COOLING WATER SYSTEMS
FOR HYDROPOWER STATIONS

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1 INTRODUCTION

The generating plant in a hydro station is supported by auxiliary systems that provide cooling water, pressure oil, auxiliary power and other services. There are many options for the design of these auxiliary systems. Auxiliary systems can have a major effect on the cost, reliability and efficiency of the generating plant and hence must be carefully designed.

The design of auxiliary systems is often left to the generating plant manufacturer. The primary aim is then providing a low cost system that works well enough to pass the acceptance tests.

Sometimes the system is specified carefully and in extreme detail by the engineer, but all to often and especially in small schemes, the system specified is complex, expensive and difficult to maintain.

This paper discusses cooling water systems. A later paper will consider other mechanical and electrical auxiliary systems.

2 SOURCES OF COOLING WATER

2.1 General

Most hydro electric generating sets need cooling water for bearings, generator air coolers and governor oil coolers. The basic requirement is for a supply of clean water at 3-10 m head in sufficient quantities. The water should be available when the set is running and should be shut off when it is stopped.

The water can be:

- pumped from the tailrace;
- tapped off the penstock;
- supplied by an auxiliary turbine;
- taken from the turbine cover.

2.2 Tailrace

Pumping from the tailrace requires two pumps per set (one duty and one standby) and a reliable power supply. It is expensive in terms of the power consumption of the pumps and the piping installation. Unless the water is very clean, self-cleaning filters will be required. If the station is on a river that carries large amounts of debris during floods, blockage of the pump intake filters is a potential problem. In most cases, a backup

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supply from the penstocks is provided to guard against blockages and failures of the power supply to the pumps. A typical system is shown in figure 1.

For reasons given below this is often a satisfactory solution for high head stations.

2.3 Penstock

Tapping cooling water off the penstock is the best option for low head stations. It is important to locate the tapping point on the side of the penstock; if it is at the top, it tends to get blocked by floating debris and if it is on the bottom, (often done because it is convenient to tap off the penstock drain), it can ingest silt, stones and other debris.

On medium and high head stations, careful design is required. The penstock pressure is greater than the cooling system can withstand, so some means of pressure reduction is required. At medium heads (<30 m) pressure reducing valves or orifices can be used and provide a very satisfactory solution. At higher heads, the energy dissipation in the valve or orifice will be high and cavitation damage and erosion can be expected. If the water is silty, erosion rates can be very high. This can lead to failure of the valve which imposes excessive pressures on the cooling system. So the extra complication of a pressure relief valve is needed, as shown in figure 2.

Alternatively, orifices can be used to reduce the pressure. If they are used, it is important to have one orifice for each cooler to make it easy to control flows. and to avoid isolating valves downstream of the cooler. (Because, if the valve is left closed, the cooler will be subject to full penstock pressure which is likely to burst it.)

A major objection to this system is that it robs the turbine of valuable water. To give an example, a 100 MW station at 100 m head would need about 150 l/s of cooling water. This represents a loss of generation of about 130 kW. If power is worth 10¢/kWh, the loss of revenue is in the range of $50-100,000 pa. The loss can be reduced considerably by controlling the water flow through the generator coolers according to outlet temperature. (This has the additional advantage of eliminating the risk of condensation on the generator coolers if the water temperature is very low.)

2.4 Auxiliary turbine

Installing an auxiliary turbine driving an induction generator which discharges into a head tank 5 - 10 m above the generator is a simple and reliable solution. The turbine output is controlled by the level in the head tank. This recovers the energy, settles out silt and reduces the pressure. In a multi machine station, it is wise to provide a backup supply via a pressure reducing valve so that the auxiliary generator can be shut down for maintenance. This configuration is illustrated in figure 3.

2.5 Tapping from the turbine cover

If Francis turbines are used, the water which leaks through the runner labyrinth seals into the top cover can be used for cooling. In our experience, this is the simplest and most efficient way of obtaining a reliable supply of filtered cooling water, and it can used over the full head range of the Francis turbines. Yet, almost every time we have wished to use it, we have had to put a lot of effort into persuading manufacturers to accept it.

The basic principle is sound. Leakage through the labyrinth seals is about 0.5% of the flow through the turbine. As the water has leaked though a gap of about 0.8mm it is already filtered. A 100 MW turbine at 100 m head would have a leakage flow of about 500 l/s, more than enough for the 150 l/s cooling flow required. On many turbines the design pressure in the turbine cover is between 2 and 10 m, which is ample for supplying cooling water; on others, it is possible to increase the pressure. Where the turbine manufacturers normally use an external balance pipe from the cover to the draft tube, it is easy to connect it to the cooling system. If balance holes in the runner are proposed, the manufacturer must be persuaded to provide a cover drain instead.

There does not appear to be a uniformly accepted philosophy for the regulation of cover pressure. Cover pressure has a major effect on turbine thrust and increases as the labyrinths wear, so one would expect it to be closely monitored and controlled. Yet some manufacturers simply provide drain holes in the runner. Others provide balance pipes with orifice plates that are carefully adjusted during commissioning, and seldom mention that the orifices should be adjusted as the labyrinths wear. Others provide valves in the balance pipes; a most dangerous practice because the thrust bearing will almost certainly be overloaded and fail if someone inadvertently turns the valve off! In our experience, cover pressure gauges are seldom provided.

The basic system we use for providing cooling water from the turbine cover is shown in figure 4. The cover drain is connected to a standpipe with an overflow. The piping is sized for the largest leakage flow expected with worn labyrinths (about twice the flow with new labyrinths). The overflow is set at a level which provides sufficient head for the cooling system. Cooling water pipes are directly connected to the standpipe at any convenient position. Individual outlet pipes are used to make it easy to observe and check cooling water flows. Isolating valves are avoided wherever possible to minimise head loss and to eliminate the possibility of inadvertent closing. Flow switches are not used because of their head loss and low reliability. Instead, RTDs are used to monitor the outlet temperature of the air or oil being cooled, giving an alarm if the cooling water fails or the coolers have become fouled.

An incidental advantage of this system is that it provides constant cover pressure and loading on the thrust bearing regardless of the load and the wear on the labyrinths.

Many engineers have reservations about this system when they are first introduced to it. Common reservations are:

- *there is no cooling water flow until after the turbine has started but you must not start the turbine until cooling water is flowing*

  leakage into the turbine cover is inherent in the operation of the turbine so cooling water will always be available when the set starts; therefore it is not needed as a pre-start condition;

- *at low loads the flow will be low, so (a) you will not get the design cooling water flow, and (b) the cooling water flow fail alarm will come up*

  (a) at low loads, the turbine and generator do not need much cooling water flow (b), we don't have cooling water flow switches;

- *you must have a cooling water filter and its head loss will push the cooling water pressure too high*

  the water is filtered by the labyrinths so we do not need another filter;

- *the cover water is very turbulent, so you can't use it for cooling*

  the use of a stand pipe eliminates problems with turbulence.

One valid objection is that with a vertical turbine the cover pressure required to get cooling water up to the generator coolers and top bearing can be too high. If this is the case, a simple booster pump is easy to install. Alternatively, cooling water pressures can often be reduced by:

- generous sizing of cooling water piping and fittings;
- connecting coolers in parallel instead of series;
- refusing to believe manufacturers when they say that cooler head losses are more than a few metres and asking them to check with the original supplier;
- paying a little extra for low head loss coolers.

It is worth remembering that cooling water from the headcover is free. So high flow, low headloss coolers are preferable to the low flow, high head loss coolers which should be used when cooling water is valuable.

3 COOLING SYSTEMS

3.1 Generator Cooling

As a first approximation, generators require a cooling water flow of about one litre per second per MVA. The design temperature rise of the water is usually between 5 and 10 °C. The coolers must be designed to cope with a certain amount of fouling (at least 10%) and it should be possible to clean the cooler tubes easily by removing the headcovers.

Vertical generators have coolers mounted around the stator and are fed by a ring pipe. It is normal to have one more cooler than is needed so that the generator can be operated at full load with one cooler removed for maintenance.

The location of coolers on horizontal generators needs to be considered carefully. It is common practice to install them beneath the generator. In our experience, this is most undesirable because:

- access for cleaning is very difficult;
- the size of the generator pit must be increased which is expensive in terms of excavation and foundations;
- the cooling system may interfere with the generator terminals and connections;
- it is difficult to remove the coolers for servicing or replacement.

Pannier (side) mounting or top mounting eliminates the above problems. Top mounting is often the simplest and best arrangement provided that drip trays are installed to prevent leakage or condensation water dripping onto the windings.

Specifications must include a water analysis so the cooler manufacturer can select materials that will not corrode.

3.2 Bearing Cooling

Bearing cooling requires 25-50% of the cooling water needed for the generator air cooler.

Bearings can be cooled by coolers integral with the bearing or by separate coolers. If separate coolers are used, it is easy to install a temperature controlled oil bypass system which regulates the outlet temperature of the oil to avoid over-cooling when starting up after a cold night. If integral hairpin coolers are used with silty cooling water, we have found that it is wise to regulate cooling water flow to limit water velocities and hence erosion of the tubes.

If it is difficult to obtain a supply of clean water an option for small units is to use an air to oil heat exchanger and so eliminate the need for cooling water.

3.3 Governor Oil Cooling

Governor oil usually needs cooling to dissipate the heat resulting from oil flowing through pressure reducing valves and leaking through clearances in the valves and servo motors. The need for cooling can be reduced or eliminated by using unloading valves or pressure controlled pumps instead of relief valves.

If cooling is needed, the general principles mentioned above for bearings also apply.

3.4 Runner Labyrinth Cooling

If the generating set is used for “spinning reserve” or as a synchronous condenser with the runner spinning in air, large amounts of heat can be generated by the churning of the air in and around the runner and the labyrinth gaps. If the runner heats up by more than about 20°C, there is a danger that it will expand and the labyrinth seals will rub. If this happens, the turbine could be seriously damaged. To prevent this, cooling water must be supplied to the runner labyrinth seals.

The cooling water can be taken from the normal cooling water supply via a control valve. For monitoring, either the flow can be monitored or, preferably, the temperature of the turbine cover can be monitored adjacent to the seal. The alarm and trip settings should be just above the highest expected water temperature to ensure early detection of the malfunction.

If twin horizontal Francis turbines are used, in a configuration where one or both turbines are in service, labyrinth cooling is easily supplied simply by cross connecting the labyrinths.

3.5 Cooling Water Piping

Cooling water piping should be amply sized and long lasting. It should be run so that it is easy to replace. Low points in piping that must be removed when the turbine or generator is being overhauled should have drains to avoid flooding when joints are dismantled.

Often cooling water piping is made of black iron pipe and buried in concrete. When the steel corrodes, water appears in the most mysterious places! Galvanizing the pipe is sometimes satisfactory but it has only a short life if the water is acidic.

In our experience pipe made from ABS, fibreglass, rigid PVC or stainless steel is best.

In areas of high humidity, piping in generator enclosures should be insulated or made of non-metallic material in order to guard against condensation.

3.6 Filtration

Cooling water filters are a potential source of trouble - especially if they are undersized. If the station is unattended, automatic self-cleaning filters should be used. These should be selected with care as any breakdown shuts the unit down.

If duplex manually cleaned filters are used, automatic change-over is preferable. At the very least, they should be generously sized and a differential pressure switch should be used to give an early alarm of impending blockage.

4 SEAL WATER

Most mechanical turbine shaft seals require a supply of cooling and flushing water of drinking water quality. The water pressure must be higher than the pressure upstream of the seal to prevent silty water entering and damaging the seal. Filtering penstock water to drinking water standard is not easy if it is dirty or silty. If the filter blocks, the turbine must be shut down to avoid damaging the seal and the sealing faces.

Wherever possible, seal water should be taken from a supply of clean water. One option is to use drainage water from the dam or the powerhouse foundations. Unless the dam is about to fail, leakage water must be clean. If it is not, the seal water filter will block and trip the set, thus effectively monitoring the safety of the dam.

The seal water problem can be eliminated by using labyrinth shaft seals which do not need a water supply unless the unit is operating dewatered in synchronous condenser mode.

5 CONCLUSION

The design of cooling systems should not be left to the manufacturers of the main generating plant. The site conditions, the water quality, the type and size of the unit, and the premium on overall efficiency and reliability all influence the optimum design.

In general, as with most things, the simpler the better. In particular, always consider spending money and effort on eliminating potential sources of trouble rather than on installing equipment to monitor them.

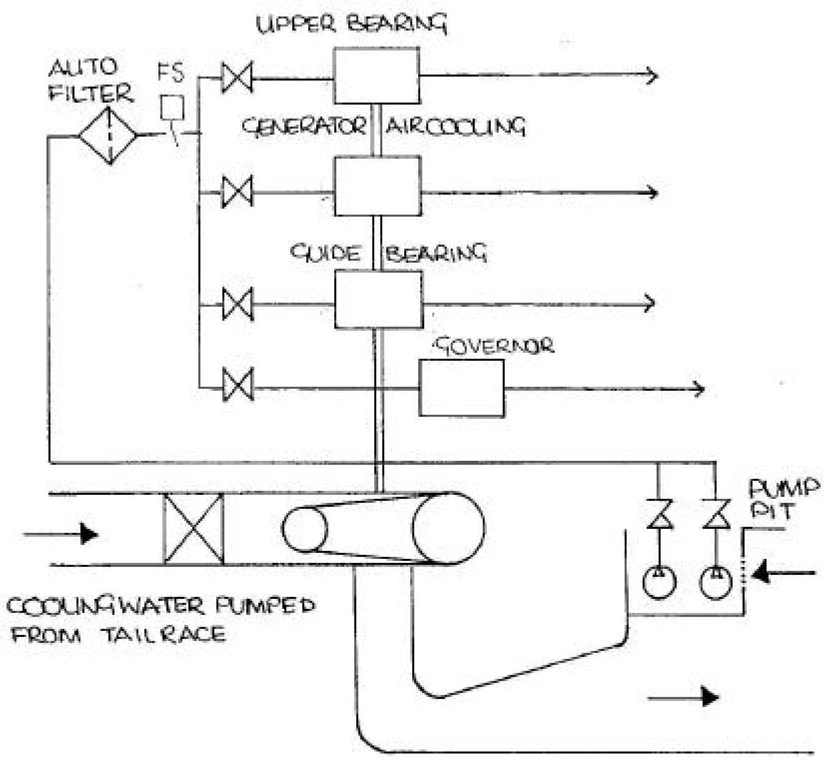
UPPER BEARING
AUTO FILTER
FS
GENERATOR AIRCOOLING
GUIDE BEARING
GOVERNOR
PUMP PIT
COOLING WATER PUMPED FROM TAILRACE

FIGURE 1

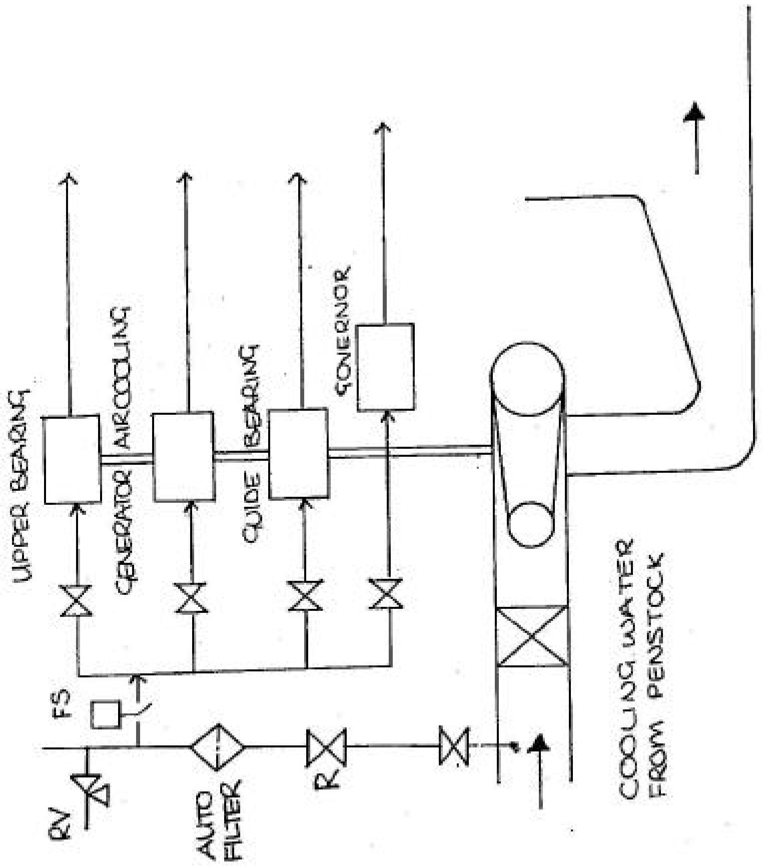
UPPER BEARING
GENERATOR AIRCOOLING
GUIDE BEARING
GOVERNOR
FS
RV
AUTO FILTER
R
COOLING WATER FROM PENSTOCK

FIGURE 2

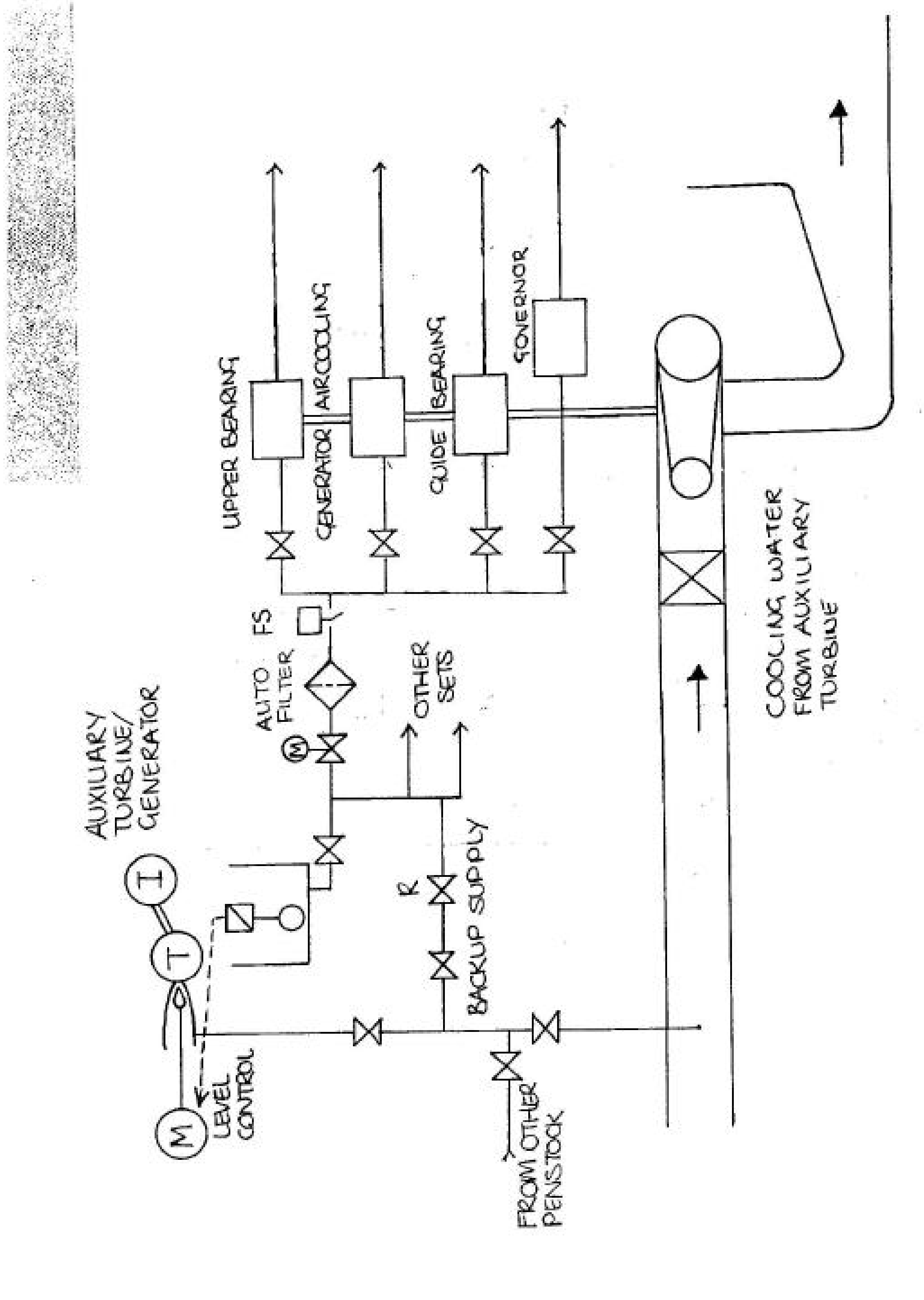
UPPER BEARING
GENERATOR AIRCOOLING
GUIDE BEARING
GOVERNOR
FS
AUTO FILTER
OTHER SETS
AUXILIARY TURBINE/ GENERATOR
I
T
M
R
BACKUP SUPPLY
LEVEL CONTROL
FROM OTHER PENSTOCK
COOLING WATER FROM AUXILIARY TURBINE

FIGURE 3

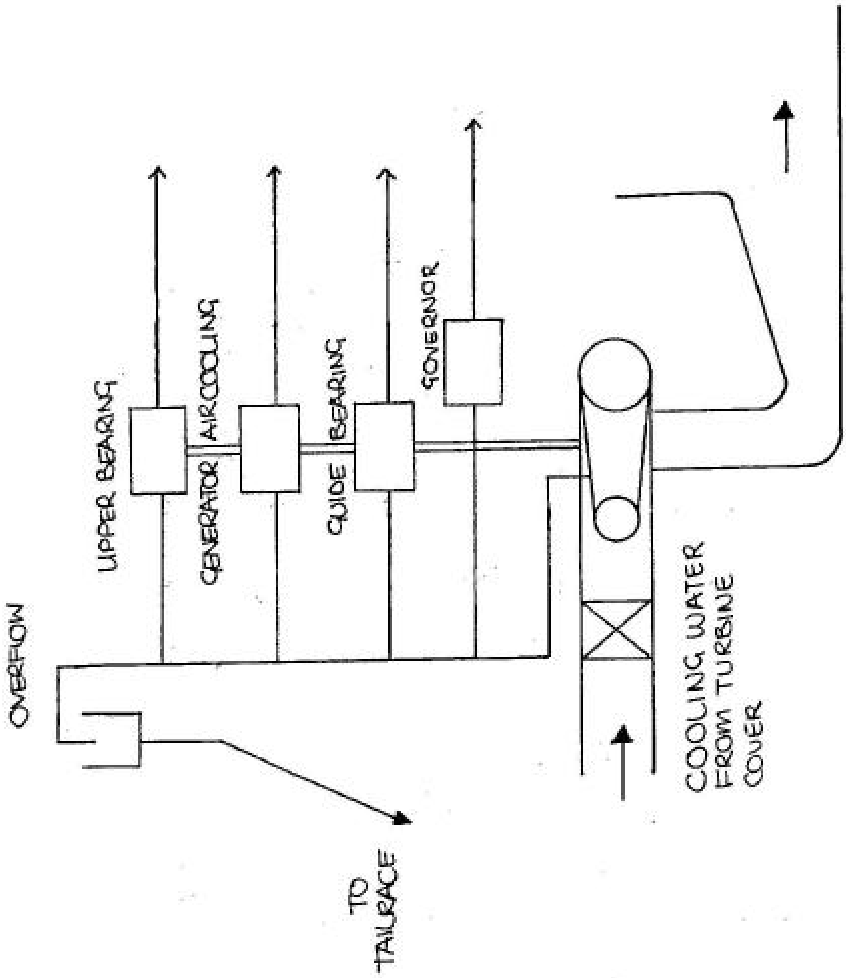
UPPER BEARING
GENERATOR AIRCOOLING
GUIDE BEARING
GOVERNOR
OVERFLOW
TO TAILRACE
COOLING WATER FROM TURBINE COVER

FIGURE 4