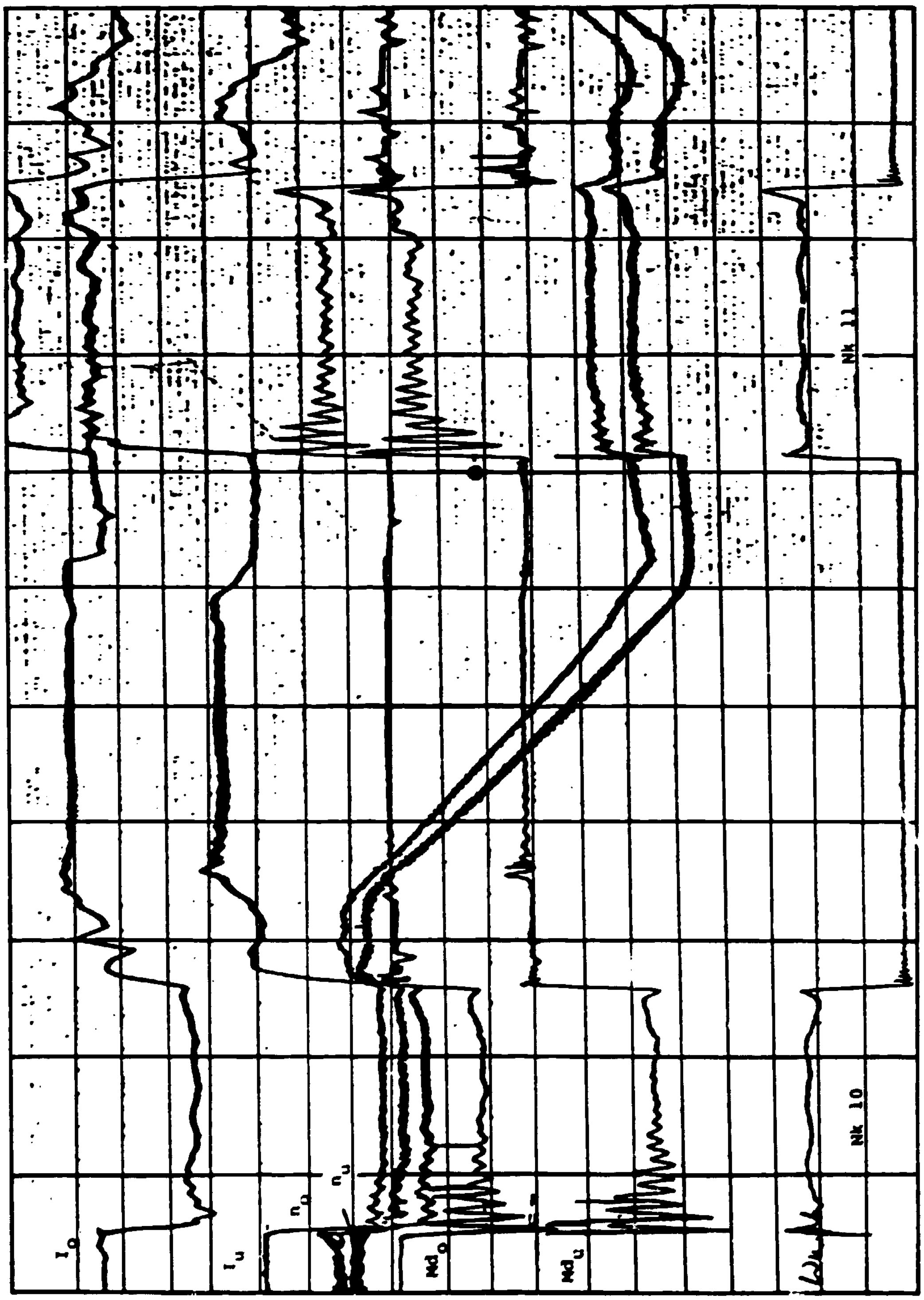


Fig. 2

1.5 Couplings

- Stiff couplings flange-to-flange connect shaft sections within a motor, also couplings of double motors are the same. There is no play in the coupling, therefore very quick speed control is possible.

- Basements of stiff-coupled motors are built without expansion joints. Shafts must be aligned exactly and bending of the shaft should be taken into consideration. Levelling is also important. Elastic couplings should be avoided as they do not allow fast speed control.

- For the drive of tachometer generators, elasticity or play is only allowed in an axial direction (Fig. 3).

- Mechanical couplings allowing deflection should have a minimum of play only. To keep this condition, careful assembling and maintenance helps. Loaded couplings require a considerable force axially or radially to get the loaded flats to slide and during the pass, a coupling without oil may be stiff.

- After some years the wear becomes greater, the drive starts scattering when loaded and the time constant of the speed control needs to be increased.

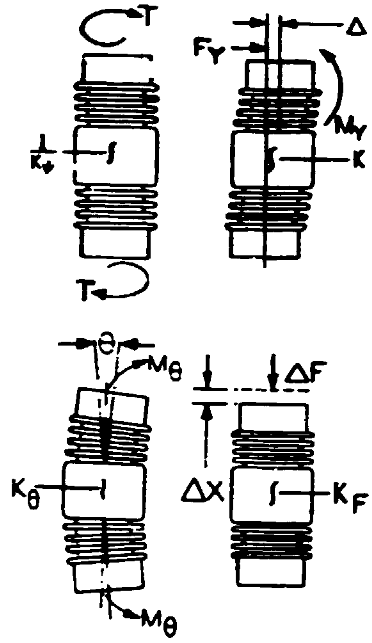


Fig. 3

1.6 Armature

Fig. 4

- The part of a DC machine which is most under stress is the armature with the highly sensitive commutator. It is subjected to high mechanical and electrical load shocks as well as centrifugal forces, and must dissipate most of the power loss.

- Good commutation excludes any vibration of the armature. All the magnetic flux must be free of damping eddy currents. The ripple of current caused by converter feeding is quite high. All bolts must be insulated on the outer diameter of the armature and all fitting bolts are to be situated outside the magnetic flux.

- The body of the armature is usually shrunk on the spider; reversing motors need additional wedges to prevent any moving of seats if there are load shocks. The spider discs or arms are welded to the armature hub. The hub itself is shrunk onto the shaft.

- The commutator is bolted directly to the spider; any connection to the shaft must be avoided. A small movement of the hubs shrunk seat of the shaft would destroy the commutator if there was an additional link.

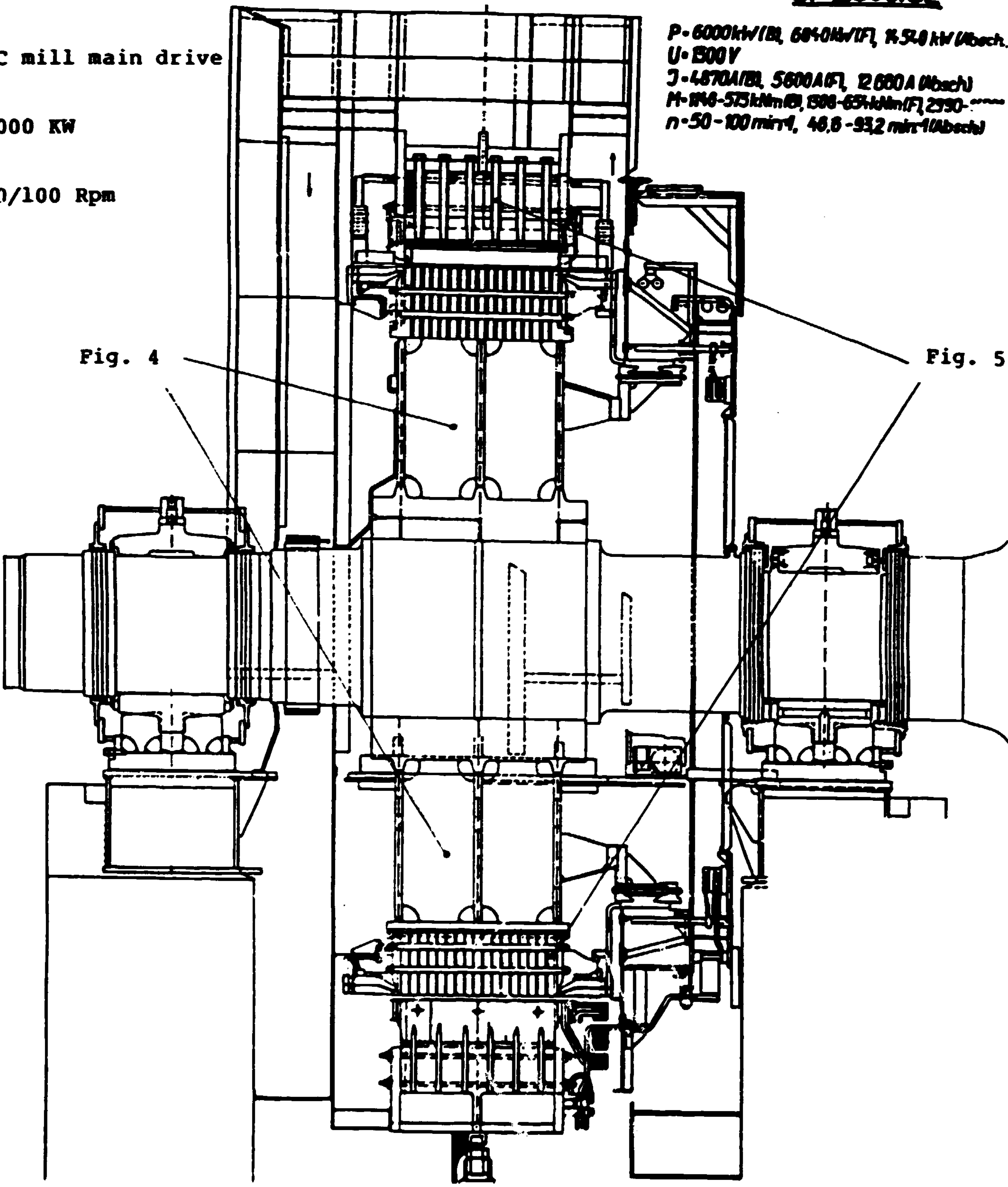
DC mill main drive

6000 KW

50/100 Rpm

GF 2600/52

P = 6000 kW (B), 6840 kW (F), 14.540 kW (Absch.
U = 1300 V
J = 4870 A (B), 5600 A (F), 12 600 A (Absch)
M = 1146-573 kNm (B), 1306-654 kNm (F), 2350-
n = 50 - 100 min-1, 46,6 - 93,2 min-1 (Absch)



- For a long life of the brushes, the commutator surface 'PATINA' must be built up. It requires the following conditions:
  . The temperature of the commutator is best between 50 and 90°C. The current per square cm. should be neither too high nor too low, the best operating range is dependent on the kind of brushes. The flow of cooling air should cool the commutator surface evenly. Vibration of brushholders, brushes, or their suspension must be avoided. The cooling air must not contain any dust or acid vapour.

- Commutator troubles:
  . If there are any grooves on the commutator, either the current is too low, the kind of brushes are not O.K. or there is dust in the air. Small wear may be corrected by grinding the commutator with a corundum block. Grooves of more than approx. 0.3 mm deep need to be turned on a lathe, or for large machines a lathe support must be fixed onto the motor. After turning the edges of the commutator bars, they must be cleaned. Excessive current, the wrong kind of brushes or defects in the motor burn the surface of the brushes and the edges of the commutator bars and they become gray and rough. To find the reason, check the position of the brushholders between the poles, also measure the current distribution, calculate the density of current and compare with the nominal data of the brushes.

- Before changing all the brushes and putting a new set on the motor, the commutator is ground down or turned if wear is already too high. The new brushes are matched to the commutator radius by grinding with a corundum cloth. Run the motor without load until the contact surface of the brushes allows loading. The temperature of the commutator should be tested occasionally; stop idling if it gets too high. Stop also if the brushes vibrate.
- Thick patina already getting black is not critical as long as the commutator surface is glossy. Pitch holes and points of penetrating current are not cricical unless bare copper strips appear on the surface. If this happens, the commutator must be ground down with a carborundum cloth as soon as possible. Current distribution is bad because the resistance of the dark patina is much higher than the resistance of the bare copper strips. Damage of the commutator could result.
- Vibrating brushes sometimes cause bad commutation. Brushes having silicone rubber plates on the top damp vibrations, so sometimes the reason is hard to find.
- The coils of the armature winding are prefabricated in a heated press and treated with epoxy resin in vacuum. After placing the coils in the armature, the rest of the space is filled with resin to get compact windings and good thermal conductivity. Another production system is 'Total Impregnation'. The prefabricated coils are assembled and all connections are made, then the armature is impregnated in a vacuum and pressure is applied. This gives a very compact armature. This method allows no testing of the separate coils before assembly which means a higher risk for the manufacturer.

- Assembling the coils without resin, the 'dry way' common years ago, gives poor thermal conduction and a shorter service life.

- Slot keys are no longer used in DC motors of new design, the coils being fixed by means of glass fibre band. Centrifugal forces must not move the coils and so there must be good tension on the band, leaving sufficient tension after heat-treating the armature. The electrical workshop maintenance crew needs the information about nominal tension and heat treatment from the supplier. Bands must be renewed if armature repair work has been carried out.

- The facilities for carrying out repairs on large DC motors are discussed when making the list of the spare parts needed.

- The list of armature windings and the position of the equipotential conductors are important for the maintenance crew. The changing of the colour of single commutator bars may be a signal to help find a bad connection, with the list at hand.

- 'Cobbles' in the mill stand cause peak torque stresses. All components of the armature should be dimensioned for ten times the nominal torque.

1.7 Stator-Yoke

Fig. 5

- The yoke is suspended in a housing of welded steel components. To prevent eddy currents, the yoke is laminated and all bolts are insulated so they are not in the commutating flux. The key transmitting the torque to the housing is placed outside the commutating flux.

- The main and commutating poles are usually fixed with insulated bolts. If the accuracy after dismantling and reassembling is not sufficient, marks are needed to enable the maintenance crew to reassemble quickly and exactly.

- The stator construction must be able to withstand the short circuit stress.

- Windings
  . The field winding is continuously heated; it must be cleaned at one or two year intervals. The surface of the winding should be smooth, and it must be accessible from both ends. The compensating rods are only insulated in the slot, but bare outside it. The insulated end is a very critical area; it must be kept clean all the time; numerous insulation defects may be found here.
  . Commutating poles are subjected to high short circuit stresses as well as continuous elongation and shrinkage due to rolling passes. All bolts, insulating tubes, and distance keepers are tested as no loose part can be allowed. In particular the locking of all nuts must be checked as one nut falling down may cause great damage to the armature (Fig. 6).

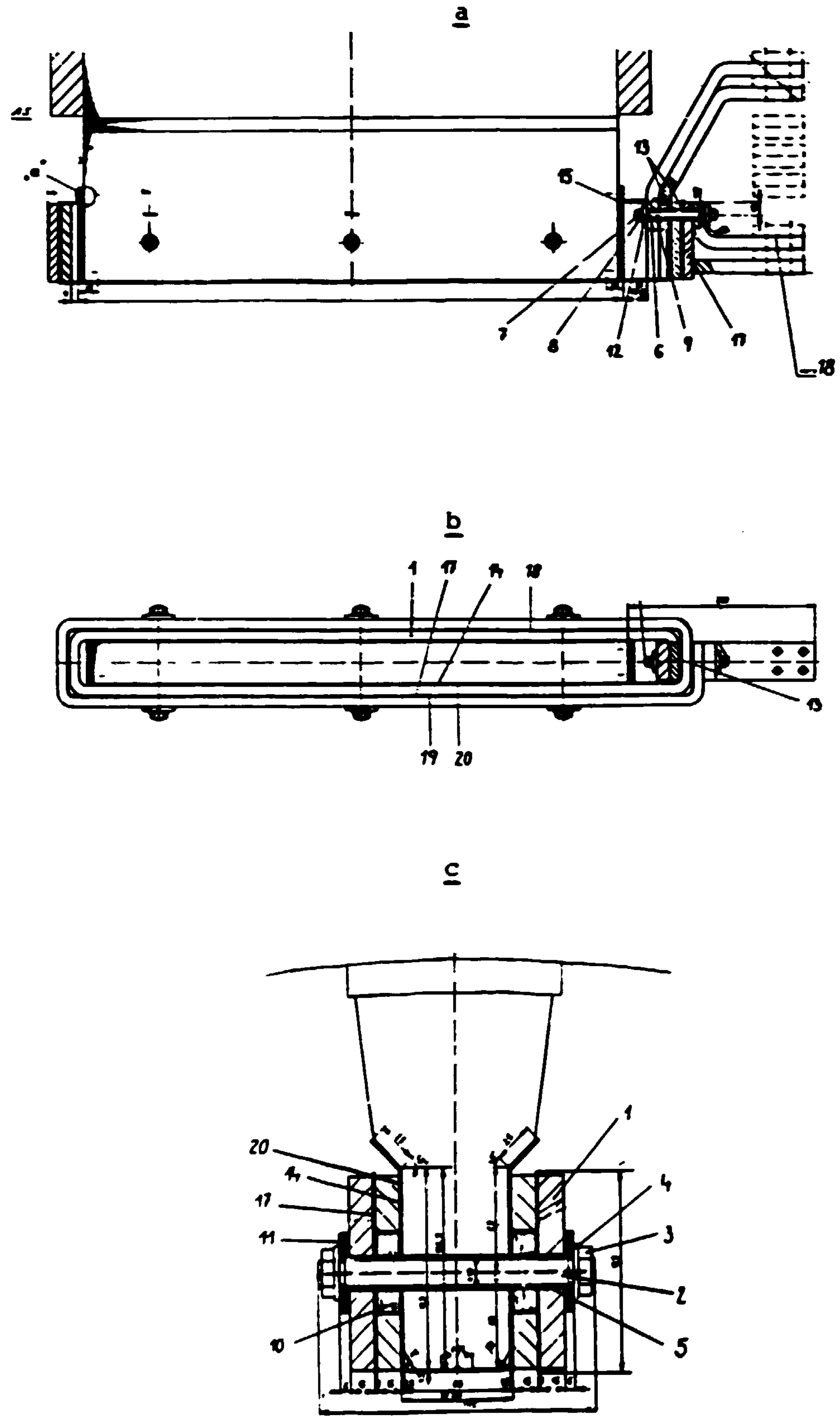


Fig. 6

- The supporting beam holding the brush apparatus is sometimes fixed directly onto the stator housing. It is better to have a separate construction for the brush-holders. The ripple of current produces vibrations in the stator which are dangerous for the brushes. Only a very stiff construction is able to suppress them.

- The supporting beams of the brushholders must not be fixed onto screens or onto insulating shields holding the commutator area separate from the rest of the armature, as all this thin material may vibrate in the forced air flow.

- Brushholders and brushes are one unit; vibration damping elements in the brushholders and on the rear of the brushes can suppress a wide band in the frequency of vibrations. If there are problems, use an instrument to measure the amplitude and the frequency, let the supplier of the brushholders and brushes know. A new set of brushes or holders will eliminate the trouble.

1.8 Casing

- The guiding of the cooling air determines the form of the casing. Large openings or a similar construction that is easy to open is needed when servicing the commutator. Space must be available for changing brushes and most important, to shape a new set of brushes with a corundum cloth.

- The length of the brushes should be checked every week; clean them with dry compressed air before closing the motor. On the driving side of the motor, inspection windows for controlling the cross connections of the armature bars are necessary.

- To avoid air losses, all enclosed circulating systems are sealed.

- The cooling air of the commutator is either exhausted or filtered thoroughly and recirculated. Exhausted air or air lost by leakage should be replaced only by filtered air. All the circulating air systems should be so well sealed that no under-pressure areas occur; this is the best way to keep dust out of the machine.

1.9 Cooling and Ventilation

- Main drive motors for rolling mills are generally forced-air ventilated and air-to-water coolers transfer the waste heat to the cooling water.

- The cool air is blown in by means of fans in the centre of the armature; it is split up in three ways passing slots in the armature core, the free ends of the armature rods and the commutator risers. Next it cools the main- and interpoles. Finally it is blown out or, in recirculating systems, cooled down again. Such systems must be sealed and held at a pressure higher than the surrounding area.

- Condensation water from the air-to-water coolers must be drained. Screens preventing water drops from reaching the windings may be necessary.

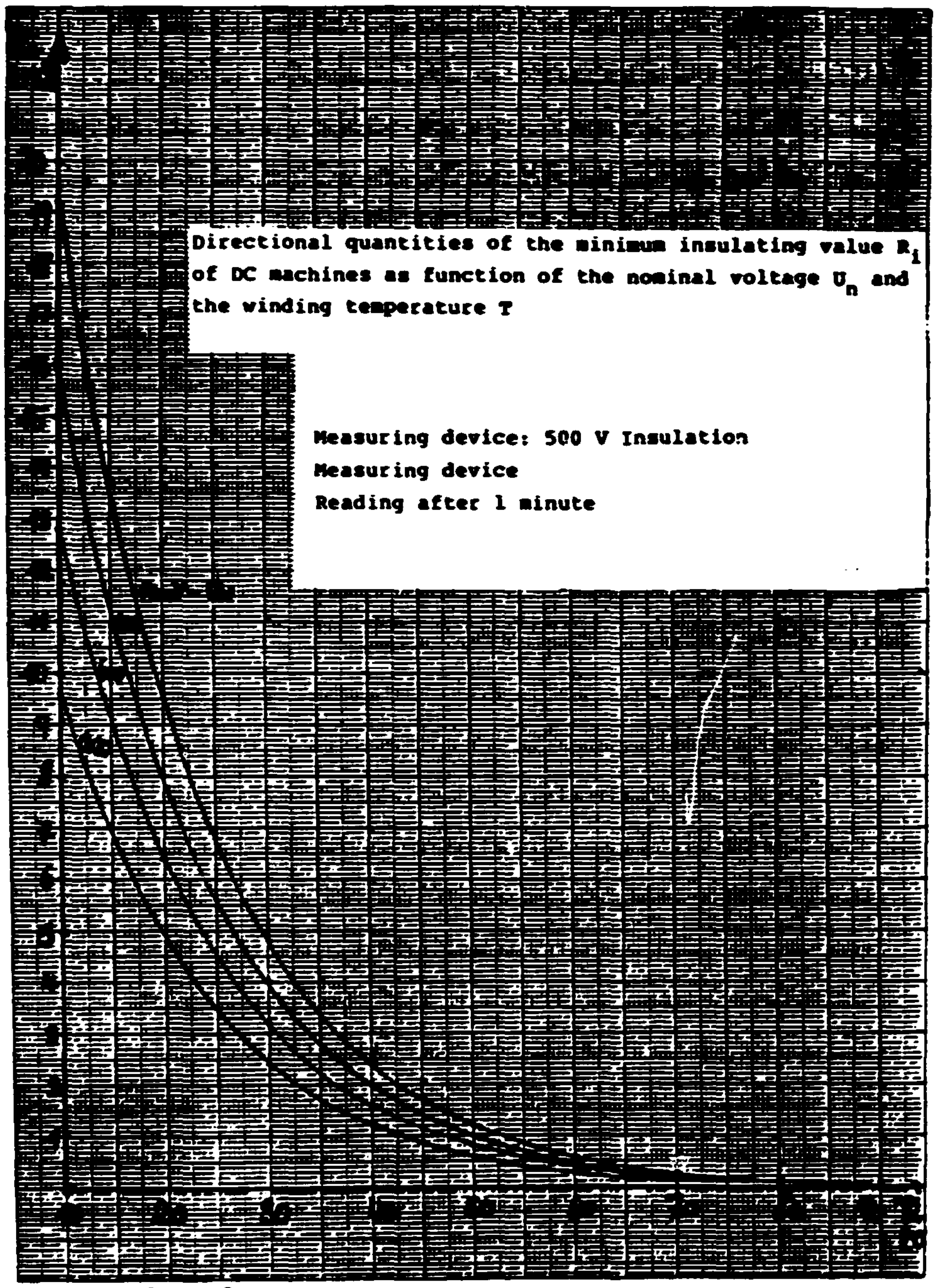
- Maintenance:
  . Air filters should be cleaned each week or if the alarm monitoring the differential pressure sounds. The commutator cabinet is cleaned once a week with dry compressed air. Every year the covers on both sides of the motor should be opened and all the windings should be cleaned thoroughly.

Detergents dissolving epoxy resin must not be used.

- The insulating resistance of the armature and the field is measured once a week with a testing voltage matched to the operating voltage. Have a list of all values and watch the temperature of the winding, as the resistance of epoxy resin changes with the temperature. The alteration speed can be watched and also the cause can be found if the values are entered into a diagram. (Fig. 7)

- Air-to-water coolers are to be inspected once a year and tested if still air tight. Temperatures exceeding the normal operating range indicate clogged coolers, usually the water way being obstructed. Check the temperature and the pressure of the water on the entry and the exit side of the cooler and compare with the data of the manual; cleaning is necessary if the temperature is outside the temperature tolerance range.

- It is a good idea to have the possibility of setting the air flow on commutator cooling. This is necessary for extraordinary loads, for excessive temperatures of the cooling water or the air in summer time, and if there is a high temperature required for a short time to form a fine 'Patina'.



Epoxy Resin
Resistance/Temperature

Fig. 7

1.10 Signals and Monitoring

- Overspeed:
  - Mechanical overspeed switches must not fail if the voltage is off; electronic overspeed is fed and operated independently of the speed control and undervoltage control is also necessary. The coupling of the overspeed device is difficult to watch and an additional field relay is not standard but gives additional safety at a low cost.

- Overvoltage:
  - The overvoltage relay must work independently of the voltage ramp; no signal should occur for short peaks as these are not critical for the motor insulation.

- Earth fault monitoring:
  - A separate earth fault relay is needed for the armature and for the field circuit. The triggering of breakers is usually delayed until the pass is finished, as a stoppage with steel in the mill stand damages the rolls.

- Overcurrent protection:
  - Standard protection is through blocking the gate of the thyristors. If the line voltage is off, the conducting thyristor can't commutate; to avoid the blowing of fuses, a high speed circuit breaker switches off the armature circuit. The actual value of the current is to be taken separately for protection and control purposes.

- Temperature monitoring:
  . Monitoring of the coil temperature in the field and armature circuit, outside the armature itself, giving signals 'Alarm' and 'Out', is standard.

- Large rolling motors are equipped with temperature measuring devices in the armature itself and in the stator coils. The transmitting of the actual value from the armature is usually done by frequency modulation and transferring AG signal. Temperature measurement in the cooling air is usually carried out in the incoming and in the outgoing air duct.

- Monitoring air flow by means of mechanical or thermal monitors is sensitive, but wear and dirt can cause problems. Most of the signals coming from air flow monitors are false alarms. A reliable temperature control of the coils is sufficient protection. Bearings are equipped with oil flow monitors; additional temperature monitoring may prevent severe damage to the slide bearings if there are slight defects on the bearing surface.

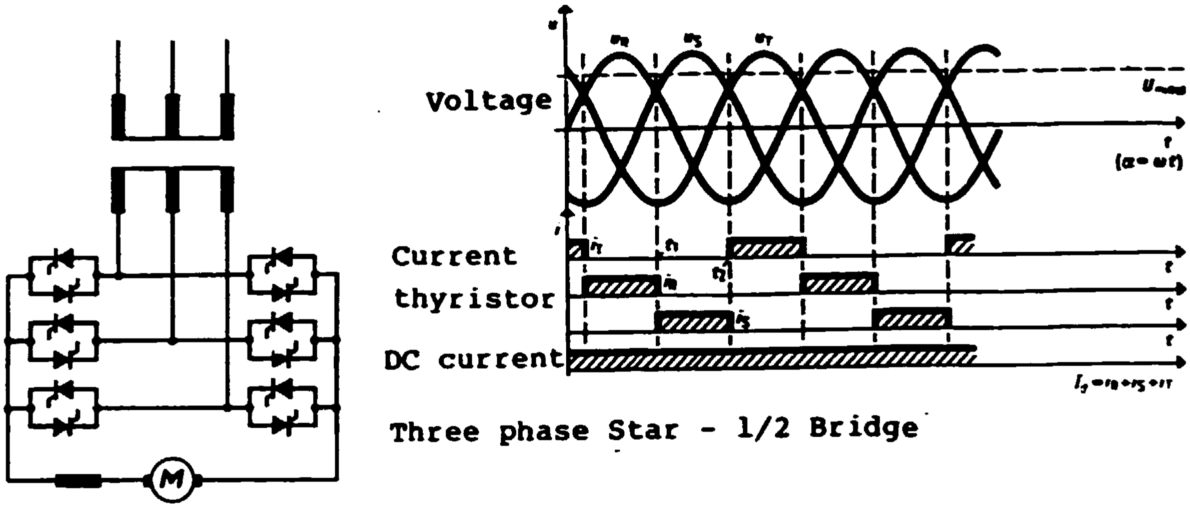
2. CURRENT SUPPLY

2.1 Thyristor Converter

Fig. 8

- The main drives for rolling mills are exclusively supplied by thyristor converters, providing the network does not drop in voltage too much when steel enters the roll gap.

- Drives up to 2 MW are fed with 3 or 6 KV line voltage, new plants use 10 KV. Bigger drives are fed with 30 KV; new plants use the same voltage. Sometimes extra-ordinary large motors have the rectifier transformers directly linked to the high voltage line. There is a separate transformer for each rectifier, the secondary voltage is matched to the nominal voltage of the motor, the switch-gear equipment, thyristor blocking voltage and cables. Note that the minimum size of cable may be dictated by the short circuit current and breaker delay as well as by the load current.



Three phase Star - 1/2 Bridge

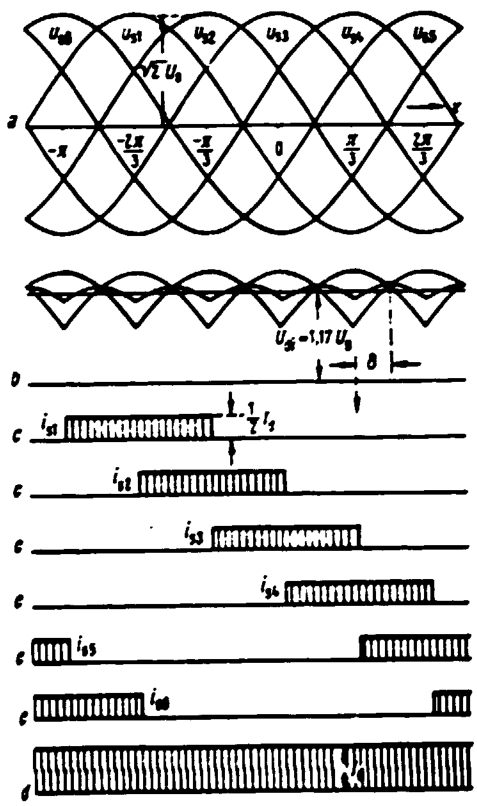


Fig. 8

2.2 Transformers for Converters

- Overvoltage, short circuit and overload characteristics are similar to those in line transformers. In addition however, there are steep current ramps, and all the harmonics produced by converter faults which may produce asymmetries in the current and cause interference in the magnetic flux.The heavy duty service requires a very strong construction of the magnetic core and all the windings. The housing must suppress vibrations produced by stray flux. Overload characteristics, necessary if another drive fails, must be matched to the motor, as the thermal time constant of transformer and motor is nearly the same.

- The current shape is rectangular in the secondary of the transformer, the harmonic filters correcting the sine form of the voltage usually operate at the 30 KV voltage level.

- Monitoring equipment:
  . Temperature monitor with 2 steps 'Warning' and 'Out'.
  . 3 Phase thermal overload relay only in large drives.
  . Short circuit protection.
  . 'Buchholz-relay' for liquid-cooled transformers.
  . Oil level indicator.

- Maintenance:
  . Clean the surface of the cooling tubes if the temperature increases. Dry transformers should have a smooth surface (cast resin or similar) which enables easy cleaning. Check the insulating strength of the oil once a year. Check all the monitoring equipment once a month.

2.3 Thyristor Converter

- The blocking voltage of modern thyristors is quite high, and so a series connection is not necessary for supplying DC main drive motors of rolling mills.

- The current of one three-phase-bridge is only sufficient for supplying an edger or a temper mill drive. Large drives however need parallel thyristors.

- The design of the converter takes a good power factor (0.9 - 0.95) into account; it enables the converter to supply the 'pass current' almost as a permanent current.

- Controlling the current power factor and cooling conditions are the main tasks of the maintenance staff.

- Monitoring only the ultra rapid fuses is not sufficient for thyristors in parallel operation. Current monitoring watches the load circuit as well as the gate control.

- Information as to the service data of the cooling equipment is necessary; a test of the leaving air temperature is not sufficient.

- A direct temperature measurement of the silicon chip is not possible in the same way as for the coil temperature. The cooling system usually has great reserves, therefore it is years before the first cleaning becomes necessary.

- Maintenance:
  - Check the current distribution of the parallel thyristors and all the cooling system as already mentioned; check additionally all the terminals and couplings in the armature circuit, aluminium bus terminals being most sensitive.
  - Check all the impulse lines, impulse transmitters and the gate terminals on the thyristors carefully. If there is a drop out of the breaker without any monitoring signal, check all gate pulses with an oscilloscope, watching the amplitude and shape of all pulses.

All monitoring equipment should be tested once a month.

- Over-voltage protection:
  - All the magnetic energy stored in the core of the transformer produces over-voltage, if the supplying high voltage breaker opens and the converter is blocked at the same time. The over-voltage protection must dissipate all this energy without any voltage peaks which are dangerous for the thyristors.

- There are three types of voltage suppressors available:
  - Selenium rectifiers in stacks having controlled avalanche characteristics; each plate starts conducting at approx. 60 V, dissipating all the magnetic energy of the transformer in the selenium layer.
  - Discharges melt some of the selenium leaving a black spot, the suppressor however remains in operation although the power capacity is now a little lower. If the suppressor has too many spots it must be renewed.
  - Capacitors supplied via diodes equipped with current limiting resistors and discharging resistors are also standard.

- This overvoltage protection has no exact limit, high frequency resonant oscillations are possible.
- A new approach is to trigger high speed thyristors, if the voltage reaches the limit, and feed all magnetic energy into a polycrystalline silicon block switched in series with the high speed thyristor.
- Triggering is usually done by means of Zener diodes; voltage ramps may also trigger the thyristors having controlled avalanche characteristic.
- This type of protection operates without power losses, the voltage limit being at a set voltage. High frequency oscillations are impossible. The function is to be tested every month by a variable voltage source.

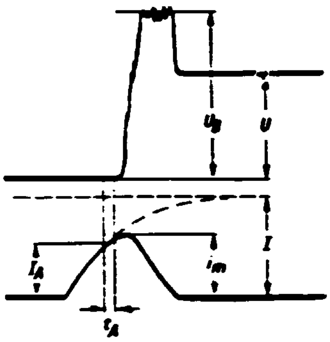
2.4 High Speed Circuit Breaker (Fig. 9)

- Rolling mill drives feed power back into the line when decelerating. If the line voltage fails, the thyristors conducting the current at the moment can't commutate. If no high speed circuit breaker interrupts, the ultra rapid fuses blow out.

- The high speed breaker must open and extinguish the arc before the fuses start to burn out. It must also use all the energy stored in the DC circuit magnetically (i^2t); this is done in the arc chamber of the breaker.

- The voltage of the arc must not exceed two times the nominal; the same voltage level stresses all the insulation of the armature circuit. The arc voltage selected by inserting deion plates in the arc chamber is usually lower than the blocking voltage of the thyristors.

- High speed circuit breakers start opening the contacts with a delay time of 2 to 3 milliseconds; the arcing time is app. 10 milliseconds; the inductance of the armature circuit and the current to be interrupted dictate this.



Oszillogramm einer Kurzschlußabschaltung
Oscillogram of a fault interruption

Operating current (setting)	I_A	kA	16
Short-circuit current	I	kA	27
Through-flow current	i_m	kA	17.8
Voltage	U	V	1500
Arc voltage (mean value of the arc drop)	U_B	V	2750
Inherent response time	t_A	ms	2.7
Circuit time constant	L/R	ms	15.5

Fig. 9

- Selectivity:
  - The energy, heating up the fuses, must not exceed the melting energy of the fuses during the time the high speed breaker needs to interrupt the current.
  - The energy heating up the thyristor during melting and arcing time of the fuses must not damage the thyristor.
  - All faults on the motor or the network must be switched off by means of the high speed breaker only; the electronic gate control may help.
  - Ultra rapid fuses must blow only if there are faults within the converter, the gate control or the current directional module.

- A serious fault occurs if the motor is feeding back to the line (generator operation) at full voltage and the commutation of the thyristors fails. The machine voltage is added to line voltage within a few milliseconds and it needs considerable inductances in the armature circuit to switch off by means of the high speed circuit breaker only, without blowing fuses.

- Maintenance:
  - Disassembly of the high speed breaker and thorough inspection of all moving parts and renewing of worn parts is necessary after at least two years of operation regardless of the number of operations.
  - The triggering level is tested with full current and a ramp similar to plant service. All this is best done in the central workshop using a special test stand.
  - A high speed recorder registers current and voltage before the breaker is put into operation again.

- All this is necessary as the ripple of DC vibrates the mechanics of the breaker and the triggering level changes with wear.
- Damaged arcing chambers must be replaced as they may cause high voltage peaks endangering all the electrics of the drive.
- Have a look in the manual as breakers sometimes need additional service.

3. CONTROL

3.1 Closed Loop Control (Fig. 10)

- Steel rolling demands different characteristics for each type of mill stand and control has to fulfill these demands.

- There is a complete control system for the armature and a second one for the field circuit, operating together.

- The thyristor set and the gate control are not closed loops, they are only settings. Each closed loop control needs a feedback of the actual value. Comparing the set-point with the actual value, the closed loop control reduces the difference.

- Closed loop control operates in levels, each one for a definite function. The "lowest" level is next to the thyristor-set, the "highest" is next to the command signal. The lower loop gets the order from the higher one.

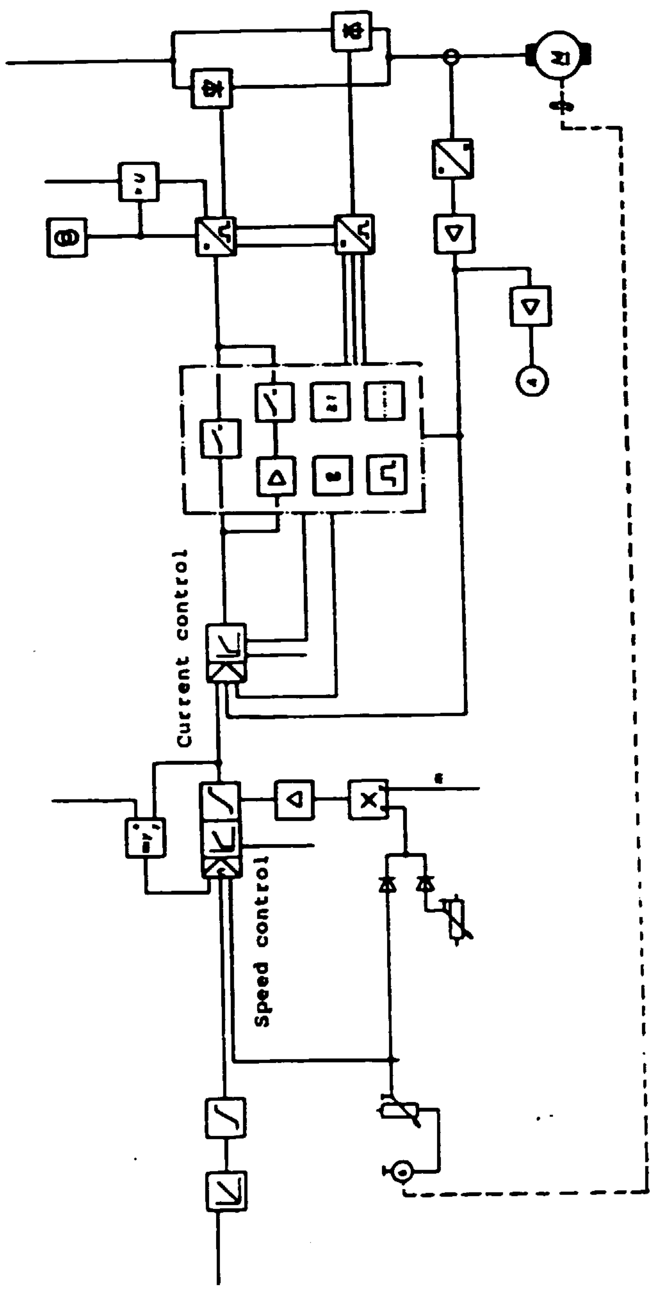


Fig. 10

3.2 Voltage Control Loop

- This control system was used for controlling motor-generator sets; it is not needed for thyristor converters. A part of its function is the governing of the output of the current controller during the time a blocking signal is on.

- The field current of a generator or the control angle of a thyristor converter corresponds to a voltage; if it is measured and fed-back, it is a kind of voltage control.

3.3 Current Control Loop

- The current controller operates very quickly, its time constant is approx. 15 milliseconds, corresponding to the armature circuit.

- The current measuring device must operate extremely quickly.

- There is usually a DC/DC converter in the armature circuit or a current measuring transformer in the feeding AC line.

- To optimize load sharing, there are sometimes a few current controllers operating in parallel, each one having a measuring device for the actual value, but as there is only one nominal value and only one time constant, these functions are usually carried out by a controller in front of the parallel controllers.

3.4 Torque Calculator

- The output of the speed control corresponds to a certain torque. To calculate the nominal current, the magnetic flux of the motor must be taken into account; sometimes the torque calculator is placed in the feedback line of the speed controller.

3.5 Speed (rpm) Closed Loop Control

- The operating speed of the controller is limited by the resonant frequency of the mechanics. The time constant varies between 0.1 and 0.5 sec.

- The speed closed loop control governs the current control loop.

- The actual speed (rpm) measured by means of a DC tacho generator must supply a voltage high enough to be able to suppress the ripple of the tacho and every other noise as quickly as possible. No play or elasticity can be tolerated in the tacho drive.

- The amplification factor and the response time of the speed control must be matched to the drive. An increase in the play of the coupling may cause scattering, also a change in the inertia or in the elasticity of the drive may cause speed hunting. In this case, the controls need to be re-set. To do so, the maintenance staff need sufficient information about the original calculation as well as the setting data of all the regulators.

3.6 Ramp Limiting

- Limiting of the current ramp is necessary for supplying motors with non laminated yoke; it must be adapted to the commutation limits of the motor; it also reduces the stress of the power drive if there is any play.

- The ramp generator commanding the speed control loop is sometimes wrongly called a speed-up regulator, even though it is not a closed loop control. Limiting the speed ramp reduces the overshooting of speed and the sensitivity of the speed control can be increased.

- The mechanics sometimes require a slow acceleration, e.g. to get oil in the loaded area of slide bearings. Transition functions in cold rolling tandem mills are very complicated, computers therefore usually calculate the nominals.

3.7 Position Control Loop

- The position control governs the speed of the control loop. The position control is necessary to guide the rolls into the correct position for roll changing.

- The actual position is usually signalled from incremental or coded digital equipment. A small computer called a "stopping distance calculator" commands the speed control, holding the current under current limit.

- All the information of the drive is stored in its memory.

3.8 Field Control

- The task of field control is to hold the field flux full up to base speed. In the higher speed range, the field control holds the voltage of the armature circuit constant by setting a lower field current. The field control is therefore an armature voltage closed loop control which uses the field of the motor for regulation.

- The time constant of the field is quite high (approx. 1 sec.), therefore it is advisable to have some spare voltage range in the armature circuit in order to control shock loads without being blocked by the voltage limit.

- This is necessary for twin drives, the finishing train of hot strip mills etc.

- If the line voltage falls, the flux of the motor must also be reduced, this is essential because inverters can't operate if the electromotive force of the motor is higher than the line voltage. Only drives without regenerative braking don't need this field reduction.

3.9 Control of Different Types of Main Drives

- Coupled motors are operated either by both armatures in series or, if in parallel, one speed control circuit commands both current controllers. This however needs two converters.

- Twin drives are equipped with two completely independent controls. They use a load sharing control for balancing the armature currents, but there are limits caused by the friction of the rolls and shape of the steel.
- Main drives of the finishing stands in hot strip mills are also independent, but they receive additional signals from the loopers to hold the loop and avoid excessive tension in the steel strip.
- In cold rolling tandem or duo mills, each stand is equipped with speed and torque control which receives additional signals to gain the exact strip tension and speed for the thickness and flatness control.

3.10 Speed Calculator

- The rolling process dictates the speed of strip. The speed control is really a 'revolutions-per-minute' control, so it needs to divide the nominal speed by the diameter of rolls. The output of the speed calculator is the input for the speed (r.p.m.) control loop.

3.11 Maintenance

- Today's electronic control apparatus does not need to be serviced, as there are no moving parts. The cooling system must be held in good condition and excessive dust should not accumulate in the electronic control cabinet.

- All the devices measuring the actual values as well as all the monitoring equipment must be tested once a month. The commutator of the tachodynamos must be clean. The coupling must be free of play and misalignment cannot be tolerated.

4. NETWORK

The short circuit power of the supply network must be sufficient to avoid a voltage drop higher than 10 % at the highest load peak.

Harmonics must not exceed the limits specified by the power plant.
Auxiliary drives are usually equipped with six pulse converters producing mainly the fifth and seventh harmonic, but these converters are not expensive.

Main drives are equipped with 12 pulse converters leaving less ripple on the DC current. Suppressing the 5^{th} and 7^{th} harmonic may be achieved by connecting one motor of a twin drive or one part of a double motor to a star-delta transformer, the other one to a star-star connected transformer. If the load is equal, the 5^{th} and 7^{th} harmonic are also suppressed.

Operating the main drives in this way gives a good load distribution in harmonic filters or harmonic suppressor circuits.

SYSTEM OF PREVENTIVE, ELECTRICAL MAINTENANCE

(Final Edition)

C O N T E N T S

1. GENERAL

The definition of maintenance is the sum of all activities of maintenance and the restoration of determined, desired conditions, as well as the inspection and assessment of the actual situation. In the following, the electrical preventive maintenance of equipment is described.

By preventive maintenance (in short form prm), we mean the planned activities before a breakdown. Some examples of the many problems of preventive maintenance will now be described.

2. AIMS AND ACTIVITIES OF PREVENTIVE MAINTENANCE (PRM) BY INSPECTION

Generally we can say that the aims of inspection are to indicate vulnerable points. The reason is to eliminate these points without stopping production and at minimum costs. According to this, the chance of breakdowns is reduced and overtime and largescale repairs are avoided.

In addition to this, activities are carried out for determining and assessing the actual situation in the same way as measurement and testing. In this way, the notion of conditioned maintenance is often used.

2.1 Checking the Insulation Value of Electrical Machines and Static Converter Equipment

- Insulation value of the motor must be measured for the determination of safety depending on voltage. The regular time intervals are dependant on the size and importance of the installation.

- To measure this, the static converter is first insulated and the insulation value of stator and armature winding is determined. The measuring instrument used is called an insulation tester (megger or, better, electronic insulation meter) and the measured value is observed after one minute of measuring time. Measuring voltage for rated voltage less 1,500 V is 500 V, and measuring voltage for rated voltage less 500 V is 250 V.

- Because the insulation value depends on temperature, it is necessary to measure at the same time the temperature T of the winding.

- Reference data for minimum insulation values for medium voltages may be derived from following formula (1) especially for large machines.

$$Ri > k.U_N \quad (1)$$

. Ri	(M)	minimum insulation value
. k		conversion factor for temperature from Fig. 1
. U_N	(kV)	nominal voltage of the motor or of the part of the motor

- The relation of insulation value to temperature can be seen in Fig. 1.

- The absolute temperature value of the winding is measured by an installed temperature sensor or is calculated after measuring temperature by formula (2).

$$TW = \frac{R_W - R_K}{R_K} \quad (235°C + T_K) + T_K \quad (2)$$

. T_W	(°C)	absolute temperature of the winding in warm condition
. T_K	(°C)	absolute temperature of the winding in cold condition

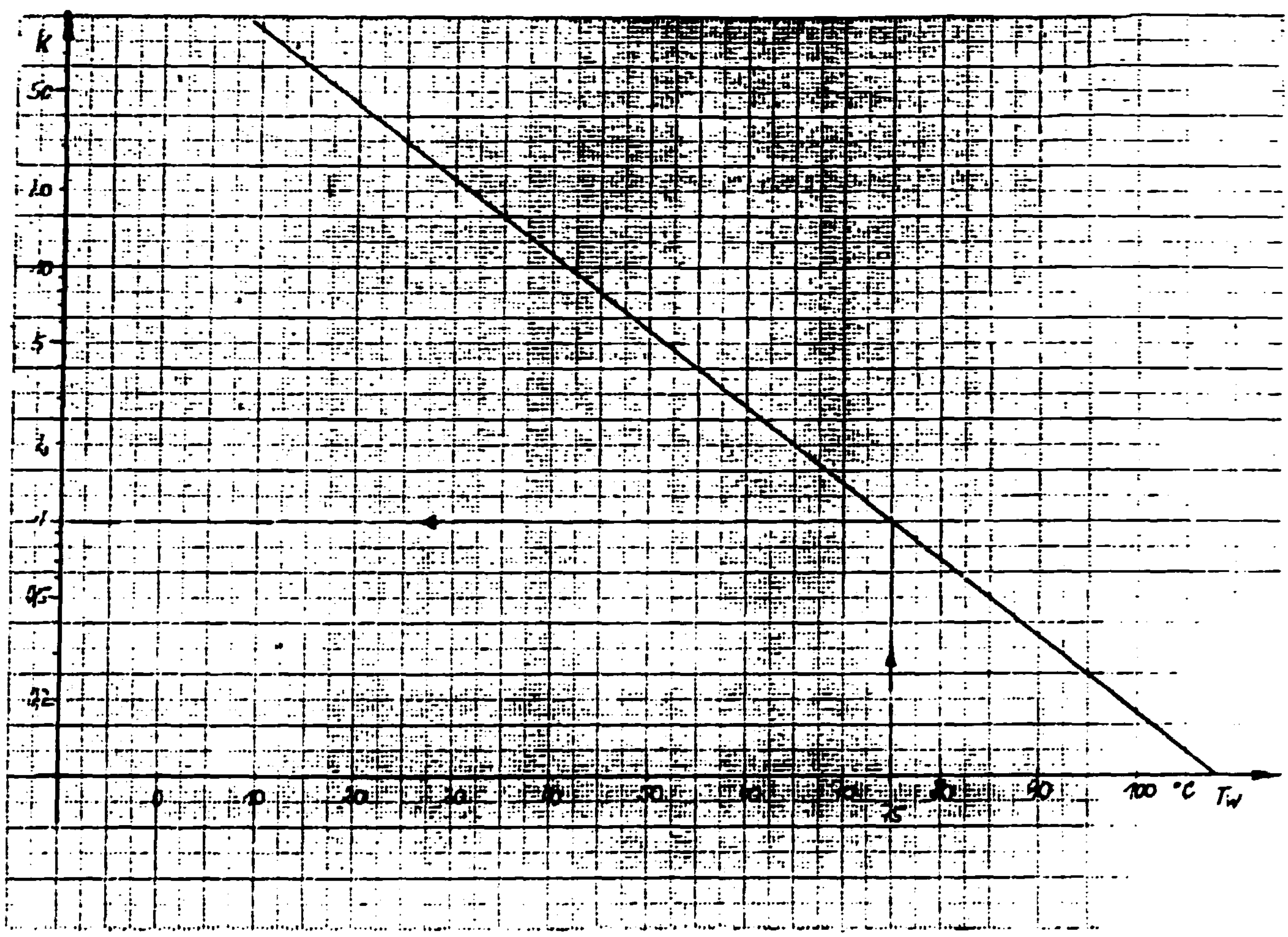


Fig. 1
Conversion Factor (k) for Temperature
Depending on Temperature of Winding T_W

. R_K (Ω) cold resistance
. R_W (Ω) warm resistance

- In Fig. 2, minimum insulation values depending on temperature are derived from formula (1). Rated voltages are 200 V, 60C V, 1,000 V and 1,400 V.

- Minimum insulation value of high voltage motors (U_N 1,500 V) is calculated by the modified formula (1).

$$Ri \geq k. \frac{U_N}{D} \quad (3)$$

. D (m) diameter of the armature if $D > 1$ m

- We must take note that the formulas written above give reference data in the way they are used by VOEST-ALPINE for assessing the insulation value. After a longer stoppage in a moist atmosphere, which favours condensation, the insulation value may be less. After some hours of work, the motor may dry out (by its own loss of energy) and the insulation value increases.

- A methoc often used is drying of the winding with the static converter of the armature disconnected and the static converter of field connected.

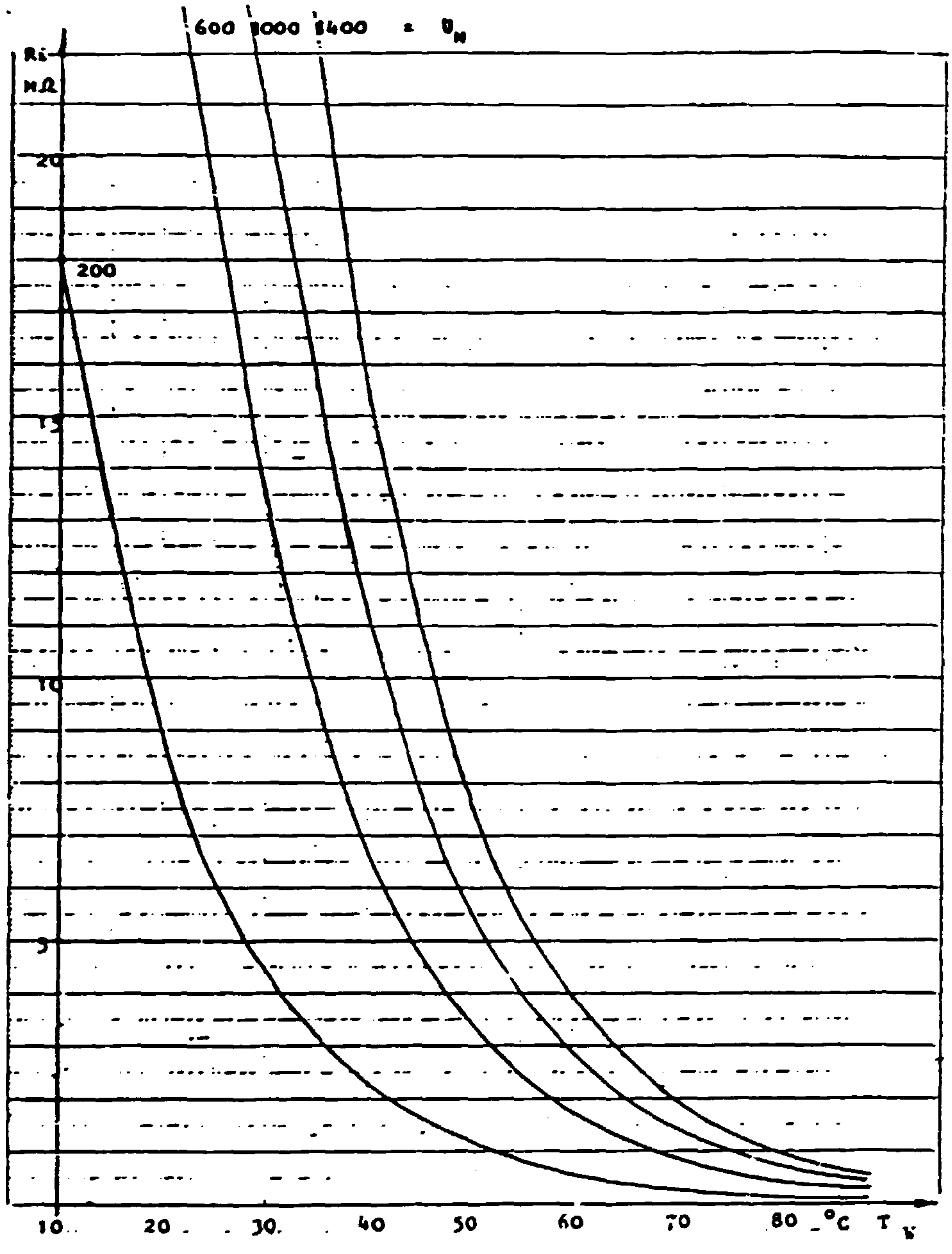


Fig. 2

Minimum Insulation Value Ri Shown as a Function of Nominal Voltage U_N and Temperature of Winding T_W

- In this case, it is very important to guarantee minimum air circulation. Local overheating of the winding is not allowed. In addition to this, temperature increase of the winding is limited (about 5°C per hour) to prevent evaporation of moisture from inside the insulation material. Carelessness could cause damage to the insulation material.

2.2 Checking Heating Up of Electrical Machines

- Using this kind of checking, it is possible to say something about the contamination of the motor, the condition of the cooling system and the expected service life of the insulation.

- The losses generated by power conversion of electrical machines bring an undesired heating, and this fact is disadvantageous to the service life of the insulation. Most important for heating are magnetic hysteresis losses and ohmic winding losses, which cause heating as shown in Fig. 3.

- An important figure is the time constant T of heating, which is a measure of the accumulation of heat.

- A small time constant means low accumulation of heat, while a large time constant means large accumulation of heat.

- After some time, the excess-temperature $T_{ü}$ does not rise further and an approximate permanent operating temperature $T_{ü=}$ gives rise to a stationary situation. The excess-temperature $T_{ü}$ is temperature difference between temperature at a special point and its surroundings.

- According to the way that losses in the winding, accumulation of heat and cooling conditions are different, there are different temperature rise profiles in the measuring points of the motor (see Fig. 4).

- The stator winding, the centre of stator losses, has least accumulation of heat and the most disadvantageous cooling conditions and, therefore, the shortest time constant and highest temperature rise.

- The stator housing outside, far away from the centre of losses, has high accumulation of heat and large surface and, therefore, the most advantageous cooling conditions. In this way the stator housing has the longest time constant and lowest temperature rise.

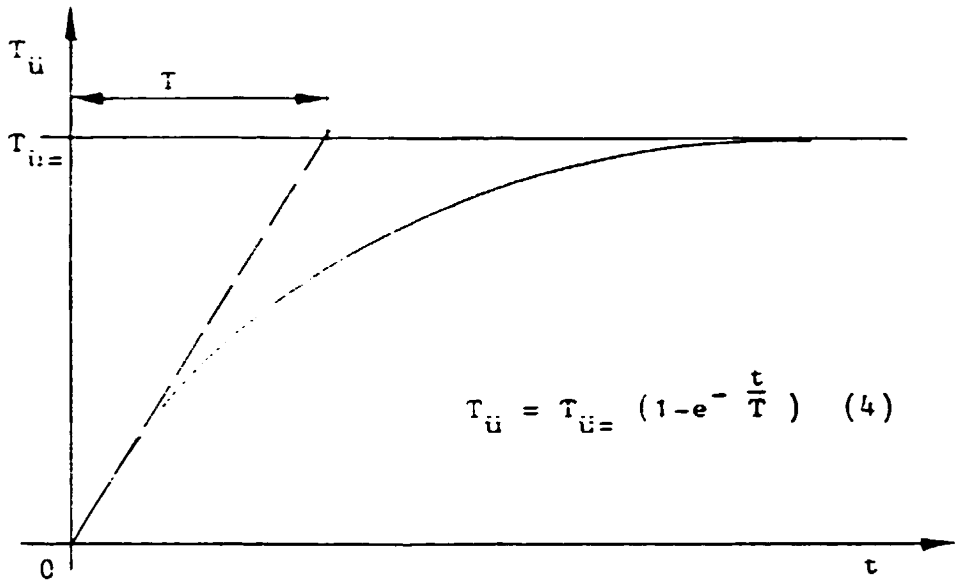


Fig. 3
Theoretical Measurement of Temperature Rise
as Function of Time

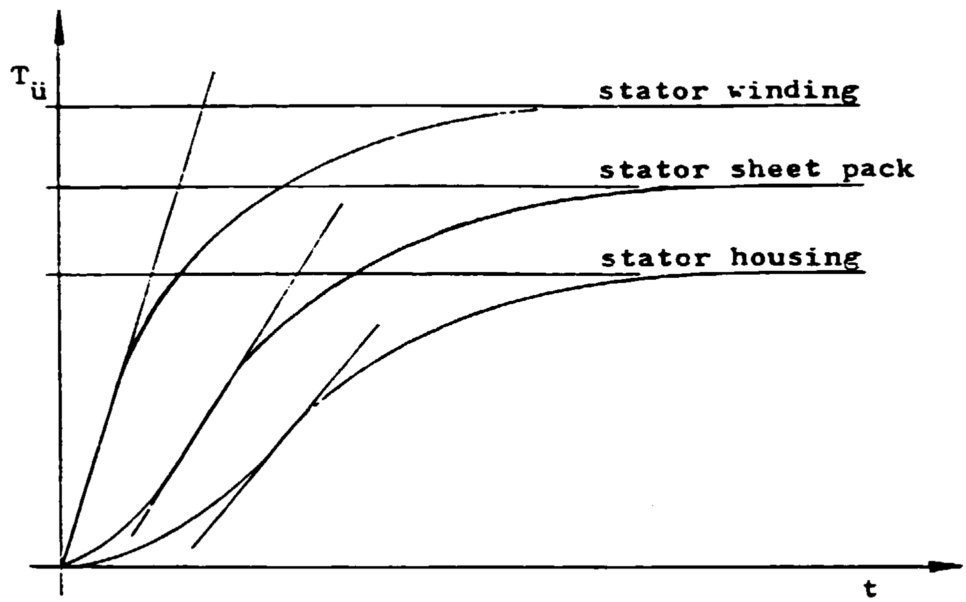


Fig. 4

Practical Measurements of Temperature Rise as a Function of Time for 3 Measuring Points Inside and Outside of the Stator

- The mathematical connexion between temperature rise $T_{ü}$, time constant of heating T, steady temperature $T_{ü=}$ and time t is shown in formula (4).

$$T_{ü} = T_{ü=} \cdot (1 - e^{-\frac{t}{T}}) \qquad (4)$$

- A very important question is the determination of temperature rise. Absolute temperature can be measured by a temperature sensor inside the windings and the temperature rise can be calculated after subtraction of the cooling air temperature.

- A second method (if sensor is not installed) is used by measuring the winding resistor in warm and cold situation. The following formula (5) is used for copper and aluminium windings.

$$T_{\ddot{u}} = \frac{R_W - R_K}{R_K} \cdot (235°C + T_K) + (T_K + T_{K\ddot{u}}) \qquad (2)$$

- $T_{\ddot{u}}$ (°K) Temperature rise of the winding
- R_W (Ω) Resistance of warm winding
- R_K (Ω) Resistance of cold winding
- T_K (°C) Temperature of cold winding
- $T_{K\ddot{u}}$ (°C) Temperature of coolant

- It is very important that cooling air flows freely (calculated air volume), no local or other warm air is sucked in and contamination is not too high (heat transfer resistor).

- After it has been shown how a temperature rise is determined, the question about admissible temperature rise is important. Excess-temperature depends on the type of insulation material and insulation class (A, E, B, F, H) shown in Table 1.

Insulation class	Highest permanent temperature
A	105°C
E	120°C
B	130°C
F	155°C
H	180°C

Tab. 1
Insulation Classes and Highest Permanent Temperature

- The above permanent temperature is absolute and independent of the coolant.
- Different permanent temperatures can be achieved for the same insulation materials using different impregnation materials.
- In Table 2, the admissible excess-temperatures between the temperature of machine part and coolant temperature in degrees Kelvin are shown.

Machine part	Insulation class				
	E	B	F	H	
AC - windings, nominal power less than 5000 kW excitation winding	75	80	100	125	°K
One covered winding with uninsulated surface	80	90	110	135	°K

Tab. 2

- Temperature rise is calculated by the above mentioned resistance measuring system. The highest admissible coolant temperature up to 1,000 meters above sealevel is 40°C.

- The average life, if the admissible temperature rise is not exceeded, is more than 20 years. If the admissible temperature rise is exceeded by only 10° K, the life of the winding will be reduced to half (law of Mint-signiere). From this one can see how important control of excess-temperature is for economic maintenance.

2.3 Control of Mechanical Vibrations of Electrical Machines

- When analysing vibrations of machines, important criteria of the condition of the machine can be made. Although all machines vibrate, one is able to notice a deterioration of the condition in the increase of the vibration level. A typical figure of vibration shape of a motor during its time of operation is shown in Fig. 5.

- In the running-in period /1/, more vibration, due to the running in of mechanical components like bearings and so on, is explainable. After some time of operation, a maintenance-engineer notices the first increase of vibration /2/. From then on the machine is observed closely. At the next control point /3/, deterioration of operation status is confirmed and a favourable repair point of time /4/ is fixed by maintenance and production department.

Defects are recognized promptly by using such monitoring systems (they may work automatically) for preventive maintenance.

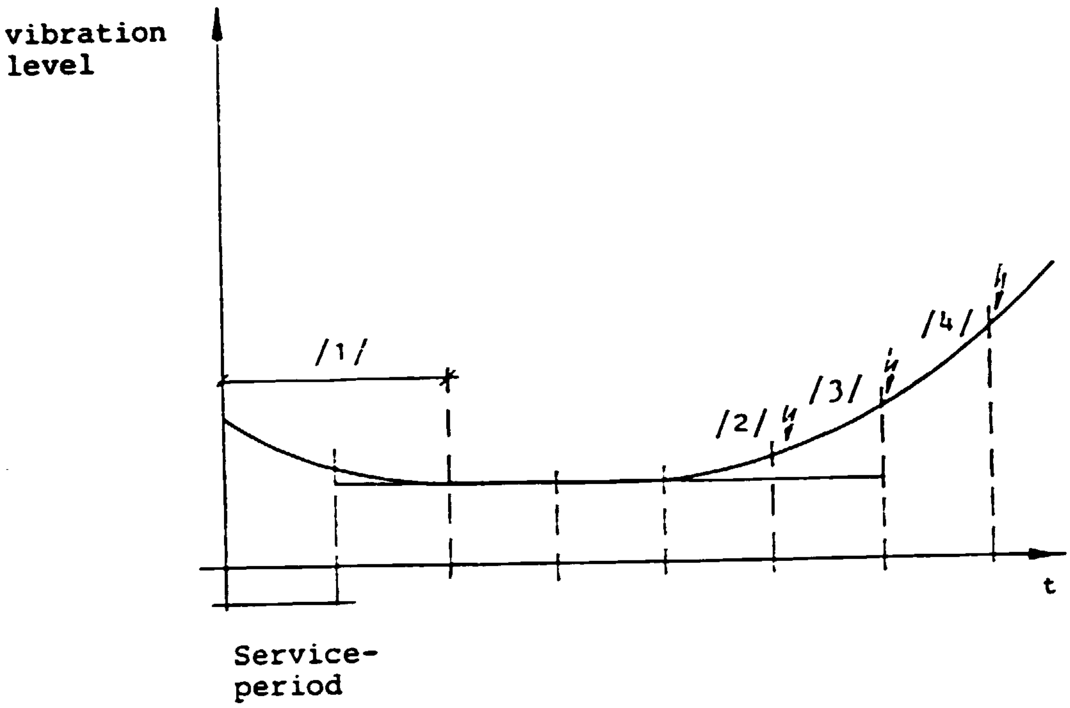


Fig. 5
Vibration Level as Function of Time

- The following three parameters are characteristic of vibration level
  . Acceleration
  . Velocity
  . Amplitude

- For monitoring of machines, RMS velocity measuring is the most suitable parameter for analysing the vibration in a wide frequency range. For assessment of vibration status of the two most important machine sizes, Table 3 can be used. Machine type 1 are medium sized machines 15 kW - 75 kW, or up to 300 kW on special foundations. Machine type 2 are bigger machines, which are erected on very special, stiff or heavy foundations.

RMS velocity mm/s

	0,45 0,71	1,12 1,8	2,8 4,5	7,1 11,2 18 28 45
Type 1	good	allowable	just tolerable	not permissible
Type 2				

Tab. 3
Criterion for Judgement by Vibration Velocity

- The highest level of conditioned maintenance is vibration frequency analysis. This is a very special test method using a vibration analyzer, and it is only mentioned for completeness.

2.4 Checking Condition of Bearings of Electrical Machines

- In rotating electrical machines, depending on installation location and operating conditions, either journal or antifriction bearings are used.

2.4.1 Checking of Antifriction Bearings

- Nominal service life of bearings shows a bandwidth of about 1:20. The reason for this is that, practically, life is a function of mounting, maintenance and operation conditions. For checking of antifriction bearings without interruption of work, the following methods are used.

2.4.1.1 Monitoring of Bearing Condition by Vibration Measurement

- What is written in Chapt. 2.3. can generally be used here in the same way, and, therefore, will not be repeated.

2.4.1.2 Temperature Monitoring

- If there is a defect in the bearings through increase of friction losses, the temperature of the bearings also increases. On the one hand there is the advantage of a cheap temperature sensor (for instance PTC resistor) and on the other hand there is the disadvantage of slowness using this measuring-system. If the defect appears suddenly, in most cases the signal of bearing defect is too late.

2.4.1.3 Monitoring of Structure Borne Noise

- Noise generated by mechanical vibrations of the machine is relative. In addition to this, other noises disturb this measuring system by noise transmission. For analysis a lot of experience is necessary.

2.4.1.4 Noise Monitoring

- Here we can say the same as above. There is also the additional uncertainty of the subjective judgement of the testing personnel.

2.4.1.5 Analysis of Lubrication Oil

- This technique uses complex chemical-physical analysis and is limited in its cost-result effectiveness. Therefore, it is used only over long periods.

2.4.1.6 Shock Pulse Measuring by SPM Method

- The measuring system is based on the rough surface of the antifriction bearing. Through the energy of the rotating rollers and their inertia they cannot follow their rolling path due to its unevenness.
  On impact, the roller creates a shock pulse which travels at the velocity of structure borne noise.

- Measuring is carried out only within the starting phase, which is a time of only some micro seconds, by an acceleration sensor which is tuned for this time interval. This measured value is an amplitude value, which is standardized for size of the bearing and speed rotation by adjustment on the measuring instrument.

- Indication shows situation of antifriction bearing and is divided into a good, average and faulty area. This system is, at this moment, one of the best measuring systems for antifriction bearing monitoring.

2.4.2 Life of Antifriction Bearings

- We must distinguish between machines without grease nipples and machines with grease nipples.
  The life of machines without grease nipples working at 1,500 revolutions per minute is 20,000 hours of operation, and with 3,000 revolutions per minute, 10,000 hours of operation. This means a period of lubrication servicing every 2 to 3 years.

- If there is a grease nipple on the motor, maintenance people should observe lubrication instructions. It is very important that lubricating is done by grease gun while the motor is rotating.

2.4.3 Slide Bearings

- For these bearings maintenance expense is higher. Oil level and bearing temperature should be tested periodically. At longer intervals, purity of oil, transport of oil by the bearing rings and free running of bearings must be checked. A suitable interval for bearing checks is about 5,000 hours of operation (maintenance period once or twice yearly).

- On this occasion it is advisable, after removing the contaminated oil, to clean the bearings with petrol.

2.4.4 Checking of Slide Bearings

- In operation, the only measuring parameter is the temperature of bearings. If standard lubrication is used, admissible temperature rise of the bearings is 50° K and if special lubrication is used, 60° K. Exact measuring is carried out with installed temperature sensors. The reasons for high bearing temperature are dry bearings, overlubricated bearings and unsuitable and dirty lubrication. Temperature is very important for the relative life and quality of the lubrication. If temperature rises, the quality of the lubrication decreases.

3. AIMS AND ACTIVITIES OF PREVENTIVE MAINTENANCE BY SERVICING

The basic problem of maintenance is keeping the equipment in good running order, especially those parts of the equipment subject to high wear. Now we shall look at one of the most important.

3.1 Servicing of Commutator and Brushes of Electrical Machines

- Brushes and commutator are in gliding contact and therefore they wear. Commutation is influenced by many factors such as humidity, contamination of air by gas, oil spray, dust, temperature of coolant, fractional load and vibrations. One of the most important criteria for assessment is arcing between brush-contact surface and commutator wear.

3.1.1 Brushes and Brushholders

- Important for good commutation is selection of the best brushes. In most cases, machine producers select a brush type which is best in the test shop or for average performance. In the plant, on the other hand, there may be other specific conditions which give rise to bad commutation.

- For assessment, sparks are classified into small, average, large, single and multiple types. Small and average sized sparks are allowed if they do not get worse.

- If there are rapid short current alterations, powerful sparks are allowed.

- An important point for maintenance is friction and therefore the life of the brushes. This depends on humidity, current density and specific brush pressure. The lower critical values for absolute humidity are 3 - 4 g/m^3 (0.0002 lbs/ft^3 or 1 $grain/ft^3$) or 20% at 20°C relative humidity. If the air is too dry, water molecules under the brushes, which is important for commutation, cannot exist. A secord important value for commutation is current density at about 5 to 6 A/cm^2 (30 - 40 $A/inch^2$). If current density is lower, the coefficient of friction rises and the life of the brushes is reduced (see Figure 6).

  Lowest brush wear occurs at a specific brush pressure of 18 kN/m^2 (180 P/cm^2, 2.5 lbs/in^2) as shown in Fig. 7. If specific brush pressure is lower, brush wear increases due to higher electrical wear (burn in). It is important that brushes are easy to move in their brush holders so as to increase the pressure on the brushes.

- Brushes should be checked every 1 to 2 weeks for wear and movement. Changing of brushes should not all be done together, but only partially (maximum 25%). When running in new brushes, the old brushes allow high current density.

3.1.2 Commutator

- After some time in operation of a new commutator with pure copper surface, a skin grows, consisting of copper oxide mixed with free particles of the brushes. A cross section of brushes and commutator can be seen in Fig. 8. It is important that the temperature of the contact area is high enough to allow this chemical process. Temperature depends on the current density in the brushes and friction losses.

- On the surface of the commutator there may be formed marks and hollows (such as grooves, ribbing, threading, banding and lining) or high or low areas. For skilled maintenance people these marks are important signs. This will not however be dealt with here.

- Minor damage to the commutator is repaired by grinding staff and maintenance people. If there is average damage, a grinding wheel is used. If the commutator is heavily damaged, worn out or rough, turning on suitable equipment is necessary. In most cases, a suitable hard metal quality, a speed of 200 m/min (660 ft/min) and a depth of cut of about 0.08 - 0.1 mm (3 mills - 4 mills) per revolution give best results. In addition, after turning, bar edges should be bevelled about 0.1 mm (see Fig. 9).

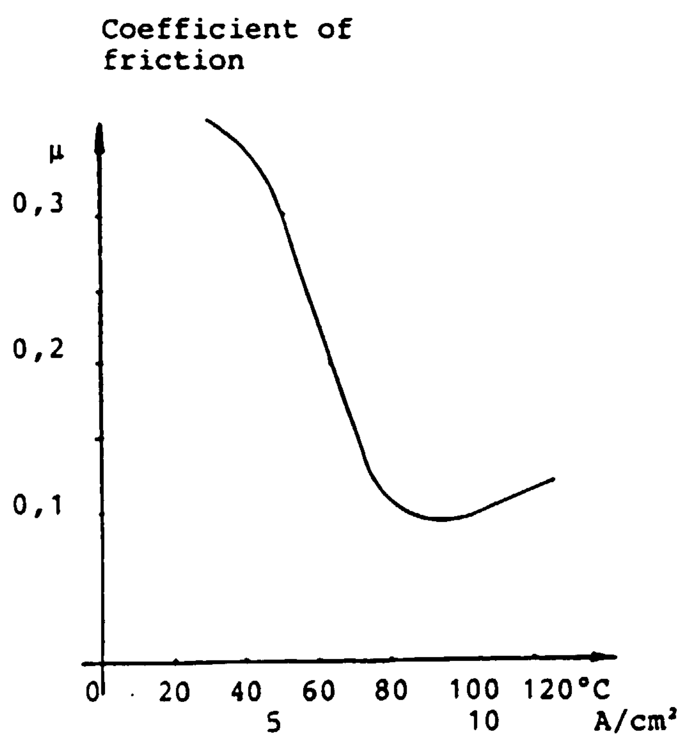


Fig. 6
Coefficient of Friction as Function of Temperature and Current Density

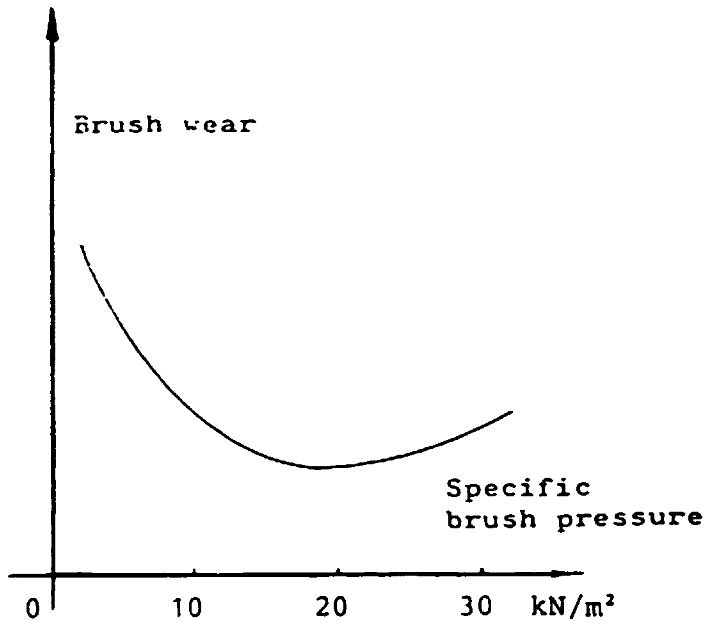


Fig. 7

Brush Wear as Function of Specific Brush Pressure

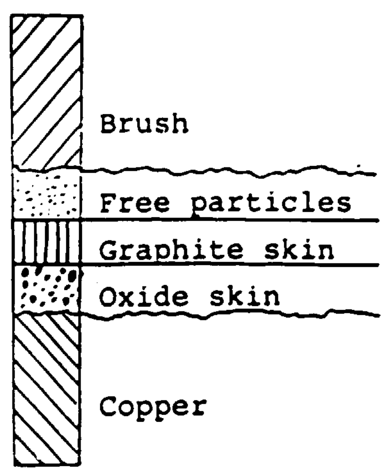


Fig. 8

Cross Section of Brushes and Commutator

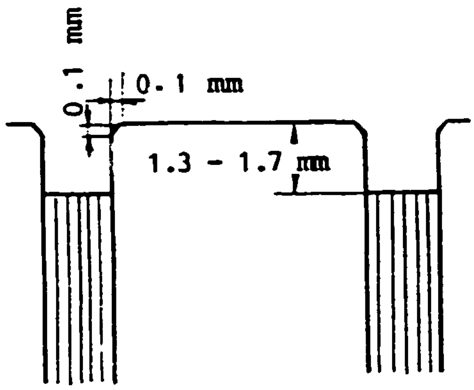


Fig. 9
Bevelling of Commutator Bar Edges

4. SUMMARY

Out of the many activities of preventive electrical maintenance only a few, important activities are described. In some places, it was necessary to go into details, and some theoretical basic knowledge and calculations were learned.

This is important, because in practice we cannot measure all values which are necessary and we have to use calculations. In qualitative, preventive maintenance we have to analyse all the existing problems and to expand our knowledge systematically.

TROUBLE SHOOTING

(Final Edition)

C O N T E N T S

TROUBLE SHOOTING

The job of the electrician is to find the reason for the trouble causing break-down or malfunction of equipment. He has to repair the damage or, in case of non-electrical equipment, order the repair.

I want to give you some guidelines for trouble shooting in mill drives.

The time available is short, therefore it is only possible to explain standard mill drives often used in steel mills. In the afternoon, we shall have the opportunity to answer your questions concerning special equipment.

1. TROUUBLE SHOOTING - SIGNALS

The signal "Interruption of production" comes either from the operator or from the annunciator equipment.

The first task of the electrician is to collect all the information conc[illegible]ng the interruption.

- Note all information given by annunciators, recorders and printers. Note the time of incoming information and the sequence of signals. The "First Signal" is very important.

- Ask the operator or anybody else for an exact report. The sequence is very important.

- Have a look at the whole equipment, including mechanics. There is no need for a serious examination of the closed loop control. If the cause is a hot bearing, the signal is of course "Overcurrent".

2. TROUBLE SHOOTING - ANALYSIS

Localisation of fault by means of information 1.

2.1 AC - Drives

- Interrupt main circuit.

- Check all fuses.

- Close the control circuit and check the function of contactors and relays when the main circuit is still interrupted.

- If it doesn't work correctly, continue with the following checks:

- Check line voltage.

- Check control voltage.

- Check control voltage starting from the feeding point following the circuit diagram step by step, using instruments or test lamps.

- All signals from the operator control, limit switches and similar devices are to be checked one by one - electrically and mechanically.

- After the check, switch off the control voltage. Check the insulating resistance-line to ground-instrument. The voltage should be at least as high as the line voltage.

- Main circuit
  . First check if the main circuit is interrupted.
  . Push in fuses and/or circuit breakers.
  . Put "clamp on ammeter" on lead.

- Starting up
  . Current lower than nominal current O.K. Current 4 to 9 times the nominal current, motor may be mechanically blocked - switch off quickly.
  . Open coupling, try again.
  . In case of asymmetrical and very high current, the overload relays drop out and fuses blow - motor or cable is faulty.
  . Disconnect the cable from the motor, check the insulating resistance and conductance at the cable.
  . If the cable is O.K., change the motor; further motor checks are to be carried out in the central workshop only.

2.2 DC - Drives

- SCR (thyristor) equipment only.

- Armature circuit
  . Switch off the feeding circuit breaker.
  . Open the high speed circuit breaker or disconnect motor terminals if there is no DC breaker.

. Check fuses for conductance (control of annunciator is not safe enough).
. Check thyristors for insulation in both directions.
. Check voltage should be 2.5 Volts minimum.

- Field circuit
  . Measure the field current and compare it with the nominal data.
  . Further trouble shooting, similar to armature.

- Thyristor control
  . Disconnect closed loop regulating circuits from the thyristor gate control (firing circuit).
  . A variable DC voltage source is to be connected to the input of the thyristor gate control.
  . Check all control pulses on the thyristor gate by means of an oscilloscope. Shift full range-rectifier to alternator.
  . Stop in position "Alternator Limit".
  . Fix "Auto Reversal Unit" in one position.

- Test run
  . Connect the motor leads to terminals.
  . Switch on auxiliary drives fans, pumps, field supply, control power supply and so on.
  . Check once again if the control pulses are still in position "Alternator Limit".
  . Close armature feeders and high speed DC breakers.
  . Watch current and voltage while shifting control pulses from "Alternator limit" to "Rectifier".

. Stop shifting if the voltage exceeds 10% of the nominal current without armature current.

. Check the main circuit including the brushes in the motor; "Caution" the motor is still on line voltage.

. Usually the motor starts turning.The current is low and sometimes interrupted.

. To get exact information about the function of the thyristor set, you need at least 10% of nominal current. To get this current go on step by step.

. Open the armature circuit breaker.

. Disconnect the field supply, block "Field watch relay".

. Fix "Auto Reversal Unit" in one position.

. Make sure that the control pulses are in position "Alternator Limit".

. Close the armature circuit breaker.

. Start shifting, control pulses, do not exceed 1/2 of the nominal current and do not run current longer than a few minutes. Otherwise the risers of the commutator could be damaged.

. Examine the wave of the current by means of an oscilloscope to see if all thyristors operate. Use DC/DC transducer to isolate armature voltage from the instrument.

- Repeat all steps once again with "Auto Reversal Unit" in the other direction.

2.3 Closed Loop Control

- Trouble shooting starts at the last loop, usually the current loop goes on in steps.

- Current loop
  . Open the circuit breaker.
  . Disconnect the input line to the current regulator
  . Be sure the current measuring device functions and is connected with the current regulator.
  . The thyristor gate control (firing circuit) is to be connected to the current regulator.
  . Check the current limits.
  . Disengage blocking signals.
  . Connect a variable voltage source to an input.
  . Close the circuit breaker.
  . Raise the voltage input constantly, watch the armature current (field is still disconnected, the field relay is blocked), do not exceed 1/2 of the nominal current, do not overheat risers.
  . Switch off the input voltage.
  . Switch on the input voltage (setting as before) and record the current rise to the check current rise rate.

- There should be only slight overshoot but no hunting. If the current oscillates (hunting), the gain is to be reduced, the time setting of the current regulator is to be increased. Do not change by large amounts. The original setting should be changed by only a few %. Otherwise, it is better to change the current regulator altogether. Be sure all settings of selector switches and rheostats are exactly the same on the spare part.

2.3.1 Current Raise Control

- The current raise rate should be matched to the motor

- Uncompensated motors 20-30 N/sec.

- Compensated unlaminated motors 30-50 N/sec.

- Compensated laminated motors 100-200 N/sec.

- Compensated laminated and free of eddy currents up to 400 N/sec.
  - Open the circuit breaker.
  - Disconnect the input line from the "Torque Regulator".
  - Connect the "raise rate" control output to the input of the current regulator (Original connection).
  - Connect a variable voltage source to an input.
  - Close the circuit breaker.
  - Raise the input steadily until the armature current reaches 1/2 of the nominal value.
  - Switch off the input.
  - Switch on the input and check the rise rate of current by means of an oscilloscope or high speed recorder. The rise rate should be equal or lower than mentioned.
  - Reverse the input voltage and repeat the last three steps to check the other direction of current, auto reversal in function.
  - Open the circuit breaker, connect the field supply, engage the "Field watch relay", connect the input line form "Torque Regulator", disconnect the voltage source from input.

2.3.2 Rotation Control Loop

- Rotation regulator and torque regulator are tested in common.
  . Be sure tacho generator is linked without clearance to the drive and connected to the rotation regulator and torque regulator.
  . Test overspeed devices carefully.
  . Disconnect inputs to rotation regulator except tacho generator.
  . Check lubrication systems, cooling equipment and current limit settings.
  . "Safety-first": nobody is to be in the vicinity of moving parts: "Danger".
  . Connect two variable voltage sources to an input.
  . Steadily increase 1 input voltage watching current and speed. Stop increase reaching 1/2 base speed.
  . Increase second voltage source to run base speed.
  . Switch second voltage source off and on again, recording current and speed on a high speed recorder. The drive should accelerate within a few seconds, current exactly on preset current limit. The speed (rotation) overshoot should not be more than 20%. If hunting does not stop, increase time constant slightly.
  . To check torque regulator, connect one voltmeter to speed regulator output and another one to torque regulator output.

. Raise input voltage slowly. The two voltmeters should rise at the same rate up to base speed. In the following field control range, the torque regulator output rises faster due to high amplification. With the torque regulator in feedback, check rotation regulator output the same away.
. Open circuit breaker, disconnect voltage sources, connect speed regulator to rotation regulator.

2.3.3 Speed Ramp Control and Speed Regulator

- The speed ramp is to be matched to the power train's mechanical limits.

- The speed regulator takes into account the influence of the roll diameter.
  . Connect voltmeter to "Roll diameter" input and speed regulator output.
  . Connect variable voltage source to speed ramp control input.
  . Close circuit breaker.
  . Switch voltage source starting in small steps raising them to full speed, then "On", "Out", full range. Watch linearity of speed rise, using recorder.
  . Change "Roll diameter" input values and observe changing speed by means of voltmeters (R.P.M. only changes).

- "Troubles": if there was any change in the mechanical inertia or there is higher play in the drive, it needs new turning. First of all set up a new calculation. Start turning with flat rise ramp, increase ramp, avoid overspeed or hunting of speed. If speed regulator is not operating, change multiplier, - the same can be done if the torque regulator fails, and this helps in most troubles.

2.3.4 Special Drives

- Twin drives
  - The control of a twin drive is responsible for load sharing and rolling flat material. These are opposing instructions. The most important is flat material. The imbalance in current must not exceed 40%/60%. Avoid rapid action for load sharing as the time constant is twice as high as for speed regulating.
  - To raise the leading end of the steel, the bottom roll turns a little faster. This "Ski" effect avoids the fouling of steel on the roller tables. The speed difference signal is to be switched off 1/2 second after the load is on the mill.

2.3.5 Finishers in Hot Stip Mills

- Finishing stands sometimes are equipped with one armature current direction only. To slow down or reverse rotation, the field is reversed. The armature rectifier is blocked during field reversal. It is important, when starting decelerating, that the alternator voltage is higher than motor voltage at the moment the control is engaged again. When reversing the motor, the rectifier starts from zero as usual.

2.3.6 Coilers

- The coilers are operated speed controlled only, if there is no steel on the mandrel. At all other times, they are responsible for holding constant strip tension. To do this, it is necessary to calculate coil diameter, accelerating - decelerating force, bending force, nominal strip tension multiplied by width and thickness and armature current. This is usually done by means of a computer. The computer function test is best done off line. There are programmes for tests available, controlling all computer functions.

- The mandrel control starts speed regulated in cold mills at low speed only; in hot strip mills 5%-10% faster than line speed. After a few windings on the mandrel, tension builds up, the speed regulator is overcharged and the limiting variable current ahead of the current regulator maintains tension constant. It receives the calculated input value from the tension computer.

- The field control is done in the same way as for main drives. If voltage reaches nominal value, the full current is lowered holding armature voltage at the same value. "Warning": there must be at least a control range of 20% of nominal voltage. The peak voltage of the thyristor set is to be higher by this amount to enable the current regulator to take peak load shocks.

- Troubles - usually the strip or pinch rolls or tension rolls slip while accelerating or decelerating. This means a wrong speed signal from the tachometer generator driven from these rolls and also a wrong input for the diameter calculator. The tension signal becomes wrong and a cobble may result.

- Malfunction of photocells, sensing front and rear end of strip may give false signals, stopping the hot strip coiler while strip is still on the roller tables. There are usually 3 photocells side by side, 2 of them are enough, but make sure all 3 are capable of operating.

- Most trouble comes from sensors like photocells, impulse tachometers, tachometer generators, limit switches, proximity switches, control switches a.s.o.

- Screwdown, sideguards - all displacement control devices need an additional control loop for motion and also a calculator for the correct speed to find the set position in the shortest possible time.

- Troubles - check all sensors carefully. See that neither speed regulator (except coilers) nor current regulator are out of range. High current after acceleration is a sign of faulty mechanics (high friction). Clearance in the power train or backlash in the gear may cause hunting as also play or elasticity in couplings.

- To find the reason for the trouble, it is necessary to record the input and output of the speed regulator as well as the current and tachometer signal on a multi-trace high speed recorder. It is important to find the cause of the trouble and not to overcome it by raising the time constant of the drive thus spoiling the regulation. Exact position regulation needs quick action of all closed loop circuits.

2.4 Relay Control

- Trouble shooting in relay circuits begins with checking supply voltage for control circuits. It should be $\pm$ 10% within nominal voltage maximum.

- Send a command from operators pulpit and watch all relays being activated.

- Compare normal function and activated relays using the circuit diagram to find the first relay out of function.

- Connect test lamp (incandescent lamps only) or voltmeter to coil terminals of non-operating relay. "Voltage on" - change relay. "No voltage" - next step.

- Keep one test terminal connected to the coil, test each contact in steps following circuit diagrams until reaching supply voltage line. Do the same with the other coil terminal fixed.
"Voltage on" means faulty contact is found.

2.5 Programmable Logic Controller PLC

- PLC has the sequence control and all interlocks in "software". All programmes are stored in the solid state memory of the controller. Without desired changes in function, never alter the software programme.

2.5.1 Trouble Shooting in PLC

- Most failures (appr. 90%) are malfunctions of external equipment-detectors, limit switches, control equipment a.s.o. The main cause of internal troubles is defective input - output points or faulty power supply (appr. 90% of the rest).

- Internal failures are usually eliminated by inserting spare prints without sophisticated examination.

- Warning - PLC is able to energize various outputs unless precautions mentioned later are taken. These malfunctions could injure personnel and damage equipment.

- Do not remove or install circuit cards with power applied.

- Circuit cards (prints) are to be inserted without force. If they can not be easily inserted, bend pins and connectors exactly straight.

- Never apply voltages exceeding the operating voltage to PLC. Do not use meggers with terminals connected to PLC for trouble shooting.

- Measurements should be executed with voltmeters having 20,000 Ohm per Volt or higher.
  . Check supply voltage-compare with nominal voltage according to manual.
  . Input does not operate, indicator light is off. First check incoming signal. If it is sure that the signal is on, indicator remains off. Switch off power supply. Change input card, switch power on again.
  . If there is still no input, another input may block signal. Check all inputs of the same group to find the error. Some PLC's are equipped with error detectors indicating the trouble immediately.
  . Output does not operate - indicator light is on-check voltage across load and current of load. Indicator light is off-switch off-change card.
  . If there is still no output, another output of the same group is blocking signal. Check all outputs of the same group.
  . For finding internal troubles, see suppliers instructions. Run test according to manual.

2.6 Power Supply

2.6.1 High Voltage Lines

- The voltage of the controlled high voltage is to be held within the limits of ±10% of nominal voltage. To avoid drop out of thyristor sets and feeding power back to line, never allow voltage on thyristor sets line terminals to drop below -10%. It may need increased control voltage over nominal, within the +10% range, to prevent troubles with supplied equipment.

- Generally there is rarely trouble shooting to do on supply lines, because the power failure is signalled directly. Cable taults are located with special instruments.

- Harmonics, exceeding normal amounts, may produce overvoltage in a network. The only way of avoiding this is to find a new network configuration free of resonance.

2.6.2 Low Voltage Lines (Without Lighting)

- These networks are usually insulated systems without an earth line. Insulation defects are signalled by relays monitoring line to earth voltage of all lines.

- For finding the fault, a voltage of low frequency is superimposed on line voltage to earth. Checking all feeders with a clamp on ammeter specially matched for this low frequency, you find the feeder and going along the signal you find the fault. This system needs no interruption of lines.

- With a double bus system, the defect is located in the following manner.
  . Disconnect busses, use circuit breaker only, earth relay indicates fault e.g. bus A
  . Couple bus A with bus B
  . Change one feeder from bus A to bus B by means of disconnectors.
  . Disconnect again by means of circuit breaker. Proceed in this manner until fault changes from bus A to B. Further localisation needs interruption of supply.

2.6.3 Power Supply for Control and Electronics

- Voltages are to be within the limits ordered in the manual. Usually $\pm10\%$ of nominal voltage.

- Test by means of voltmeter is O.K. for unstabilized voltage only.

- Stabilized power supplies are to be tested carefully using oscilloscopes, watching for peaks, drops and ripple (noise) of voltage. Also testing by loading the supply with current impulses is to be performed.

2.6.4 Synchronisation Voltage for Thyristor Sets

- Last but not least this voltage will be mentioned. The phase angle as well as the sine waveform is essential for the function of thyristor equipment. A large amount of trouble, burnt fuses and sometimes defective thyristors result from bad synchronisation voltage.

- Taking synchronisation voltage from thyristor feeder terminals directly is worst for voltage drop due to high current impact , but phase angle is best. Obtaining it by means of voltage metering transformers from the high voltage supply is usual, but there are no inductance coils placed between metering transformer and rectifier transformer. Good filtering, a usual way of doing it, means longer response time for voltage changes in power supply.

- Blown thyristor fuses without reason may be due to synchronisation voltage. Check all terminals carefully, watch waveform by means of oscilloscope for a long period. In particular, harmonics causing a ripple near zero voltage are most critical. Large reversing mill drives may produce this ripple.

2.7 <u>General</u>

- Sometimes there are faults causing failure of equipment and after switching on, all is O.K. with nothing to find.

- In a steel mill, you should never move any wire or test equipment while steel is in a vessel, a caster or a rolling mill.

- With wrong procedure, the resulting damage can be very high.

- When connecting instruments or scopes, first check resistance of instruments or probes.

- A one by ten probe of an oscilloscope may cause the failure of a big drive, if connected to a highly sensitive point.

- If there are sporadic failures, proceed in this way
  - . Connect event recorder (transient recorder) if there is no steel in vessel or in mill stand.
  - . Record current, voltage and speed first.
  - . Vary trigger signal from quick electronic device.
  - . Test function of event recorder, especially trigger point, storage time and resolution.

- After the next failure, try fault analysis. If nothing is found, connect output of current loop regulator plus input and output of speed regulator to recorder, ignore if necessary unimportant information.

- During a downtime, check
  - Current metering transformers, DC/DC converters metering current by means of shunts.
  - Synchronisation circuits.
  - All connections of wiring, especially loose connectors or bad soldering.
  - Check overvoltage and overspeed devices (not essential).
  - Check all gate connectors on thyristors. If there is not enough time to do so, watch current by means of scope and bumper thyristor cabinet if there no steel in the mill. Do this in rectifier mode only, in alternator mode it's dangerous.

- Be sure to have all spares at hand, correct instruments in good condition and, last but not least, do not hurry.

LOCAL MAINTENANCE ORGANIZATION/HOT ROLLING MILLS

(Final Edition)

C O N T E N T S

1. ATTENTION OF PLANTS

1.1 Slabbing Mill

Machine scarfing with three units including filter plants, slab grinder and cross transfer.

1.2 Plate Mill (4.2 m)

- pre-heating pits; 1 bogie hearth furnace
- 12 soaking pits; 1 pusher-type furnace
- 4-high rolling stand, 4.2 m, with descaler
- hot-levelling machine; cooling bed
- shearing line; 3 normalizing furnaces
- 2 cold-levelling machines
- cross transfer and finishing equipment, such as torch-cutting plants and plate grinding equipment
- plate processing with shears
- punching machines and burning machines
- equipment for the manufacture of multi-layer plates (plating shop)

1.3 Hot Strip Mill (56")

- 2 pusher-type furnaces, 350 tons/h each including roller tables for charging, discharging machines and hot roller tables

- Roughing mill with 4-high reversing stand including descaler, edging stand, trimming stand, centering manipulators, roller tables

- finishing line with cropping shear

- seven 4-high finishing stands

- run-out roller table

- strip cooling line

- 3 underground coilers

- coil transport equipment up to connection point to cold rolling mill 1 and for supply of cold rolling mill 2 via sheet and light plate finishing shop 1 shearing line with uncoiler

- circular trimming shears

- cutting shear

- leveller and stacking equipment

- 2 plate shears

- 1 pre-sampling system.

2. PERSONNEL SITUATION

2.1 Salary Earners

1 plant manager
1 typist
3 plant engineers
4 method engineers
1 for order system
1 senior foreman
4 shift foremen (currently, 3 more positions, however expiring)

15 (18)

2.2 Wage Earners

	slab scarfing/ plate mill	hot strip mill	total
4-shift op.	60	60	120
2-shift op.	13	13	26
day shift	11	8	19
total	84	81	165

2.3 Distribution According to Working Groups

4-shift operation:

slab scarfing and plate mill	4 x 8 = 32 plant fitters
general shop	4 x 1 = 4 turners
	4 x 1 = 4 Diesel transp.
	4 x 1 = 4 tool issue
plate finishing shop	4 x 4 = 16 plant fitters
hot strip roughing mill/furnaces	4 x 5 = 20 plant fitters
hot strip-finishing line and shearing line	4 x10 = 40 plant fitters
	120

2-shift overall dept.	2 x 13 = 26 fitters

day shift	
mech. workshop	1 x 6 = 6 fitters
finishing line group *	1 x 3 = 3 fitters
transport	1 x 2 = 2 fitters
hydraulics group	1 x 5 = 5 fitters
stock attendance group *	1 x 3 = 3 fitters
	19

* These small groups of the day-shift are supervised by a group leader.

2.4 Wage Earners - Supervisors

In case of absence, the foreman is replaced by a senior worker (4-shift). Each of the working groups is supervised by 1 senior worker as well as skilled workers with knowledge of hydraulics and welding. The groups of the 4-shift are further equipped with semiskilled workers for lubrication.

In case of absence of the supervisors, the senior fitter will be in charge and will assume the responsibility for workmanlike performance.

2.5 List of Workshops and Work-Stations

- 1 common workshop with machining equipment, tool and appliances storage room for the entire plant occupied by day-shift personnel

- 1 fitter's workshop equipped for repair work and manufacture, occupied by 2-shift personnel and by 4-shift personnel for slab scarfing and plate mill

- 1 fitter's workshop for repairs in the immediate vicinity of the finishing line occupied by the pertaining 4-shift personnel as well as 1 day-shift group for hydraulics.

- 1 work-station each for
  - roughing mill incl. furnaces (4-shift)
  - stock attendance for work rolls finishing line (4-shift)
  - stock attendance for back-up rolls finishing line (4-shift)
  - coilers of the finishing line(4-shift)
  - change of blade cassettes for the 4.2 m shearing line (day-shift).

3. SCOPE OF TASKS AND DUTIES

3.1 Plant Manager

The plant manager is responsible for coordinating the activities of the plant engineers. He is in liaison with the production administration and also has a number of administrative tasks and tasks of an organizational nature.

3.2 Plant Engineers

Each plant engineer has been assigned a certain area for which he has the full technical responsibility within the scope of regulations.

3.3 Methods Engineer

The area of responsibility of the methods engineers is identical to the area of responsibility of the plant engineer. Besides his work as methods engineer, he is also responsible for the procurement of spares.

3.4 Order System

This department is responsible for the administrative and commercial implementation of the orders received.

3.5 Senior Foreman

The senior foreman is responsible for flexible deployment of the entire crew and for supervising the inspection service department.

3.6 Foreman

The foreman is responsible for workmanlike and due implementation of repairs.

3.7 Personnel and Wage System

For all local shops, there exists a central personnel and wage department which is responsible for coordinating administrative activities in connection with personnel aspects and wages.

3.8 Liaison with Production Administration

The services to be rendered by the local maintenance shop require coordination with the production shop issuing the orders. In particular it comprises the following:

- Exchange of information. Requests for production assistance.

- Coordination of operating and standstill times to meet production requirements and execution of repairs that become necessary.
  Selection and determination of priority of services including chronological implementation.

- Coordination of assistance with the production shop by deployment of personnel to operate the equipment and cranes as well as assistance in fitting work including cleaning.

- Changes during the implementation of work depending on production, including changes subject to coordination with the production programme.

- Taking over work or forwarding other work to central shops, as well as maintenance work, such as manufacture of makeshifts, changes in the course of production runs, etc.

All this is organised by the persons responsible in both shops (plant manager, plant engineer and also senior foreman if so required) partly at fixed downtimes or as required.

From time to time a discussion is held between the maintenance and production shop on plant improvements carried out or necessary, weak points and on additions and modifications required. Such activities are checked for profitability and the actual work depends on improvements in efficiency.
The preparation of the preliminary estimates for maintenance expenditure and operating requirements for one financial year requires coordination between both parties to enable submission of suggestions and special requests.

In case of breakdowns, technical problems and work connected with production such as roll grinding, blade exchange, etc., the production foreman will contact the maintenance foreman directly to ensure quick action and establishment of work sequences.

VOEST-ALPINE
INDUSTRIAL SERVICES

WORK SEQUENCE IN THE WORK PREPARATION DEPARTMENT

(Final Edition)

C O N T E N T S

WORK SEQUENCE IN THE WORK PREPARATION DEPARTMENT

C O N T E N T S

1. RECEIPT OF INFORMATION

All information, such as damage reports, pre-scheduled repairs, modification work etc., is forwarded to the work preparation department on a standard form, the information sheet. The properly prepared information sheet contains - apart from the issuer and the date of issue - the prospective commencement of work and completion deadline date, as well as plant and plant part with accurate description of the work to be performed and the estimated expenditure of labour.
In the work preparation department, this information is stored on a wall chart according to plant and weeks per year.

2. PROCEDURE IN CASE OF DISTURBANCES

Within normal working hours, the information sheet with the order number given by telephone is placed in the day section.

Outside normal working hours, i.e. for the second and night shift as well as for week-ends and holidays, blank tracer cards are made available for possible breakdowns, on which the shift foreman fills in the following columns:

- Work to be performed
- Scope of work with indication of the plant
- Date of issue
- Work sequence with detailed indication of work performed and still to be performed
- Date, names, and hours of blue-collar workers
- Material used and material possibly required

For opening an order, this blank tracer card is forwarded to the work preparation department on the following workday.

3. ORDER PREPARATION BY THE WORK PREPARATION DEPARTMENT

When the competent methods engineer has received the information sheets, he examines them for further work content,, and - if there is time enough - they are immediately dealt with, otherwise they are held over to a later date.

After checking and possible correction of the text, it is transferred from the information sheet into the order requisition book with the following additions:

- Cost centre and inventory number

- Estimated cost of hours and material.

After these additions have been entered, the order requisition book is forwarded to the order department.

4. ORDER HANDLING BY THE ORDER DEPARTMENT

In this department, the order requisition with order number and the tracer card with 2 copies are issued and the strip is lettered for sight registration. One copy of the tracer card is placed in the suspended folder by cutting it to match the control card and the sight strips. The order folder with tracer card in 2 copies and control card is returned to the work preparation department.

The order requisition is forwarded to the plant management to be signed and then to the production shop.
After receipt of the approved order, the work preparation department is informed of this fact, and the individual order sheets are forwarded to the competent departments.

5. COMPLETION OF THE ORDER FOLDER BY THE WORK PREPARATION DEPARTMENT

If required, the order folder is completed with appropriate drawings, material withdrawal sheets, delivery notes, sketches, suborders, instructions for repair and - upon demand - appropriate work sequence or network schedules.

After entry of the material, the copy of the tracer card remains in the work preparation department.
The order folder completed in this way is forwarded to the control department.

6. DURING REPAIR

If required, in case of an operational deviation from the existing schedule, the methods engineer takes steps to issue any sub-orders required, to request additional information, and to issue delivery notes etc.

After completion of the repair, agreement is reached by the plant engineer and the foreman involved in the repair sequence as to repair costs, working time and possible improvement of the sequence in order to achieve the best possible efficiency on subsequent repairs.

7. COMPLETION OF ORDER

7.1 Evaluation of the Tracer and Material Cards by the Work Preparation Department

- The work actually performed is entered in the repair card index. Drawing and work documents which can be further used are filed. The order folder with tracer and material card is forwarded to the order department.

7.2 Completion of Order by the Order Department

- The strips for sight registration are destroyed and the order folder is filed for further use.

- After receipt of the tracer and material card, the order is ready for completion, provided all documents, such as sub-orders, invoices, material withdrawal sheets etc., are available.

8. WORK SEQUENCE WITH SEVERAL ORDERS

8.1 Permanent Orders

The preliminary permanent orders are implemented and supervised by the work preparation department. In marginal cases, with small-scale repairs, agreements are made between the work preparation department and the senior foreman. Tracer cards with pre-determined hour volume are forwarded to the control department.

8.2 Sub-Orders

If sub-orders are required in addition to main orders including crane and transport requisitions, they are requested either directly by the methods engineer or by the foreman via the work preparation department.

8.3 Shop Orders

These orders are entirely implemented by the work preparation department. The requisitions are forwarded to the work preparation department by means of an information sheet or orally. The further work sequence is the same as with plant repair orders.

8.4 Investment and Large-Scale Repair Orders

Orders which are directly issued to local shops are further dealt with in the same way as plant repair orders. These orders are planned together with the plant engineers. The control as to costs and deadlines is solely incumbent on the work preparation department. Orders in which local shops are not involved are beyond the competence of the work preparation department.

8.5 Spare Part Orders

- New Parts
  At variable time intervals, the methods engineer and the department for spare part procurement agree upon subsequent orders. Usually, the minimum stock is determined. Purchase orders and other orders are issued by the department for spare part procurement. For new parts manufactured in local shops, the order is further implemented by the work preparation department.

- Repairs
  For repairs of spare parts, the order is requested by means of a delivery note sent by the work preparation department to the department for spare part procurement. In case of compelling urgency - but only exceptionally -, the order number is given by telephone beforehand and the delivery note is subsequently sent. For spare parts which are to be delivered to the central workshop for repair, a delivery note is issued and one copy is forwarded to the department for spare part procurement which takes over the further procedure.

9. INQUIRIES, PURCHASE ORDERS, AND REQUISITION OF MATERIAL

For all orders placed by the local shops, the request for offers, issuing of the purchase orders and supervision of receipts are performed by the work preparation department. Claims and notes of defective goods supplied are also issued by the work preparation department.

10. WORK PROGRAMMES

For standstills of entire shops, production units, and plants, and for weekend and holiday periods, a work programme is prepared by the work preparation department in cooperation with methods engineers and foremen; in this work programme, the personnel and labour requirements are determined.
The evaluation of these programmes as to work performed and expenditure of labour required is carried out by the work preparation department.

11. FURTHER ACTIVITIES OF THE WORK PREPARATION DEPARTMENT

Preparation of network diagrams and bar charts
Instructions for repair
Setting up and keeping of the repair card indexes
Keeping of the drawing archives
Request for drawings
Issuing of material withdrawal sheets
Request for and implementation of sub-orders
Participation in keeping spare parts lists
Participation in tracing weak points
Preparation of sketches
Preparation of maintenance schedules and inspection deadline schedules
Checking of the inspection intervals
Arranging for oil tests
Participation in proposals for improvement
Participation in drawing up the A + B programme
Keeping of the central brochure archives with lists
Acceptance and handling of goods received etc.

Finally, it should be stated that there are differences between the individual local shops in the distribution of tasks and the work sequence for operational and organizational reasons.

VOEST-ALPINE
INDUSTRIAL SERVICES

STRUCTURE OF THE LOCAL WORKSHOP/HOT ROLLING MILLS

(Final Edition)

C O N T E N T S

1. GENERAL

Local mechanical maintenance is carried out by a service shop. Its task is to undertake maintenance activities related to the utilization of plant. In the same way it has to supply services necessary for a proper operational sequence and which, for its implementation, demand the deployment of skilled personnel. Attention has to be paid to the fact that certain activities have to be carried out in accordance with the course of the production process. It is this fact which calls for personnel skilled in technical and plant operation aspects being available in the direct vicinity of the production plants.

2. THE LOCAL SHOP AND ITS TASKS

This shop has to supply services to the corresponding production shop. As a specialized department, it must carry out all work transpiring in its range of activity, be it of a mechanical or hydraulic nature.
Normally, it is the only partner of the production shop and is responsible for all the activities of maintenance. With a view to high efficiency, it carries out the deployment of well-trained specialized personnel with adequate knowledge of maintenance and repair of hydraulic devices and machine tools as well as of welding work. Work demanding skilled groups and/or specialized personnel with specific tools, devices and equipment is carried out by central specialized departments. Such action is intended to guarantee quick and workmanlike handling with regard to highest-possible profitability.

The local shop functions as coordinating agent for all specialized shops.

The various specialized departments and responsibilities:

- Central workshop: machine shop, welding shop and construction fitter's shop. Used for new construction, repair and reconstruction.

- Pipe shop .. for all pipelines

- Power and fuel shop .. for instrumentation

- Construction shop .. for enclosures and foundations

- Vehicle workshop .. for transport vehicles

- Crane shop .. for all cranes

- Refractory construction .. for linings of furnaces and converters

It is the task of the trained manpower of the various specialized departments to assist the local crews specialized in plant operation. They supply groups of specialists or, in case of extensive work such as large-scale repairs in close contact with the local shop, shop personnel may be placed completely or partially under their direction.

It is possible, by specific deployment of these specialized departments, to keep the number of men employed in local shops as low as possible and to demand additional personnel for coping with order peaks, especially from the central workshop.

3. THE LOCAL WORKSHOP

3.1 Location

- The workshops are placed as near as possible to the production plants. This results in short distances to be covered by the repair crews, and in manpower availability on the spot for the production shop in case of operational disturbances.

- For economic reasons, service posts manned round the clock directly in the production plants should represent an exception. If the establishment of such service posts placed directly in the production plants is indispensable for carrying out repairs or maintaining production, they should only be manned if needed. These working places are equipped with the necessary tools and devices.

3.2 Equipment

- The equipment of the workshops is such as to be able to transport dismounted subassemblies during plant repairs and even do machining in case of small-scale repairs.

3.3 Implementation

- Repairs are mainly carried out in accordance with the technical instructions set up by the work preparation department. Workmanlike implementation of the work is controlled by the foreman. Coordination with the production shop during repair such as desired cleaning, operators, crane drivers, notes on final completion etc. is the responsibility of the senior foreman and foremen.

3.4 Crew

- Due to the variety of tasks, the crews of the local workshop are divided into shifts as economically feasible.

3.4.1 4-shift operation

- The manpower on these shifts is mainly deployed for trouble shooting, maintenance and implementation of routine work. In order to eliminate idle time, these shifts are provided with additional work by the control service department.

- Operation is according to a shift plan, and overtime hours are compensated for by holidays adapted to operational requirements.

3.4.2 2-shift operation

- Working time of the 2-shift manning is from 6 a.m. to 2 p.m. and from 2 p.m. to 10 p.m.

- The main activity of this group consists in plant repairs during repair days and, moreover, it is deployed to assist the 4-shift crews in case of breakdowns. Operation is in accordance with a shift plan with holidays being given for overtime hours adapted to operational requirements.

3.4.3 Day-shift

- Its field of activity comprises work not directly relating to plant such as preparatory work, trials, transport, auxiliary activities, repair of tools etc.

- Working time is 40 hours per week, i.e. from 7 a.m. to 4 p.m. Monday to Thursday and from 7 a.m. to 1 p.m. on Fridays.

3.4.4 Qualifications

- Basic qualifications of the men working in the local mechanical maintenance shops are those of a plant fitter.

- Moreover, there are also men available with additional training as required.

- Additional training
  . Plant fitter qualified in hydraulics and pneumatics
  . Plant fitter with special welding qualification
  . Plant fitter qualified in machine tools.

- In the local shop of the hot rolling mills, there are plant fitters with qualifications in hydraulics and pneumatics deployed as follows:
  . in 4-shift operation:

slab scarfing plant and plate rolling mill:	4x1 = 4
plate finishing plant	4x1 = 4
wide strip roughing line and furnaces	4x1 = 4
hot strip finishing line	4x3 =12

  . in 2-shift operation

whole plant	2x2 = 4

  . day-shift

whole plant	1x5 = 5

- Plant fitters with qualifications in machine tools:

. in 4-shift operation	4x1 = 4
. day-shift	1x2 = 2

- Auxiliary workers like lubricators and store-keepers work in 4-shift operation.

4. THE LOCAL WORKSHOP AND ITS EQUIPMENT

4.1 Foremen's offices with work control

This is the place of work of the senior foreman who coordinates all shift foremen of the 4-shifts and who allocates the work to the various groups.

He is responsible for the day shifts (approx. 20 workers) and at the same time for the deployment of the 2-shift teams which are deployed for carrying out tasks in the entire plant. If needed, undermanned 4-shift crews are reinforced by 2-shift plant fitters.

The foremen of the 4-shift crews are responsible for the projected work according to priorities and working groups in the "day" part of the control chart. They are responsible for issuing work resulting from actual operational needs, which is either trouble shooting or repairs. They are in constant contact with their production partners as to the operational activities within their range of responsibility. Deviations from the planned condition, unusual values or measurements and/or evidence of faults are recorded in writing. Beside the assignment of work, each foreman has to communicate important events, which exceed his shift time, to the foreman of the next shift in the shift record book.

The foreman's office comprises:
1 office for the senior foreman with control chart
1 office for four shift foremen
including change and sanitary rooms in the direct vicinity of the workshop.

The outpost still in existence of a similar foreman's office for the hot strip mill has been closed down as a result of termination of double foremen deployment.

4.2 Workshops and working places

The common workshop comprises
- 1 mechanical workshop
  with an area of approx. 400 m^2 with the following machines and equipment:
  . 2 lathes
  . 1 vertical milling machine
  . 1 shaping machine
  . 1 slotting machine
  . 2 pillar-type drilling machines
  . 1 universal drilling machine
  . 2 hacksaws
  . 1 circular saw
  . 4 wheel stands
  . 1 levelling block
  . pulling-off press
  . various erection aids and adequate lathes.

Work is carried out on components by a day shift group (6 workers, including 1 lathe operator and 1 milling machine operator).

This comprises dismounting and remounting and exchange and repair of elements respectively. In the same way manufacture of new products and repairs in above-mentioned connection or separately in the spare parts sector are carried out. Finally, minor changes, additions, tool manufacturing etc. are carried out on demand by the production shop.

- 1 fitting shop with an area of approx. 480 m^2

  This is the place of work of the 4-shift crews for the slab scarfing shop and the wide strip mill comprising 4 x 4 workers as well as the 2-shift crews comprising 2 x 11 workers.

- Adjacent to the mechanical workshop, there is 1 bay area (approx. 400 m^2), where the changing of the work rolls for the plate mill is currently carried out.

  In the future, this area is planned to be merely a storage area for construction components in order to avoid excessive storage in the fitting shop and to make possible partial transfer of work from the finishing line workshop.

  In this area, there is also the working place of the 4-shift crews with lathes belonging to the plate mill, comprising 4 x 8 workers.

This common workshop includes one fitters' room with sanitary facilities and one room for the senior workers.

- Other workshops located near the plants:
  - 1 fitting shop with an area of approx. 130 m^2 in the direct vicinity of the finishing group with
  - 1 room for 4 x 7 workers plus
  - 1 drilling machine, 1 cutting-off device, 1 wheel stand, surface plate and lathes as well as
  - 1 room for 4 workers on the day shift and 2 workers on each of the 2-shifts with surface plate, thread-cutting machine, small devices for testing hydraulic functions, 1 cutting-off device and pipe fitting shop for the whole plant.
  - There is a fitters room between the two rooms as well as a senior workers' room with a signalling device of the various operational data from the auxiliary equipment.

4.3 Tool and machine shop

area approx. 120 m^2

Borders the mechanical workshop and contains tools, machines, devices, auxiliary aids, small materials such as screws, special castings etc., cleaning material, and working clothes.

This is the work place of one tool fitter issuing material to the 4 shifts who also carries out repairs on tools.

1 material intermediate storage for sections, pipes, and other material: approx. 60 m^2.

1 room for special tools: approx. 20 m^2, in which the lists of consumption and procurement of tools etc., material, working clothes, cleaning and body protection material and industrial safety articles are kept. The respective skilled worker during the day shift is also responsible for the entire tool and machine equipment as well as transport. There is an established time-table for handing out material.

4.4 Work places

Staffed according to demand:

- 1 work place near the roughing line for 4 x 5 workers, with the fitter with special hydraulic qualifications being mainly present in the pump room

- 1 working place for maintenance of the work-roll bearings for the hot strip mill with slewing crane, pulling-off equipment various erection tools, and 1 washing machine

- 1 work place for maintenance of the back-up roll bearings (morgoil friction bearing) of the finishing mill with depositing stands and erection equipment for 3 - 4 day shift workers

- 1 work place for remounting the boxes with shearing knives of the shearing line in the plate area with corresponding tools for three day shift workers

- 1 work place for hydraulic fitter near the coilers with drilling machine, thread-cutting machine and various tools for one-man day shift and 4 x 1 men 4-shift.

00.	GENERAL INTRODUCTION, ORIENTATION COURSES
00.38	MACHINE ELEMENTS, TOOLS
00.38.77.26	FAILURE ANALYSIS OF ANTIFRICTION BEARINGS

CONTENTS:

1. INTRODUCTION

In practice it is not always so easy to find out the primary cause for a damaged bearing. It is of greatest importance to analyse these antifriction bearing damages in order to conclude indications for the solution of bearing failures and preventive measures.

In many cases certain conclusions can be drawn e.g. from current records. Safe measures for preventing future damages can only be taken if the operating conditions, the lubrication and the entire design are known.

Damage analyses shall not be made too quickly, the respective operational circumstances should be considered as well.

The piece of evidence - the defective bearings with the lubricants and the auxiliary parts, such as sealing elements or casings should be put in safe keeping as soon as possible.

In difficult cases the unexperienced should contact on expert on antifriction bearing for assistance in order to find out the reasons for damage.

Then, it is very important to know how the bearing damage was noticed and which auxiliary symptoms were noticed.

We will deal with the reasons leading to the following damages: damages before the installation, wrong installation, shortage of lubricant, corrosion, dirt, oscillations, hot run, current passage as well as normal fatigue.

There is, however, a wide variety of possible combinations of damage criterions, which can not all be dealt with in this lecture.

2. DAMAGES OCCURING BEFORE THE INSTALLATION

Due to irresponsible non-observance of the instuctions for use it may happen, that the bearings are already damaged before their installation.

Corrosion at running and bearing surfaces may occur inspite of careful packing and storage at the manufacturers - after a longer storage period when parts are stored in a room with a relative air humidity of more than 60 % or with considerable temperature fluctions

Mechanical damages of the running surfaces, such as rolling body impressions and scraping marks (the latter ones can mostly be observed in the center of the running surface) can be caused by concussions during transportation. Improper assembly of dismountable bearings (e.g. cylindrical roller bearings) and improper swinging in and out by hand of the external rings of self-aligning roller bearings can result in scrapings and dents which reach from the edge to the center of the running race. Such dents and scrapings are the reasons for loud running noises during operation and finally they lead to roughening and peeling off of the races.

Occasionally slight, blank marks can be detected at the rolling surfaces of roller bearings. These slight marks are not yet considered as surface damages causing running noises or a progressing roughening of the races.

When the packing of an antifriction bearing is damaged during transportation or in the storage facility, there is the danger of corrosion and contamination. If the bearings are not used immediately they must be cleaned, once again treated and the packing should be carefully replaced by a new one.

Storage of bearings

Normally antifriction bearings are protected by an anti-corrosive packing. In their original packing they can be stored for some years. The relative air humidity in the storage room must not exceed 60 %, for shorter storage periods 75 % max. is permissible.

Bearings with cover disks should not be stored for more than 3 years, otherwise the filled in grease ages too much; after extended storage periods the friction moment in those bearings is mainly higher at the beginning than in normal operation. In addition, the grease can be used for a shorter time only.

3. CORRECT DIMENSIONING AND MEASURES FOR DESIGN

When designing a bearing it is very important to provide adequate facilities allowing to pull off a bearing by means of a pull-off device immediately at the fixed bearing ring.

Fig. 1 shows three groves in the shaft shoulder of a bearing seat, allowing engagement of the pull-off device. A design of the shaft shoulder without grooves would necessitate heating up of the internal bearing ring for dismounting. There is, however, a considerable danger of overheating leading to microstructural change combined with hardness losses which can lead to rapid failure of the bearing. Fig. 2 also provides grooves at the shoulder allowing pressing out of the external bearing ring.

Fig. 3: this picture shows threaded bore holes for pressing off the fix bearing ring of a selflocking bearing. Thus pulling-off starting from the internal ring over the rolling bodies to the fixed external ring is prevented.

Wear design of the housings or shafts very often result in a deformation of these parts and abnormal stresses resulting again in early failure of the bearings.

Antifriction bearing rings must be well supported on the shaft and in the housing. If the bearing surface is interrupted by a groove or other device for greasing, the stresses are increased and deformations in the bearing race and damages of the roller path can result

4. DEFECTIVE INSTALLATION AND DISMOUNTING

4.1 General advice

For the installation of antifriction bearings knowledge and cleanliness are a precondition for smooth-running and a long life of the bearings. The installation should be done, if possible, in a dustfree, dry room. The working place must not be in the vicinity of cutting machines or dustgenerating machines.

The bearings should be taken out of their original packings immediately before installation so that they are not contaminated. It is not necessary to remove anti-corrosives applied to new bearings. If bearings were contaminated due to improper treatment (damaged packing) it is necessary to wash them out before installation. For washing-out of brand-new bearings, the same cleaning agents can be used as for bearings which have already been in operation.

All parts of the bearing (housing, shaft ends, et.) should be carefully cleaned and deburred before installation; non-machined surfaces within cast housings must be free from mould sand. The parts to be installed should also be checked concerning shape and dimensions.

Smooth operation of the bearings is only guaranteed when the operating instructions are observed.

4.2 Installation errors

Installation errors can be caused by wrong assembly or defective design and bad installation conditions.

An unusual course of the rolling traces indicates internal stresses. Such stresses are caused by too tight fittings, too strong axial adjustment, by defects of the shape in the housing or of the shafts, alignment defects or by tight fitting of the loose bearing.

Local damage of the roller paths, such as grooves, scratch marks or dents indicates improper assembly. This kind of damage occurs when: e.g. the inner ring of a cylinder roller bearing is not pushed into the the external ring straight but canted, or when the pressing force is led via the rolling bodies.
Fig. 4 and Fig. 5

If a self-locking bearing must be pressed simultaneously on the shaft and into the housing, an erection disk should be placed between bearing and impact hood This erection disk transfers the mounting force uniformly onto the lateral surfaces of the internal and external ring during pressing into the housing bore hole. Fig. 6. For simultaneous mounting onto the shaft and into the housing an impact hood with one seating surface, each for the internal and external ring, can be used instead of the mounting disk. The two seating surfaces should be on the same level. Fig. 7.

4.2.1 Larger bearings can not be pressed onto the shaft in cold condition in general as the mounting forces rise considerably with increasing bearing size.
The bearings, bearing rings or internals should therefore be heated before their installation.

An excessive and non-uniform heating up of the bearings during the preparation for installation leads to a permanent dimensional modification of the bearing rings, which causes an unintentional change of the bearing play. Furthermore, the hardness of the rings and of the antifriction bodies is reduced. Heating up by means of a torch cutter is forbidden. The manufacturers recommended heating-up devices, which allow a uniform and limited heating up to 120° C max.

The required temperature difference between bearing ring and counter piece depends on the interference fitting and on the bearing size.

Bearings with cover and sealing disks must only be heated up to temperatures of approx. 50° C before installation because of the grease filling.

The bearings should be heated in an oil bath or in a heating chamber. When using electric heating plates or gas-fired heating plates in order to prevent direct heating of the bearings, they should be turned over several times in order to ensure uniform heating up.

4.2.2 Impacts on the bearing rings, cages or rolling bodies should be prevented by all means! Such impacts damage the bearings.

If the hardened antifriction bearing rings are hit during the installation by hardened tools, piercers or directly by hammers, it is highly probable that parts of these rings will crack off. Hair cracks are also possible. These cracks cannot be noticed straight away but under stress they can damage the bearing.

Border breakouts can be the result of bumps of the rolling bodies against the edges, when the rings are pushed onto the seat by too strong a jerk. These bumps can also cause scratch marks and ball impressions in the roller paths. Breakouts are always widening in a trough shape in the direction of force - a hint for the detection of the cause of breakouts.

The installation forces given by the fit tolerances must not be guided from the external ring via the rolling bodies onto the interal ring nor in the other direction. The seat surfaces should be slightly oiled.

The ring with the tighter fit is generally mounted first. In case of smaller bearings and not too tight fittings the bearing ring can be pushed to its seat by slight hammer blows via a soft metal drift or via a tube piece. The blows should be such around the ring so that the bearing does not cant. Impact hoods allow centric force contacts. For the installation of larger numbers mainly mechanic or hydraulic presses are used.

A deformation of the cage is also possible in case of improper handling of the erection tools. This cage can be made of iron or brass plate or in case of solid design of plastic, light metal, iron or brass.

4.3 Some examples show

When driving the external ring of a cylinder roller bearing with an outer diameter of 90 mm into the bore hole of the housing, one side of the solid brass cage was accidentally hit with a drift and considerably deformed at one point (Fig. 8). The cylinder roll at the impact side was pushed to the opposite edge of the external ring by the impact onto the cage. The external ring showed shell-shaped breakouts (Fig. 9).

Fig. 10 shows the results of improper treatment. One roller which was removed for test purposes was pushed back by a hammer. In due course the roller caused a dent in the roller path near the recess in the guide rim, and then hit the guide rim, from which a large piece was broken out.

The impact was then transferred over the broken off part of the guide rim and one roller onto other roller rows, so that the support rim broke out.

Simultaneously the ring cracked transversally. The individual breakout at the rims are normally wide towards the direction of the impact. From the appearance of the fracture points the direction of force can be recognized. The internal ring of a self-aligning roller bearing as shown in Fig. 11 was hit by an impact on the external side of the support rim.

During the installation of the cylinder roller bearings it may happen that the roller ring is pushed edgewise on the running race of the already fixed ring. This causes scratch marks, see Fig. 12. In the course of the operation these scratch marks are the reason for unsmooth run tending to oscillations, which again lead to local overloads on the running surface of the bearing rings, finally leading to peeling off or breaking out of the material (Fig. 13).

If the bearings are installed without the aid or erection rings or bushings, the use of which is recommended by the manufacturers, damage on the running surfaces must always taken into consideration.

The dents in the ball spacing at one rim of the spheric external ring race of a two-row self-aligning roller bearing with 90 mm outer diameter, Fig. 14, indicate that the force was guided via the internal ring and the ball of the bearing when the external ring was mounted.

The associated internal ring, Fig. 15, also shows the strong ball impressions in the corresponding roller path on the die side. Improper mounting can, in addition cause the fracture of the ring.

Too loose a seat of an antifriction bearing in the housing or on the shaft leads - in case of a circumferential load on the corresponding ring - to sliding of the same on the seat surfaces. At the sliding points thermal stresses can cause cracks which eventually result in the rupture of the rings and finally to complete damage of the bearing (Fig. 16). On installing the bearing it should be taken into consideration that the lateral surfaces of the bearing do not touch the adjacent components, otherwise sliding marks will be formed on the surfaces as well and thermal stresses can lead to cracks.

Occasionally grooved ball bearings are slightly axially adjusted in order to reduce the play and noise. In addition, axial load leads to slight lateral shifting of the running marks in the roller paths of grooved ball bearings (in many cases). These eventualities should be considered before indicating axial distortion.

The external ring of a self-aligning roller bearing with an outer diameter of 80 mm (Fig. 17) shows considerable lateral shift running marks in the spherical roller path due to axial distortion. One ball row had to absorb the entire load of the bearing. The associated running mark is on the right side of the photo at the border of the roller path. In this section the surface of the roller path has already come off. Caused by this damage, the rim of the ring was chipped-off at one point.

Fig. 18 shows the results of a strong axial distortion on cylinder roller bearings. On the photo you can see the internal ring with roller ring of the cylinder roller bearing with a bore of 65 mm. On the front side the rollers were tensioned between the associated rims and thus were obstructed in their run, being interfered. The cage was deformed and the bearings were running hot.

Fig. 19 shows a section of the inner ring of a self-aligning roller bearing with a bore of 30 mm as well as an associated bevel roller. Due to too tight adjustment the rollers with their large front sides were firmly pressed to the guide rim of the internal ring, so that the corresponding surfaces finally jammed.

The results of the axial distortions were:
very high heating, formation of cracks due to thermal stresses at the guide rim, which finally lead to the rupture of the internal ring.

In case of a radial distortion of an antifriction bearing, as shown in Fig. 20, the running marks are of the same intensity and are uniformly distributed over the entire circumference in the roller paths of the rings and the surface of the roller path is damaged in their section. The running marks are "normal", i.e. are not staggered in their position or direction.

The reason for the radial distortion is a much too tight seat on the shaft or in the housing resp. the selection of a bearing with too little radial play for the installation.

The different possibilities for a radial distortion in antifriction bearings shall be demonstrated by this especially severe case.

The hot run of an antifriction bearing was observed several times successively at a machine with high ambient temperatures causing the plant management to take special measures. The housing comprising the external ring of the bearing was cooled with water.

The cooling of the housing resulted in the fact that the bearings ran hot even more often resp. within a shorter time. What was the reason for this behaviour? Via the shaft the internal ring of the bearing was heated to such an extent that it expanded. The external ring remained in its dimension due to the cooling of the housing or even shrank. The behaviour caused by the

the thermal influences of the rings led to a complete compensation of the radial play in the bearing and finally the rolling bodies were exposed to pre-stresses. The radial distortion then caused the hot run of the bearings.

The danger of radial distortion is especially high in case of conical seat on the shaft or if tensioning or withdrawal sleeves are used. In such cases the radial clearance of the installed bearing or - if this is not possible - the run of the same should always be checked. A considerable obstruction of the run indicated a distortion.

Fig. 20 shows as already described above - the two roughened running marks in the spherical external ring roller paths of a radially distorted selfaligning roller bearing having an external diameter of 110 mm. This bearing had to be dismounted after a short operation period due to loud running noises.

A bearing, the rings of which cannot be swung against each other - in contrary to all so-called self- aligning roller bearings - are subject to diagonal distortion if the rings have been installed in canted condition. Fig 21a is a schematic representation of the kind and course of the running marks in the internal and external ring roller paths of a grooved ball bearing when the internal ring rotates. Fig. 21b shows the condition of the rotating external ring (2). Fig. 22 shows the internal ring race of a diagonally distorted grooved ball bearing with a bore of 20 mm, the external ring of which rotated. In diagonally distorted cylinder roller bearings the rollers run canted. The high edge pressure causes premature material fatigue in the over-stressed sections of the running surfaces of rings and rollers. Fig. 23 shows the damaged internal ring of a cylinder roller bearing with a bore of 60 mm. Roughening resp. peeling extends from one rim of the running race to the other one.

Peelings at the internal ring running race of a diagonally distorted bevel roller bearing with a bore of 50 mm are similarly arranged. Fig. 24 compression across the edges of the bevel rollers.

The reason for oval distortion is the housing bore which is out-of-round when the fit is too tight. We have the same condition when the housing cover is put on the wrong way (in case of split bearing housings) or when the cover bolts aree tightened too much. The special characteristics of damage caused by oval distortion are the highly indented and damaged running marks in the external ring running race in two diametrically opposed zones. Fig. 25 shows the external ring of a self-aligning roller bearing which was cut in half. The damaged points in the two running races are clearly visible.

One of the installation defects is the non-uniform supporting of the rings on the seat surfaces, which causes a locally limited overloading of the antifriction bearings. Such defects can also be caused by the design.

The Fig. 26 and Fig. 27. shows the effect of fastening the external of a grooved ball bearing with an outer diameter of 100 mm on using a pressure screw in the housing. At this point the running race was peeled off: starting from the damaged point the ring broke.

A bearing is also locally overloaded when the seat surfaces are contaminated (e.g. by metal chips) or when they are "punch-marked". Also the use of shim plates in order to "improve" the fit often cause conditions as shown in Fig. 26 and Fig. 27.

We would also like to point out that unbalanced masses cause considerably higher loads than originally scheduled. The higher loads again result in locally limited damage at the races of antifriction bearings.

5. MAINTENANCE RESP. LUBRICATION OF BEARINGS

In the antifriction bearing the lubricant prevents the immediate metallic contact of rolling body, bearing rings and cage and protects the bearing from wear and corrosion.

The most favourable operating temperature of an antifriction bearing is achieved when only the lubricant quantity required for an optimum lubrication is supplied. This lubricant quantity is relatively small. The lubricant quantity supplied to the bearing point also depends on the additional tasks the lubricant has to perform (e.g. sealing or heat dissipation).

If too much lubricant is supplied the bearing can be heated and this results in a premature failure of the same.

The lubricity of the lubricant diminished in the course of time due to mechanical stresses and aging. For this reason the lubricant consumed and conatiminated during operation must be topped-up resp. changed after certain periods.

Antifriction bearings can be lubricated with grease or oil, in special cases even with solid lubricants. Axial self-aligning roller bearings should be lubricated with oil due to their design; greasing is also possible in special cases and at low speed.

Decisive factors for the selection of the lubricant are first of all the temperature range and the required operating speeds.

Grease lubrication

Under normal operating conditions antifriction bearings can be greased in most cases. Compared with oil, grease has the advantage of better retainability in the bearing point and it even contributes to sealing of the bearing against humidity and contaminations.

Generally the free space in the bearing and housing should only be partly filled with grease (approx. 30 to 50 %), as too much grease will cause considerable temperature rises at higher speeds. Only bearings which rotate slowly and which must be protected against corrosion can be filled entirely with grease.

If bearings are lubricated with grease, a certain speed limit should not be exceeded. This speed limit can be drawn from a bearing list.

Greases for lubrication purposes

Lubrication greases are oils (mineral oils or synthetic oils) which are thickened by thickeners, in most cases by metal soaps. The consistency of the grease depends on the kind and quantity of the thickener used. For the selection of the type of grease it is very important to consider the consistency, the temperature range for which the grease is suitable and the behaviour of the grease towards water.

The temperature range of the individual lubrication greases is of special importance:

e.g. Lime soap greases up to 60° C
Soda soap greases from -30° to +80° C
Lithium soap greases from -30° to + 110° C
Prime quality greases up to +150° C

The silicone greases and diester oil greases based on synthetic basic oils are suitable for lower and higher temperatures than greases on a mineral oil basis.

Consistency

The classification introduced by NLGI (National Lubricating Grease Institute) groups the lubricating greases according to their consistency (DIN 51818). Metal soap greases of consistency classes 1, 2 and 3 are suitable for antifriction bearings. Their consistency should not change too much within the operating temperature range when they are exposed to temperature and stresses. Greases which soften at higher tempratures can easily emerge from the bearing points; greases, which become stiff at low temperatures can obstruct the run of the bearing. In bearings which are exposed to frequent vibratons, the grease is highly stressed. For this type of bearing greases with high stability against working are recommended.

Addition of solid lubricants (dry lubricants) and graphite, Molykote (molybdenum disulphide) should be prevented in any case, because it leads to premature damages in antifriction bearings. For this reason take special care that greases with solid lubricants are not mixed up by mistake with normal greases.

Mixability

Special attention should be paid to the mixability of lubrication greases when the type of grease is changed for special reasons at one bearing point. When incompatible greases are mixed, the highest admissible operating temerature can be lowered to such an extent, that very often bearing defects occur.

Lubrication with the same thickener and similar basic oils can be mixed without any disadvantageous consequences, e.g. one soda soap grease with another soda soap grease. Lime and lithium soap greases can be mixed with each other; they can, however not be mixed with soda soap greases.

Lubrication period

The lubrication period of grease lubricated bearings depends mainly on the type of bearing, the bearing size, the speed, the operating temperature and the quality of the grease.

A required re-lubrication depends on the service life of the grease, the approximate value of which can be calculated using the following formula:

$$t_f = k \frac{14.10^6}{n\ d} - 4 . d$$

t_f = the service life of the grease in operating hours

k = a coefficient

k = 1 self-aligning roller bearing
bevel roller bearing
axial ball bearing

k = 5 cylinder roller bearing, needle roller bearing

k = 10 radial grooved ball bearing

n = speed (rpm)

d = bore diameter of bearing (mm)

This formula is applied for bearings of stationary machines under normal load and at normal operating temperature as well as for all bearings with cover or sealing disks. In case of smaller bearings especially in grooved ball bearings, the service life of the grease is often longer than that of the bearing itself. In most cases relubrication is therefore not necessary. Medium sized and large bearing, however, must be lubricated after regular periods - the so-called lubrication interval. The lubrication interval t_f indicated in operating hours, is - for operational safety reasons - rated much shorter than the service life of the grease.

Oil lubrication

Oil lubrication is generally used, when high speeds or high operating temperatures do not allow greasing any more, when friction or outside heat should be dissipated from the bearing point or when adjacent machine parts (e.g. toothed wheels) are already lubricated with oil. The speed limit for every bearing being oil lubricated can be drawn from the bearing tables of the individual bearing manufacturers.

Types of oil lubrication

The simplest type of oil lubrication, the oil bath lubrication, can only be used for low speeds. The oil is taken along by the rotating, rolling bodies, is distributed in the bearing and subsequently flows back, to the oil bath. When the bearing is not moving the oil level should be slightly below the center of the lowest rolling body.

Higher speeds increase the operating temperature and accelerates the aging of the lubrication oil. In order to prevent frequent oil change, an oil circulation system lubrication is recommended in many cases. This system provides cleaning of the oil and cooling down - if required after the oil has left the bearing. So only clean oil is re-fed to the bearing. Due to re-cooling of the oil the operating temperature of the bearing can be kept low. The oil circulation is mostly achieved by a pump.

If higher speeds are involved make sure that a sufficient quantity of oil gets into the inner part of the bearing and that it dissipates the considerable frictional heat. A highly effective lubrication system for this type of application is the oil injection lubrication. here oil is sprayed into the bearing by one or several nozzles, under high pressure which is generated by a pump. The jet speed must be so high (≥ 15 ms) in order to allow one portion of the injected oil to pass the air whirl circulating together with the bearing.

In the oil mist lubrication system oil is atomized and is supplied by an air current to the bearing point. The oil mist is generated in an oil atomizer. The dry compressed air taken from the central compressed air system is filtered in the oil atomizer and is regulated to a pressure of 0,5 to 1 kp/cm². The oil mist is supplied by pipe lines to the different bearing points. In most cases a compressor nipple is arranged in the pipe line immediately before the bearing point. In this nipple the atomized oil is precipitated to a large extent. The air flow through the bearing housing cools the bearing and generates, furthermore, a slight overpressure, which prevents the penetration of contaminations into the housing. As this system operates with small, precisely dosed oil quantities the part of the lubricant friction is small compared with the total bearing friction, it is mainly used for rapidly rotating bearings.

Lubrication oils

As lubrication oils for antifriction bearings mostly non-alloyed mineral oil raffinated are used. Alloyed oils with additives for the improvement of certain oil properties (pressure absorption capacity, aging resistance, etc.) are only necessary for special operational requirements. Up to now synthetic oils for antifriction bearing lubrication serve mostly as basic oils for lubrication greases and in some extreme cases (e.g. at very high temperatures) only.

Selection of the lubrication oils

The viscosity is one of the main characteristics of a lubrication oil. It decreases proportional to rising temperature. At the operating temperature of the bearing, the viscosity of the lubrication oil shall not drop below a certain minimum value, so that a sufficient bearing lubrication film can be built up on the contact surface between rolling body and running path. On the other hand, the viscosity must not be too high at high speeds, as otherwise the friction and the generation of heat increases highly in the bearing.

For the medium sized and large bearings the viscosity at operating temperature should not be below 12 cSt (2 E). For smaller rapidly rotating bearings thin-bodied oils shall be used due to the starting friction.

For extremely low and high speeds and for extra- ordinary lubrication conditions the suitability of the scheduled oil for a sufficient lubrication must be proved by an investigation.

Oil change

The interval from one oil change to the other mainly depends on the mechanical and thermal stresses to which the lubrication oil is exposed to and on the available oil quantity.

In an oil bath lubrication it is in most cases sufficient to change the oil every two years if the bearing temperature does not exceed 50° C and if there is only slight contamination. Higher temperatures and other aggravating operating conditions necessitate a more frequent oil change, e.g. every 6 months at operating temperatures of approx. 100° C.

For oil circulation lubrication the interval between the oil changes depends on the number of circulations of the entire oil quantity per time unit, on cooling of the oil, etc. The precise time for the oil change can therefore only be determined by checking the oil and by permanent observation of the lubrication oil. The same applies to the oil injection lubrication.

The oil mist lubrication is in most cases a so-called oil loss lubrication, i.e. the oil is only once supplied to the bearing point.

Checking and cleaning of the bearing

Like all other important machine parts, antifriction bearings must be checked and cleaned from time to time. The time and the mode of the checks depend on the operating conditions.

If the condition of the bearing can be checked during operation by listening to running noises or checking of the lubricant, it will generally be sufficient to check and carefully clean the bearing (rings, cages and rolling bodies) and all other parts of the bearing in intervals of approx. one year. Rolling mill bearings for example, which are highly stressed, will, however, be checked after 6 months.

After cleaning of all bearing parts with petroleum ether, acid-free petroleum or another suitable cleaning agent, the bearings must immediately be protected from corrosion by oiling or greasing. This is very important for machines which are not used for a longer period before they are again in operation.

Examples of unsatisfactory lubrication

Unsufficient lubrication results in a premature wear at the running surfaces and especially at those parts in the bearing which are subjected to sliding friction - these are the roller front sides and the rims as well as the cage.

The highly worn solid brass cage shown in Fig. 28 is part of a self-aligning roller bearing with an outer diameter of 290 mm. The bearing had not been re-greased in due time. Fig. 29 shows a roller of an axial self-aligning roller bearing of series 293 with considerable wear marks on the large front side.

This bearing had been lubricated with grease instead of the prescribed lubrication oil.

The cages of the antifriction bearings are not highly stressed under normal operating conditions. If, however, lubrication is insufficient the contact surfaces to rolling bodies and bearing races are worn. Excessive wear can lead to rupture of the cage and to blocking of the bearing. Fig. 30 again shows a solid brass cage of a self-aligning roller bearing with wear at the webs as well as on the bottom of the roller bags and in the bore. In Fig. 31 the wear has got worse. The webs are thinner and the bores have become bigger, furthermore, one web has broken off.

The rupture of a cage can also caused by damaged rolling bodies or running paths or by particles which peeled off and have got stuck between the rolling body and the cage.

Also material which has penetrated into the bearing from outside can lead to wear of the cage and other bearing parts and thus to rupture of the cage and blocking of bearings.

As experience has shown it is recommended to investigate first the lubrication conditions and the lubricant in case of cage damages. Blank wear surfaces at the rolling bodies and roller paths are proof for insufficient lubrication.

6. CORROSION

The corrosion at the fine-ground running surfaces and also at the bearing surfaces can have quite different reasons.

Among these reasons are:

6.1 Defective sealing of the bearing points against humidity and acid-containing vapors from the outside.

6.2 Formation of condensation water due to temperature fluctuations, corrosion at fittings and contact corrosion.

6.3 Unsuitable lubricant

6.4 Lubricant shortage

In case of insufficient sealing of the bearing point or wrong installation of a sealing element, water can get into the bearing and can cause corrosion at the running surface or at the rolling bodies.

The corrosion has two effects on the depth of the running mark.

- The iron oxide has a considerable abrasive effect and thus causes a rapid increase of the bearing clearance.

- The reduction of the supporting surface in the race and at the rolling bodies due to a great number of corrosion marks. The bearing looses some of its bearing capacity. Deep corrosion marks can finally have such a notch effect - due to hard and jerking run - that parts of the rolling bodies and the race ring break off.

During longer standstill periods or unsuitable storage of a bearing defective sealing allows water to penetrate into the bearing and this leads to contact corrosion. These are corrosion marks in the contact surface between the race rings and the rolling bodies, i.e. corrosion marks in the spacing of the rolling bodies. Contact corrosion can also be caused by condensation.

Acid-containing lubricants or penetration of acid vapours also lead to corrosion. Lubricant shortage causes easy penetration of humidity.

Friction corrosion also called fretting corrosion, caused by steel parts and cast iron parts rubbing against each other. Even the slightest motion has this effect, very often it is not more than a so-called "breathing" between the parts. Small material particles are torn off, which very rapidly oxidize in the air due to their large surface and thus cause corrosion. Greasing of the rubbing surfaces can only retard the formation of friction corrosion, since most lubricants are very soon pressed away from the contact surfaces. The formation of friction corrosion can, however, be reduced by phosphating and subsequent treatment with molybdenum disulphide.

Friction corrosion is highly dangerous for bearings with snug fitting between inner ring and pin, Fig. 32. Fig. 33 shows an inner ring which is cracked in the bore due to fricton corrosion.

If friction corrosion gets into the bearing, no dents are formed, but the wear is considerable. The fine distributed iron oxide acts like a grinding or polishing agent.

Fretting between shaft and inner ring, as shown in Fig. 34, can cause seizing of the bearing at the shaft. Drawing off of this bevel roller bearing - on the occasion of a machine repair - required enormous forces so that the bearing was damaged and could not be used any more.

Corrosion attacks are highly dangerous. Rubbed off rust leads to strong wear, and rust marks in the races can cause peelings too. Furthermore, it is possible that cracks are formed, no matter whether the corrosion pits are in the races - where they are of course most dangerous - or in other surfaces of the bearing.

fig. 35 shows corrosion pits at the inner ring of a self-aligning roller bearing; water penetrated into the bearing due to unsuitable grease. The bearing was then not used for some time, so that the contact points between rollers and rings corroded. The hardest corrosion attacks are therefore in the roller spacings and appear as transversal strips on the bearing rings.

Fig. 36 shows a bearing ring with corrosion damage, which was caused by an unsuitable lubricant.

Another example are two bearings which were installed in a strip pickling line and the housings of which had defective sealings, allowing the sulphur-containing vapours to penetrate into the bearings and to cause strong corrosion damage.

Fig. 37 shows corrosion damage at the inner ring of a bevel roller bearing, which resulted in a strong operational noise of the bearing.

Fig. 38 shows the corrosion marks in the ball race of an external ring of a self-aligning roller bearing which were caused by the acid-containing vapours during a longer standstill period of the bearing. These marks conincide with the ball spacing.

7. CONTAMINATION

Contamination occurs when, due to insufficient sealing of the bearings, impurities could get into the bearings or when the used lubricant resp. the lubrication devices and the lubricant tanks were not kept clean. We would like to point out again that the bearings should be protected against any kind of contamination as carefully as possible - when they are installed. Such careful handling already starts when the bearings are removed from their original package. Bearings shall only be taken out from their package immediately before installation.

The roller bearing of 25 mm bore shown in Fig. 39 had to be dismantled after very short operation time because of the loud running noise. The running mark of the inner ring shows foreign body dents between the two rims. These dents extend from the top to the bottom. Even a small number of hard dirt particles can cause such damage. The damage features shown in Fig. 39 should be distinctly distinguished from the alterations at the surface, which can under normal conditions be noticed at the running surfaces of antifriction bearings after a relatively short operation period already. It will then be a very slight dulling or a surface appearance, which is similar to that caused by burnishing.

8. VIBRATION DURING STANDSTILL

If an antifriction bearing is subjected to permanent vibrations during standstill, the rolling bodies form dents in the load zones of the race surface. The result are deep dents which cause loud running noise when the bearing is set in operation and finally result in a premature roughing and peeling off of the running surfaces. The chatter marks can be identified in most cases by the reddish friction rust.

Vibrations during standstill can occur as transportation damage in bearings in completely mounted machines. Nowadays - just to give you an example - the rotors in electric motors are wedged towards the rotor by a shim plate when they are transported, in order to neutralize the influence of the mass forces occuring.

Formation of chatter marks is also possible in the bearings of spare machines, if they are mounted permanently on a common baseplate with a permanently operating main unit.

The external ring race of a cylinder roller bearing with an outer diameter of 110 mm (Fig. 40) shows chatter marks of about a third of the circumference (load zone). These chatter marks are the result of vibrations during standstill. Fig. 41 presents an enlargement of this damage.

In some cases vibration damage can have an appearance as shown in Fig. 42, where the inner ring did not stand still entirely. This damage differs from corrugation due to electric current flow, by the fact that the dents are blank or have fretting corrosion, whereas in the case of current passage the dents and elevations have a dark colour.

9. OSCILLATIONS DURING OPERATIONS

Each part of a machine has a natural oscillation. Especially gear shafts supporting gear wheels or drive spindles resp. articulated shafts very often are subject totorsional vibrations. The sum of several individual oscillations - if they have not the same frequency or a multiple of the basic oscillation - is a resonant vibration. The result of a resonant vibration is also chatter marks in the races of the antifrictionbearings. The bearings must be replaced after a short operation period.

Fig. 43 shows the external ring of the cylinder roller bearing with strong chatter marks due to resonant oscillations. This bearing was installed in a hydraulic pump; the resonant oscillation was caused by a pump unit connected parallel which had the same oscillation lation frequency and a rigid tube connection.

10. DAMAGE DUE TO CURRENT FLOW

The bearings in electric machines are sometimes damaged by arc-overs or permanent current flow. Strong arc-overs with relatively high current intensity cause welding points at the contacting surfaces of the rolling bodies and races in the area of the current flow. Fig. 44 shows the running surface of the inner ring of a ball bearing installed in a 110-kW electric motor, with crater-shaped pits caused by arc-over.

The permanent current flow (at relatively low current intensity) together with simultaneous vibrations lead to rippling on the contacting surfaces, which naturally can be noticed most clearly in the races. Loud operation noise makes it obvious very soon that the bearing is damaged. On the basis of the race of the exter nal ring of a grooved ball bearing with an outer diameter of 130 mm, the ripples (of brown colour) as a result of permanent current flow can be clearly recognized (Fig. 45). The bearing was installed in an electric motor. In the race of the inner ring of this bearing only a wide continuous, brown coloured mark could be noticed. At other bearings both rings showed corrugations parallel to the axis in the basis o. the race. In self-aligning roller bearings and cylinder roller bearings these corrugations could even be no[illegible] t the shell surface of the rollers.

In electrically driven rail vehicles antifriction bearings occasionally act as current bridges. Under certa[illegible] operation conditions this must lead to [illegible]or-m[illegible]n of ripples.

In revolving roller bearings with current passage very often a dark covering is formed after some time on the rolling bodies and races. This covering turns eventually into so-called ripples, see Fig. 46. Rippling starts in the zone of the race which is heavily stressed. From there it expands and in a roller bearing it can even be found in the two rings and on the rollers. The depth of the ripples in the direction of the race is slight - some μ only between the lowest and the highest points. This irregularity can, however, cause the so-called "peeling" which makes the bearing useless.

11. RUNNING HOT OF ANTIFRICTION BEARINGS

If an antifriction bearing was completely damaged by running hot, it is hardly ever possible to identify the reasons for the damage of the bearing. In the damage analyses the most frequent causes for the running hot of an antifriction bearing are the following:

- Any kind of distortions

- Insufficient quantity of lubricant

- Excessive lubricant supply of the bearing (especially in case of grease lubrication!)

- Severe contamination

- Heat influence from outside, e.g. excessive heating of the inner ring via the shaft which was not noticed before.

12. WORKING LIFE RESP. NORMAL FATIGUE

The permanent load change in an antifriction bearing causes a normal fatigue of the material. Small cracks are formed under surface of the races of the rolling bodies. These cracks eventually lead to crumbling away of material particles of their surface - the so-called peeling.

The period until such damage occurs - as far as only normal operating stresses have taken place - is called the effective working life of a bearing. These damages are then called peeling due to normal fatigue. In some cases, however, peeling can occur considerably earlier than the nominal working life finishes, when considerable additional stresses - also locally limited ones - are applied to the bearing due to influences which can not be foreseen e.g. wrong installation, lack of cleanliness etc. At the beginning of such fatigues there are several symptoms which can mostly be recognized by a trained expert only and so the reason for the premature termination of the working life can be concluded.

Fig. 47 shows - clearly noticeable - a part of the external ring of a self-aligning roller bearing which is damaged due to normal fatigue of the material.

In addition to the peeling, the running noise of the bearing becomes louder - a signal that the bearing should be replaced. Peeling which is only limited to small points at the beginning, expands rapidly during further operation of the bearing. Small particles come off continuously until the entire stressed zone has peeled off, Fig. 48 and Fig. 49. Together with progressive peeling the running noises become louder and the bearing temperature becomes higher.

Peeling due to normal fatigue is relatively rare during the normal operating periods of modern machines. In most cases the operators have enough experience that they know very well the stresses which can occur at the machine, thus they can select the correct bearing of sufficient working period.
An exception are the components for which bearings with short working life are used, deliberately.

It can be taken as a rule that peelings occuring during the normal operation period of a machine are caused by abnormal stresses.

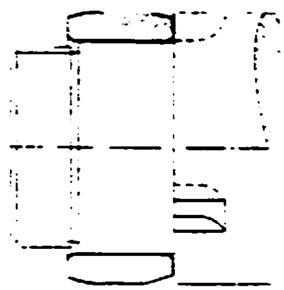
13. SUMMARY

This lecture tried to explain the most common damages occuring at antifriction bearings and to give examples from practical service. In order to make the facts clear we have selected such damaged bearings for which the detection of the causes of the damage was easy and clear. Unfortunately the interpretation of the damage symptoms is not so easy in practice as they are very often a combination of several influences.

At the end we would like to point out again that the details given on bearings should not worry the reader, but should be taken as a guide for the detection of antifriction roller bearing damages.

Examples to 3)

Correct dimensioning and measures for the design



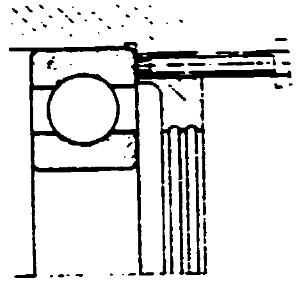


Fig. 1 Grooves in a shaft shoulder for attaching the pulling-off tools

Fig. 2 Bore holes for the use of lifting screw

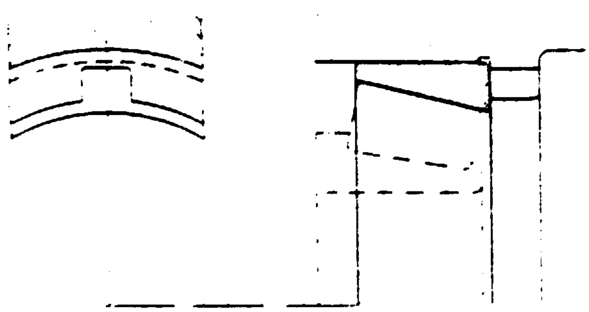


Fig. 2 Grooves for pressing out the external bearing ring

Bearing damage to 4)

Defective installation

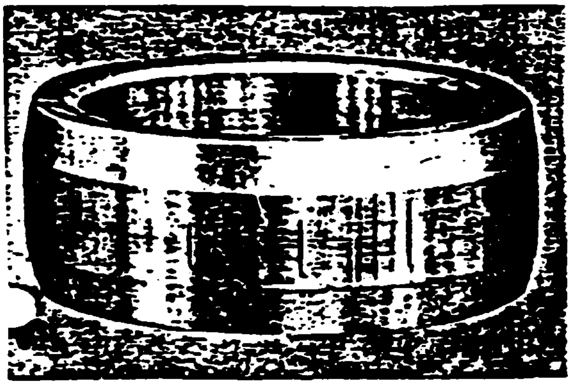


Fig. 4 Scratching marks at the inner ring of a cylinder roller bearing caused by lack of accuracy when installed

Fig. 5 Peeling due to race damage according to Fig. 4

Installation of bearing to 4)

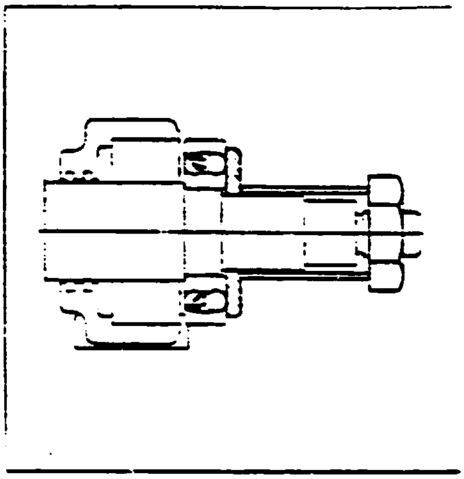


Fig. 6 Installation of a bearing with angular movement (e.g. self-aligning roller bearing) with erection disk into the housing, in order to prevent canting of the outer ring.

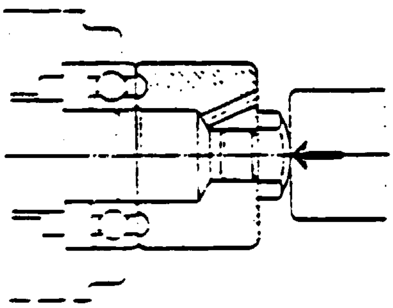


Fig. 7 Installation of a self-supporting bearing, simultaneously on the shaft and into the housing, with an impact cover.

Bearing damages to 4)

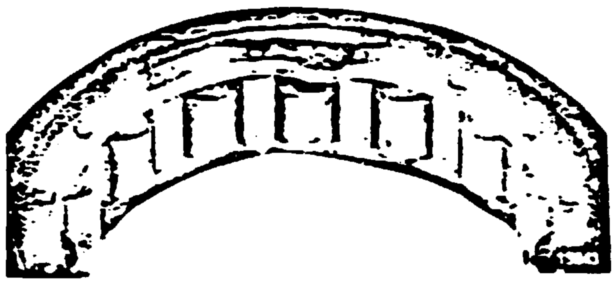


Fig. 8 Impact point on the front side of the solid brass cage of a cylinder roller bearing NU 210.

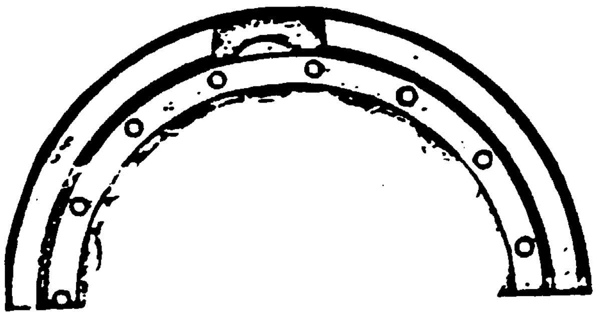


Fig. 9 Rear side of the bearing shown in Fig. 8 with a shell-shaped fissure on the edge of external ring opposite to the impact point.

Bearing damage to 4)

Defective installation

Fig. 10 The guide rim and a support rim of the inner ring of a self-aligning roller bearing are chipped off due to impacts.

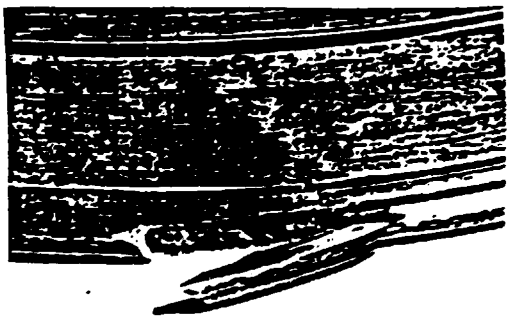


Fig. 11 A hammer blow hit the outer side of a support rim of an inner ring of a self-aligning roller bearing and broke it.

Bearing damages to 4)

Scratches due to defective installation

Fig. 12 Inner ring race of a cylinder roller bearing NJ 2209 with deep scratching marks in the roller spacing. The shaft with the inner ring slided into the already mounted outer ring with roller flange in canted position.

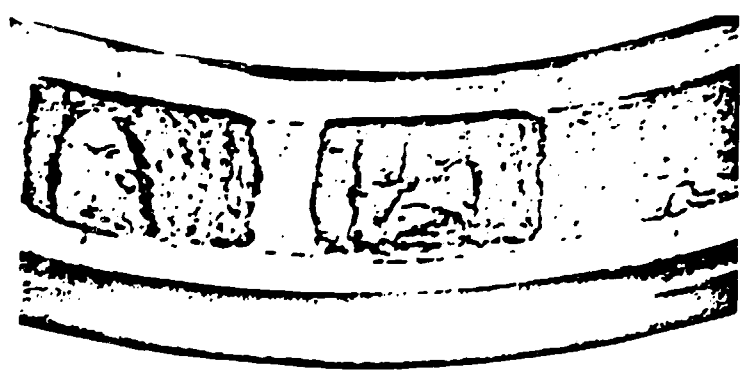


Fig. 13 Race of the outer ring of a cylinder roller bearing with peeling which developed from scratching marks occuring during the erection.

Bearing damages to 4)

Defective installation

Fig. 14 Dents in ball spacing at one edge of the external race of a ' ow self-aligning roller bearing 1210 due to defective installation.

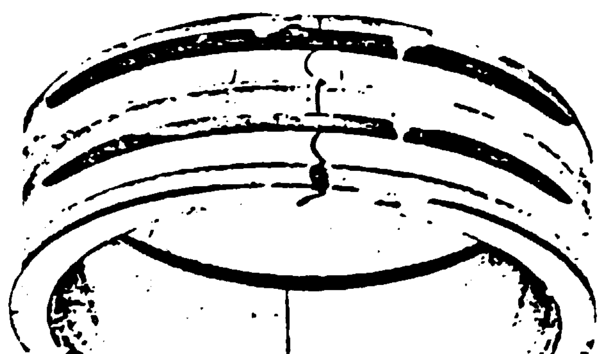


Fig. 15 Cracked inner ring of the same self-aligning roller bearing. The ball impressions can be noticed here as well.

Bearing damages to 4)

Defective installation

Fig. 16 Inner ring of a grooved ball bearing 6311, which turned on the shaft having a wrong fitting (too small). This caused cracks due to thermal stresses.

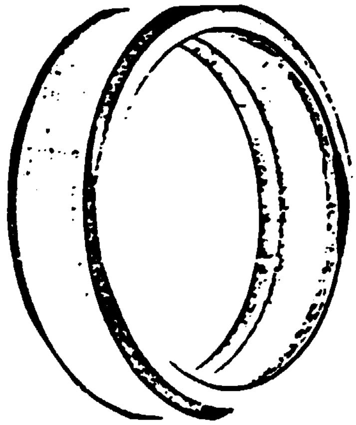


Fig. 17 Outer ring of a self-aligning roller bearing 1307 with scaling off and a splinter in the considerably displaced trace of a ball row.

Bearing damage to 4)

Defective installation

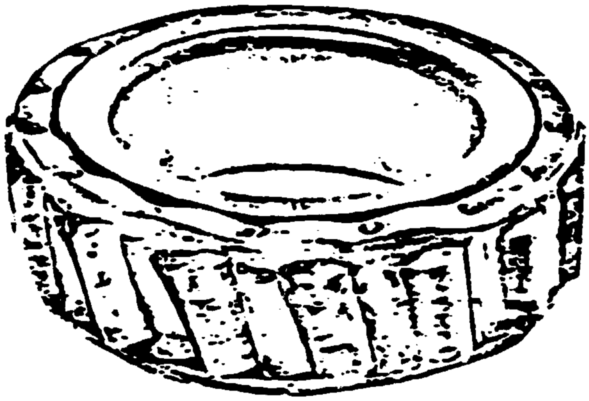


Fig. 18 Inner ring with roller rim of a cylinder roller bearing N 2213, which was heavily damaged by axial distortions.

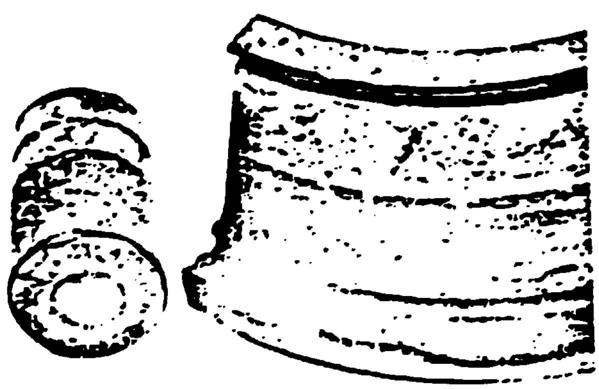


Fig. 19 Section of the inner ring of a bevel roller bearing 32306 and suitable bevel roller. The bearing was severely damaged caused by a too tight adjustment.

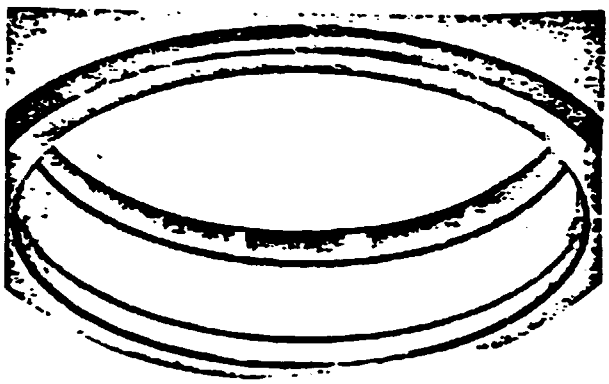


Fig. 20 Running marks in the outer ring of a radially distorted self-aligning roller bearing 1310. They are of uniform intensity spread over the entire circumference and not displaced.

Bearing damage to 4)

Defective installation

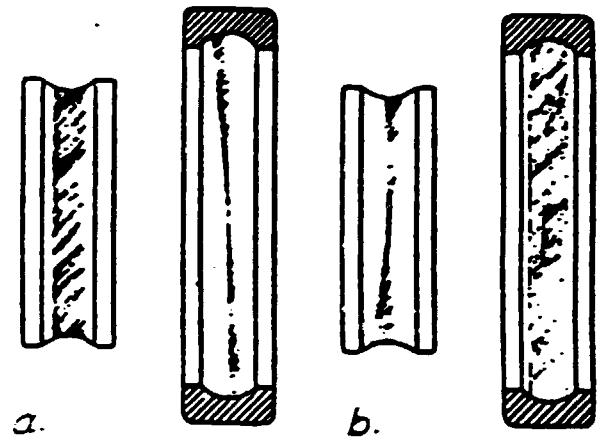


Fig. 21 Schematic representation of the running marks in transversally distorted, not replaceable antifriction bearings
a) with revolving inner ring
b) with revolving outer ring

Fig. 22 Inner race of a transversally distorted grooved ball bearing 6204, the outer ring of which revolved.

Bearing damage to 4)

Defective installation

Fig. 23 Inner ring of a transversally distorted cylinder roller bearing NU 2312 with noticeable change of the screwing traces resp. peeling off from one edge to the other edge of the race.

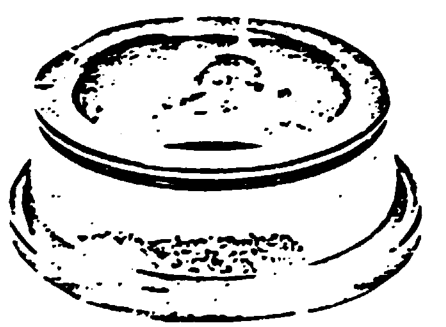


Fig. 24 Inner ring race of a transversally distorted bevel roller bearing 30310 with peeling off, being of similar arrangement as shown in Fig. 23. The bevel rollers turned under end pressure.

Bearing damage to 4)

Defective installation

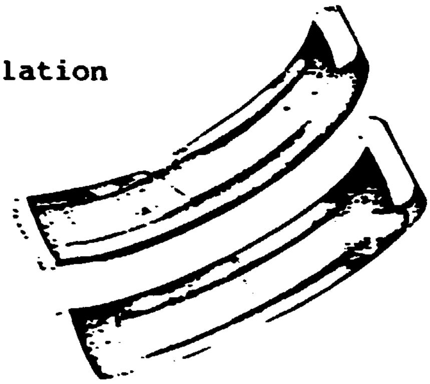


Fig. 25 cut outer ring of an ovally distorted self-aligning roller bearing with the opposite damage points at both running marks.

Fig. 26 Outer ring shell surface of a grooved ball bearing 6309 with the impression of a pressure screw and a transversal crack.

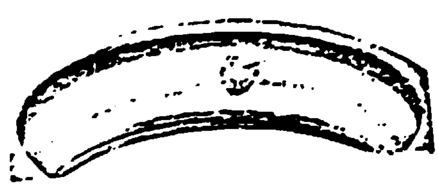


Fig. 27 Peeling off point in the outer ring race of the grooved ball bearing 6309 acc. to Fig. 26.

Bearing damage to 5)

Maintenance of the bearings resp. lubrication

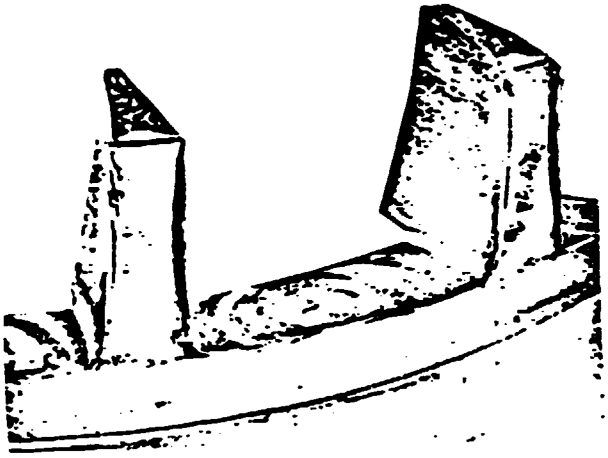


Fig. 28 Highly worn solid brass cage of two-row self-aligning roller bearing 23 038 due to lubricant shortage.

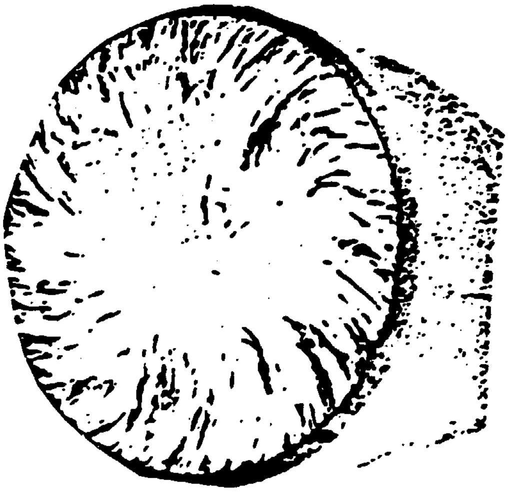


Fig. 29 Roller of an axial self-aligning roller bearing of row 293 with strong wear marks at the front due to lubricant shortage.

Bearing damage to 5)

Insufficient lubrication

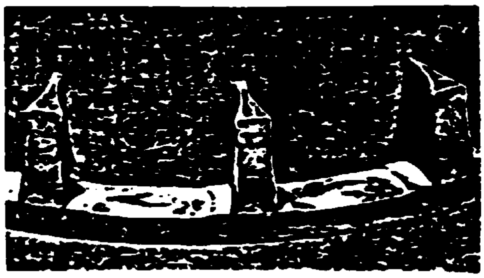


Fig. 30 Severe wear at the solid brass cage of a self-aligning roller bearing

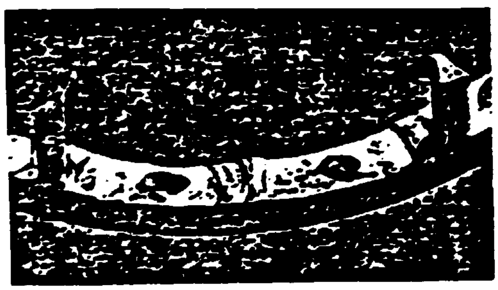


Fig. 31 The wear became so strong that some webs broke off.

Bearing damage to 6)

Corrosion

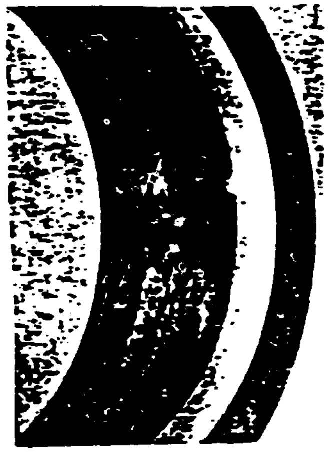


Fig. 32 Friction corrosion in the inner ring bore hole of a self-aligning roller bearing.

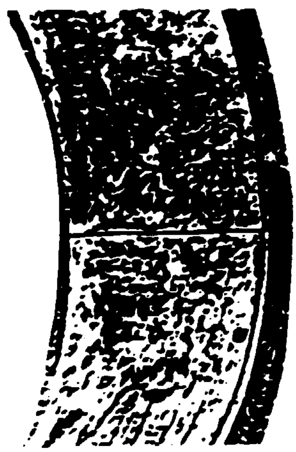


Fig. 33 Inner ring of a self-aligning roller bearing which cracked due to friction corrosion.

Bearing damage to 6)

Corrosion

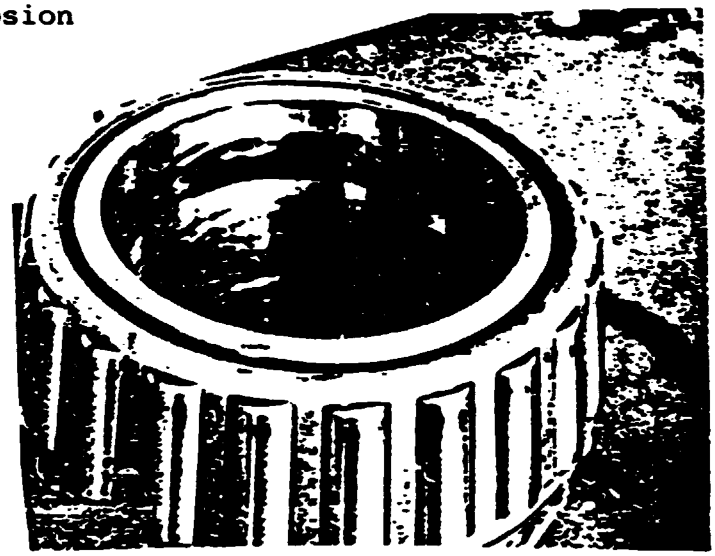


Fig. 34 Fretting corrosion in the inner ring bore of a bevel roller bearing.

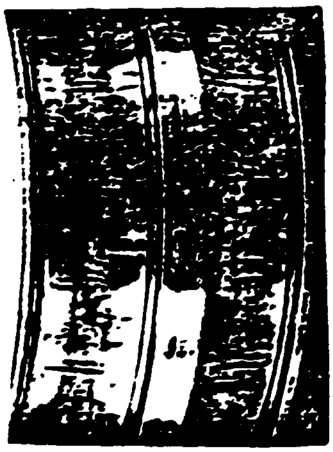


Fig. 35 Corrosion marks in the inner ring of a self-aligning roller bearing.

Bearing damage to 6)

Corrosion

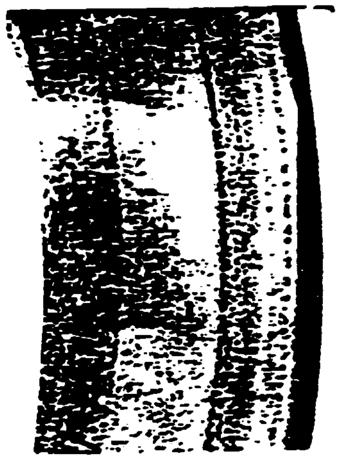


Fig. 36 Inner ring of a self-aligning roller bearing with corrosion damage due to the application of unsuitable lubricants.

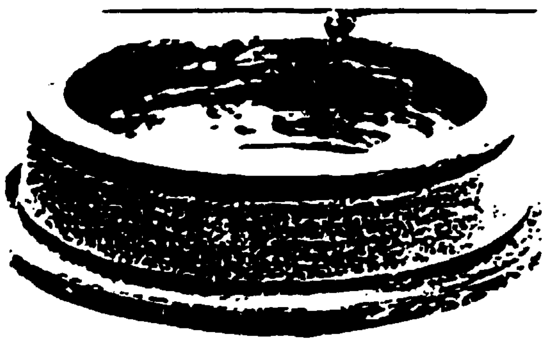


Fig. 37 Corrosion damage at the inner ring of a bevel roller bearing.

Bearing damage to 6)

Corrosion

Fig. 38 Etching marks in the roller race of an outer ring of a self-aligning roller bearing.

Bearing damage to 7)

Contamination

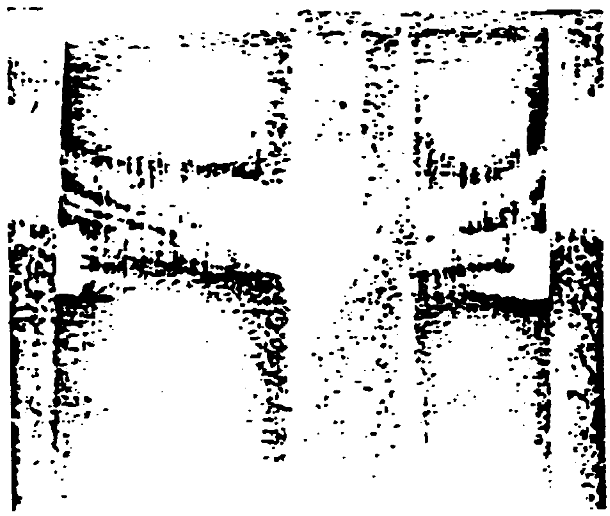


fig. 39 Inner ring race of a grooved ball bearing 63005 with dents caused by foreign matter in the race.

Bearing damage to 7)

Vibrations during standstill

Fig. 40 Outer ring race of a cylinder roller bearing NU 212 with chatter marks as a result of

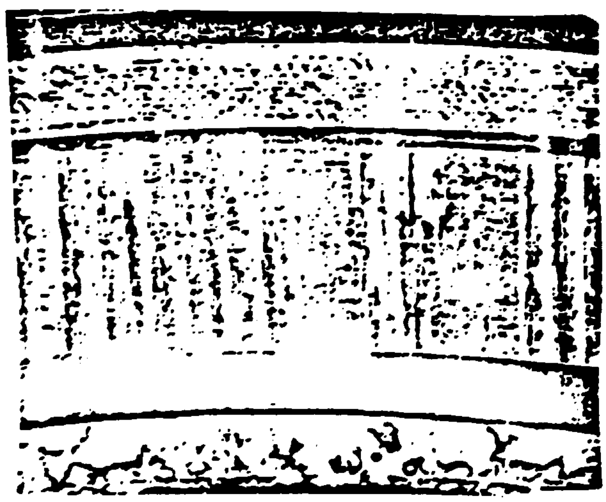


Fig. 41 Enlargement of the chatter marks of Fig. 32

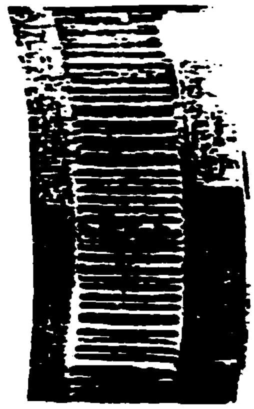


Fig. 42 Outer ring of a cylinder roller bearing with corrugations due to oscillations. The inner ring did not stand still entirely.

Bearing damage to 9)

Oscillations during the operation

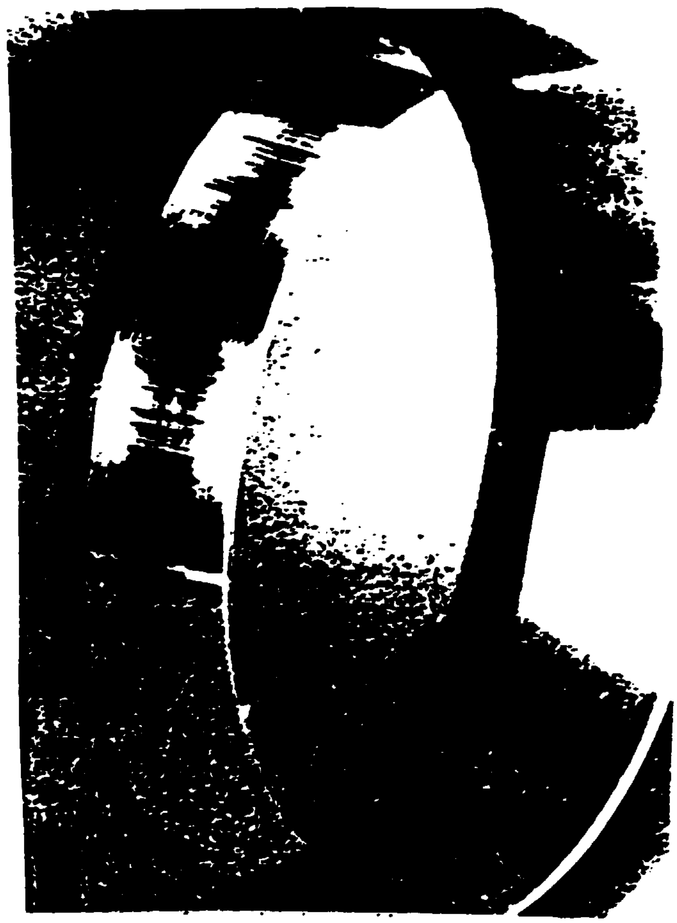


Fig. 43 Outer ring of a cylinder roller bearing with strong chatter marks due to resonant oscillations.

Bearing damage to 10)

Current passage

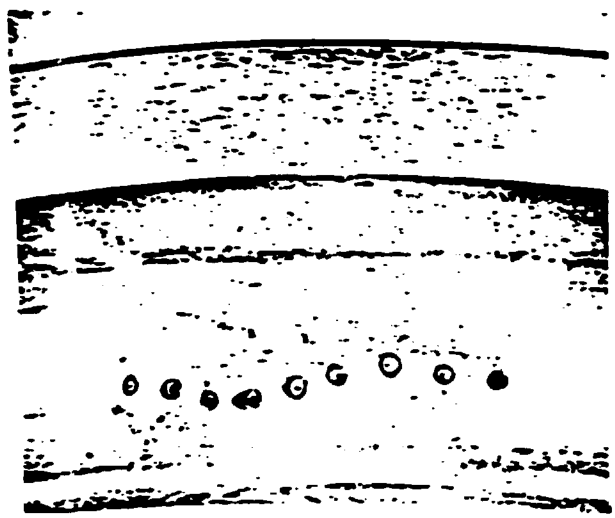


Fig. 44 Running surface of the inner ring of a ball bearing with crater-shaped pits caused by arc-over.

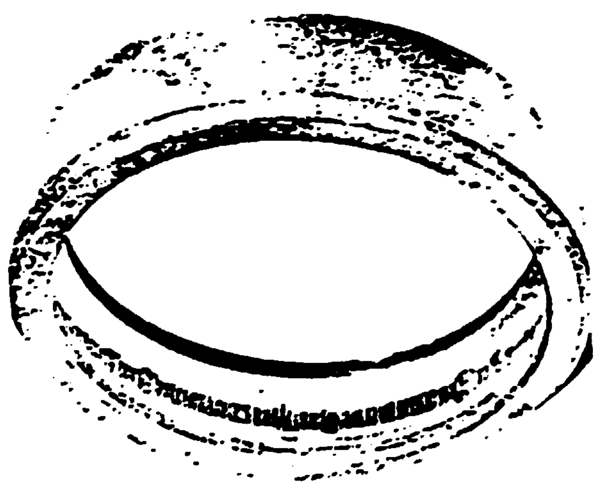


Fig. 45 Outer ring of a grooved ball bearing 6312 with brown coloured corrugations in the race, which were caused by continuous current passage.

Bearing damage to 10)

Current passage

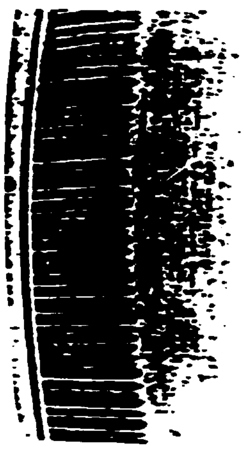


Fig. 46 Formation of corrugations at the outer ring of a self-aligning roller bearing after current passage.

Bearing damage to 12)

Working life resp. normal fatigue

Fig. 47 Peeling due to normal fatigue in the initial phase

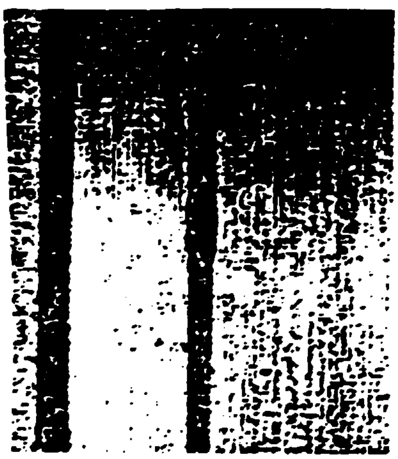


Fig. 48 The same peeling as shown in Fig. 47 but in advanced condition

Fig. 49 Peeling at the outer ring of a self-aligning roller bearing in highly advanced condition.