NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

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3 - Equipment & Systems Principles - T.T.4

4 - Turbine, Generator, and Auxiliaries

-1 - General

0.0 INTRODUCTION

This lesson will introduce the course "Turbine, Generator and Auxiliaries" in a general way.

1.0 INFORMATION

Before we proceed with the main body of the lesson, clarification of a few terms that are going to be used would be helpful and these will therefore be defined as follows:

Prime mover - a machine that can convert natural forces into mechanical power. Examples of prime movers are: hydraulic turbine, steam turbine, gasoline engine, etc.

Heat engine - is a device used to convert heat energy to mechanical work. For example a steam turbine is a heat engine in that it uses the heat energy in steam to do mechanical work.

Unit Turbine Boiler Plant or when abbreviated we just say "unit" refers to the turbine with all its cylinders, the generator, the boiler and all the auxiliary equipment associated with one particular turbine-boiler in a power station.
In a nuclear power station this would also include the reactor and its associated equipment.

Turbo-generator - an electric generator driven by a steam turbine. It is connected to the electric supply system or grid and supplies power to any electrical load connected to the grid. This may also be referred to as a turbo-alternator or just plain "generator" as is the North American practice. The term generator is not to be confused with steam generator which is another name for a boiler.

Megawatt - 1,000,000 watts or 1,000 Kilowatts. This is written in abbreviated form as MW.

Enthalpy - is heat energy contained by a substance such as water or steam. This heat energy is measured in British Thermal Units.

1 British Thermal Unit is the amount of heat required to raise the temperature of 1 lb. of water 1°Fahrenheit.

Auxiliaries - in general it includes all the equipment of a particular unit, other than the turbine, generator, boiler and reactor, required to help produce electricity. In this particular course auxiliaries will refer only to the additional mechanical equipment required to make the turbine and generator operate. The boiler and reactor are not included in this. Auxiliary equipment is often also referred to as ancilliary equipment.

Conventions

1. Left-hand side and right-hand side of unit. It is conventional to say that when you're standing at the high pressure end of the turbine looking towards the generator that the side to your left is the left-hand side of the unit. The side to your right is the right-hand side of the unit.

2. Inboard and outboard. Convention has established that the generator bearing nearest the turbine is the inboard bearing and one farthest away from the turbine is the outboard generator bearing.

The advancement of industry depends to a very large extent on man's ability to build prime movers which can convert natural forces into mechanical power. A good example of a prime mover is a steam turbine which is used to drive a generator in an electric generating station. In fact the steam turbine is such a good prime mover that there is more steam turbine generating capacity installed in both electric generating stations and industrial plants than all other prime movers combined.

Steam turbines vary in size from units of less than 1 H.P. to units of up to 1,340,000 H.P. (1,000,000 KW.) They are built to run on steam at inlet pressures from less than atmospheric up to pressures of over 5,000 psig and with inlet temperatures up to 1200°F. They can be run at variable speeds as well as speeds held to a value that will not vary by more than about 0.1% from the specified rpm. These steam turbines are versatile and in comparison with other prime movers using heat as the motive power, they are ideal for the generation of electric power.

Steam turbines may also be used to drive mechanical loads other than generators. For example they may be used to drive pumps, air compressors, etc. There are many examples of directly driven mechanical loads for which a turbine drive may be used and some of these may be included as auxiliaries in a turbine generator system. These will be discussed in more detail above the T.T.4 level.

Of course there are other prime movers such as hydraulic turbines, diesel engines, and gas turbines which are being used to produce electric power. Hydraulic turbines can produce electric power more economically than steam turbines. However, to operate them, large flows of water dropping from a great height are required. These conditions, when they do exist in nature, are often far away from load centres in which case transmission losses are so great as to make such hydraulic power projects uneconomical. Ontario Hydro has developed all its water resources near to the load centres and therefore has to resort to other prime movers for electric power. The heat engine type of prime mover is not so limited as to its location. Diesel engines and gas turbines can be used as prime movers for small electric generators. However, next to hydraulic turbines, the best choice for a prime mover to produce power in a large electric generating station is a steam turbine for the following reasons:

1. They can be built to more than 10 times the size of gas turbines or diesel engines thus requiring fewer units.

2. They operate more economically than gas turbines or diesel engines. Up to certain limits it is generally true that the bigger the prime mover, the more economically it will operate.

In a nuclear electric generating station, the heat produced by fission in a reactor, is used to generate steam. This steam is converted first to mechanical energy in the turbine and then to electrical power by means of the alternating current generator.

The turbine generator, as developed up to the present time for electrical power generation, is a complex piece of engineering machinery which requires a number of auxiliaries for safe and efficient operation. For this reason, the turbine generator and its auxiliaries can be regarded as a complete system (sometimes broken down into a number of individual systems), containing a number of components each having its own function but each contributing to the more efficient operation of some other part of the system or to the system as a whole.

In general, it must be realized that although all steam turbine generator units and their auxiliaries work on the same fundamental principles, there are an enormous number of variables in the details of design and arrangement which differ from country to country, manufacturer to manufacturer and generating station to generating station.

In this course, it will not be possible to study all possible arrangements of plants but an attempt will be made to give a general outline of the reasons why equipment is used and how it operates, so that the principles of the turbine plant which may be found in any nuclear electric generating station may be understood. At the T.T.4 level we shall first discuss a brief outline of the system as a whole and then more details of each major component separately.

D. Dueck

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4 - Turbine, Generator, and Auxiliaries

-1 - General

A - Assignment

1. Define prime mover.
2. Explain what is meant by the term "unit turbine boiler plant"?
3. Why do we use steam turbines as prime movers in large electric power stations? Give 2 reasons.

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3 - Equipment & System Principles - T.T.4

4 - Turbine Generator and Auxiliaries

-2 - Closed Feed Cycle

0.0 INTRODUCTION

This lesson will describe the closed feed cycle and briefly deal with each of the major components in the cycle.

1.0 INFORMATION

A steam turbine driving an electrical generator normally works on a closed feed cycle or system. That is to say, the steam which is supplied to the turbine from the boiler, is passed through the turbine, doing work and is then condensed to water. As water, it is pumped back into the boiler to be re-evaporated and used over again.

Figure I is a diagram of a simple closed feed cycle. As mentioned in the above paragraph steam at high pressure and temperature is produced in the boiler. It is then led to the turbine by means of the main steam line. As the steam passes through the turbine it gives up its energy to the turbine rotor and thereby does work. In order to do work it expands from a high pressure at inlet to a low pressure at the exhaust. A condenser is connected to the exhaust end of the turbine, so that after the steam has given up all its available energy in the turbine it is condensed to water. This condensate then collects at the bottom of the condenser in an area called the hotwell.

In order to condense steam, cooling water is required which is circulating through tubes in the condenser--therefore it is called circulating water which is generally taken from a river or lake. This water is not allowed to mix with the condensate.

Coming back to the condensate again, after it has collected in the hotwell it is extracted by a condensate extraction pump which raises its pressure discharges it through a low pressure feed heater (L.P. heater). From here on in till the water reaches the boiler, it is known as boiler feedwater. Here the water is heated. The heat is supplied by steam which has been extracted from the turbine via a steam extraction line. From the L.P. heater the oxygen and other gases are removed from the water. A deaerator is generally

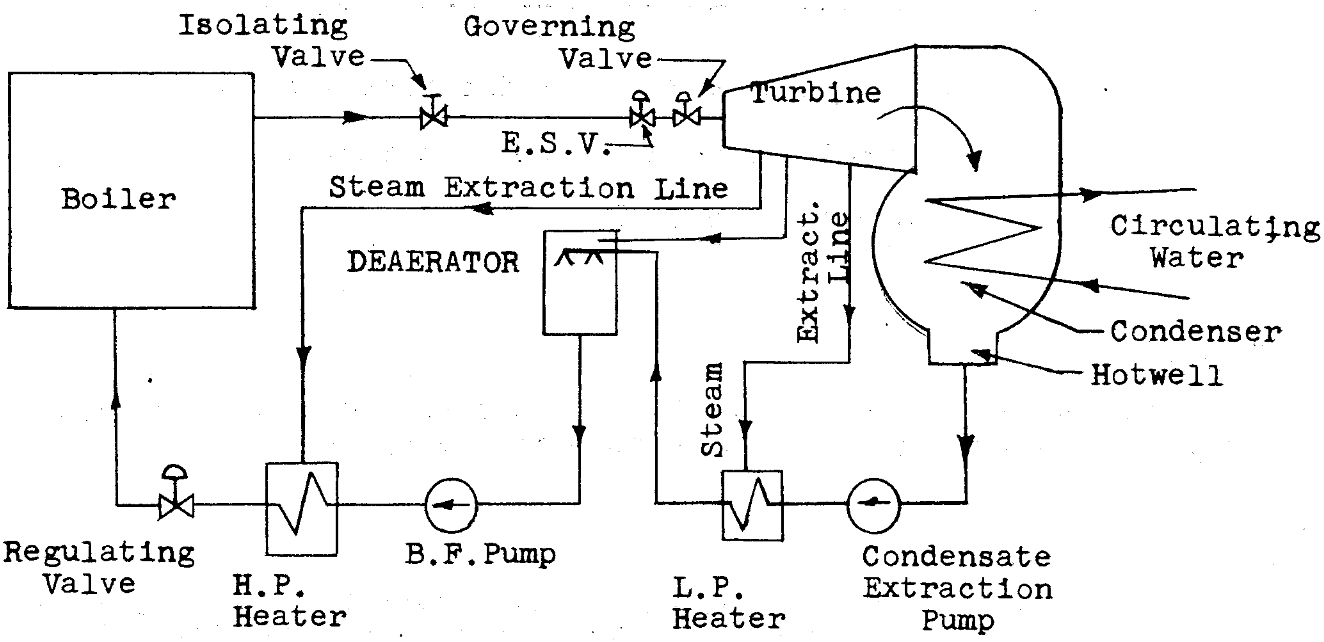

Fig. 1 - Closed Feed System

only required for large units. For small units such as N.P.D.-2 the condenser will adequately remove all dissolved gases in the system, and a deaerator is omitted from the system.

Boiler Feed pumps (B.F.P.) draw the feedwater from the deaerator raise it to a still higher pressure and discharge it through a high pressure heater(H.P. heater), through a regulating valve into the boiler. The water is then evaporated again and passed on to the turbine.

The L.P. heaters deaerator, H.P. heaters, steam extraction lines and all the equipment associated with the feedheaters are actually a system within a system. All together these components are known as the regenerative feedheating system.

There are three valves located in the main steam line figure 1 which we have not mentioned as yet. These are the isolating value, emergency stop valve (E.S.V.) and governing valve. Their significance will be discussed in the next lesson.

Now having described the closed feed cycle, on might well ask: Why is it important to have a closed feed cycle? There are a number of advantages to be gained by it which are as follows:

1. A saving in water. Since very pure water must be used in the system for reasons which will be discussed later, a closed cycle represents a very considerable saving in cost of water purification equipment. The steam flow for a medium sized unit such as Douglas Point G.S. is around 2,500,000 lb/hr. The purification of this much water, to the required standard would be a very expensive proposition.

2. A gain in efficiency. The exhaust pressure of a turbine influences the efficiency of the cycle to a very large extent. If the turbine were exhausting to the atmosphere the lowest pressure it could exhaust to would be 14.7 psia. Where as in a closed cycle with a condenser connected to the turbine the turbine can be made to exhaust to an almost perfect vacuum. A turbine exhausting to atmosphere will have only about 2/3 the output of a turbine exhausting to a near perfect vacuum, even though they start off with the same steam conditions at inlet. Hence a closed cycle is much more efficient.

   Also in a closed system, the condensate formed in the condenser is at a higher temperature than raw water from natural sources would be. Therefore less is required to raise it to boiling point before it is evaporated in the boiler. This also means a gain in efficiency.

3. Deaeration of water. Raw water from natural souces contains a good deal of dissolved oxygen which causes metal to corrode, especially at high temperatures. In a closed cycle this oxygen may be removed by deaeration in the condenser and deaerator and by injecting chemicals into the feedwater line to the boiler.

4. Facility for feedheating. The feedwater returning to the boiler is normally heated by steam extracted from the turbine. This increases the efficiency of the cycle as a whole for reasons which will be discussed in a later lesson.

Dick Dueck

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-2 - Closed Feed Cycle

A - Assignment

1. Make a diagram showing a simple closed feed system. Label all the components and use arrows to indicate the direction of flow.

2. Give 4 advantages of using a closed system.

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4 - Turbine, Generator & Auxiliaries

-3 - Mechanical Flow Control Devices

0.0 INTRODUCTION

In the previous lesson we have briefly described the closed feed cycle. The flow in this cycle has to be varied considerably from no load to full load. (The term "load" refers to generator output.) The mechanical devices we use to control this flow are: isolating valve, emergency stop valves, governing valves and regulating valve. These will be dealt with in this lesson, as well as giving a brief description of the main steam line.

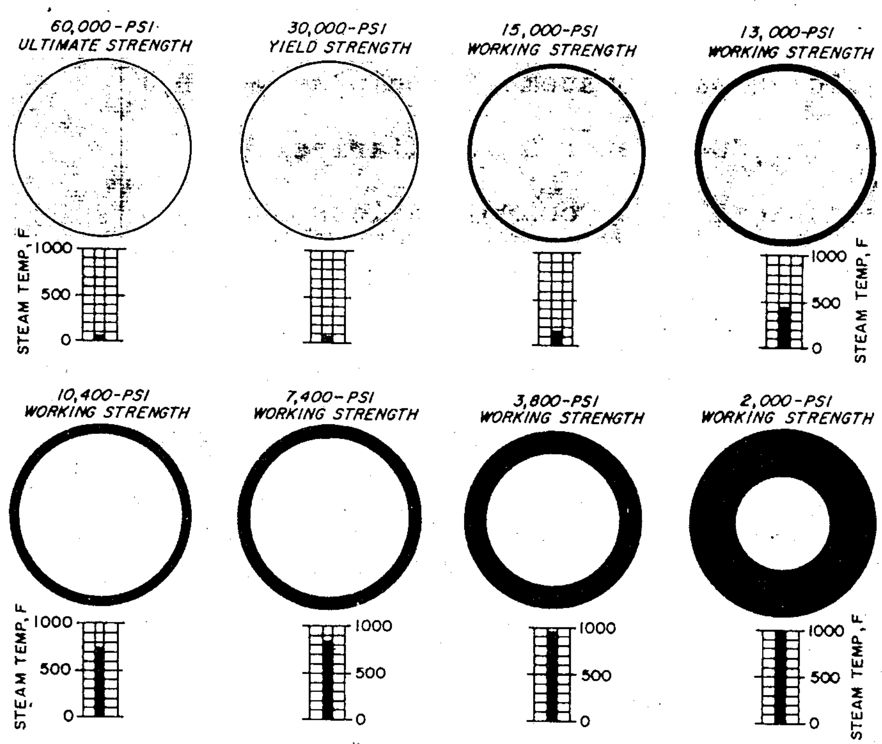
1.0 INFORMATION

Main Steam Line

The main steam line which leads from the boiler to the turbine is usually made of steel and must be large enough in size to carry all the steam required by the turbine at full load without excessive pressure drop in the line. If the pressure dropped by about 50 psi as the steam flowed from boiler to turbine the pipe size would be considered adequate. Another criterion for sizing the main steam line is that the flow should not be more than about 11 feet/sec. at full load, otherwise too high a vibration may be induced in the pipe.

The strength of metal decreases rapidly as its temperature increases. Figure 1 illustrates this point. All the pipes in this example are designed to hold fluid at 1000 psig. In the upper left hand corner for a steam temperature of less than 100°F the ultimate strength of a steel pipe is quite high - 60,000 psi. Consequently the pipe wall need only be quite thin. As the temperature of the steel increases its strength decreases, hence requiring a thicker wall for the same internal pressure.

At a steam temperature of 450°F the working strength of the same steel has reduced to 13000 psi, and consequently the pipe wall must be made thicker for the same pressure as compared with the first pipe. At a steam temperature of 1000°F the working strength of steel is only 2000 psi. and hence the pipe wall has to be much thicker than the first pipe for the same pressures.



A pipe designed to hold high tempe= rature fluids at high pressure cannot have sharp bends in it other- wise very high stresses are esta- blished when the pipe expands. Therefore this type of pipe always has large loops in it whenever it changes direction.

Figure 1. Here's how thick pipe walls must be for different conditions when built for holding fluid at 1000 psig pressure.

Isolating Valve on main steam line.

This type of valve is used for stopping steam flow entirely. It normally has two positions, either fully closed or fully open. Generally it is located near the boiler.

An isolating valve is installed so that maintenance work can be done on the turbine without the need of reducing pressure and temperature in the boiler. Also when raising pressure in the boiler at start-up, if the isolating valve is closed the boiler does not have to fill the main line with steam (which can be quite a large volume) and thus the pressure in the boiler can be raised more rapidly.

Emergency Stop Valve (E.S.V.)

Usually the main steam line (or lines) passes into steam chests at the front end of the turbine - one on the left hand side and one on the right hand side. Before the steam enters the turbine it has to pass through two different valves. One of these valves is made for very sudden shut-off of steam flow in case of an emergency fault on the turbine or generator. This one is called an emergency stop valve. It is fully open during normal operation, and fully closed during shutdown. There are generally two of these valves for one turbine - one for each steam chest. Figure 2 is a typical illustration of a steam chest showing an E.S.V. and two governing valves. These valves are opened hydraulically by high pressure oil. They are closed by spring action.

Governing Valves.

The other valve that the steam has to pass through before entering the turbine is a governing valve. There are generally 4 or more governing valves for one steam turbine. If they are located in the steam chests, as is the case for large units then there are usually two in each chest. A pipe leads away from each governing valve into the turbine front end.

For small units the governing valves may be located on top of the turbine and the governing valve casing may be integral part of the turbine casing.

Governing valves are used to regulate the flow of steam into the turbine. At low generator output, a low flow of steam is required in the turbine.

At high generator output a high flow of steam is required in the turbine. Governing valves throttle the steam when not fully open. Throttling involves a loss in available energy in the steam. When 4 governing valves are provided the practice in North America is that only one or two valves are opened when the generator is at low load. These valves are gradually opened as the generator load increases till at half load two governing valves are fully open. At 75% of full load three governing valves are fully open and at 100% full load all four governing valves are fully open.

There are variations to the above, as for example when the turbine is provided with an overload inlet in which case there may be five governing valves.

In Europe the practice is to open all four governing valves at the same time and at the same rate. If the turbine-generator is operating on full load most of the time and the valves have to be fully open in any case then it is an advantage to have this type of arrangement. However, if the turbine-generator is operating on part load more often than at full load then the North American practice is of greater advantage.

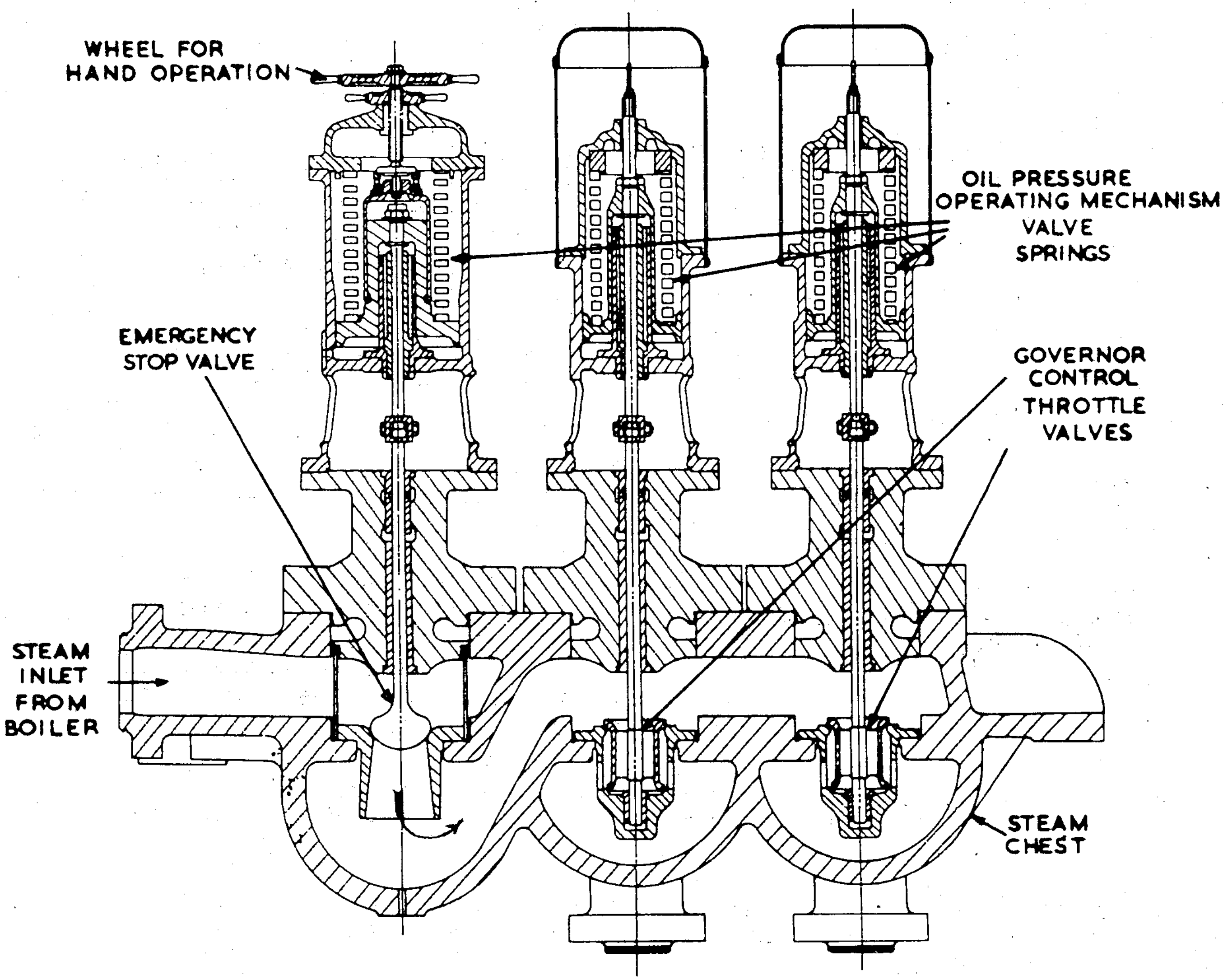


Figure 2 - Steam Chest Assembly

Regulating Valve

The regulating valve as can be seen from Figure 1 of the previous lesson is located in the boiler feed line just after the H.P. heaters. Its function is to regulate the feedwater flow into the boiler drum.

For large boilers, this valve is generally controlled by what is called a three-point element. That is the extent to which the valve is opened is determined by the steam flow in the main steam line, the water level in the boiler drum and the feedwater flow which is already taking place in the feedwater line.

Up to this point in the course we have introduced a number of terms with which the student should be familiar. We can now proceed to describe the major components in the feed cycle in greater detail . This will be done in the remainder of this course at the T.T.4 level.

D. Dueck.

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-3 - Mechanicla Flow Control Devices

A - Assignment

1. Why is the wall of the pipe carrying high temperature fluid much thicker than the wall of a pipe carrying low temperature fluid even though the pressure in the two pipes may be the same?

2. What is the function of the following valves in the closed feed cycle:

   a) Emergency stop valves
   b) Governing valves.
   c) Regulating valves.

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4 - Turbine, Generator and Auxiliaries

-4 - Steam Turbine & Generator

0.0 INTRODUCTION

This lesson will deal with the steam turbine and generator in a general way. Since this is a fairly elementary lesson we will be discussing relatively small turbines only at this stage. However, the terms introduced here are also applicable to large turbines.

1.0 INFORMATION

Figure 1 shows what a small turbine generator (15 MW) looks like when it is all assembled in an electric generating station. As you can see the turbine is all covered with metal cladding. Underneath the cladding is the turbine casing. Between the cladding and casing is a layer of insulation. On either side of the turbine underneath the floor are the steam chests. The box shaped objects above the steam chests are housings for the governing valve stems and the power pistons which are used to open and close the valves. The turbine shaft is directly coupled to the rotor of a generator.

At the front of the turbine where various handwheels can be seen is the front pedestal. This pedestal is a housing for the front bearings, and some of the governing gear. More will be said about this later on.

Figure 2 shows the upper & lower halves of a casing for a turbine similar to the one in fugure 1, only of slightly larger output. This is the way the turbine appears without insulation or cladding. The governing valves would be "connected to the inlet pipes". It is not shown clearly on the diagram but for this particular turbine there are four inlets - two at the top and two at the bottom.

Notice also the flange. Steam turbines generally have a horizontal flange, splitting the casing into an upper half and a lower half. You will see that the flange is much thicker in front than at the back. This is because of the high steam pressure and temperature in front. As steam passes through the turbine and does work it reduces in pressure and temperature so that at the exhaust not nearly as much force is required to hold the casing together. In fact the pressure at or near the exhaust end is most probably below atmospheric pressure and the atmospheric pressure would tend to force the upper and lower halves together here. Therefore the

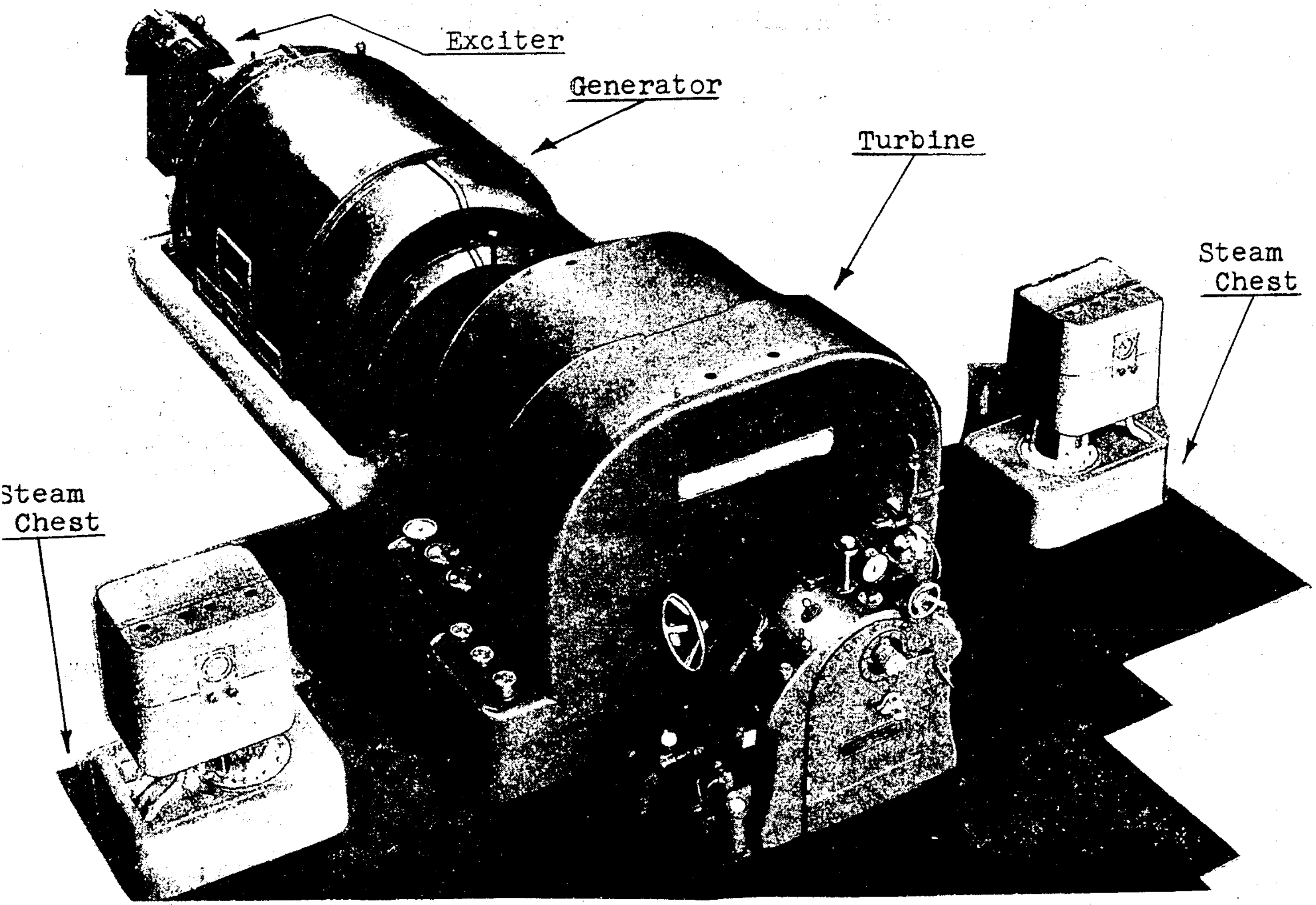

FIGURE 1 - View of a 15 MW Turbine-generator.

size of the bolts also decrease correspondingly towards the exhaust end.

Figure 3 shows a photograph of the lower half only of the same turbine as shown in figure 2. The view is taken looking from the exhaust end towards the high pressure end. You can tell by the size of the bolts. Small bolts signify low steam pressure, large bolts signify high steam pressure. Another way of telling is that the exhaust end is always larger than the inlet end. The reasons for this will be explained later on.

The turbine shaft fits into the semi-circular hollow space in the middle of the turbine.

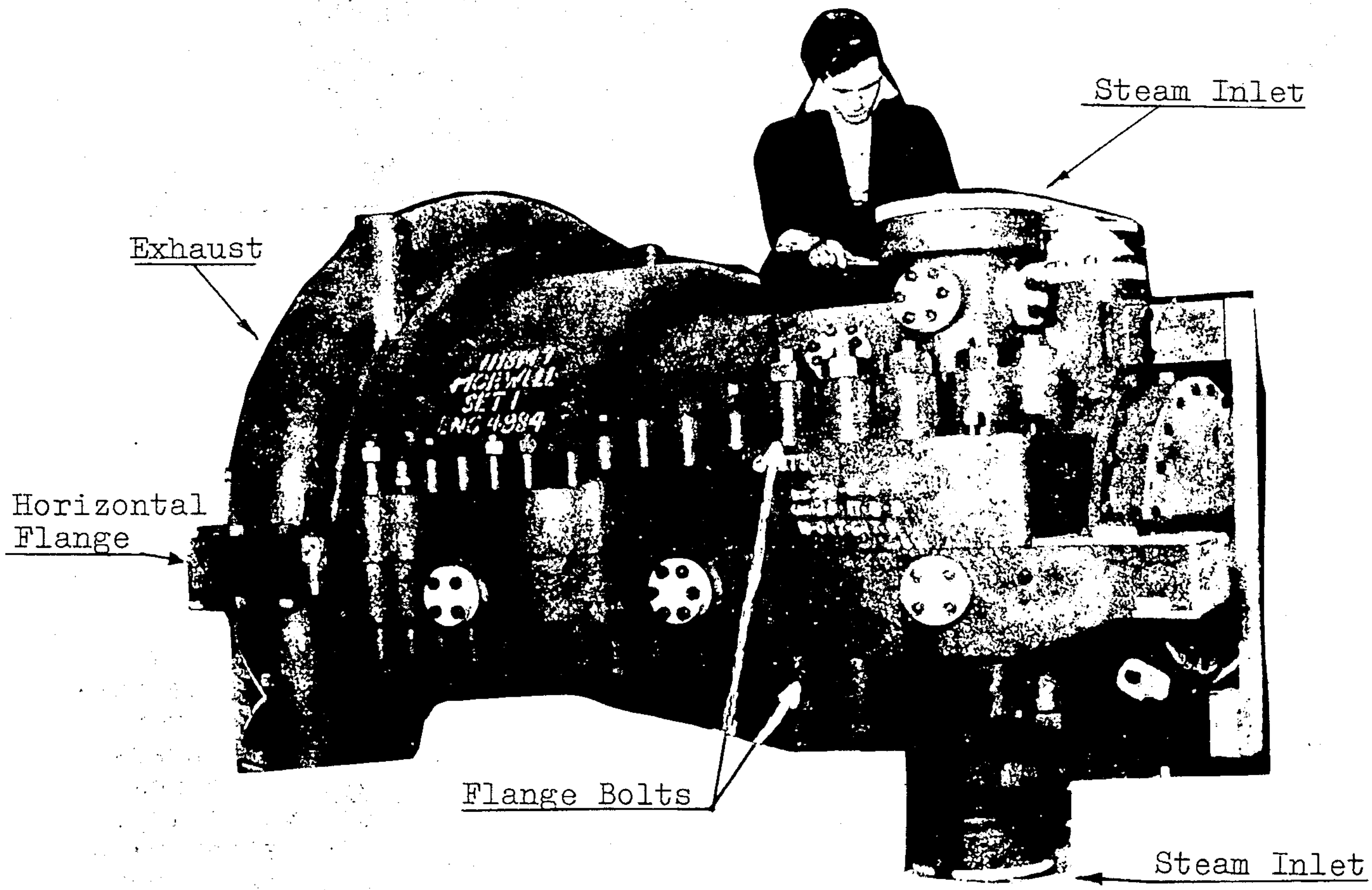

FIGURE 2 - View of bare turbine casing with upper and lower halves bolted together. This particular casing is ready for pressure testing in the manufacturer's shops.

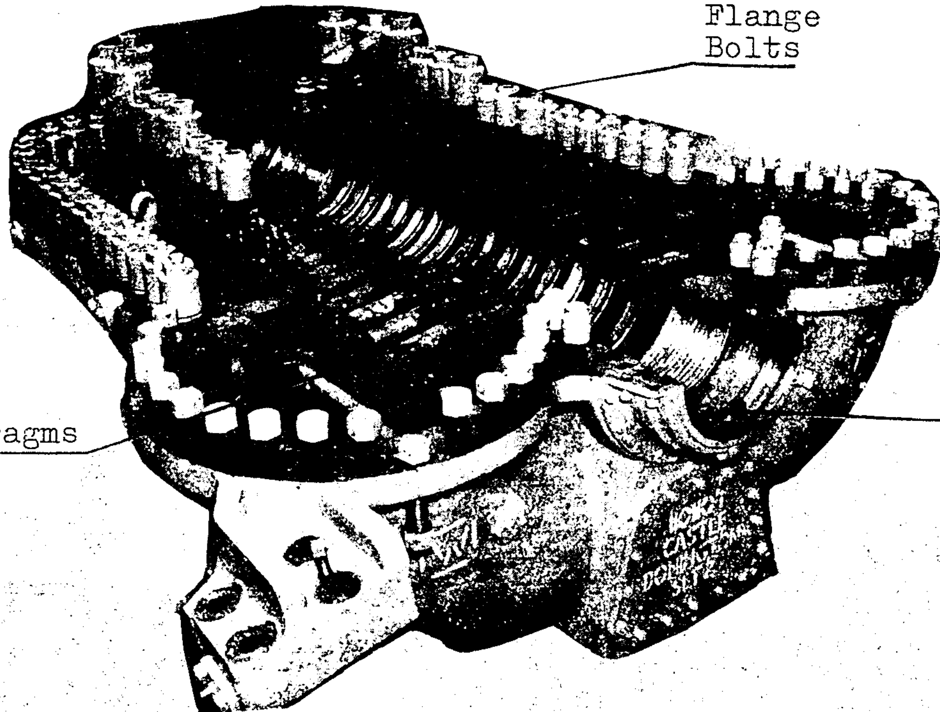

FIGURE 3 - View of the lower half of the same casing depicted in figure 2.

Having got a general idea of what a steam turbine looks like let us now proceed to describe briefly how a turbine works. We have said in a previous lesson that the steam turbine is a prime mover. It's ability to do work comes from the steam. Steam at high pressure and high temperature has what we call heat energy. This heat energy can be used to give the steam a very high velocity. Things that have velocity are said to have kinetic energy. The steam with its high kinetic energy can be directed at a wheel which has a row of buckets or blades on its outer edge. This causes the wheel to rotate, in a manner similar to the way wind at high velocity can be made to rotate a windmill. Then, if we put a shaft on the wheel and surround it with a casing we have a small turbine. To make a larger turbine we use 10 or 12 such wheels in a row, all attached to the one shaft.

In front of each rotating wheel is a row of stationary blades which concentrate the steam into jets and guide these jets in a direction such that they will strike the rotating blades at the correct angle. One row of stationary blades together with the metal they are fastened to is called a diaphragm. Diaphragms are firmly fixed to the turbine casing so they cannot rotate. Figure 3 shows the lower half of the diaphragms installed. The upper casing would contain the upper half of the diaphragms. The wheels on the turbine shaft would fit in between these diaphragms. Figure 4 illustrates a complete built-up diaphragm.

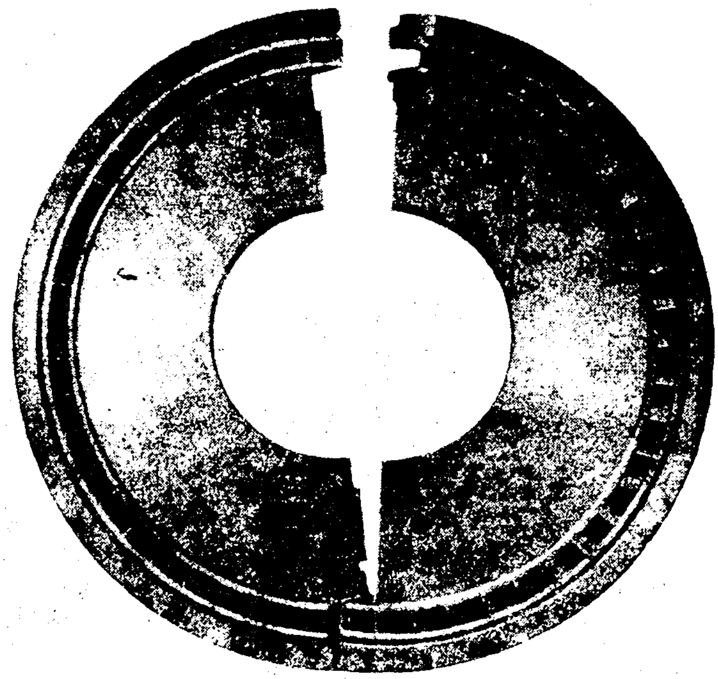

FIGURE 4 - Complete built-up diaphragm

One row of stationary blades together with one row of moving blades is called a stage.

Figure 5 shows a typical steam impulse turbine. Don't worry about the term "impulse" at the present time. It will be explained in later lessons. This diagram will help to associate some of the terms with what the objects actually look like.

In this particular turbine, the governing valve casings are a part of the turbine casing. This is the way the turbine for NPD-2 has been built also. The bleed steam outlet is for supplying extraction steam to one of the feedheaters.

The turning gear is for rotating the turbine shaft immediately after a shutdown. The turbine will be quite hot immediately after shutdown and if the rotor is left stationary while it cools off there will be eneven cooling - i.e. the bottom cools faster than the top. No doubt you know that if you heat a bar of metal it increases in length and if you cool it, it contracts. For the turbine rotor as it cools, this means that the bottom is contracting at a faster rate than the top. Therefore the rotor will bow upwards causing damage to blades on the rotor wheels as they push against the diaphragms. It could also damage the shaft. When the shaft is rotated as it cools, it cools evenly and damage doesn't occur.

The turning is generally done by electric motor nowadays. A speed of about 3 rpm. would be sufficient to prevent distortion, but speeds of about 30 rpm. are generally used to create turbulence within the cylinder, thus cooling the cylinder uniformly.

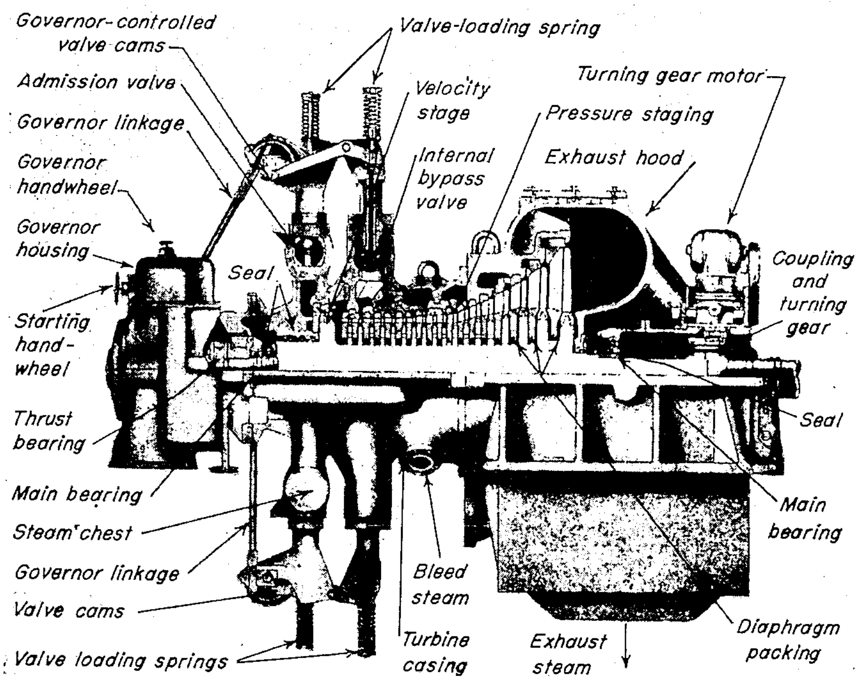

FIGURE 5 - Sectional view of typical impulse turbine. Wheels carry buckets or blades; diaphragms carry nozzles separating stages.

Observe that figure 4 shows a cutaway view of the blading. Starting from the exhaust end, because the blades can be seen more clearly there, the first blade is one on a turbine wheel attached to the shaft. The second blade is a stationary one on a diaphragm. The third one is one on a turbine wheel again etc.

You will notice that the front bearings and the governor are contained in one housing. This is referred to as the front pedestal. In addition to housing this equipment it must be strong enough to support the load of one end of the rotor.

The function of the governor of a turbine is to regulate automatically the speed and power output, and to enable changes in these to be made when required. The governor handwheel is used to increase or decrease the turbine output at will and in turbine-generator jargon this is known as the speeder-gear. The speeder-gear in modern turbines can also be operated by an electric motor which can rotate in both directions and so the turbine output can be changed remotely from the control room.

The turbine shaft with wheels on it is called a rotor or spindle. It can weigh up to several tons and therefore has to be supported by big bearings. There is a main bearing at each end. These are of the journal type. Also as the steam flows through the turbine there is considerable thrust on the turbine wheels. This thrust is transmitted to the shaft. In order that the shaft does not move longitudinally with respect to the casing and foul the blading, a thrust bearing is also installed. It holds the shaft in the same position relative to the casing at all times. Figure 6 shows the top and bottom halves of a combined journal and thrust bearing. The thrust bearing consists of small metallic pads, one of which is shown separately in the illustration. The pads are shaped so that as they come up against the thrust collar of the shaft they form a wedge. Oil in contact with the pads and thrust collar is thus wedged in between these two surfaces as the shaft rotates and this lubricates the thrust bearing. The accepted name for this type of bearing is Michell tilting pad bearing. The lubrication of bearings will be dealt with in a later lesson.

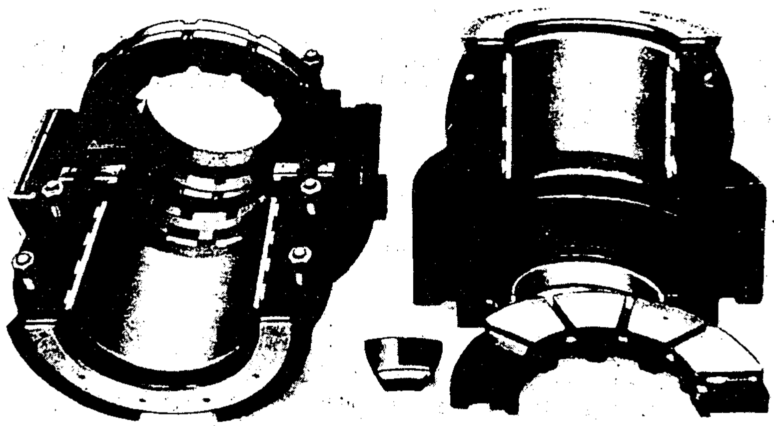

FIGURE 6 - A combined journal and thrust bearing.

This, briefly is what a small steam turbine looks like.

Generator

The electric a-c generator in a steam power station as shown in figure 1 is coupled to the steam turbine and converts mechanical energy to electrical energy. The electric energy or electric power is produced in the stator or stationary windings of the generator. In order to produce power a generator has to have an electromagnetic field. This is supplied by a current flowing in the windings of the rotor. The current supplied is direct current. In North America the speed of the rotor is 3600 rpm. or 1800 rpm. so that the alternating current produced in the stator is 60 cycles/second. (cps.)

The direct current for the rotor is produced by what is called a main exciter which is really a direct current generator. It is also shown in figure 1. The main exciter also needs an electromagnetic field which, in small units is supplied by a pilot exciter.

The pilot exciter can be either self excited, or get its electromagnetic field from an independent source or from permanent magnets in its stator.

In order to make the D.C. from the exciters as reliable as possible both the main exciter and pilot exciter are driven by the a-c generator shaft. Up to a generator size of 60,000 KW. the exciters can be directly coupled to the generator shaft. Above this size they are generally driven through reduction gearing, but still driven by the main shaft.

For units of 40,000 KW. and up the nominal voltage at the exciter terminals are 250 volts. For smaller units the nominal voltage is 125 volts at the exciter terminals.

For large units, say 200 MW and over, the exciter is generally driven by an a-c motor (a motor-generator set). In newer stations the pilot exciter is replaced by what is called an amplidyne which is also a direct current generator.

Also recently another type of exciter has come into use which is designed to replace the main and pilot exciters. It consists of a motor driven generator which supplies a-c power at 360 cps. The a-c is then rectified to d-c which is then fed to the generator windings to produce the electromagnetic field.

D. Dueck

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & Systems Principles - T.T.4

4 - Turbine, Generator & Auxiliaries

-4 - Steam Turbine

A - Assignment

1. Explain briefly how a steam turbine uses steam to do mechanical work.
2. What is a diaphragm?
3. What is a stage in a steam turbine?
4. What is the turning gear used for?
5. What purpose does the thrust bearing serve?
6. What is the function of the pilot exciter? the main exciter?

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

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4 - Turbine, Generator & Auxiliaries

-5 - Surface Condenser

0.0 INTRODUCTION

In the previous lesson we discussed the steam turbine which is a major component in the closed feed cycle. We've said that the turbine steam exhausts to a low pressure and is condensed. This low pressure and condensation is brought about by another major component in the closed feed cycle--namely the surface condenser. This lesson will deal with the surface condenser.

1.0 INFORMATION

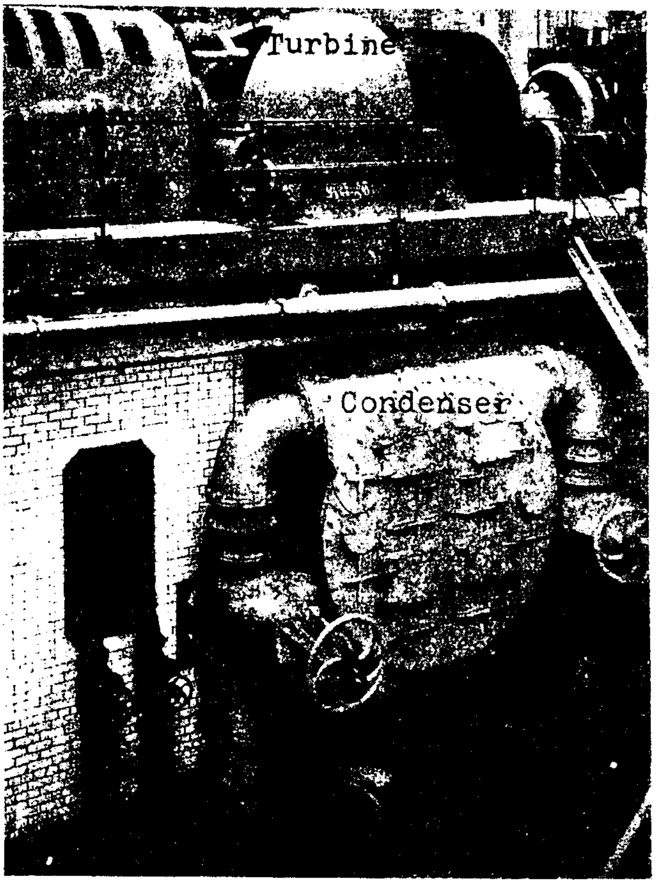

Fig. I Surface condenser for a small steam turbine.

The photograph in figure I shows a typical type of surface condenser used for a small steam turbine. This arrangement with the condenser connected directly to the turbine exhaust and located underneath the turbine floor is the common type of arrangement in a thermal electric generating station.

Of course there are many different types of condensers. This represents only one of them.

The term surface condenser is very appropriate because it contains a great number of cooling tube which provide a large cool surface on which the steam can condense. Take for example the 220 MW unit for Douglas Point. The condenser tubes for this unit provide a cooling surface of 158,000 sq.ft.

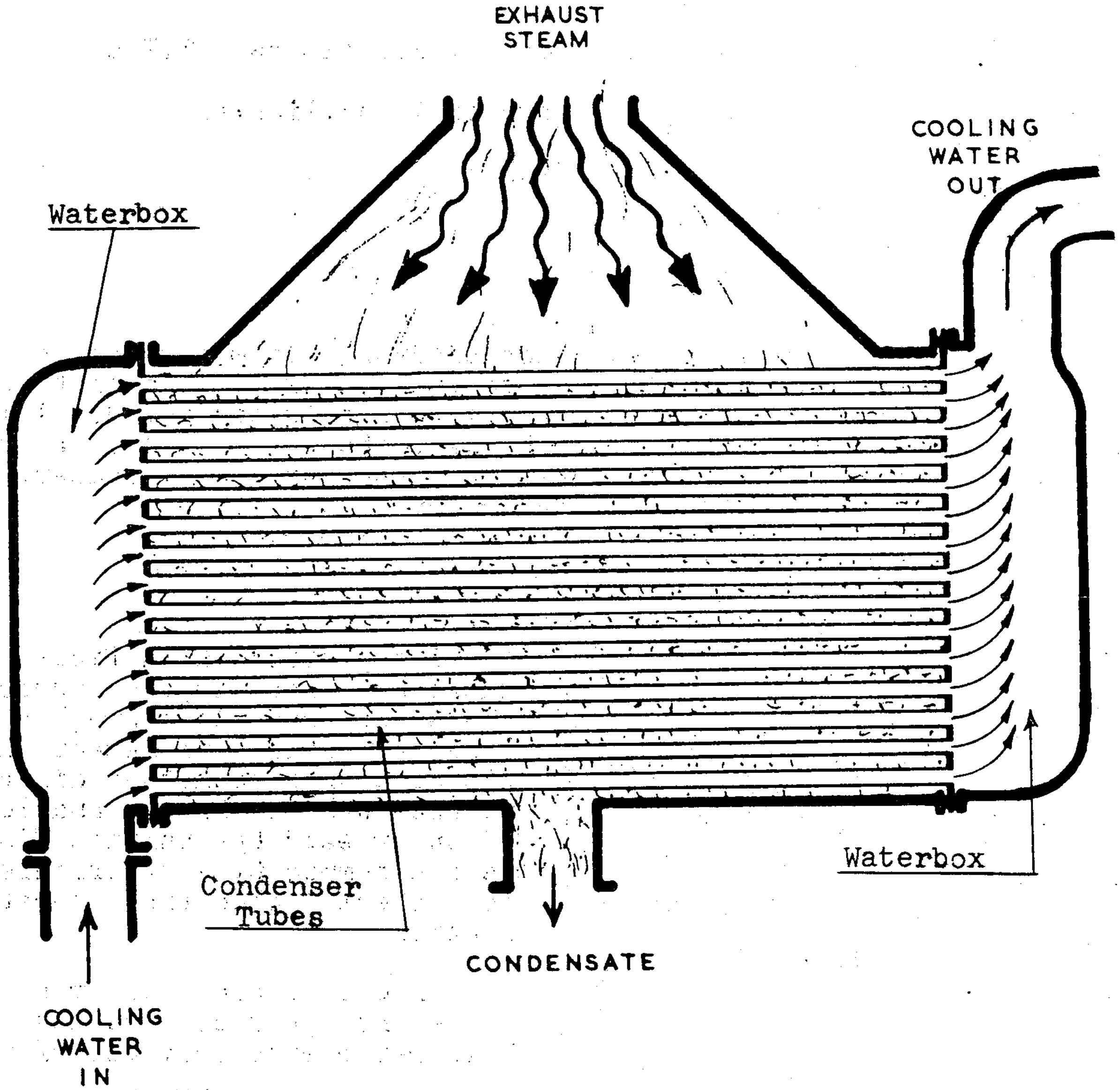

Fig. 2 Schematic view of a surface condenser.

Figure 2 depicts a schematic illustration of the flow of steam, condensate and cooling water in the condenser. Cooling water (or circulating water) taken from a river or lake, is pumped to the condenser. It enters a water box in the condenser as shown on the left hand side and flows through the condenser tubes to the waterbox on the other end. The cooling water is then discharged back to where it came from. The water keeps the outside surfaces of the condenser tubes cool at all times when the turbine is in operation.

Steam from the turbine exhaust enters the condenser at the top and flows in between the condenser tubes. As the steam passes over the cove tubes it condenses and drips down to the bottom of the condenser where it is collected in what is called a hotwell. In the surface type of condenser there is no direct contact between the steam and cooling water. When steam condenses it gives up a large quantity of heat. This quantity of heat is absorbed by the cooling water and carried away. For this reason the cooling water temperature will rise by about 20°F from inlet to outlet of the condenser.

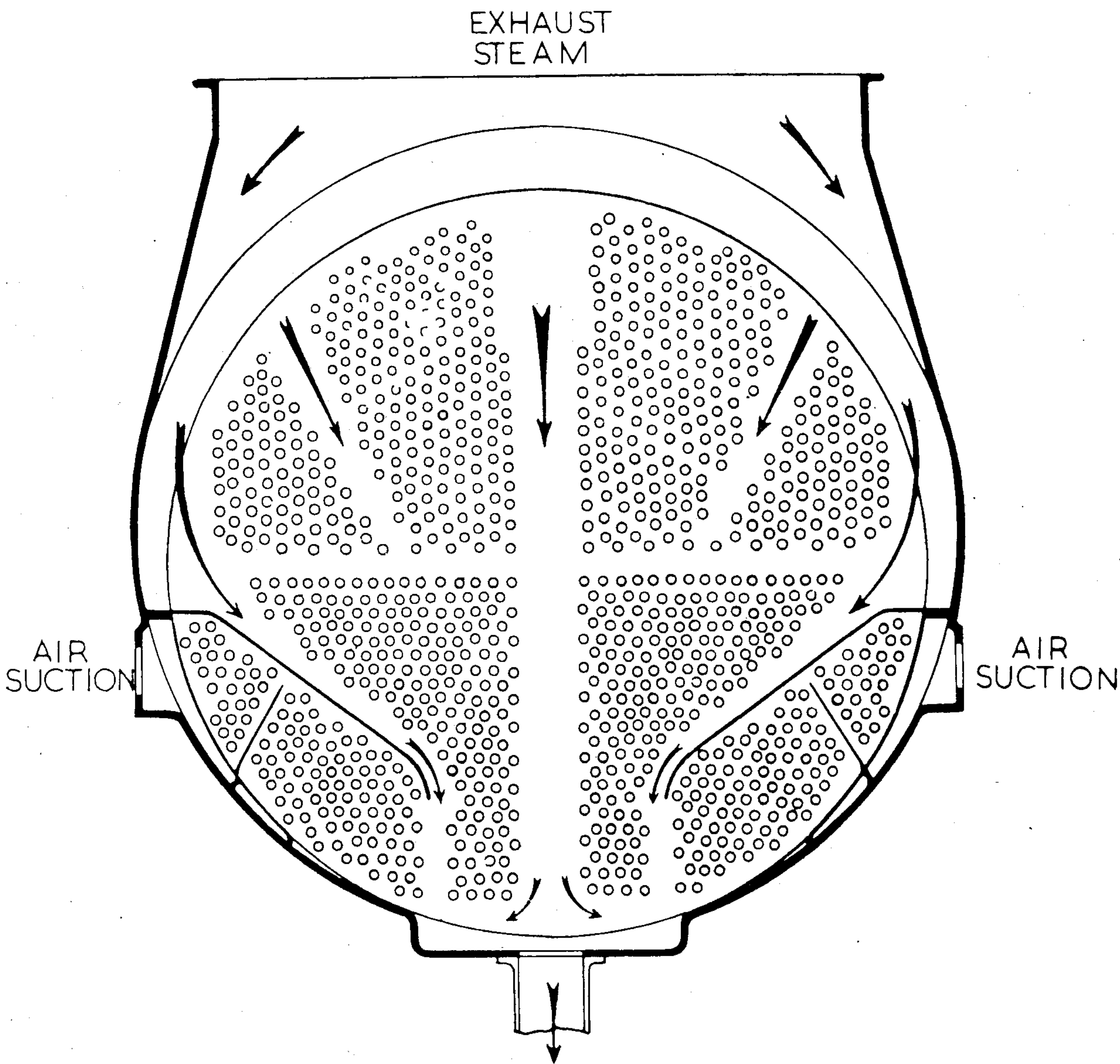

Fig. 3 Typical condenser showing arrangement of tubes in banks with wide steam lanes.

Figure 3 shows an end view of the inside of a typical condenser. Each one of the small circles represents the end view of a condenser tube. Steam can flow in all the spaces between the tubes. As you can see the tubes are arranged in groups or banks with wide lanes in between banks. If these lanes did not exist the flow of steam towards the lower part of the condenser would be restricted and the top tubes would have to do most of the condensing. With the wide lanes present, a major portion of the steam can flow right down to the bottom half of the condenser and the cooling capacity of all the tubes can be used effectively.

Air Extraction

You will notice that the condenser in Fig.3 has an air suction connection on either side. These connections are there for a specific purpose. Water generally dissolves air and non-condensible gases which can be quite corrossive to metal. Oxygen is one of the more serious offenders in this regard. Because of the near perfect vacuum conditions in the condenser there is a tendency for air to leak in at any joint which is not sealed tightly. In order to prevent the air and non-condensible gases from dissolving in the condensate they are extracted via the air-suction connections. This can be done either by means of air-jet ejectors or vacuum pumps called air extraction pumps. More will be said of this later on.

Figure 3 shows the air suction as being taken from the bottom of the condenser. This is an old design. The newer type of condensers have a suction pipe right in the middle of the condenser.

Reject Condenser

The reject condenser is also a surface condenser, but only used in some nuclear power stations. N.P.D.-2 is one example where it is being used.

In a nuclear power station, situations arise where the turbine may have to be shutdown but the reactor may not be required to be shutdown and in fact it may be an advantage to keep the reactor operating to prevent poisoning out. If a reactor poisons out it cannot be restarted for approximately 30 hours.

If the reactor is kept in operating condition, then the problem is what to do with the steam produced since the turbine is not using any. The problem is solved by diverting the steam flow to a reject condenser where it is condensed and the condensate is pumped back into the boiler again.

The reject condenser is also used during rapid unloading when the turbine doesn't use all the steam that the boiler is producing.

Conclusion

This lesson has been a brief introduction to the surface condenser. This same subject will be treated in greater detail at the T.T.3 level.

Dick Dueck

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & System Principles - T.T.4

4 - Turbine, Generator and Auxiliaries

- 5 - Surface Condenser

A - Assignment

1. Explain why the term "surface condenser" is appropriate to the piece of equipment discussed in this lesson.
2. Where are the waterboxes located in a condenser?
3. What is the purpose of the wide lanes for steam between banks of condenser tubes?
4. Why is there air extraction from a condenser?

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & System Principles - T.T.4

4 - Turbine, Generator and Auxiliaries

- 6 - Feedwater Heaters

0.0 INTRODUCTION

In the lesson on "The Closed Feed Cycle" low pressure heaters, and high pressure heaters were mentioned as part of the overall system and specifically as part of the regenerative feedheating system. This lesson will deal with feedheaters in a general way.

The terms feedheaters and feedwater heaters are interchangeable; however, it is more common to say feedheaters.

1.0 INFORMATION

The purpose of the feedheating system is to ensure that an adequate supply of feedwater at high temperature is returned to the boiler at such a rate as to maintain a normal water level in the drum. The system is also used to deaerate any dissolved air and gases (which could cause corrossion) from the feedwater.

The feedwater is generally heated to about $100^{O}F$ below the boiling temperature in the boiler drum. There are several advantages to heating the feedwater before it enters the boiler. These are as follows:

1. It improves the efficiency of the closed feed cycle.
2. It causes less of a thermal shock in the boiler if the water is hot. Cold feedwater would cause severe metal stresses in locallized areas of the hot boiler.
3. The boiler doesn't need to add as much heat to produce steam.

There are four different types of feedheaters. However, at this stage we will only mention two of them. These are:

1. The closed type
2. The open type or contact heater. It is also known as a deaerating heater.

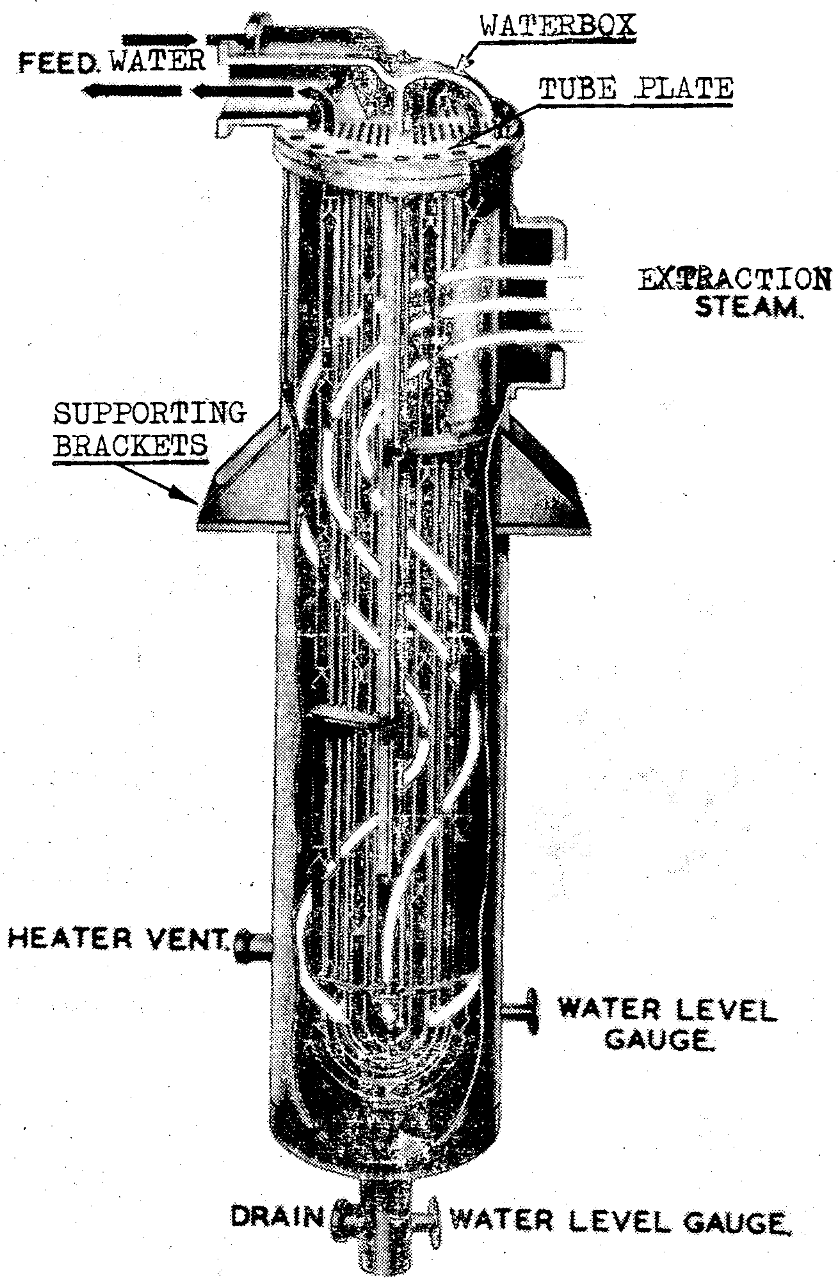

Fig. 1 Sectionalized view of typical low pressure feedheater.

The Closed Feedheater

The closed feedheater is also known as a surface type heater and consists of a number of tubes, usually U shaped, which are enclosed by a shell (a steel cover to confine the extraction steam.)

Figure I shows a sectionalized view of a closed feedheater. The tubes are fastened at their open ends to a tubeplate. A waterbox is bolted to the tube plate. The waterbox has a division wall so that the feedwater entering the heater must flow through the tubes before leaving the outlet side of the waterbox.

If you follow the arrows for the feedwater you will notice that it passes up and down the heater four times before it discharges from the waterbox. This results in more efficient heating than just two passes would.

The hot extraction steam comes from the turbine and enters the heater at the top. By means of a series of baffles the steam is made to follow a spiral path as it moves to the bottom of the heater. This is done so that the steam will flow across all the tubes in the heater and give up its heat to the feedwater most effectively.

Why does the steam flow in a steady path to the feedheater? It is because of the difference in pressure between the turbine and the steam side of the feedheater. As steam gives up its heat, it condenses and drips down to the bottom. As one lb. of steam condenses it changes from a large volume to a relatively small volume. (The same weight of water occupies a much smaller volume than the same weight of steam.) This tends to establish a void towards the bottom of the heater, which means there will be a lower pressure here than at the extraction point in the steam turbine. Therefore, as long as the feedwater flows through the heater to absorb heat and condense the steam there will be a flow of extraction steam into the heater.

The condensate formed at the bottom is drained away. However a certain condensate level has to be maintained at the bottom so that steam cannot escape through the drain and thus be wasted.

Closed type of feedheaters can be either the vertical or horizontal type. Low pressure heaters and high pressure heaters are generally similar except that the high pressure heaters have to be built much more strongly. The pressure of the feedwater in the latter heaters is higher than the boiler pressure and therefore have to be designed to take this into account. This is the reason they are called high pressure heaters.(<u>or H.P. Heaters</u>) In low pressure heaters (<u>or L.P. heaters</u>) the feedwater is at a low pressure.

Deaerating Heater

The deaerating heater is called an open type or contact heater because the heating steam comes in direct contact with the feedwater and in fact mixes with the feedwater. Figure 2 shows a sectionalized view of this type of heater. The part shown in figure 2 is generally 15 to 20 feet high depending on the size of unit.

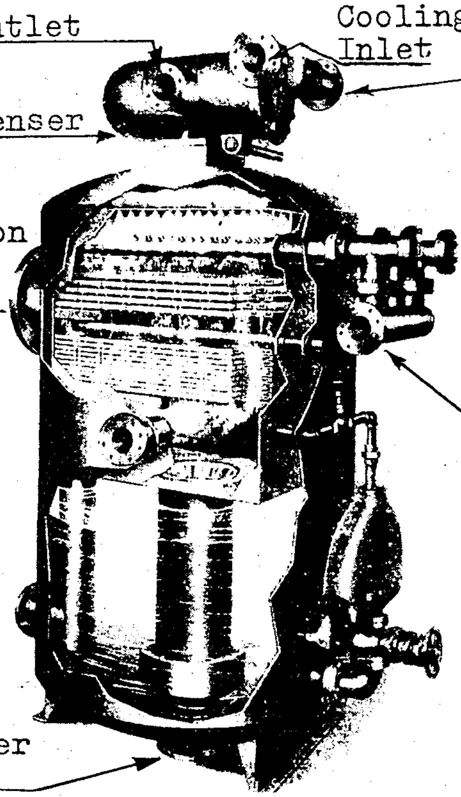

Figure 2. Tray-type deaerating heater takes in heating steam through upper left shell connection to surround inner shell. Steam enters top of inner shell to mix with feedwater sprayed from pipes. Water and condensed steam cascade over trays to accumulate at bottom of inner shell, flow into sealed storage area below.

Extraction steam enters the deaeration through the upper left shell connection and surrounds the inner shell. From here the steam enters the top of the inner shell to mix with the feedwater which is sprayed from pipes. The steam can be at a pressure of 3 psig or upwards, and heats the feedwater to 220°F or higher.

The feedwater has been deaerated in the condenser but it may still contain entrained gases such as oxygen, carbon dioxide and other gases which can be corrossive. Impure feedwater will cause frequent outages because of heater tube failures. For this reason the feedwater has to be thoroughly deaerated. At a temperature of 220°F and over, the water can no longer contain the entrained gases and they rise to the top of deaerator where they can escape, through a connection, to the atmosphere. Some steam will also rise with the gases so the steam and gases are first directed to a vent condenser to condense the steam and from there the gases pass through the gas outlet. The condensate drips down into the deaerator.

The stacks of trays in the deaerator tend to thoroughly scrub and mix the feedwater and steam as they cascade downward which aids in the deaerator process.

Before the feedwater enters the inlet at the deaerator it passes through the vent condenser and acts as a coolant here. A connection from the vent condenser then allows the feedwater to pass into the deaerator, where it is sprayed into the space above the trays.

As steam mixes with the feedwater between the trays it condenses and all the water drips downwards and collects at the bottom. A connection at the bottom leads to a reservoir tank below where the feedwater collects. The boiler feed pumps take their suction from this reservoir tank.

The disadvantage of an open type of heater is that it requires a pump to raise the feedwater pressure before it will pass on to the next heater. The advantage of the open type heater is that it can be used as a deaerator.

The deaerator is generally located about 50 ft. above the level of the boiler feed pumps to provide sufficient head to the suction side of the pumps. A low head on the pump suction would cause the pumps to become vapor locked. The pumps then lose their pumping capacity and overheat. For this reason deaerators are always located high up in a steam power station.

In our discussion on feedheaters so far we have covered three stages of feedheating--i.e. low pressure heater, deaerator and high pressure heater. For a large modern unit (say 300MW) there are generally 6 to 8 stages of feedheating. Eight stages are rare but seven are quite common. The seven would probably consist of three L.P. heaters, one deaerator and 3 H.P. heaters, although this may vary from station to station. More of this subject will be covered at the T.T.3 level.

Dick Dueck

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & System Principles - T.T.4

4 - Turbine, Generator and Auxiliaries

-6 - Feedwater Heaters

A - Assignment

1. What is the purpose of the feedheating system?
2. Describe a closed feedheater.
3. Describe how the gases are removed from feedwater in a deaerator.
4. What is the purpose of the stacks of trays in a deaerator.

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & Systems Principles

4 - Turbine, Generator and Auxiliaries

-7 - Lubrication

0.0 INTRODUCTION

The modern steam turbine and generator are carefully designed pieces of equipment constructed of well selected materials. Its satisfactory performance and useful life in service, depend among other things, on the maintenance of proper lubrication. This is one of the best insurances against turbine outage. (i.e. time periods when the turbine is shut down for maintenance or repair.)

This lesson will describe a typical lubricating oil system for a turbine generator in a power station.

1.0 INFORMATION

The lubricating oil for turbine-generators does three distinct jobs:

1. It reduces friction losses between rubbing surfaces, as in bearings, reduction gearing, and couplings, and so reduces wear and improves efficiency.
2. It aids in removing heat from the bearings which may either be generated by friction in the bearing or be conducted along the shaft metal from areas which are at high temperature.
3. It acts as a hydraulic pressure fluid. It provides relay oil to operate the governing system and power oil for the servomotors which open the steam flow control valves.

Figure 1 is a schematic diagram of a typical lubricating oil system for a turbine-generator.

Oil Circuit

Referring to figure 1 let us follow the oil circuit starting from the oil tank. The tank itself generally has a capacity of 1,000 to 2,000 gallons or more depending on the size of the unit. Pumps take suction from the oil tank through strainers and discharge the oil at high pressure.(Pressures of 80 to 120 psig are representative.)

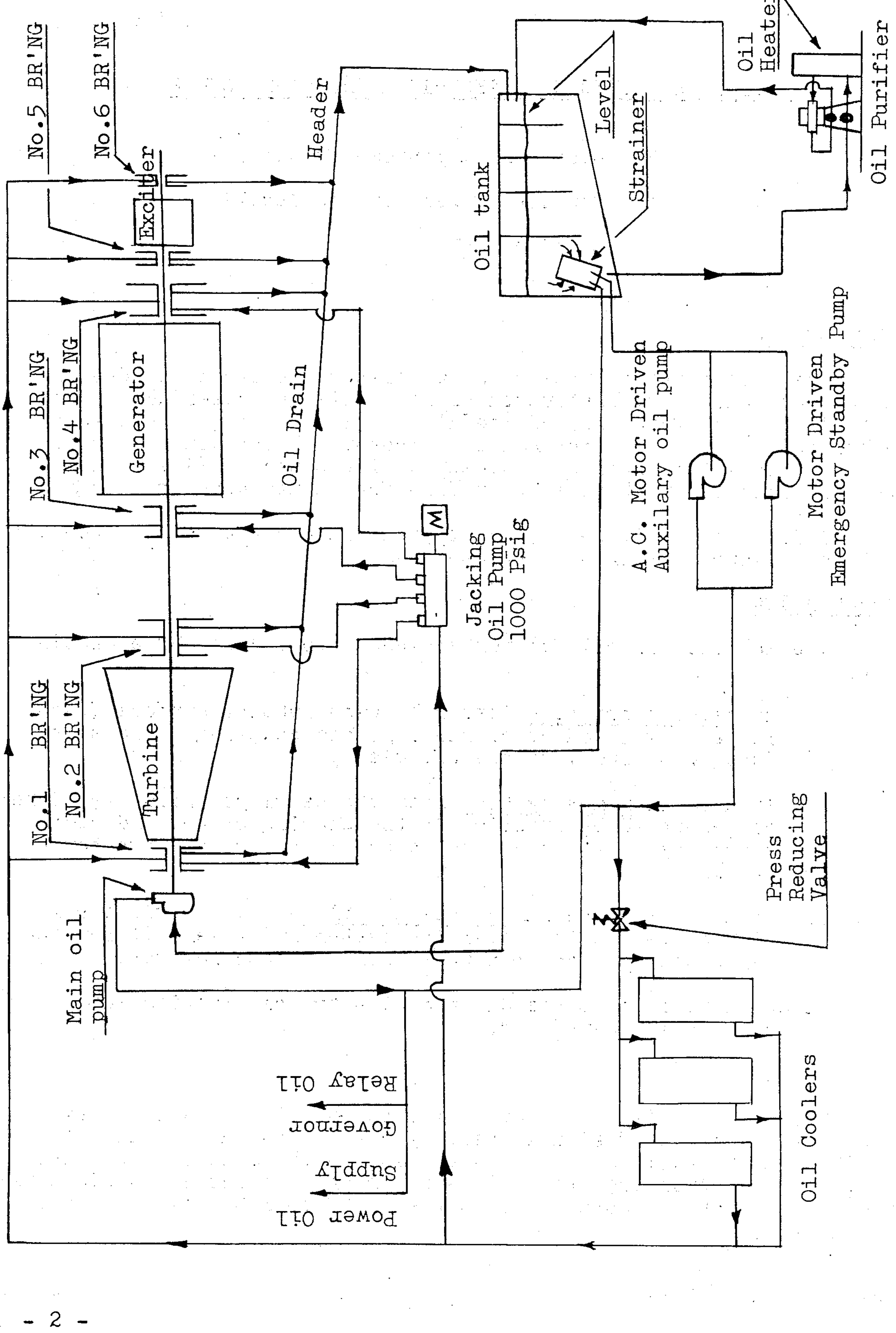

Fig. 1 Typical Lubricating Oil System

From here the oil can flow in two different directions. It can flow into the line which provides a supply to the power oil and governor relay oil or it can flow to the oil coolers and thence to the turbine generator bearings.

Power oil acting in servomotors opens the emergency stop valves and governing valves by hydraulic pressure. Governor relay oil acts as a sensitive regulating medium. Both of these have to be at high pressure. This is a very brief explanation of power oil and relay oil and more will be said about them later on in this course.

Oil that is used for lubrication does not have to be at a very high pressure. (10 to 20 psig is representative.) Therefore, before the oil passes to the coolers it flows through a pressure reducing valve. If the turbine has been operating for quite some time the oil from the oil tank will be quite warm and will need cooling before it flows through the bearings - hence the reason for the coolers. Outlet temperatures from the coolers may be in the 110-120°F range.

Inside the bearings the oil will act as a lubricant between moving surfaces and will also act as a coolant for the bearings. Note that No. 1 bearing would include the thrust bearing as w ll as a journal bearing. Thrust bearings are generally at the front of the turbine.

From the bearings the oil drains into a header which leads back into the oil tank. A thermometer is generally placed in each line draining from the bearings to indicate bearing temperature. This is quite important for reasons discussed below.

Bearings

We have said turbine bearings get hot due to friction and due to conduction along the shaft from hot parts of the turbine. The journal bearings are normally lined with white metal sometimes known as anti-friction metal or babbitt. This is a lead tin alloy and has a melting point which can be as low as 360°F. (The melting point depends on the composition of the alloy.) However, it gets quite soft long before this temperature is reached. For example the hardness number of babbitt at 212°F is less than half of what it is at 68°F. For this reason it is important that the bearing temperature does not exceed the level recommended by the manufacturer.

Normally, when the turbine is operating, the oil temperature draining away from the bearing is in the neighborhood of 140°F. Maximum allowable temperature of drain oil is around 160 to 175°F. Above this temperature there is danger of bearing failure.

A bearing failure is a very serious incident as far as the turbine-generator is concerned and could cause extensive damage. For this reason it is important to have sufficient oil flow through the bearings at all times for cooling purposes. Much more oil flow is required for cooling purposes than would actually be required for lubrication.

Note: that the temperatures and pressures given above are representative only and may well differ from this for different units. The figures given are only to give a rough idea as to the range of values we're talking about.

Main Oil Pump

The main oil pump is the one that delivers all the oil requirements for the turbine-generator at high pressure during normal operation. It is direct-driven from the turbine shaft and is generally

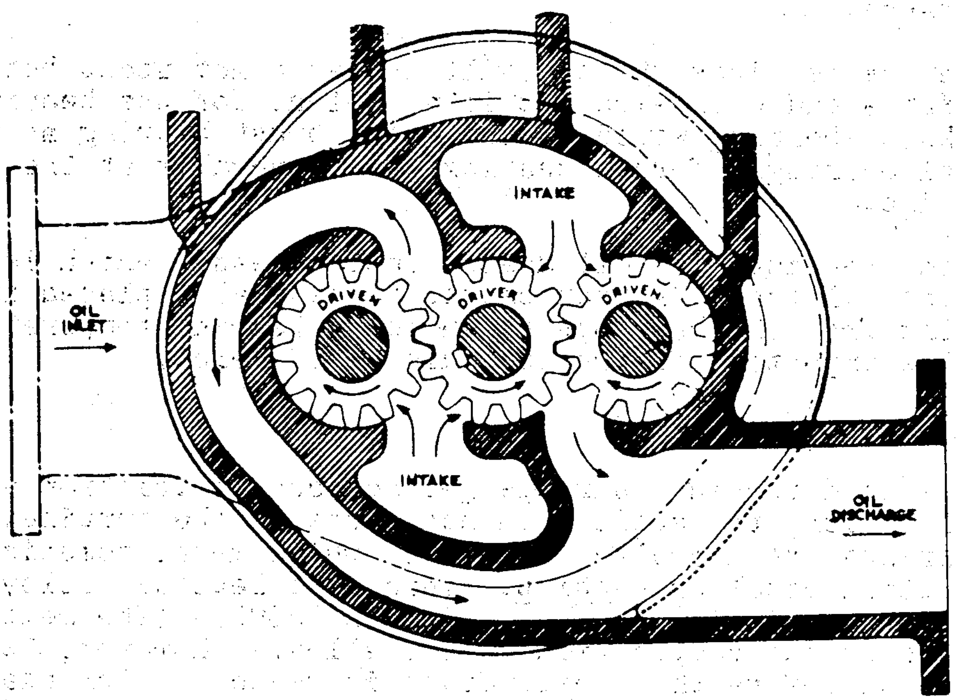

FIG. 2 - Main Oil Pump

located at the front of the turbine. For small units the main oil pump is generally a gear pump similar to the one portrayed in figure 2. For large units a gear pump may not be able to deliver the required quantity of oil at the desired pressure and in this case a centrifugal type pump is used, but it is still driven by the turbine shaft.

Auxiliary Oil Pump

The auxiliary oil pump has two functions:

1. It operates during startup and shutdown of the unit. At these times the turbine shaft is not rotating fast enough to enable the main oil pump to deliver any oil.

2. It acts as a standby. If the main oil pump fails for some reason or other the auxiliary oil pump would instantly start up automatically. This is for reasons discussed under the heading "Bearings". Therefore the pump must be of a size to be able to deliver enough oil for all requirements of the system. (The pump is started and stopped by a pressure switch in the main oil supply line. A drop in pressure in the main oil line will start the pump.)

The auxiliary oil pump is normally driven by an A.C. electric motor, although sometimes it is driven by a small auxiliary steam turbine.

Emergency Standby Pump

Since it is very vital to have an oil supply to the bearings, units generally have a second standby oil pump called an emergency standby pump or turning gear oil pump. This pump is started automatically by means of a pressure switch located in the line supplying oil to the bearings.

When would this pump be used? In a situation where the turbine trips and the normal A.C. power supply is not avialable, the auxiliary oil pump would fail to start. However, from full speed the turbine rotor takes about 20 to 30 minutes to come to rest. During this time the bearings need lubrication. In such a situation the emergency standby pump would start. The power supply to the driving motor of this pump must be very reliable as this is the last line of defence to save the turbine from damage. It is normally supplied from either D.C. batteries or from the most reliable A.C. power.

Since this pump only supplies enough oil for lubricating the bearings its capacity is quite a bit smaller than the main oil pump or the auxiliary oil pump.

This pump is also often used when the turbine is on turning gear - hence the name turning gear oil pump.

To summarize, this pump has two functions:

1. As an emergency standby pump.
2. As a turning gear oil pump.

Jacking Oil Pump

This pump is generally used for large turbine-generators only, and at that only during the first several rotations of the shaft.

When the heavy turbine-generator shaft is at rest it will squeeze the oil film away from underneath itself at the bearings. If the shaft is then rotated there will be metal to metal rubbing until the oil can work its way underneath the shaft.

To avoid this type of situation the jacking oil pump injects oil at high pressure (around 1,000 psig.) into the bearings at the bottom of the shaft; this tends to lift or jack the shaft a few thousandth of an inch so that there will be no metal to metal contact during initial rotation. Once an oil film has been established it can be built up due to the rotation of the shaft and the jacking oil pump is no longer required. Hence it runs for about 15 seconds and then shuts down.

Notice that the jacking oil pump in figure 1 takes its suction from the oil line supplying the bearings. This means that the auxiliary oil pump must be running before the jacking oil pump comes into operation. The lines to the bearings from the jacking oil pump are only 1/8" to 1/4" inside diameter since the oil flow required is small. The pump itself consists of a series of reciprocating type plungers similar to a diesel pump.

Oil Purifier

After being in service, lubricating oils of turbines become contaminated with water, soluble impurities and deposits known as "sludge". Sludges form after an oil has been in use for considerable time and are due to changes resulting from exidation, foreign matter and emulsions.

Water, soluble impurities and sludge can be removed from the oil by means of a centrifuge. Figure 1 shows an oil purifier schematically and figure 3 shows a sectional view of an oil purifier bowl, which acts as a centrifuge.

The purifier takes dirty oil from the bottom of the oil tank, cleans it and returns it to the main oil tank again as shown in figure 1.

Referring to figure 3 dirty oil enters the bowl at the top. (This bowl is rotating at around 15,000 rpm.) The oil flows downward into spaces "B" and then through holes "C" to area"D", where there are a series of stacked platelets whirling around at shaft speed. The oil is flung outwards here due to centrifugal force. However, since the sludge and water have a higher specific gravity

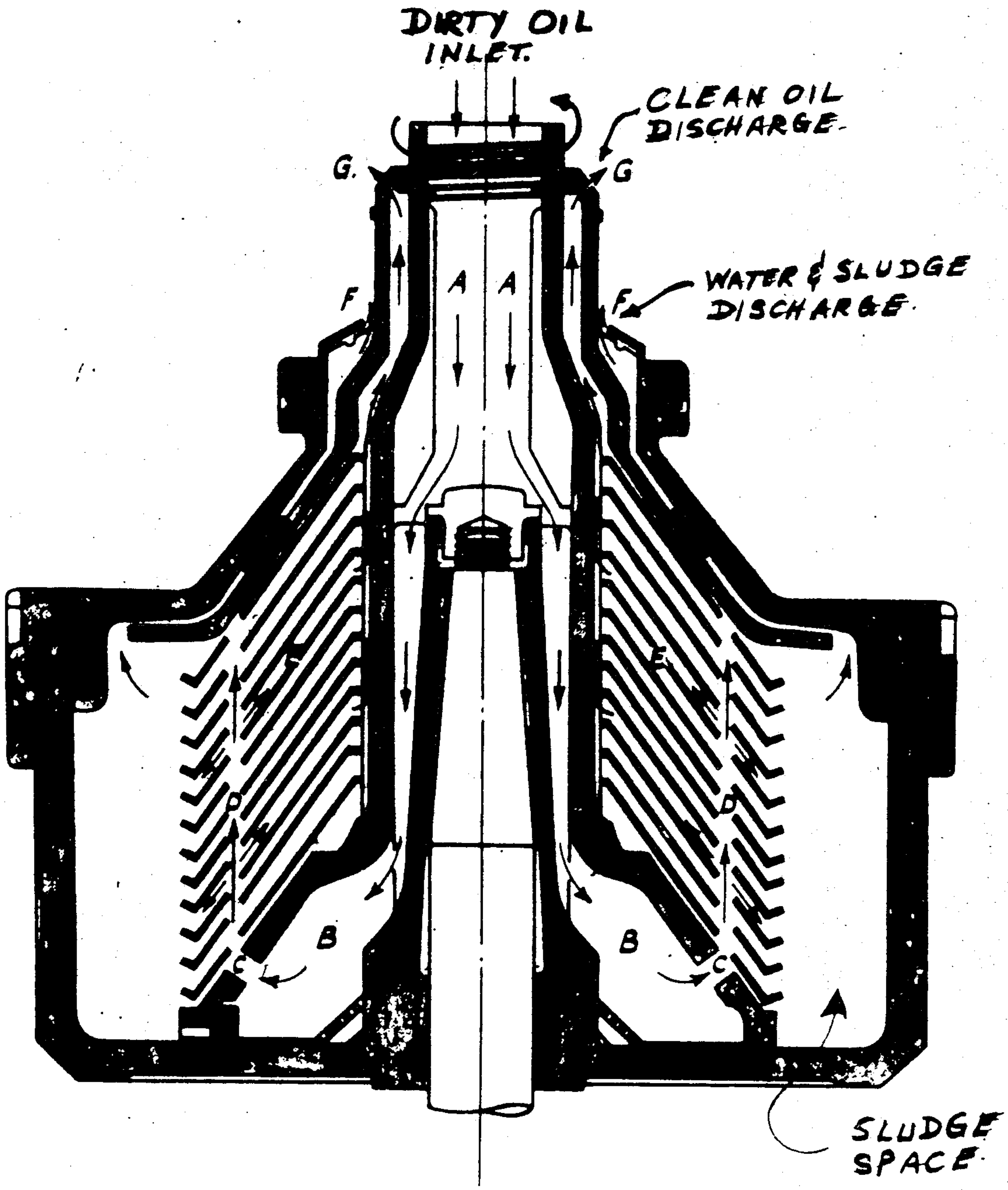

FIGURE 3 - Sectional View of Oil Purifier Bowl.

than oil, they will be flung outwards farther. Hence, the clean, lighter oil will be forced through spaces "E" and upward through openings "G" and from there back to the oil tank. The sludge and water will collect near the outside surface of the bowl and will be forced out through openings "F" and collect at the bottom of the purifier. This sludge has to be removed at regular intervals.

The oil may be heated before it enters the purifier since this makes it more fluid and improves the separation of impurities from the oil. Also water may be deliberately added to the oil before the purifier to dissolve impurities. All the water, of course, is centrifuged from the oil before it is returned to the system.

Centrifuges of sufficient capacity to purify all the oil in the system once every 6-10 hours, are normally installed.

It is also normal practice to run the purifier before start-up to clean the oil and preheat the oil in the storage tank before starting the turbine.

The oil in the lubricating system is normally changed at intervals of several years and it is the efficient operation of the oil purifier which permits such lengthy periods of operation between oil changes.

D. Dueck

NUCLEAR ELECTRIC G.S. TECHNICAL TRAINING COURSE

3 - Equipment & Systems Principles - T.T.4

4 - Turbine, Generator and Auxiliaries

-7 - Lubrication

A - Assignment

1. Name the three jobs done by lubricating oil for a turbine-generator.

2. Why is it important to have sufficient oil flowing through the bearings at all times?

3. Briefly what is the purpose of each of the following pumps:

    a) Main oil pump.
    b) Auxiliary oil pump.
    c) Emergency standby pump.
    d) Jacking oil pump.

4. Briefly what function does the oil purifier perform?