CORRESPONDENCE TUITION SCHEME

COURSE FOR POWER PLANT OPERATORS

LESSON 7 - THE OPERATION OF THE MODERN STEAM TURBINE

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1 INTRODUCTION

This lesson covers many of the features of the operation Of modern steam turbines.Due to variations in design and arrangement of machines, the text is in general terms only and is not intended to apply to any particular type of turbine.

The modern steam turbine is a large, complicated machine, driven by high pressure, high temperature steam and running at high speed. It is also required to be started and loaded as quickly as possible, twice, or more, daily.

The safe, reliable and efficient operation of the modern turbine requires the plant operator to have complete knowledge of the plant in his care and its characteristics, so that full use can be made of controls and instrumentation.

2 CONTROL ARRANGEMENTS

The number of controls, together with the appropriate instruments, have increased with the size and complexity of the turbine. It is interesting to trace development from the one or two pressure gauges, vacuum gauge and tachometer mounted directly on the older turbines.

As the size of machine increased, steam pressures and temperatures rose, and feed heating systems gained favour, so the number of instruments increased to give proper control of the plant. This trend has continued with the large modern machines.

The turbine controls have followed a similar trend and a situation could arise where a large number of operators would be required for reliable operation due to the dispersed control positions.

Developments in remote indicating instruments and remote operation of valves, allowed considerable scope for grouping controls and instruments. Grouping may be carried out for convenience and for improved operation.

This subject will be considered in more detail in Lesson 15, but some operational aspects are given in the following:-

2.1 Centralised Control

Any form of grouping of controls constitutes centralisation. Grouping has been carried to the stage where all the controls and instruments for the turbine, together with certain auxiliary instruments are located on a panel, or perhaps several panels, adjacent to the turbine. The grouping on each panel would depend upon its location, for example, main turbine controls located at the governor end.

There are many possible arrangements of panels and one example is shown in Fig. 1.

Complete centralisation as regards turbine plant would mean the controls and instruments, including remote starting for pumps and remote operation of valves, being concentrated on one panel. The arrangement would be similar to that in use on some large boilers, where practically all operation is carried out from the panel.

Development has not reached this stage for turbine plant alone, because of the adoption of the boiler/turbine unit, to be dealt with in Lesson 8.

The comparison with boiler plant could be taken a stage further. It is possible in some plants to control several boilers from a central master panel and stations are now operating where all units are operated from one control centre.

2.2 Main Turbine Panel

Irrespective of the arrangement of panels, there will be one panel which will be regarded as the main turbine panel. On this panel will be grouped the controls and instruments for the normal supervision of the turbine on load. Other instruments used for starting, that is, the turbovisory equipment and also any recorders, may be mounted at the rear of the main panel or on a separate panel.

This arrangement would also apply in boiler/turbine unit control rooms. The operator is thus able to concentrate on essentials without being confused by controls and instruments which are only used for starting up or shutting down.
A typical arrangement of controls and instruments on a main turbine panel is shown in Fig. 2.

2.3 Necessity for Separate Panel for Auxiliaries

Once a turbine is on load, most auxiliaries, for example, steam ejectors or air extractors, extraction pumps and feed heating system, require little attention provided the plant is in order.

As mentioned in 2.2, indication of these auxiliaries is provided on the main turbine panel. Full control and instrumentation would be provided on the separate panel, so that an operator can start up the auxiliary plant according to instructions and the instrumentation allows detailed checks to be made if the main turbine panel instruments and alarms indicate something wrong.

An example of controls and instruments on an auxiliary panel for steam ejectors is shown in Fig. 3 and for a deaerator, in Fig. 4.

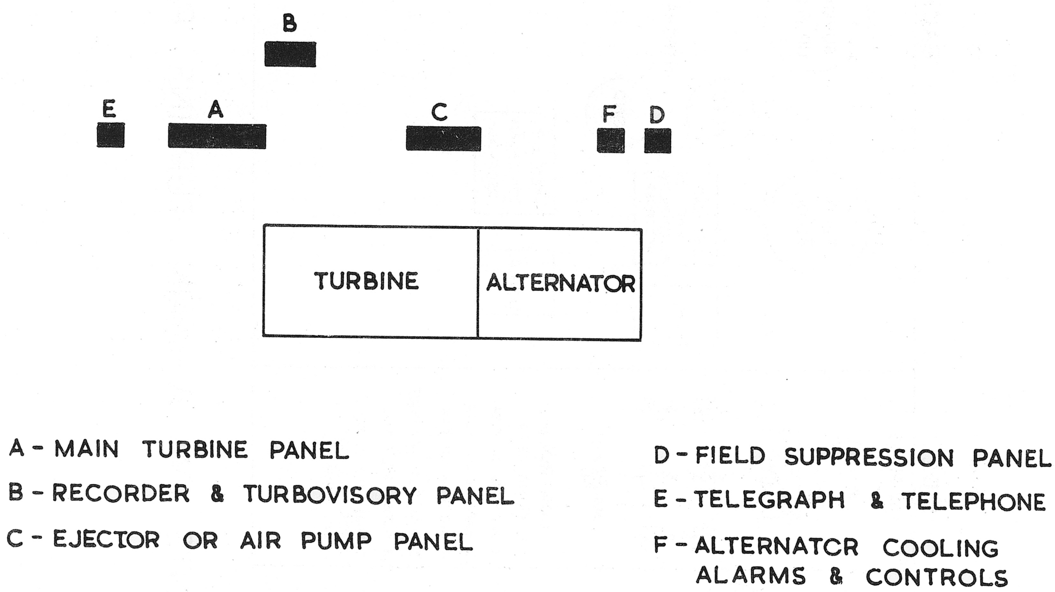


Figure 1: ARRANGEMENT OF TURBO-ALTERNATOR INSTRUMENT AND CONTROL PANELS

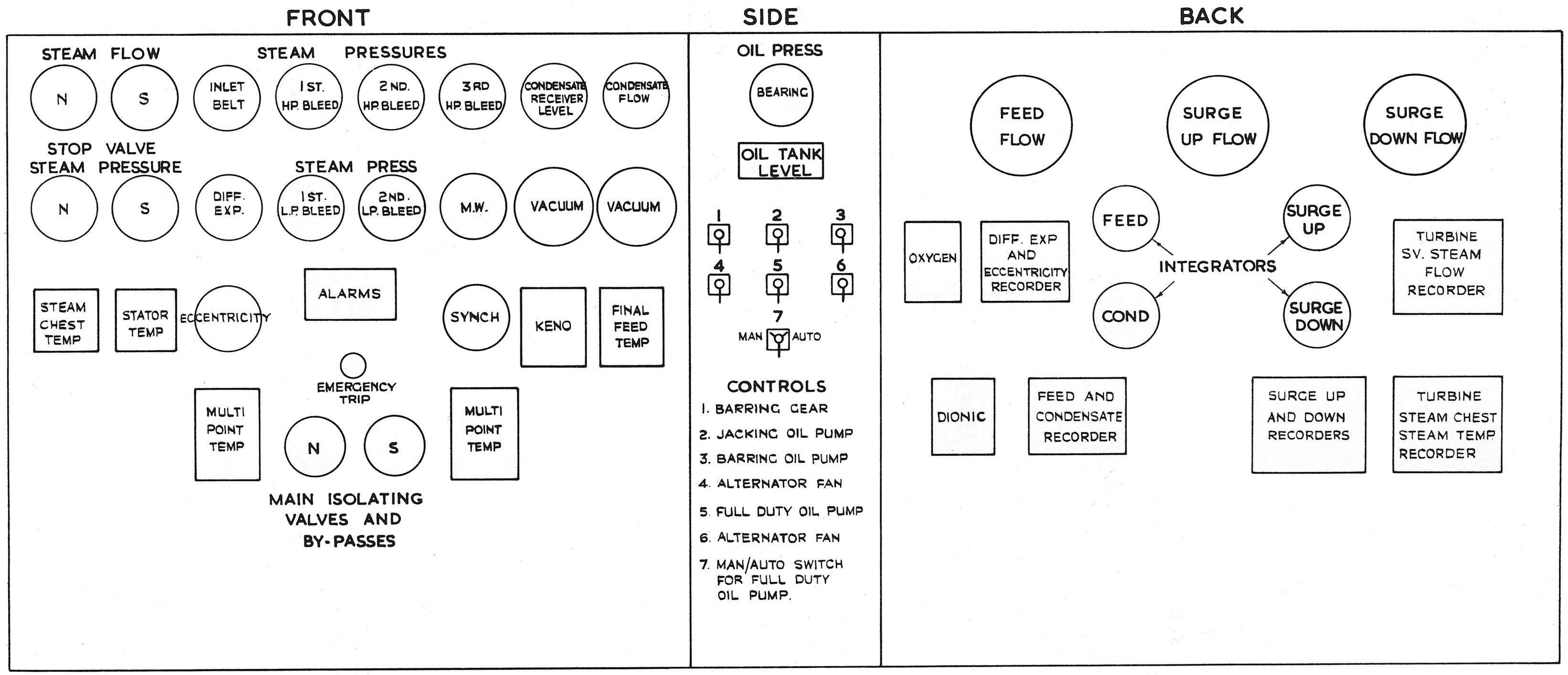


Figure 2: CONTROLS AND INSTRUMENTS ON A MAIN TURBINE PANEL

3 GENERAL OPERATION

3.1 Initial Commissioning

A steam turbine, on first commissioning, must be complete in all respects. At this time a turbine requires extra care in supervision and operation compared with later when operators have become more familiar with the characteristics of the plant. Therefore, full availability of controls, instrumentation and protection are essential before any preliminary runs are attempted and in addition there must be safe access to all parts of the plant.

New machines may be damaged by dirt and debris from steam and oil pipes being carried into blading, glands and bearings. Precautions are taken to minimise damage from this cause, before the turbine is first run. These precautions involve the thorough cleaning and inspection of the oil system, the condenser shells, the condensate tanks and pipework and the steam piping. Cleaning methods include:-

(a) Flushing with clean water.

(b) Blowing through with steam.

(c) Acid cleaning.

The method used depends upon the item to be cleaned and also upon station conditions. It may not always be possible to make a visual inspection. It is important to close the system immediately after cleaning to prevent ingress of other dirt or debris.

A useful step in the commissioning of a turbine is the trial of auxiliaries as soon as steam and electrical supplies are made available. In particular, the vacuum raising plant may be tried before the turbine is first run; gland sealing may be proved and checks carried out for leaks.

If a turbine is started up without adequate lagging on H.P. steam pipes and on the H.P. cylinders, damage may occur due to distortion.

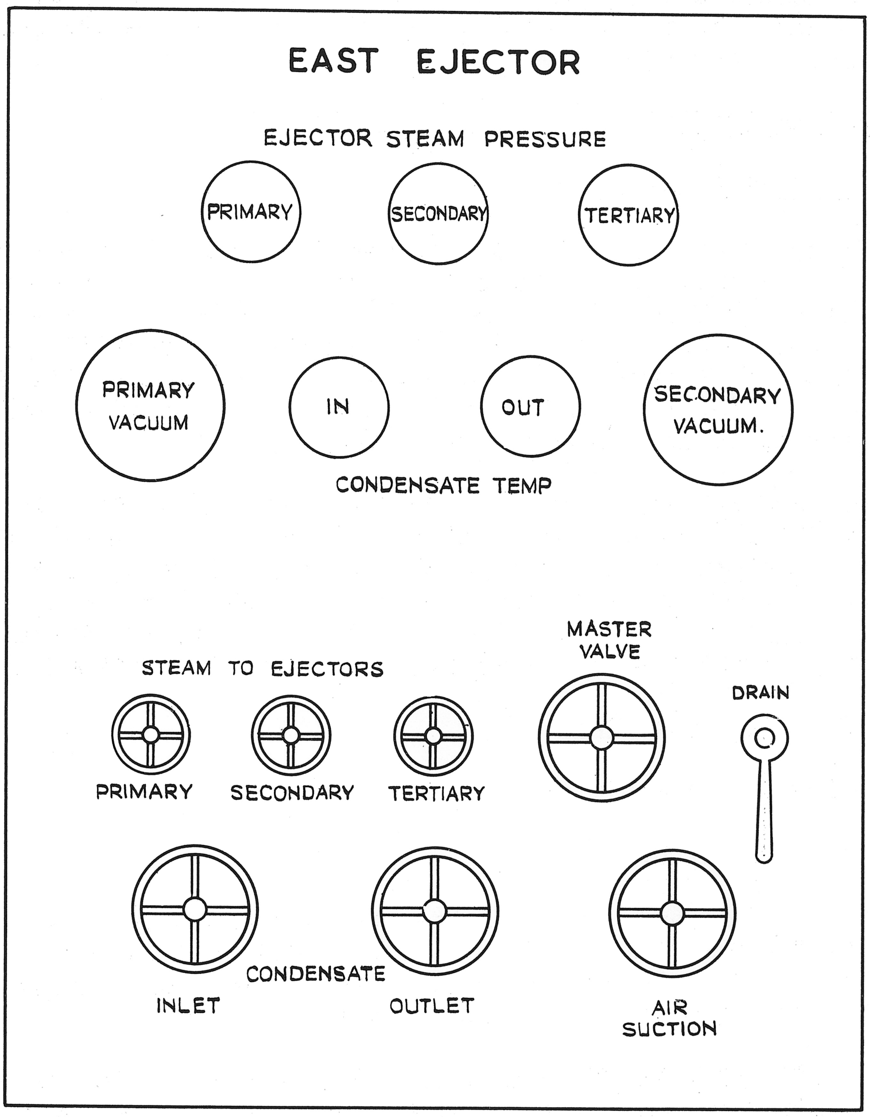


Figure 3: ARRANGEMENT-OF CONTROLS & INSTRUMENTS ON AUXILIARY PANEL FOR EJECTORS

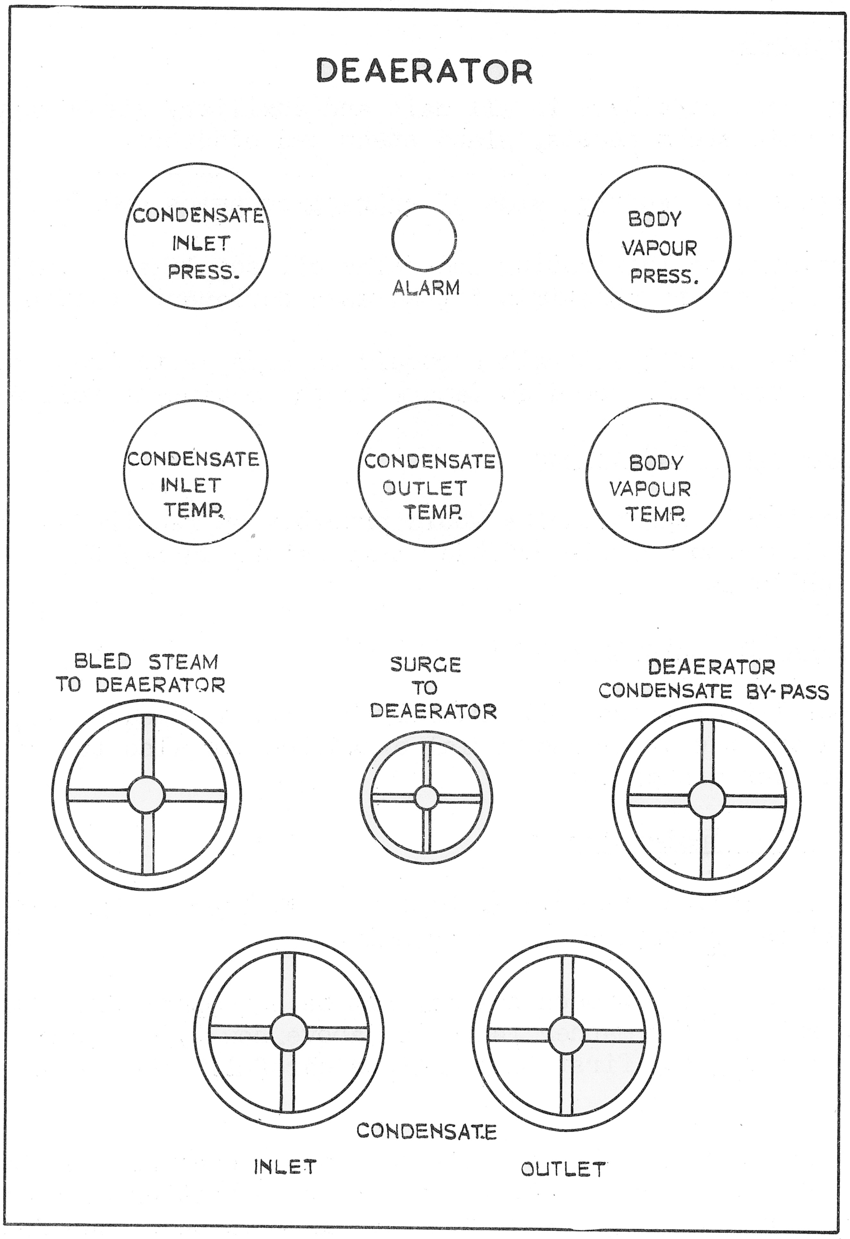


Figure 4: ARRANGEMENT OF CONTROLS & INSTRUMENTS ON AUXILIARY PANEL FOR DEAERATOR

In addition to the complete instrumentation of the unit the following additional equipment will probably be fitted.

Strainers
Fine mesh strainers in all main and auxiliary steam supplies such as main steam chests, gland steam and ejectors.

Strainers on suction side of extraction pumps and drains pumps.

Strainers on lubricating and relay oil supplies. Full flow fine strainers are sometimes fitted as a permanent feature.

The design of the strainer should be such as to trap any particle of matter that could do damage to the equipment following.

Temperature Indicators
Additional Thermocouples would probably be required on the H.P. cylinder to measure cylinder temperature during the loading of the machine.

Expansion Indicators
Special indicators will probably be fitted on each cylinder to measure the axial and radial expansion and also to measure cylinder distortion.

Vibration Indicators
Additional indicators will be fitted to measure the transverse and vertical vibration of the spindles.

Whilst all new machines may not be equipped with additional instruments in the manner indicated above, new types before being placed in service for the first time will be carefully checked on the above lines.

The readings obtained will be used in conjunction with the permanent instruments to obtain a correct operating procedure for starting and stopping the machine and also to check the design.

3.2 Starting-Up

It is not possible to give detailed instructions for starting-up steam turbines because of the differences between various makes of plant. There are, however, some important points in any starting procedure which require careful attention, and these are dealt with in the following sections. The maker's instructions should be followed, with variations introduced in the light of experience.

3.2.1 Starting from Cold

Starting a turbine from cold generally follows a lengthy shut down, either on standby or for maintenance. Consequently, it is desirable for the starting procedure to be systematic, with careful checks carried out at each stage. Nothing should be taken for granted. If maintenance work has been carried out, the usual valve settings may be disturbed and certain items of auxiliary plant may be untried.

For any start from cold, particular attention should be paid to the following items:-

(a) Lubrication and Oil System generally
This is a complex system on modern turbines and full use should be made of instruments and sight glasses to ensure correct levels in tanks and reservoirs and to confirm oil flow at all bearings. The operation of the various auxiliary oil pumps and automatic cut-outs will be proved as they are used in the starting sequence.

(b) Drainage
Considerable drainage may be expected from a cold machine and it is important to check and set all drains according to instructions and check temperature instruments provided.

(c) Barring Gear
The turbine shaft will have been turned with the barring gear for the recommended period of, say, eight hours after the previous shut down. Then, prior to the start-up, a short barring period only is required to enable a check to be made for rubbing or unusual noises and also to check the eccentricity of the shaft.

(d) C.W. System
The starting-up of the C.W. system presents little difficulty unless condensers, pipes or other parts have been drained, in which case careful use of air release valves is necessary when charging. Particular attention is required in setting the C.W. flow to oil coolers, to ensure that the oil is at the correct temperature for starting up.

(e) Vacuum Raising
Before vacuum is raised, the turbine shaft glands must be sealed. It is important to make the correct adjustments to gland steam for starting. One make of turbine has water sealed glands and no sealing steam. Usually vacuum is allowed to build up to about 20" Hg. before starting the turbine.

(f) Trips
The trip gear for vacuum and boiler pressure should be isolated for the start-up and recommissioned when the turbine is on load.

(g) Control Valves
The exercising of control or governor valves and also interceptor valves on reheat machines, is now accepted practice to ensure smooth operation throughout their full travel. Provision is made on some machines for venting the governor oil relay system.

(h) Running-Up
After steam is admitted and the machine accelerates, watch should be kept on the rate of increase of speed to conform to the laid down programme. It is desirable to make frequent checks on such items as correct operation of turbovisory gear, oil pressures and flows and governor operation near full speed. Any evidence of rough running, or unusual noises during the run-up should be investigated at once.

Starting-up a new turbine for the first time usually takes a longer time than a normal cold start because of the frequent checks made at each stage. After a turbine reaches full speed for the first time, the operation of the emergency governors would be checked and adjusted, if necessary, to the required overspeed for tripping.

The correct operation of the various oil pumps provided is an important part of the starting procedure and a key diagram for a typical 120 MW set is given in Fig. 5.

3.2.2 Starting-up from Hot

When starting a turbine from a hot condition, the general precautions given in Section 3.2 still apply with some modifications and much less time is needed for the operation. The more important features of starting from hot are described below:-

(a) Auxiliary Plant
If a turbine has been shut down for less than, say, twelve hours, then certain auxiliaries, such as the barring gear and oil pump will already be running.

(b) Drainage
When a turbine is hot, proper drainage of cylinders and steam pipes is much more important than when the turbine is cold. This is due to the possibility of water causing severe local cooling and damage to blades and joints.

(c) Vacuum Raising
If a turbine is kept at barring speed with the glands sealed for too long a period, there is a risk of local shaft expansion and glands may be damaged. Consequently, it is desirable to raise vacuum as quickly as possible, using booster ejectors or exhausters. A special case of starting a turbine from a hot condition is called "Quick Starting". This is dealt with in more detail in Section 4.

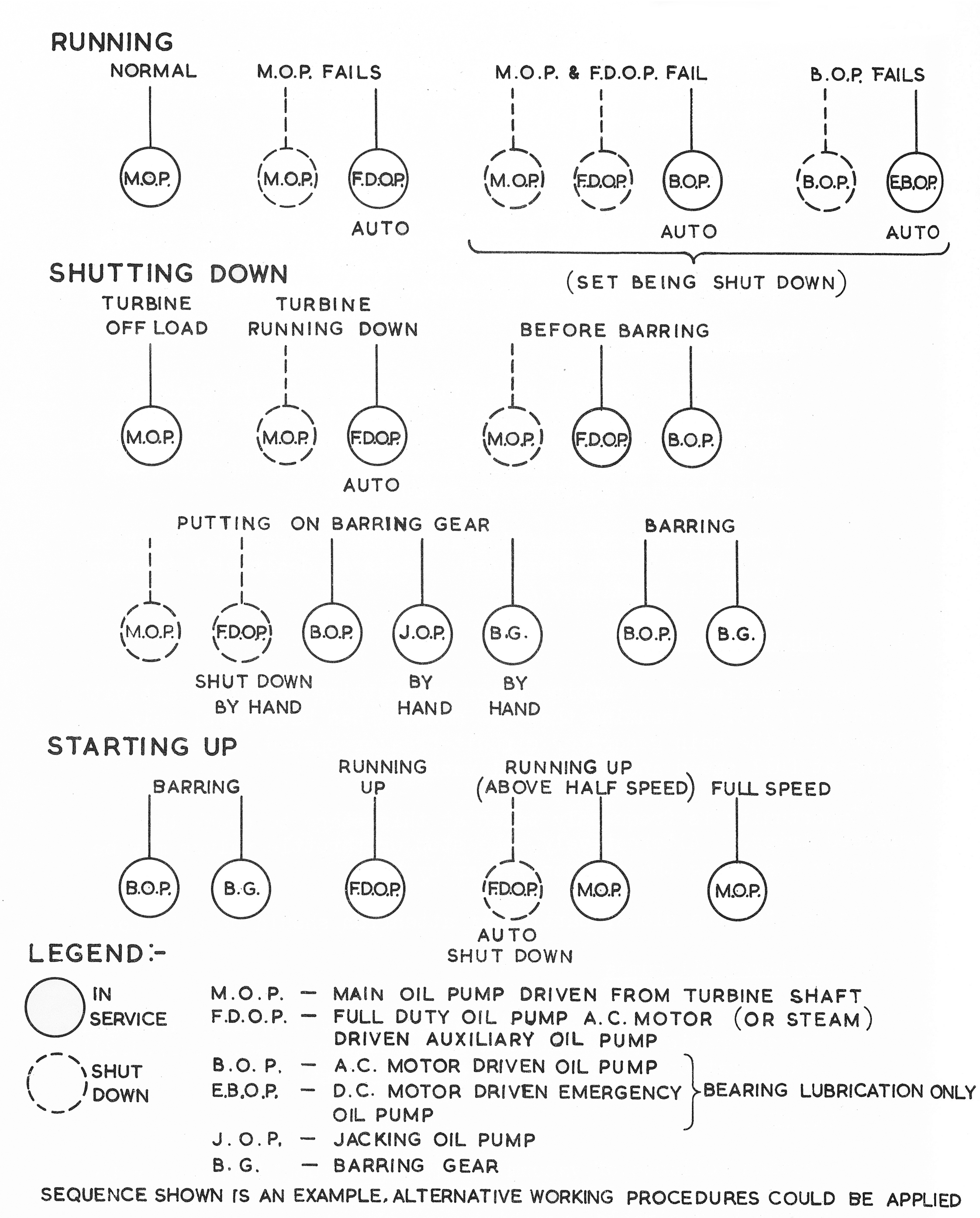


Figure 5: SEQUENCE SHOWN rs AN EXAMPLE, ALTERNATIVE WORKING PROCEDURES COULD BE APPLIED DIAGRAM SHOWING SEQUENCE OF OIL PUMPS & BARRING GEAR

3.3 Shutting Down

The unloading of a turbine prior to shutting down is dealt with in Section 3.5. Assuming that the machine has been completely unloaded and the main generator circuit-breaker opened, it will be running at full speed and under full vacuum.

Opportunity is frequently taken at this stage to check the overspeed trips. Alternatively, the stop or throttle valves may be tripped by operating the emergency gear by hand.

As the turbine slows, particular attention should be paid to:-

(a) Auxiliary Oil Pumps
The various auxiliary oil pumps provided are usually arranged for automatic operation in a given sequence (see Fig. 5) and operation may be checked at each stage.

(b) Vacuum
A sudden collapse of vacuum at high speed would cause air to act as a brake and overheat the rotor. A slow decrease of vacuum is desirable, reaching zero when the rotor stops. For this purpose vacuum breakers are fitted on modern turbines.

(c) Barring Gear
When a rotor has come to rest, it is advisable to start up the jacking oil pump and low pressure oil pump and to put the rotor on the barring gear as soon as possible. The barring of a hot rotor at low speed helps to prevent a bend developing due to uneven cooling.

(d) C.W. System
The shutting down of the C.W. system depends upon the temperature of the oil leaving the oil coolers, which should be kept at the value laid down.

(e) Steam and Drain Valves
Usual practice when a turbine is shut down is to close the steam isolating valve. The drains should be opened as given in plant instructions.

3.4 Loading

Load is applied to a turbine after the generator has been synchronised. The rate at which a machine is loaded in MW per minute, depends upon the condition of the machine and upon the requirements of the loading engineer at the Grid Control Centre.

A turbine must absorb a large quantity of heat before it becomes steady as regards expansion of shafts and casings. This absorption of heat takes several hours and the process must not be forced, owing to risk of distortion, vibration and blade damage (see Fig. 6).

A cold turbine will absorb a much larger quantity of heat than a hot turbine. It follows, then, that a longer time is required before fully loading a cold machine and the rate of loading will be lower than when the machine is hot. Rates of loading of 2 MW per minute have been achieved with hot sets.

With highly efficient machines generating at low cost per unit, it is desirable to increase to full load as rapidly as possible after running up. In this case, loading is part of "Quick Starting" technique dealt with in Section 4.

During any change of load, particular attention should be given to:-

(a) The Thrust Position
Changes according to load should be known for a particular machine. On some large machines difficulties have been experienced with locked flexible couplings. A sudden load change may be required to free the lock. The use of solid couplings will eliminate this on modern machines.

(b) Gland Sealing
Gland sealing requires careful supervision, even with automatic devices. Both over-sealing and under-sealing are undesirable; the former by wasting heat and the latter by allowing air ingress via the glands. Apart from its effect on condenser vacuum, air flow through the glands may produce local cooling, damage to glands and shaft vibration (see Fig. 7).

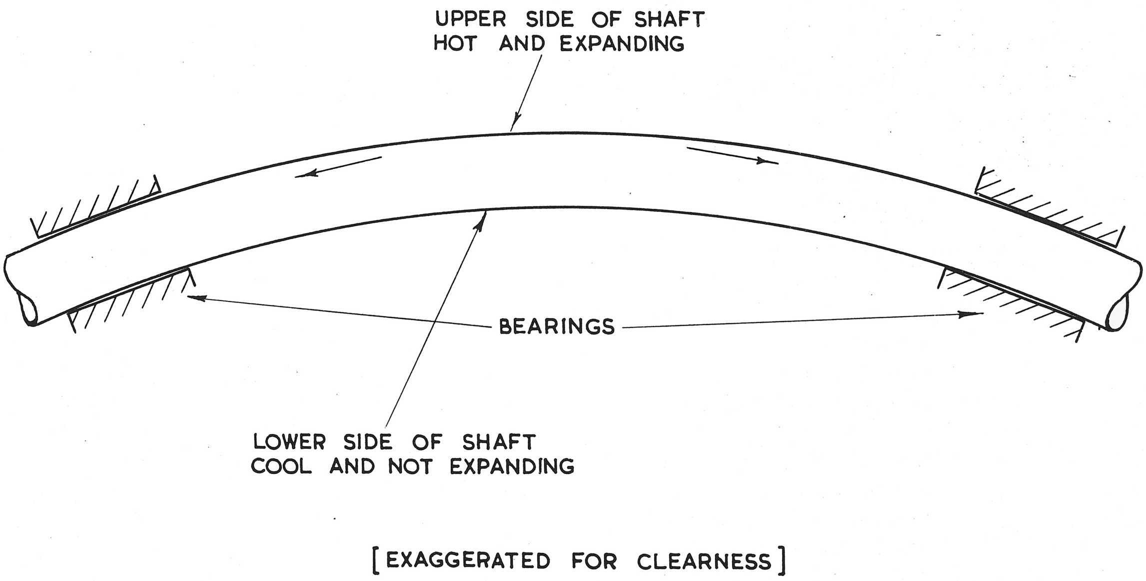


Figure 6: DIAGRAM SHOWING HOW A BENT SHAFT IS PRODUCED BY UNEVEN HEATING

3.5 Unloading

The unloading Of a machine, which takes place at various times during a day, is part of the Grid Control Loading Engineer's programme and little is required of the operator beyond the precautions mentioned in Section 3.4. Unloading of a turbine prior to shutting down may be considered under two headings:-

(a) Normal

The rate at which load is taken off a turbine depends to some extent on the required rate of re-loading after the shut-down. Rapid loading may necessitate rapid unloading to conserve heat in the machine.

It would be necessary to carry out tests to establish the correct rate. On some machines, the steam rotors contract sharply on a load reduction and there would be danger of the back edges of the moving blades fouling the fixed blades. A typical arrangement of a velocity stage wheel showing the relative size of clearances is given in Fig. 8.

(b) Emergency

The unloading of a turbine under emergency conditions may be carried out manually using the governor control or emergency trip button, or automatically by a protective device. In such cases normal control is abandoned for a rapid shut-down. The most severe Case of emergency unloading occurs when the main generator switch opens on full load. The governor and overspeed protection must be completely efficient to avoid a wrecked machine.

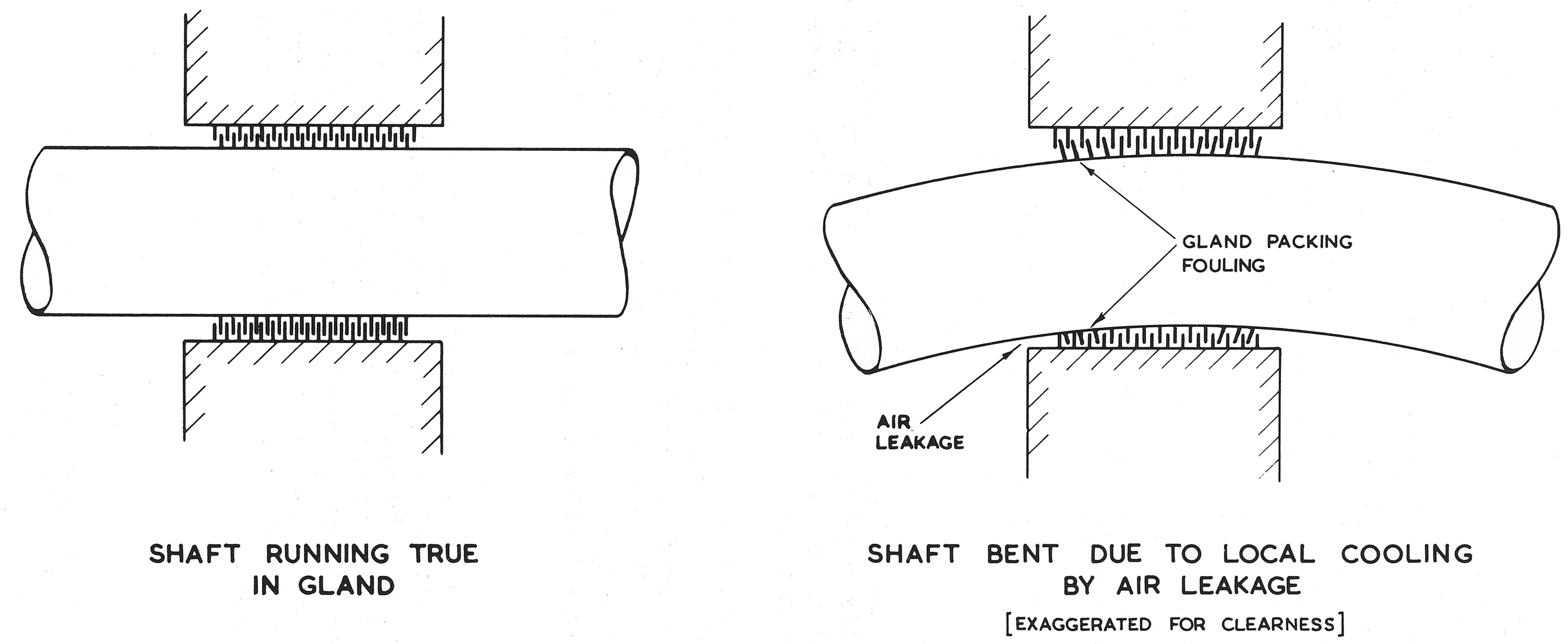
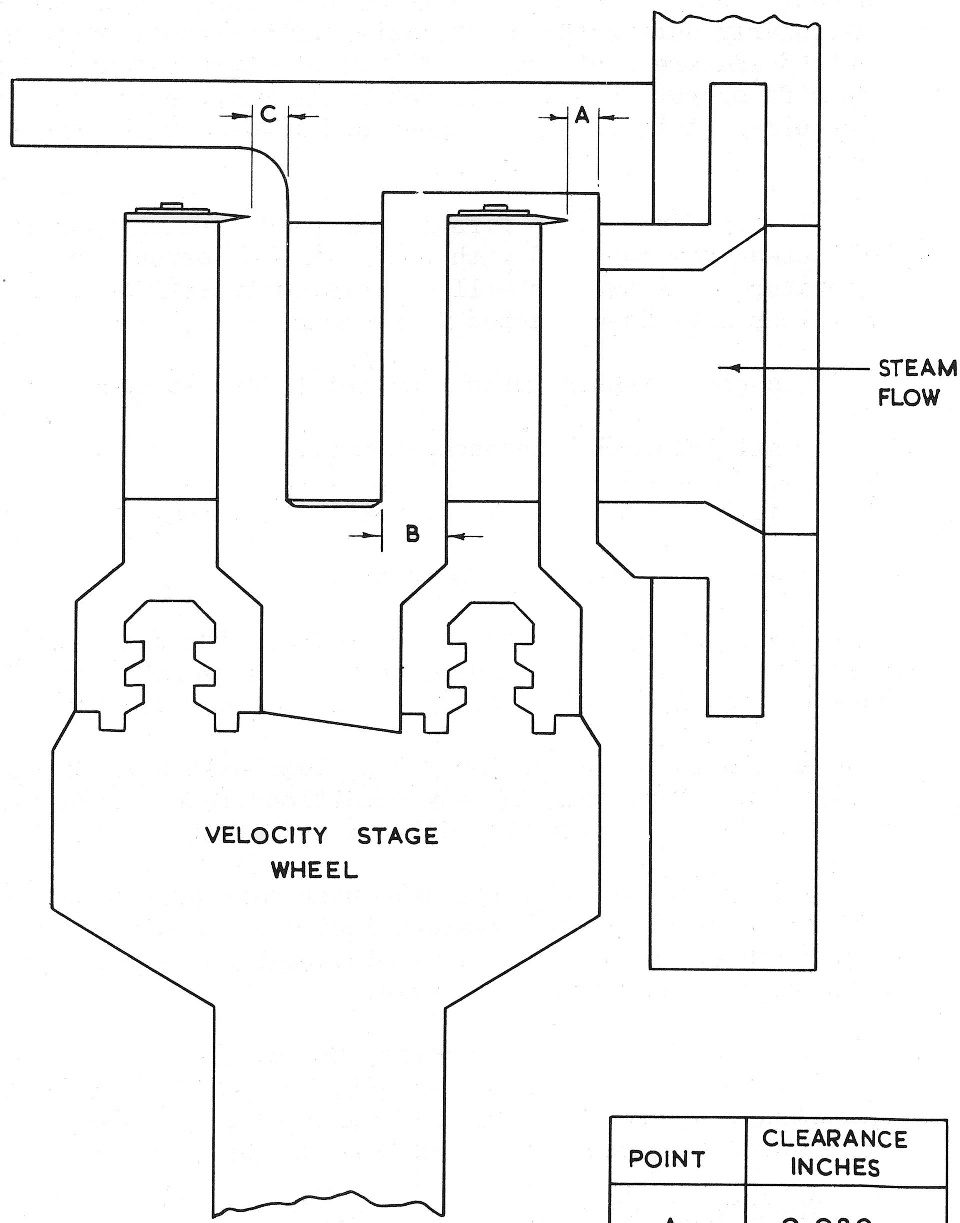


Figure 7: DIAGRAM SHOWING EFFECTS OF UNDER SEALING GLANDS



POINT	CLEARANCE INCHES
A	0·080
B	0·200
C	0·080

Figure 8: STEAM FLOW VELOCITY STAGE CLEARANCES

4 QUICK STARTING

4.1 Introduction

During peak load periods, it is necessary to run most of the available generators in the country but, during off-peak periods and particularly during the night, many turbine-generators are not required and are shut down. All modern turbines are designed for two-shift operation and it is desirable that when a turbine-generator is required it is run up to speed and loaded in the shortest possible time.

A steam turbine is firstly designed to carry its load at its full Speed when supplied with steam at the correct pressure and temperature. A turbine will do this quite satisfactorily once steady conditions have been reached which means:-

(a) correct temperatures from inlet down to exhaust,

(b) all internal clearances normal,

(c) all expansion completed without binding,

(d) shaft alignment satisfactory.

"Quick starting" aims at controlling the rate at which heating takes place so that the turbine is up to speed and loaded and the above mentioned steady conditions reached, as quickly as possible.

As discussed in Section 3.4, less heat will be required to restore a hot turbine to steady conditions than a cold turbine. The procedure for quick starting will be different for the two conditions.

A large number of tests have been carried out on different machines to establish the basic principles of quick starting, but on any particular machine special tests would be necessary before an operating procedure could be given.

In any quick start operation, it is essential to have, firstly, a knowledge of the temperature conditions in the turbine before startup, as these govern the rate of heating and, secondly, an exact knowledge of the mechanical condition of the turbine.

The first requirement may be obtained from cooling curves. Fig. 9 shows a curve taken for a 1000 MW turbine.

The second requirement would be obtained from special instruments, generally referred to as turbovisory equipment. Fig. 10 shows a typical, arrangement of these instruments on a turbine.

Each Of these requirements is now considered in more detail.

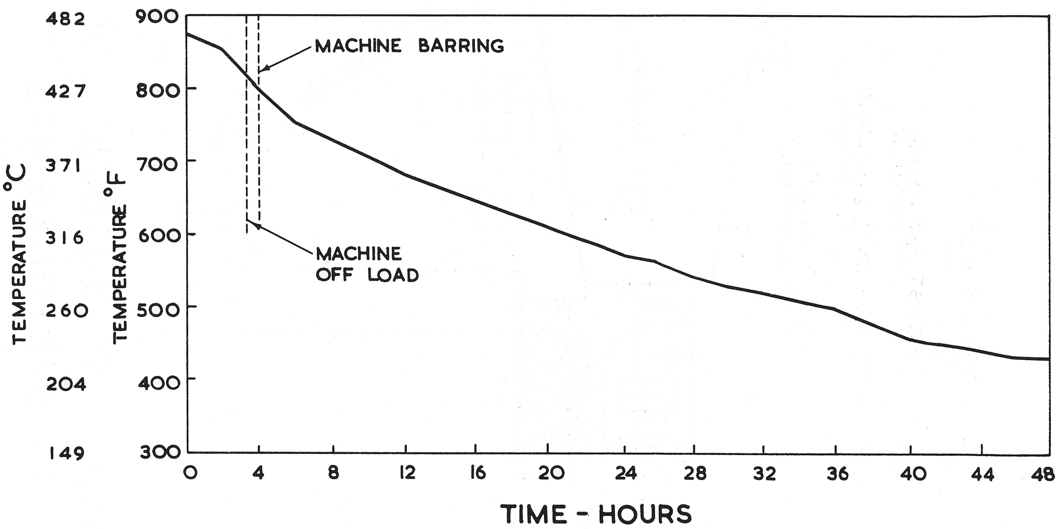


Figure 9: COOLING CURVE OF INLET BELT METAL 100 MW TURBINE 1500 lb/IN^2 566°C 1050°F.)

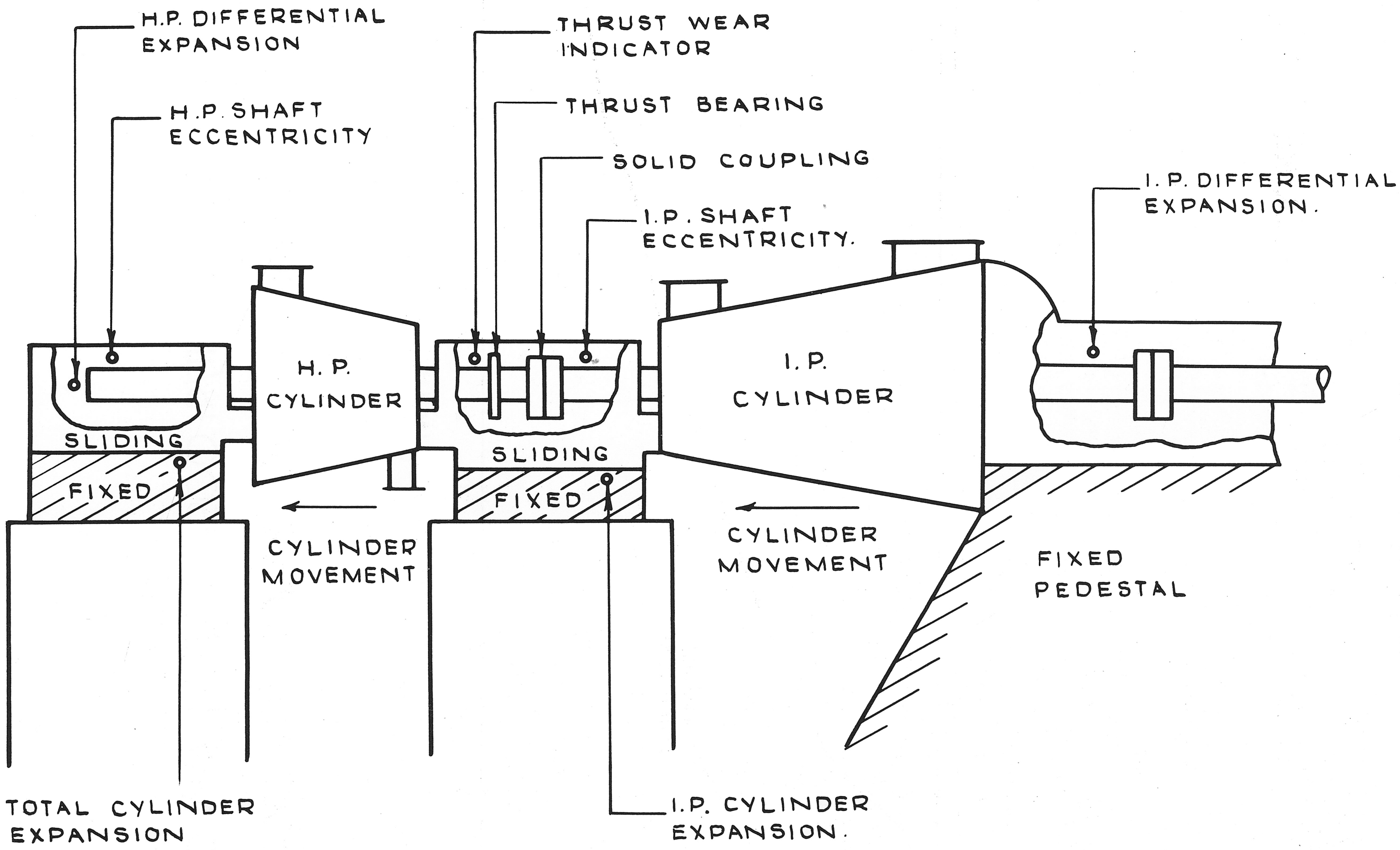


Figure 10: ARRANGEMENT OF TURBINE SUPERVISORY INSTRUMENTS

4.2 Use of Turbine Supervisory Equipment

Turbine Supervisory equipment is installed to take measurements at various points on the turbine and the information is used to augment the skill of the operator. The actual instruments are described in Lesson 15, but the measurements and their importance are considered separately in the following paragraphs:-

4.2.1 Cylinder Expansion

A large modern turbine consists of two or three cylinders solidly connected together. The centre of the L.P. casing is anchored to the bed plate and expansion of the machine is allowed for towards the governor end.

The total expansion of the machine is indicated by the movement of the governor end bearing relative to the bed plate This movement may amount to about 1.0 inch.

It is important to realise that the movement of the governor end bearing is the sum of the expansions of all the cylinders Instruments are usually fitted to measure the expansion of each cylinder and proper understanding of the behaviour of a turbine depends upon the correct interpretation of the measurements.

To illustrate this point, two examples may be quoted:-

(a) The intermittent movement or "jumping" of the governor end may not, in fact, be due to any fault in the H.P. cylinder, but may be due to trouble in the I.P. cylinder.

(b) Although the total expansion may appear correct at the governor end, this may, in fact, be due to excessive expansion at the L.P. end, possibly due to overheating from prolonged low-load running. The H.P. and I.P. cylinders may not be fully expanded.

In both these examples the readings of the cylinder expansion indicators would show the reason.

4.2.2 Shaft Axial Position

Modern turbine shafts are solidly coupled; there is thus in effect, a continuous shaft from governor to exhaust which is located by a thrust bearing and the shaft position is given by an axial position indicator, sometimes called a thrust wear indicator. Provided the thrust bearing pads are in good condition the relative shaft axial position depends upon the load.

4.2.3 Differential Expansion

This is the most important of all the measurements. When a turbine is heating up, both the cylinders and the shaft will be expanding at the same time but at different rates. The differential expansion indicator shows the expansion of the shaft relative to the cylinder. The shaft, containing less metal, will expand faster than the cylinder. If the shaft expansion is uncontrolled, the safe limit may be exceeded, with the danger of a rub occurring between fixed and moving blades or in the glands. The differential expansion indicator gives information on the internal clearances of the turbine.

4.2.4 Shaft Eccentricity

A shaft may run out of truth, that is eccentric, for several reasons. There may be mechanical unbalance, bearings may be worn, or the shaft may have been heated or cooled unevenly, causing a bend. Shaft eccentricity indicators are fitted near the bearings, which is the only place where measurements can be made. Bends due to uneven heating or cooling, usually disappear after turning at slow speed with steam or the barring gear. Eccentricity due to unbalance will increase with speed.

4.2.5 Bearing Pedestal Vibration

Usually the eccentricity measurement, as described in Section 4.2.4, is sufficient for indications of machine balance. Sometimes, however, it is necessary to make further investigations into causes of vibration at bearing pedestals. For this purpose, a portable type of vibrometer is used as it is not usual to have permanent instruments for this measurement.

4.2.6 Speed

When any tests are carried out for quick starting, the turbine speed is always measured and recorded because it provides a reference scale for other indications.

4.3 Thermal Effects on the Turbine

Modern turbines use high temperature steam and the H.P. rotors and cylinders consequently run at high temperature. The heating up of a turbine to its running temperature has been referred to in Sections 3.4 and 4.1. The amount of heat and the rate of heating depends upon whether the turbine is hot or cold at start-up, which, in turn, will depend upon the time the machine has been shut down. There are roughly three classes of turbine start-up:-

(a) After a period of from 6 to 8 hours, such as overnight. This is called a "hot" start and causes the least difficulty as the machine temperatures and expansions are closer to normal working conditions. The results obtained on a typical "hot" start are shown in Fig. 11.

(b) After a shut-down of from 12 to 48 hours, such as for week-end maintenance. This is called an "intermediate" start and may cause more difficulty than Class (a), as the machine will have had more time to cool.

(c) After a shut-down of more than 48 hours, such as for overhaul. In this case, difficulties will be greatest as the machine is completely cold and the full heating-up programme is necessary. A "cold" start is shown diagrammatically in Fig. 12.

Some of the effects of heating-up a turbine are described below.

4.3.1 Stresses in the Cylinder

When there is a large temperature difference between the inside and outside of a thick steel cylinder such as a turbine casing, the inner surface being hottest, expands first. The outer, cooler surface will expand only slightly. This difference in expansion may cause severe stresses in the metal and eventual cracking, as shown in Fig. 13.

The temperature difference across the cylinder wall is obtained from thermo-couple readings on the outside. The steam temperature to the turbine is then regulated so that it is never more than ll0°C. (200°F.) above the outside cylinder metal temperature.

Temperature differences will also occur between the flange surfaces of the horizontal cylinder joint and the bolts. In this case, the parts of the flange nearest the steam will expand before the outer part and the whole flange expands before the bolts. Again, severe stresses will be produced and may cause damage to the joint faces as shown in Fig. 14.

The use on modern turbines of double-walled cylinders, with heating steam between and also flange heating, helps to prevent metal over-stressing. A diagram showing double-wall construction is given in Fig. 15. Flange warming is illustrated in Fig. 16.

4.3.2 Distortion of the Cylinder

All turbine cylinders are complicated, in that the shape is not uniform, the metal thicknesses vary and pipe connections have to be provided. As a general rule there is always some distortion because the complicated nature of a cylinder must result in uneven heating. This distortion has no permanent effect on the cylinder, but it may upset small clearances, for example, at the glands.

Modern machines are designed as simply as possible with uniform metal thickness.

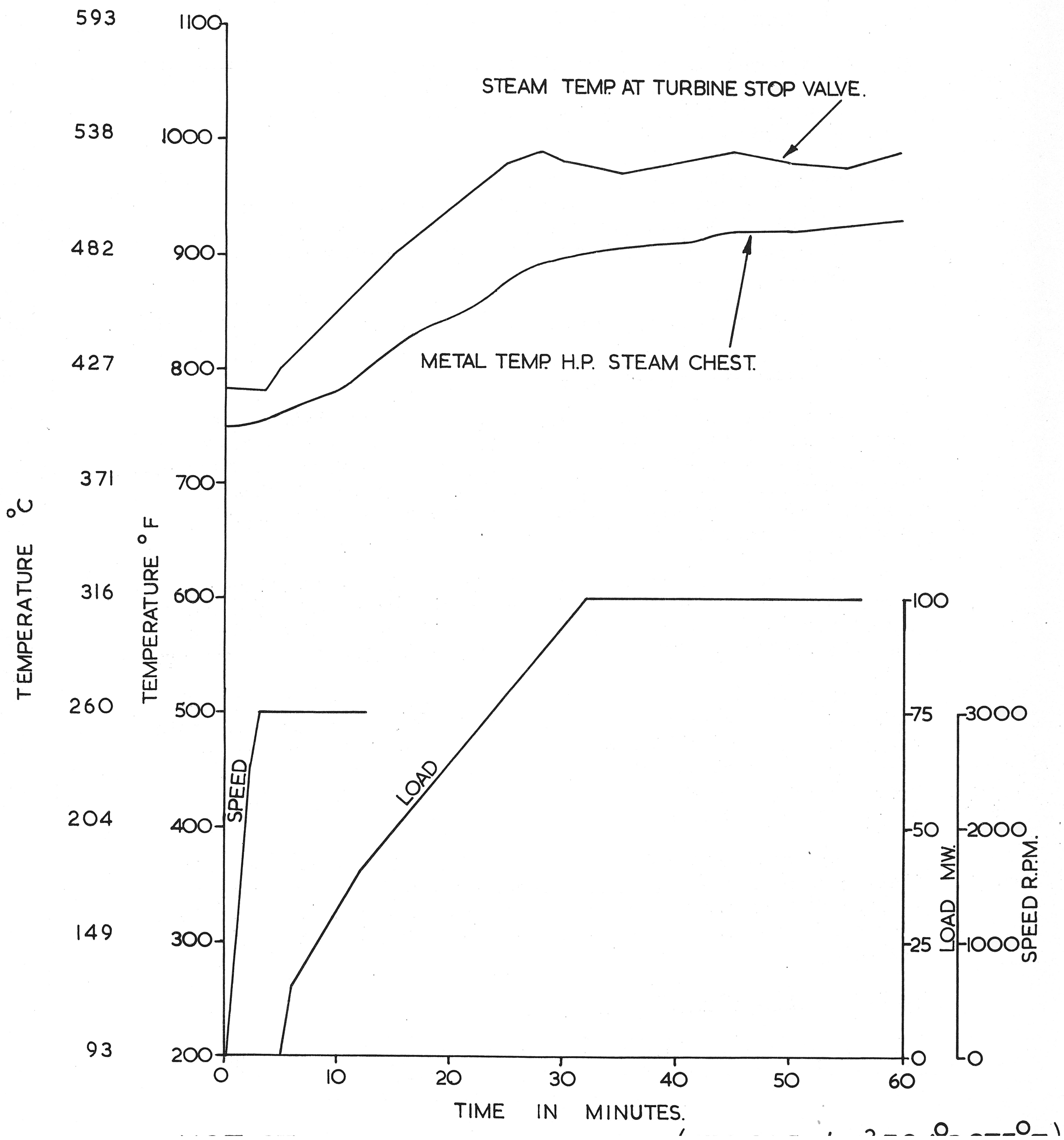


Figure 11: HOT START OF 100 MW TURBINE(1500 LBS/IN^2,524°C,975°F)

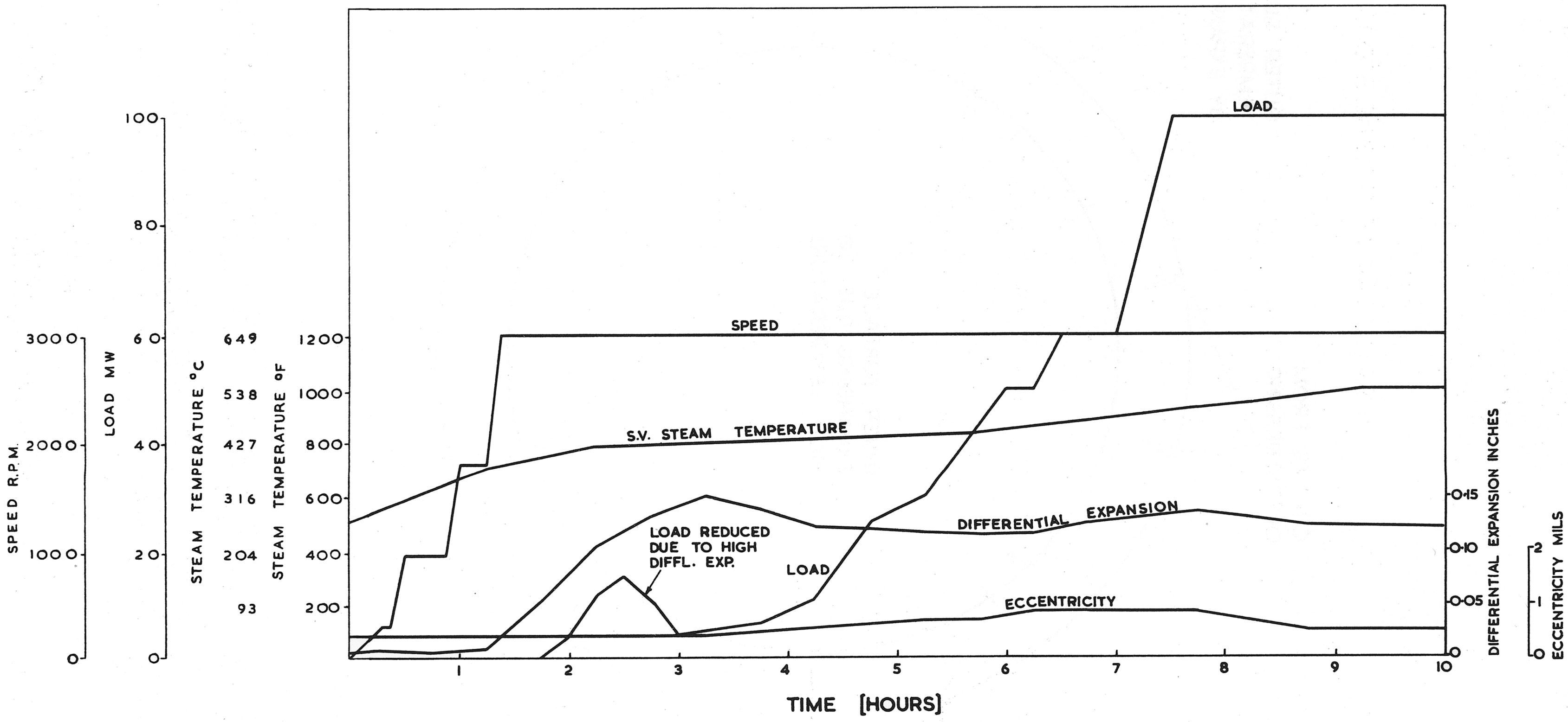


Figure 12: COLD START ON 100 MW TURBINE

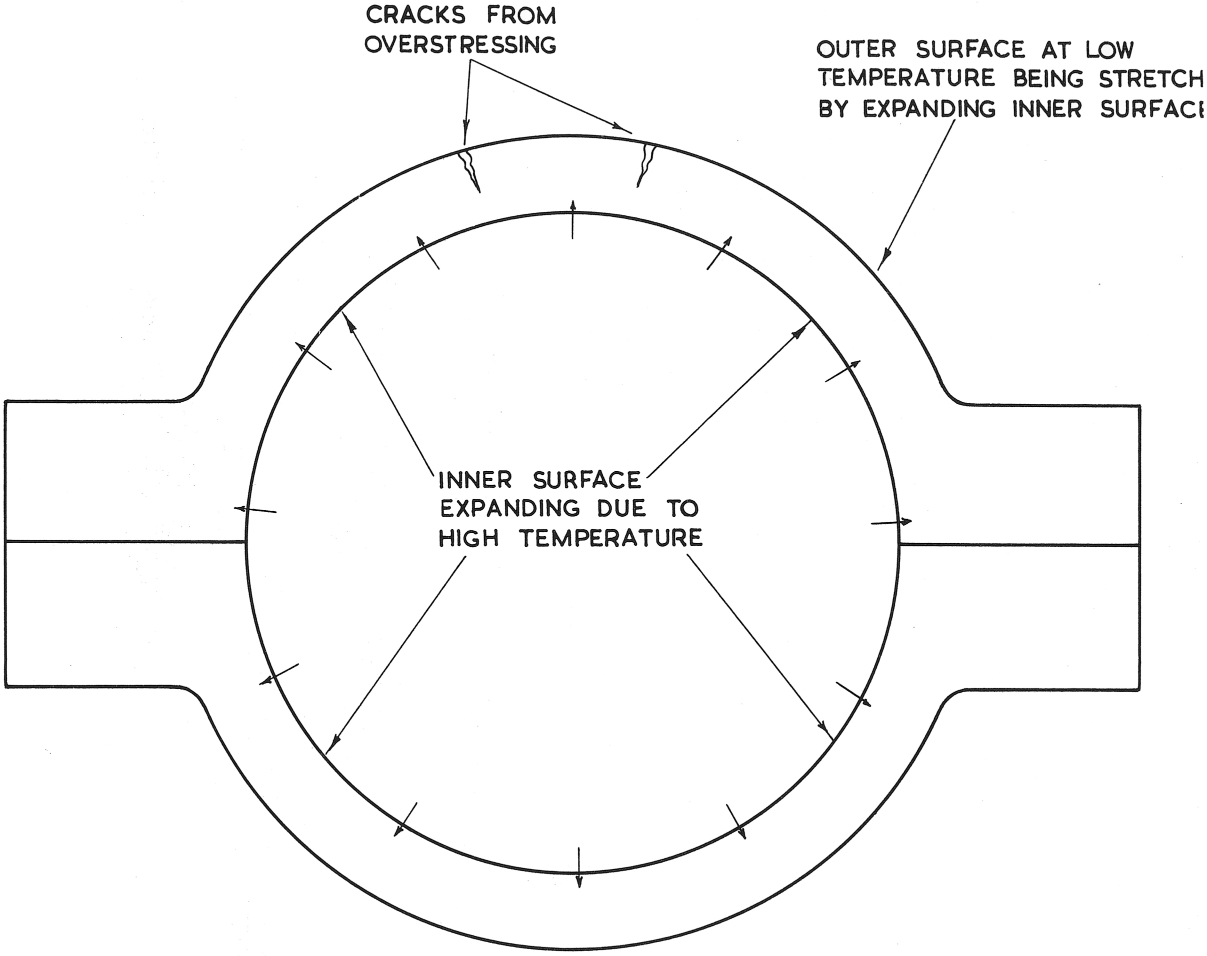


Figure 13: DIAGRAM SHOWING OVERSTRESSING OF CASING BY EXCESSIVE TEMPERATURE DIFFERENCE

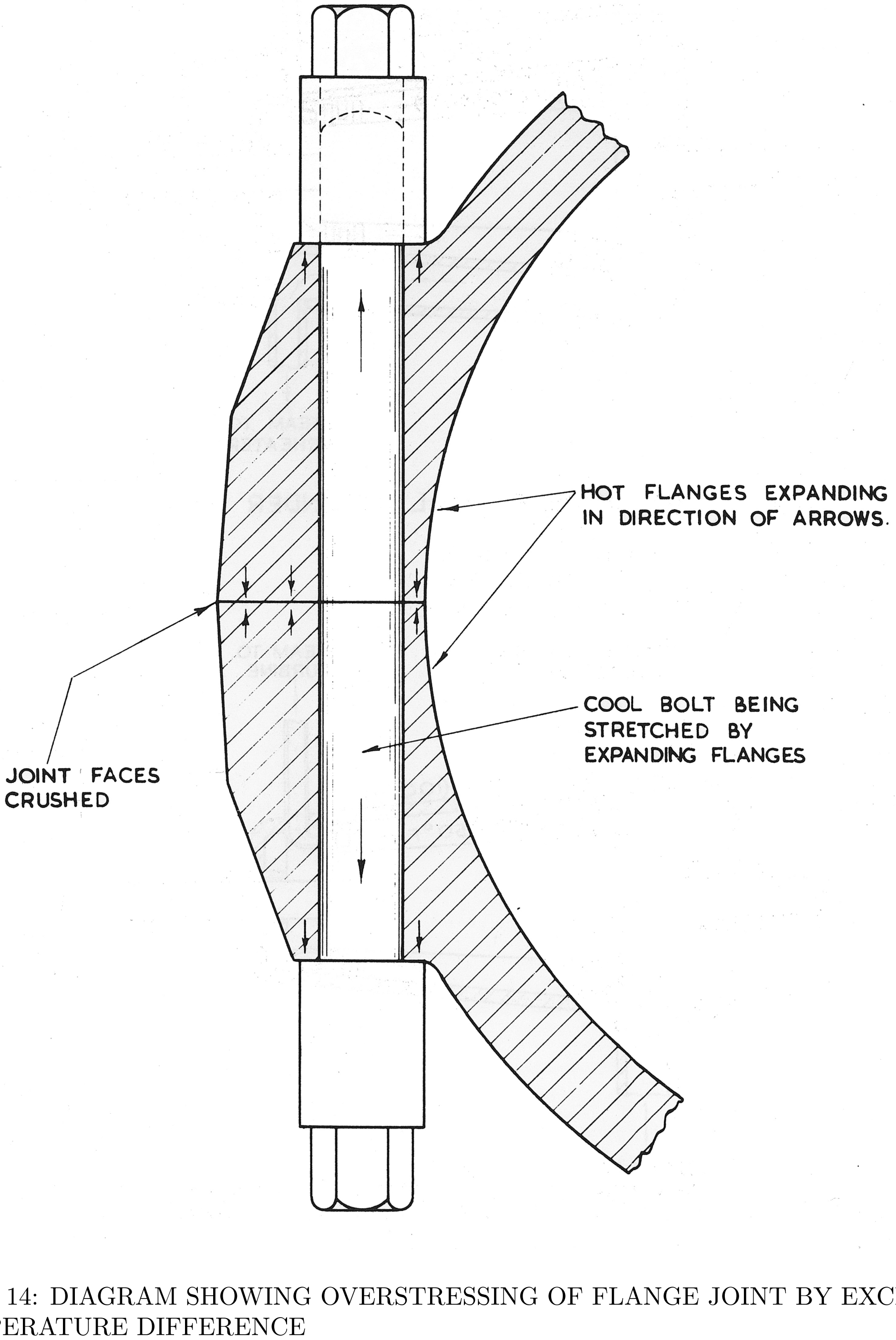
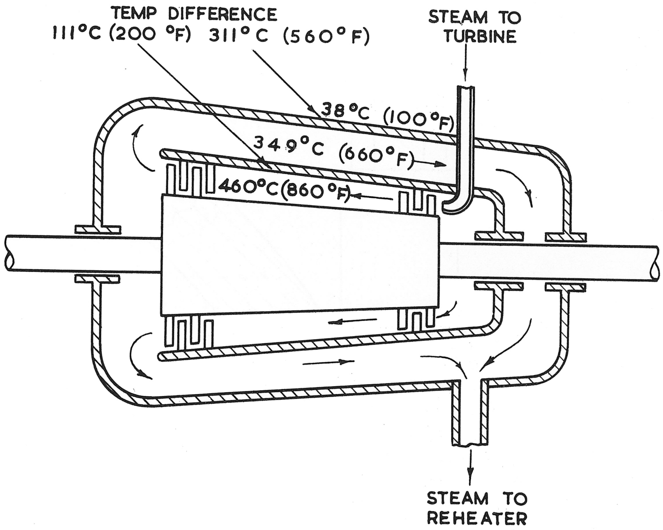
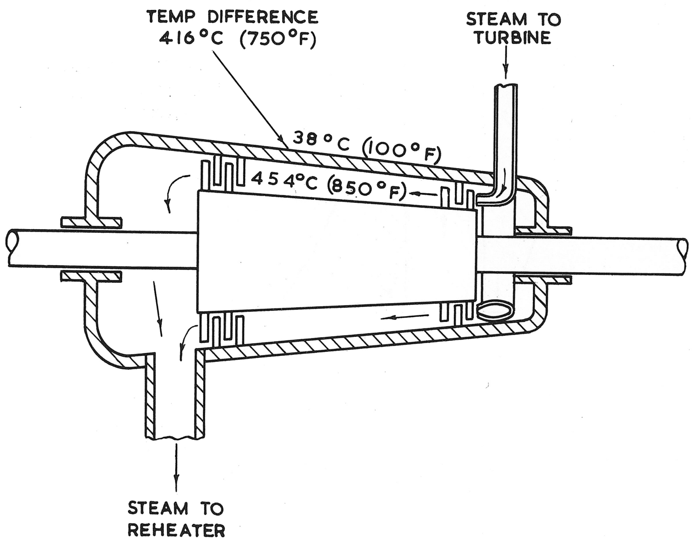


Figure 14: DIAGRAM SHOWING OVERSTRESSING OF FLANGE JOINT BY EXCESSIVE TEMPERATURE DIFFERENCE



(a) DOUBLE WALL CYLINDER



(b) SINGLE CASING CYLINDER

Figure 15: DIAGRAM SHOWING HOW DOUBLE WALL CYLINDER REDUCES TEMPERATURE DIFFERENCE THROUGH METAL CASING

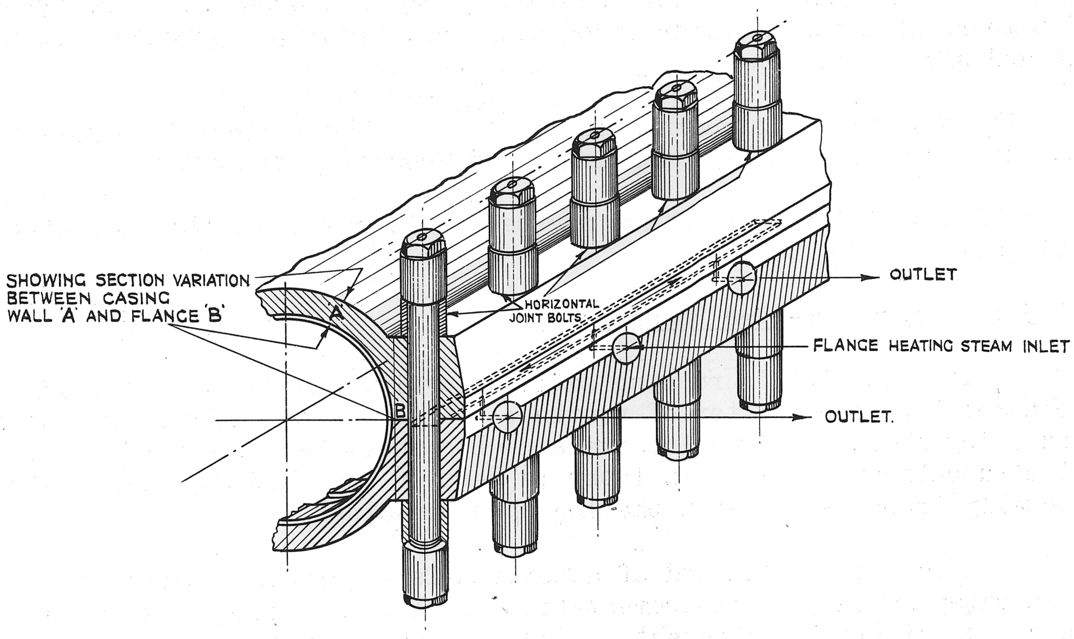


Figure 16: HIGH PRESSURE CYLINDER FLANGE WARMING AND DIFFERENCES IN METAL THICKNESS BETWEEN CASING AND FLANGE

5 USE OF GENERAL INSTRUMENTATION

The arrangement of instrumentation was discussed in Section 2 and the actual instruments will be dealt with in Lesson 15. The types and numbers of instruments provided will vary widely, depending upon the make and size of turbine.

The object of instrumentation is to give the maximum information about the turbine and its auxiliaries and feed heating system.

The use of instrumentation may be considered under the following headings:-

5.1 Normal On-Load Supervision

If a turbine is running satisfactorily, supervision on load becomes largely a matter of routine. Instrument readings are entered on a log sheet at fixed intervals. Log Sheets and the reading of instruments are dealt with later in Section 6, but supervision is equally important between the log sheet readings.

A very high standard of attention is required, because changes indicated by turbine instrumentation usually take place slowly and are thus difficult to detect. Sudden changes that occur are likely to be emergencies.

Sudden changes call for swift and accurate assessment of instrument readings so that appropriate action may be taken.

Generally, on-load supervision of a turbine will include the following:-

(a) Mechanical Conditions

- **(i)** Oil pressures
- **(ii)** Lubrication of bearings
- **(iii)** Gland sealing
- **(iv)** Steam Tightness of joints
- **(v)** Vibration
- **(vi)** Thrust position
- **(vii)** Any unusual noises

(b) Thermal Conditions

- **(i)** Keeping to the best conditions of pressure, temperature and flow in the various parts of the system as established by tests, or as-given by the makers.
- **(ii)** Maintaining the correct and most economical vacuum as obtained by tests.

5.2 Performance

General instrumentation provides information about the performance of the turbine, its auxiliaries and the associated feed heating system. Performance, as given by the turbine-heat rate, will be worked out weekly for the Station Operating Statistics from the information on the log sheets. As already stated, changes in turbine instrument readings occur slowly, so that the information will be examined over a period of weeks, or perhaps months, before a particular trend can be seen.

The turbine heat rate is obtained by first calculating the steam rate:-

$$\text{Steam rate} = \frac{\text{lbs of steam used}}{\text{kilowatt-hours generated}}$$

and this will be in lbs of steam per kilowatt-hour.

Then the turbine heat rate is calculated as follows:

Turbine heat rate = steam rate × difference in heat per lb of steam at stop valve and heat per lb in the final feed water.

The heat in the steam and feed water is obtained from Steam Tables as explained in a previous Lesson.

The turbine heat rate is an overall performance figure for the whole turbine plant. If the turbine heat rate increases, then use of the instrumentation as explained will enable the separate parts of the plant to be checked and corrective measures taken or planned.

Brief reference to the effects on the overall performance of the separate parts of the plant is given below:-

(a) Turbine

- **(i)** Steam Pressure
  Little effect is caused by fairly wide variations. Steady steam pressure is, however, essential to efficient boiler operation.
- **(ii)** Steam Temperature
  A reduction of 22°C. (40°F.) from the correct temperature will cause a 1% increase in heat rate. Also, with modern high temperature plant, smaller variations may cause vibration.
- **(iii)** Blade Fouling and Erosion
  These both cause increases in heat rate because the shape of the turbine blades is altered and the blades will not then extract the full amount of work from the steam and more steam must be supplied to do the same load.

(b) Generator
This item is dealt with in detail in Lesson 10. Careful attention to the adjustments to the cooling system, hydrogen or air, will reduce the auxiliary power used to a minimum.

(c) Condenser
Correct operation of the condenser plant to maintain the back pressure as near to the specified figure as possible, is the most important of all the items affecting performance. Roughly, a rise in back pressure of only 0.25 inch of mercury will increase the turbine heat rate by 1%. Instrumentation will indicate tube fouling on water, or steam, sides and air leakage.

(d) Feed Heating System

There is usually ample instrumentation on the feed heating system and checks can be made on bled steam pressure, temperature rise of feed water and drain temperature. A drop in final feed temperature of ll°C. (20°F.) could increase the turbine heat rate by 0.5%. If the temperature rise of the feed water is low with normal bled steam conditions, then the tubes may be oiled up from a turbine oil system defect. Alternatively the heater venting may be faulty, causing air blanketing of the tubes.

5.3 Testing

The checks on performance discussed in Section 5.2 will be under normal running conditions, using panel instruments. The results should be compared with test figures, for which special instruments are installed.

Full scale tests are carried out soon after a turbine is first commissioned to check the heat rates and general performance that the maker has guaranteed.

Similar tests are carried out at intervals during the life of the plant to keep a check on performance. Tests are also carried out when defects, such as blade erosion or fouling, are suspected.

For full scale heat rate tests special precautions must be taken to isolate the turbine from other machines if on a range type plant. If the plant is of the boiler/turbine unit type, then the unit is usually tested as a whole.

Fig.7.5 17 shows a typical three-cylinder turbine with five Stages of feed heating isolated for test. Drains and vents have been omitted for clearness. Connections for the test venturi flow meter are shown. The hot well connection may be blanked.

6 THE IMPORTANCE AND INTERPRETATION OF READINGS

The modern steam turbine is provided with many instruments and for these to be used to the best advantage, the operator should know:-

(i) How to read instruments correctly.

(ii) How to interpret the readings.

(iii) The characteristics of different instruments.

(iv) The use to which readings are to be put.

The actual instruments will be described in Lesson 15, but the following sections cover the above operational principles.

6.1 Indicating Instruments

As its name suggests, this type of instrument gives an indication of pressure, temperature or flow. The readings of these instruments show the conditions as they exist at a particular time, but not the readings as they were a few seconds or minutes before.

Continuous observation of indicating instruments on turbine plant by an operator is impracticable and unnecessary under stable conditions. Indicating instruments must, however, be observed at intervals so that changes can be seen and corrected. The log sheet is a means of recording these readings.

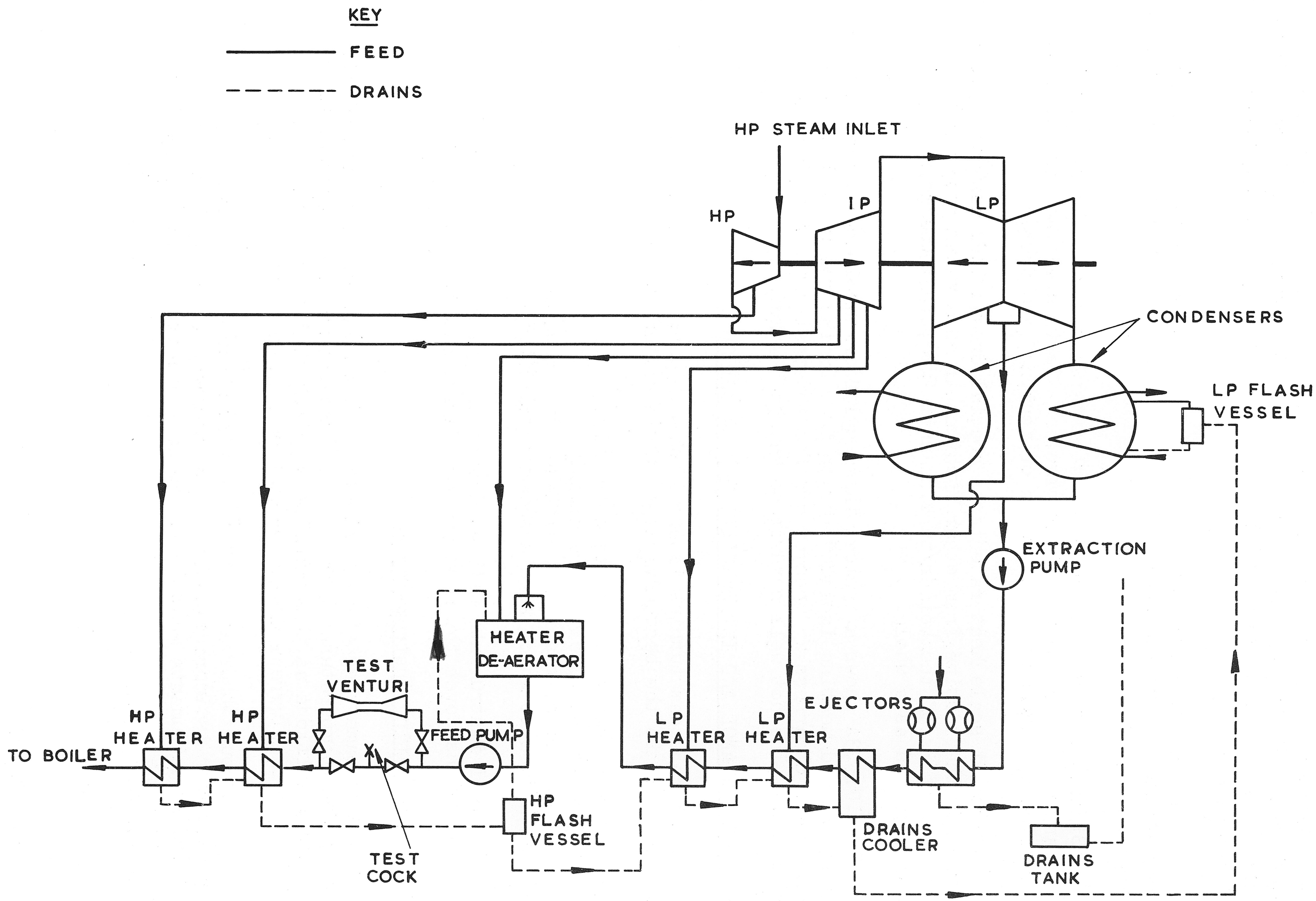


Figure 17: 3-CYLINDER TURBINE WITH 5 STAGES OF FEED HEATING ISOLATED FOR TEST

It is essential that any changes are observed and Corrections or adjustments made, without waiting for the set time for log sheet readings.

Some instruments require balancing or zero reading correction at frequent intervals, for example, temperature measuring instruments and the Kenotometer. It is important that this be done, or the readings will be inaccurate.

When reading instruments, due regard must be paid to the scale calibration. Temperature scales may be marked at intervals of 5°C. or 10°C.; pressure gauges may be marked every 10 lb/in.^{2} Or 20 lb/in.^{2}.

The accuracy of readings will be given in instructions. Estimates of l°C. in a scale interval of 5°C. may be difficult, or unnecessary. On pressure gauges scaled every 10 lb/in^2, the width of the pointer may cover 2-3 lb/in^2.

6.2 Log Sheets

There are many different types and sizes of log sheet, but generally, a log sheet is an aid to the systematic and regular observation of indicating instruments. Log sheets also provide a record of a day's operation which can be analysed and studied. Certain special log sheets may be provided at times, on which selected readings are entered at shorter time intervals than on the main log sheet. These sheets may be to cover tests, such as for quick starting, or for some infrequent operation, such as blade washing. Reliable log sheets depend on:-

(i) The correct reading of instruments.

(ii) Keeping to the times laid down for logging.

(iii) Making adjustments to the plant as and when required and not just prior to the logging time.

It is sometimes the practice to have standard readings taken at certain loads, say, 60%, 80% and 100% of full load. These readings are then printed on the log sheet at the top of the columns. The readings form an aid to the operator in checking conditions.

The sets of standard readings would be checked at intervals of, say, one month. The procedure would be to set the machine at each of the standard loads for not less than one hour, at the end of which time the complete readings would be logged and noted as check readings.

6.3 Recorders

These instruments may be looked upon as continuous log sheets. Charts may be circular or strip. Circular charts may be changed daily and 24-hour lengths of strip charts may be cut off and studied or analysed.

In practice, only certain selected readings are recorded, these would include :-

(i) Turbine stop valve temperatures.

(ii) Differential expansion.

(iii) Eccentricity.

(iv) Condensate purity (Dionic).

(v) Dissolved oxygen.

(vi) Steam and condensate flow.

From an operating point of view, a recorder has the advantage of showing past readings.

By looking at a recorder line, a particular reading may be noted and, in addition, the value it had shortly before, The amount of any change will thus be shown. More important than the amount, the line will also show the rate at which the change took place.

This is best illustrated by the chart specimens shown in Figs. 18 and 19. Both charts refer to stop valve steam temperatures; (A) shows a falling steam temperature, but the fall has taken place over a period of approximately half-an-hour; (B) shows the temperature falling the same amount as in (A), but in a very short time.

The temperature drop in both cases is excessive, but in (A) there would probably be little effect on the turbine as there would be time for expansions to follow the temperature. In (B), the sudden drop would probably upset the differential expansion and cause vibration. Rapid action may be required to reduce load or possible shut down.

7 AVAILABILITY AND MAINTENANCE

7.1 Cost of Outage

Modern turbine plant, operating with high pressure, high temperature steam, probably with reheat, is much more efficient than older machines and generates electricity at a much lower cost per unit.

Should one of these modern machines be out of commission, then older, less efficient plant must be run to take its place. The cost of generating electricity will be increased depending upon the transmission system conditions and also the particular day and season of the year that the outage occurs.

In round figures, a 60 MW set at 900 lb/in^2 and 482°C. (900°F.) out of commission during a week in the summer would mean extra costs of £1,000 per day and in the winter £2,000 per day. A 120 MW set at 1,500 lb/in^2 and 538°C. (l,000°F.) with reheat, would cost £2,000 per day in the summer and £4,000 per day in the winter.

The extra costs are higher in winter because, due to heavier load demands, less efficient plant-is available to meet outages than in the summer period.

These figures show the importance of keeping plant available, or, if plant is out of commission for maintenance, of returning it to service as quickly as possible.

7.2 Causes of Outage

Turbine plant must be taken out of service at times for condenser cleaning, changing generator or exciter brushes, or for inspection. These operations will be known beforehand and can be planned for nights or week-ends when the load is lighter and costs are not increased very much. Other causes of outage are breakdowns, accidents or a serious drop in performance.

Some of these causes are discussed in the following sections:-

7.2.1 Breakdown

A breakdown may be considered as any unplanned outage of the turbine for repairs and maintenance. Some breakdowns are due to bad design, faulty workmanship in erection, or faulty material. These will not be discussed further, except to refer to the importance of keeping strictly within the designed conditions of pressure and temperature.

Breakdown will also include severe steam, Water, air or oil leaks; valve defects, bearing defects or governor faults. Most of these causes of outage are due to normal wear and tear and deterioration in service.

A fault on auxiliary plant may also put a main turbine set out of commission, although most auxiliaries are duplicated or can be bypassed.

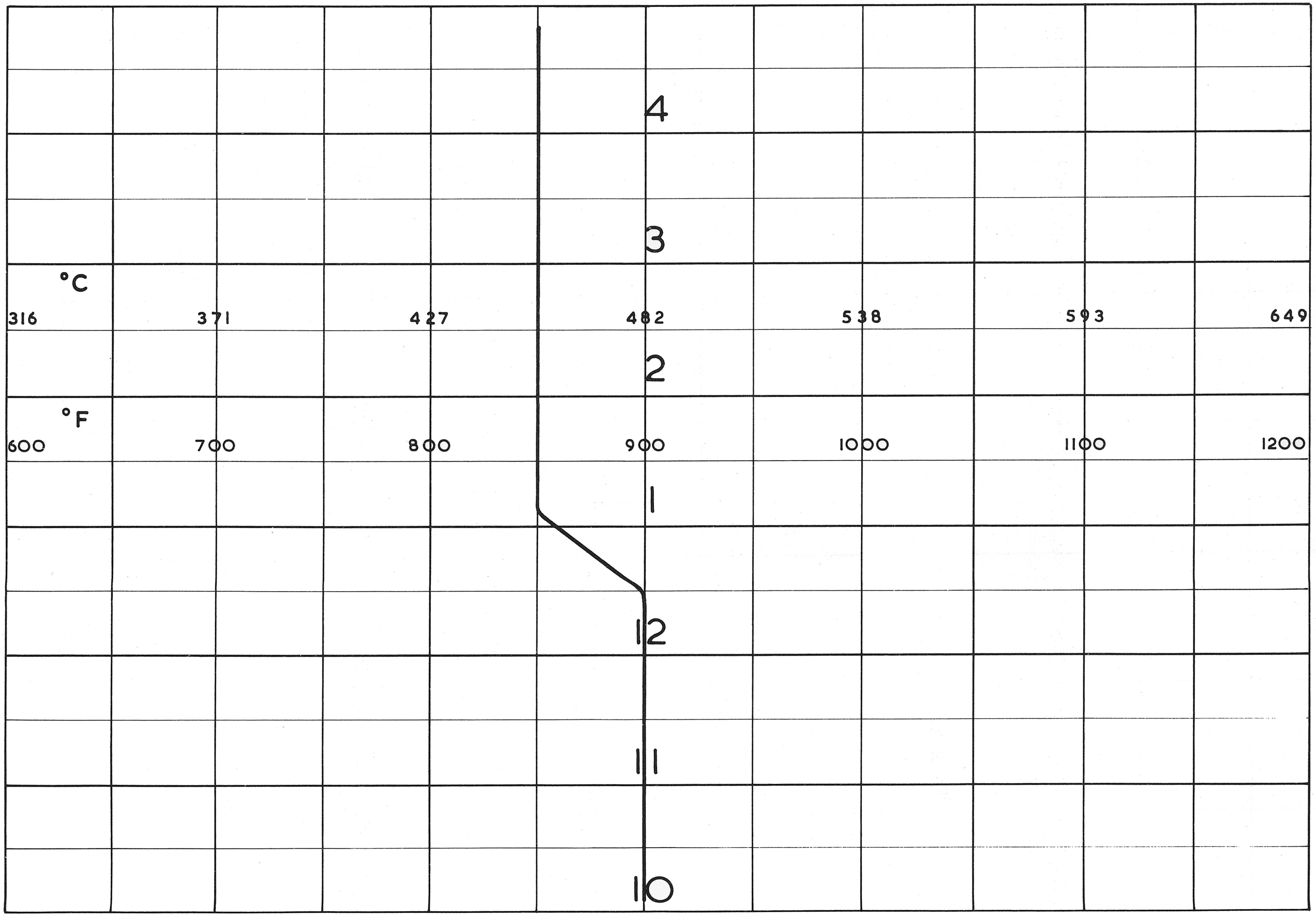


Figure 18: RATE OF CHANGE OF STEAM TEMPERATURE

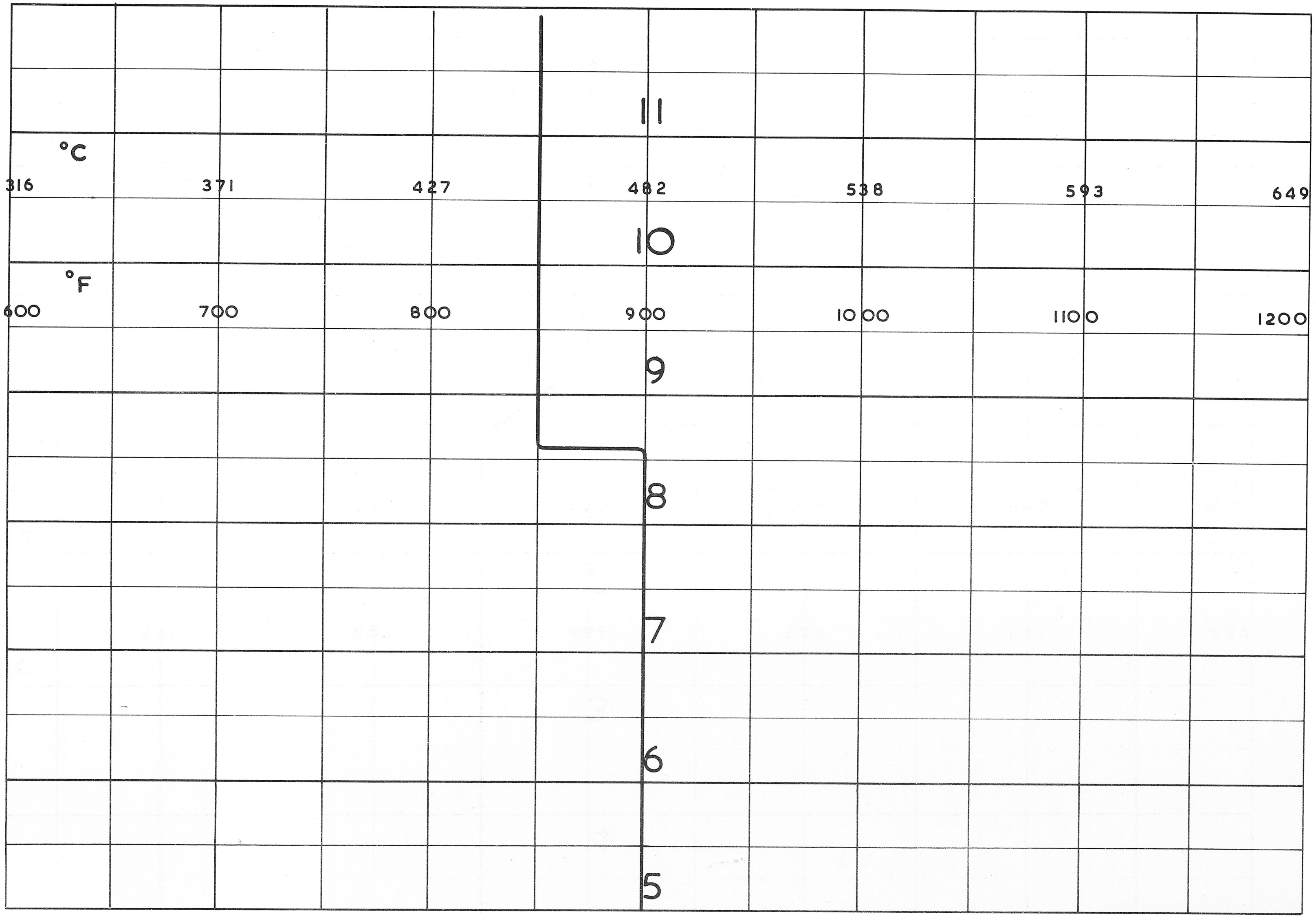


Figure 19: RATE OF CHANGE OF STEAM TEMPERATURE

7.2.2 Mal-operation

Outages from mal-operation may be divided into errors, that is, carrying out a wrong operation, or carrying out a particular operation too quickly. In addition, outages may be caused by insufficient attention to routine supervision.

It is difficult to quote particular cases of incorrect operation, but examples are:-

(i) Pumps being run without water.

(ii) Mistake in valve operation, such that oil is lost from the system.

(iii) Drainage not properly carried out.

(iv) Steam being supplied to heat exchangers without adequate water flow.

Examples of operations carried out too quickly include running up the turbine, valve operation and generally the putting into service or shutting down any piece of plant, including charging steam pipes.

Sudden changes may produce excessive strain on mechanical parts such as linkages and valve operating mechanisms. Another example is hammer in steam and water lines caused by incorrect valve operation.

If steam is supplied too quickly to a pipe run or piece of plant, excessive temperature differences and differential stresses will be produced with possible cracking of material and joint failure.

The items of routine supervision in which insufficient attention may cause outage would include:-

(i) Lubrication - causing jammed valves and bearing faults.

(ii) Gland steam - causing vibration and damage to packings.

It is important to realise that mal-operation does not necessarily mean an obvious defect straight away. The defect may show up later at a most inconvenient time.

7.2.3 Other Causes

Under other causes of outage are those which mean a serious drop in performance or load restriction. These causes are other than known mechanical defects. There are two main causes under this heading, both outside the control of the operator, blade fouling and condenser fouling.

Blade Fouling
Blade fouling is caused by impurities being carried over with the steam from the boiler into the turbine. These impurities stick to the blades in certain stages down the turbine and restrict the steam flow and also alter the shape of the blades. Indications of blade fouling will first be given by increases in the high pressure, and decreases in the low pressure bled steam points. This change can be shown very clearly by a diagram (see Fig. 20).

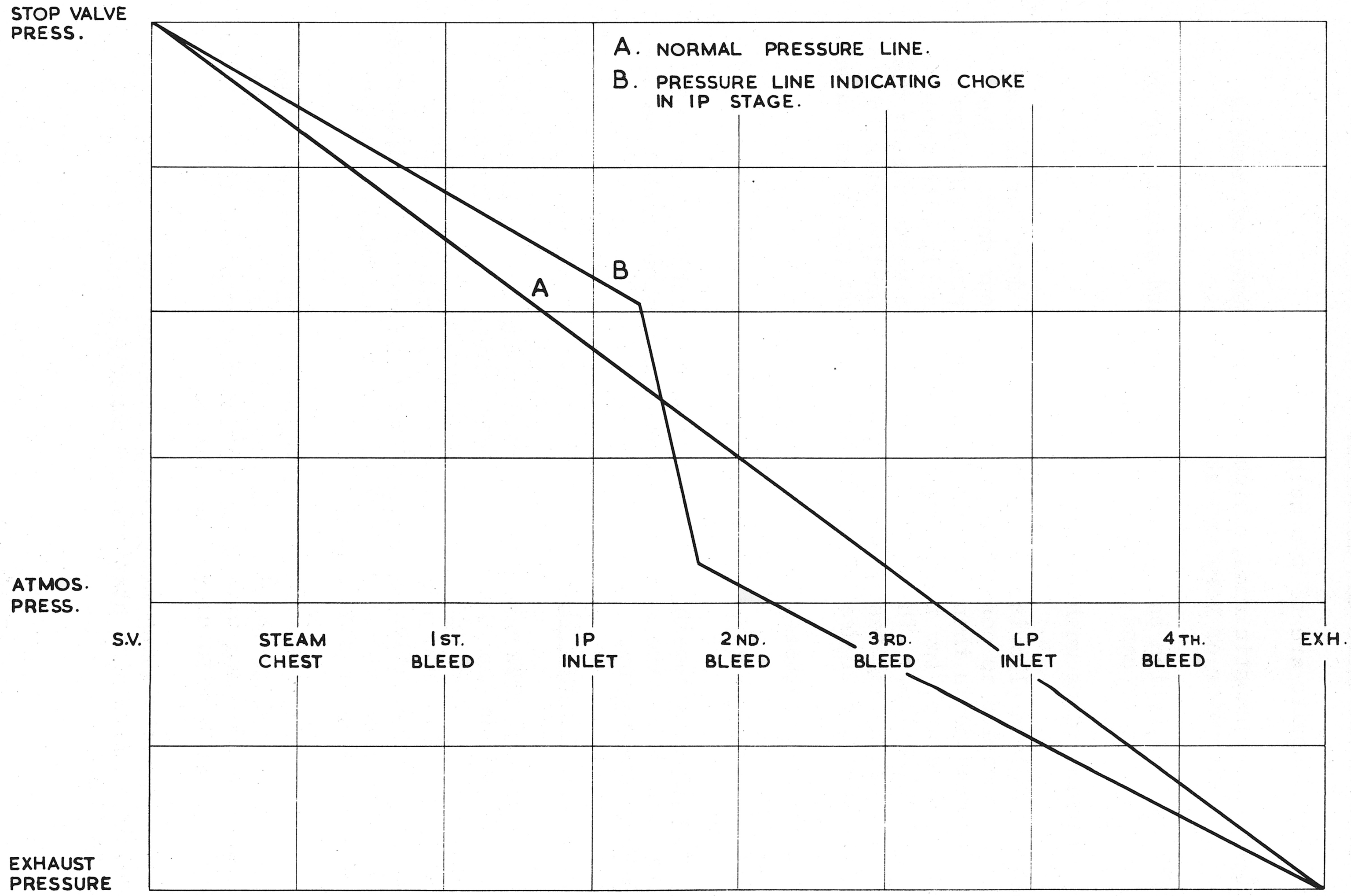


Figure 20: TURBINE BLADE FOULING INDICATED BY STAGE PRESSURES

If blade fouling is allowed to increase, more control valve or throttle valve opening will be required to maintain the same load. Eventually, a stage will be reached when throttle valves are fully open, but the turbine will not do full load. Turbines are not allowed to get into this condition without some attempt to remove the deposits.

The deposits are of two main kind:-

(a) either caustic soda, which can be removed by washing with water or very wet steam,

(b) silica, which has to be removed by hand scraping or by a form of sand blasting.

Turbine blade washing for:-

(a) involves allowing the machine to cool down for as long a period as possible, say three to four days. The machine is then run at 800 to 1,000 r.p.m. with low pressure, low temperature steam, possibly with water injection. The condensate is run to waste during the washing and tested until the Dionic purity falls to a suitable figure. The turbine is then run up as normal.

(b) Silica deposits require the turbine to be opened up.

Turbines on two-shift operation rarely suffer from blade fouling because of the washing action of wet steam each time the set is started up.

Condenser Cleaning
Condenser tubes sometimes need cleaning on the steam side, but more often on the circulating water side. The effect is the same whether the tubes are dirty on either side, that is, the heat transfer from exhaust steam to circulating water is restricted. Indication of dirty tubes is given by the difference in temperature between exhaust steam and the circulating water outlet being greater than normal.

The steam side of condenser tubes may collect an oil film from a faulty turbine bearing and complete outage of the set is necessary for cleaning with a solvent or detergent, followed by thorough flushing with clean, hot water.

On the circulating water side, condenser tubes collect mud internally in riverside stations and sometimes scale in cooling tower stations.

Mud is usually removed by firing specially made "bullets" through the tubes, using compressed air or high pressure water. Examples of these bullets are shown in Fig. 21.

Removal of scale requires an outage for acid soaking followed by clean water flushing.

Sets are normally shut down for circulating water side cleaning, but on-load cleaning is possible if the condenser is in sections which can be separately isolated and drained on the circulating water side. The load is reduced and the vacuum will be worsened during this operation.

Another method of on-load cleaning is to blow air through the isolated and drained section, as shown in Fig. 22. This dries the mud which curls away from the inside of the tube. When the condenser is recharged with circulating water the mud flakes are swept away. Certain types of mud do not lend themselves to this method.

During any cleaning operation, the tube plate should also be cleared of any debris which would block tubes.

In addition to the above methods of cleaning, a method known as the Taprogge system (see Fig. 23) is now being used at several stations where the particular conditions are suitable. Small rubber balls are injected on load into the C.W. inlet of the condenser section to be cleaned and are of such size that, as they pass through the tubes with the water they remove the deposits from the inside of the tubes. Arrangements are provided at the C.W. outlet of the condenser section to trap the balls for recovery and re-injection at the inlet.

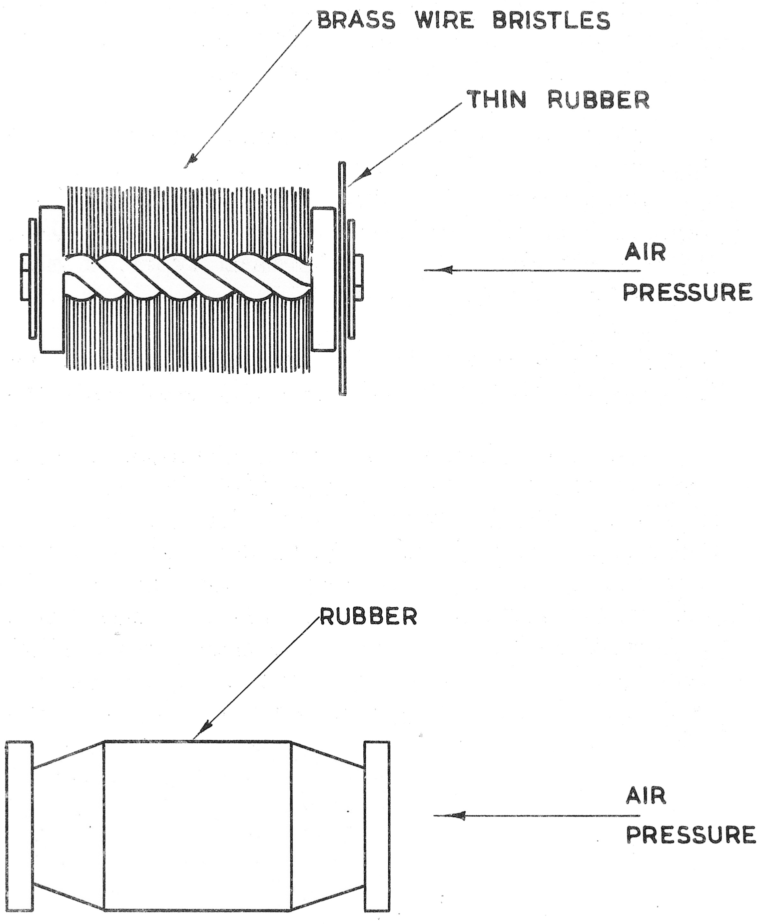


Figure 21: CONDENSER TUBE CLEANING BULLETS

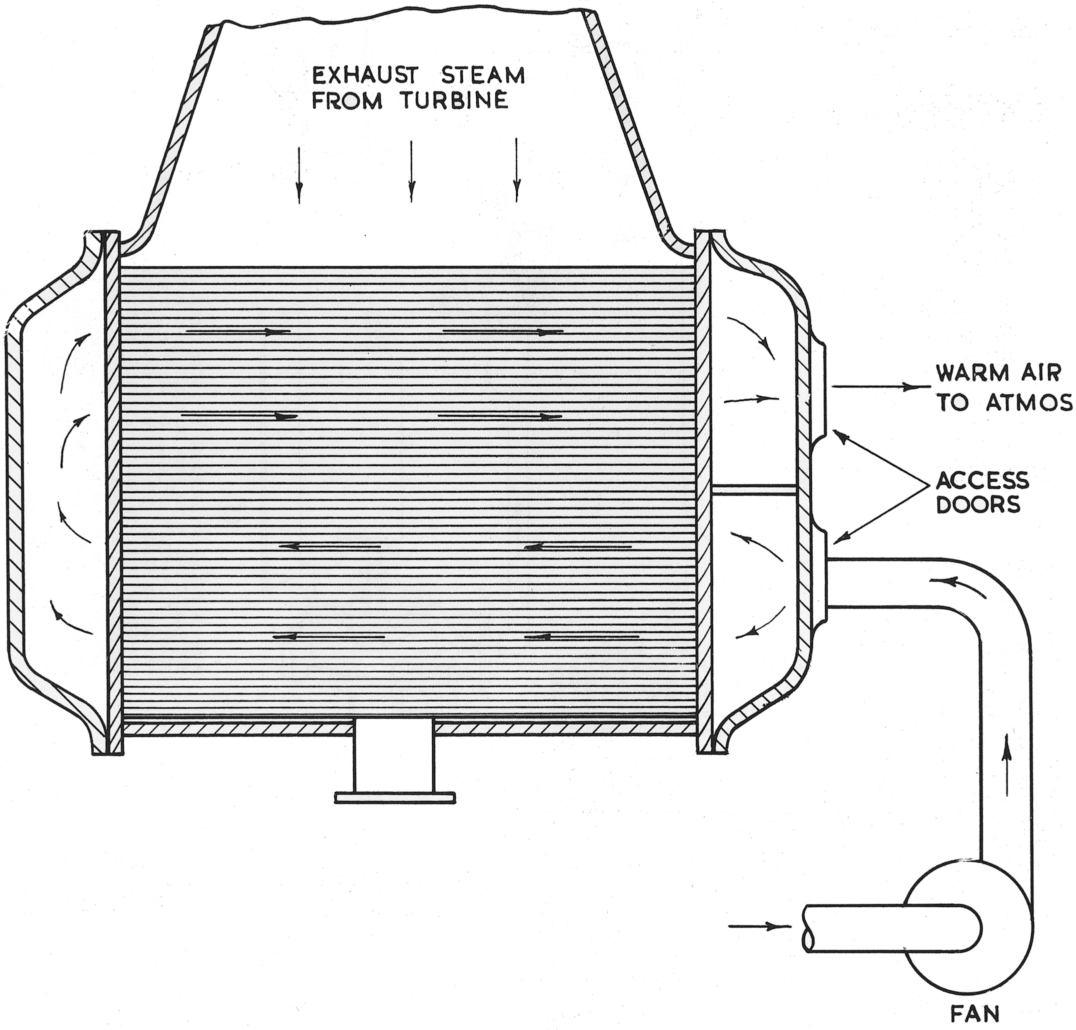


Figure 22: ARRANGEMENT FOR CONDENSER CLEANING BY MUD DRYING

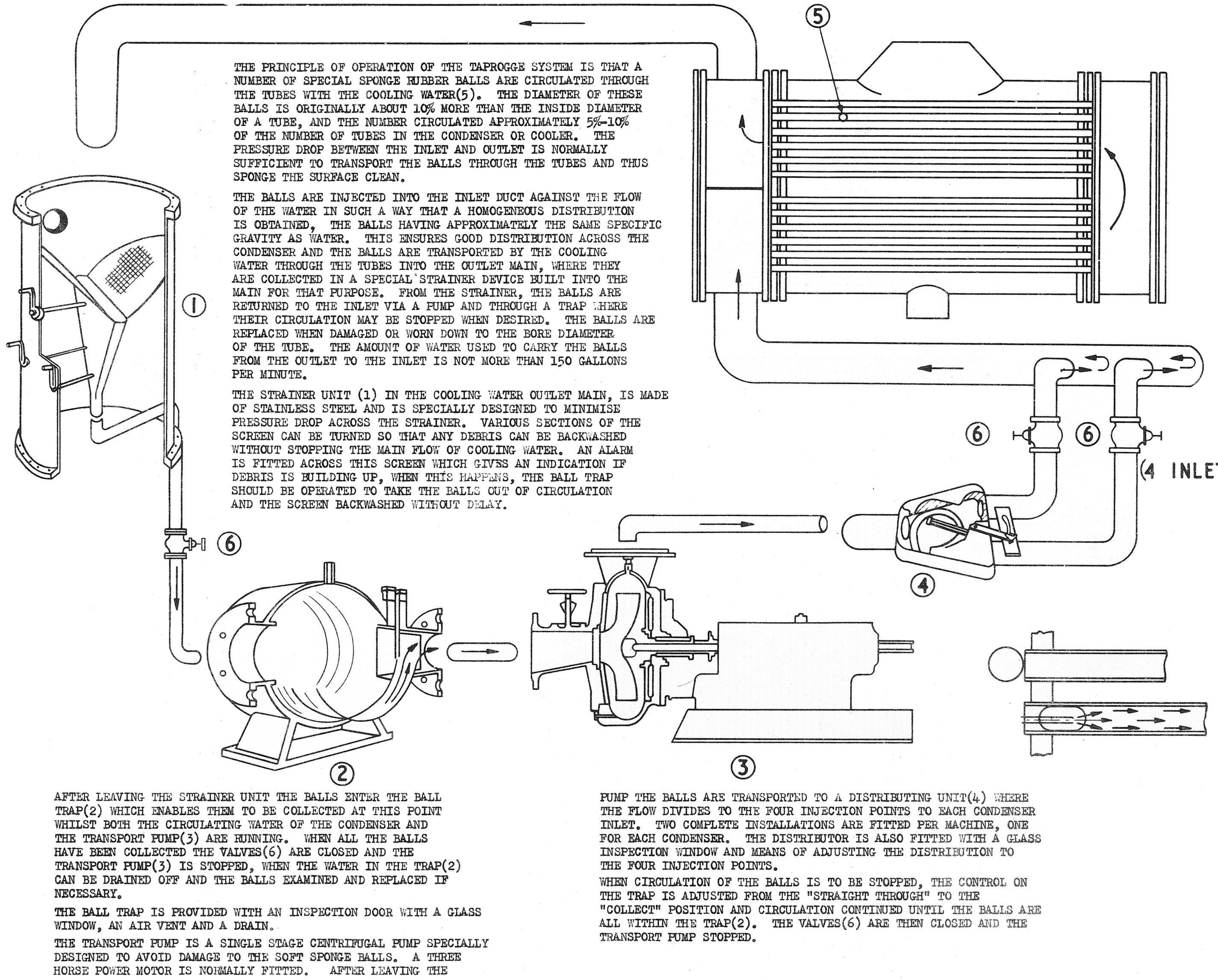


Figure 23: TAPROGGE SYSTEM OF ON LOAD CONDENSER TUBE CLEANING

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Questions on Lesson 7 - The Operation of the Modern Steam Turbine

Please answer any four of the following questions

- Give reasons why extreme care is necessary on first commissioning a turbine and make a list of the essential precautions.
- Explain why load is applied at a slower rate to a cold machine than to a hot machine.
- For any quick-start operation, list the measurements made on the turbine and the reasons for each.
- What effects on the turbine may be caused by excessive temperature differences between steam and metal?
- List the items covered by on-load supervision of a turbine running normally.
- Explain briefly the differences between indicating and recording instruments from the operator's point of view.