NOTES & REFERENCES

Module 234-4

AUXILIARY STEAM SYSTEMS

OBJECTIVES:

After completing this module you will be able to:

4.1 a) For each of the two types of the reheat system, explain how the flow of reheater heating steam is regulated through the whole range of turbine load. ⇔ *Pages 3-4*

b) Explain the reason why reheating must be limited during turbine startup and operation at light loads. ⇔ *Page 4*

c) State three reasons why reheaters should be valved in (out) slowly. ⇔ *Page 5*

d) State the operating concern caused by exceeding the limit on the side-to-side steam temperature difference at the LP turbine inlet. ⇔ *Page 5*

4.2 a) For each of the two types of the reheat system, describe how the normal drains level is controlled. ⇔ *Page 6*

b) State the automatic actions triggered by improper reheater drains level: ⇔ *Pages 6-7*

i) Too high a level (4);

ii) Too low a level (2).

c) Describe the adverse consequences/operating concerns caused by improper reheater drains level: ⇔ *Pages 6-8*

i) Too high a level (3);

ii) Too low a level (2).

d) List two causes of each of the following reheater drains level upsets: ⇔ *Pages 8-9*

i) Too high a level;

ii) Too low a level.

4.3 a) Describe three adverse consequences/operating concerns caused by a significant loss of reheat if no corrective action is taken. ⇔ *Pages 9-10*

NOTES & REFERENCES

Pages 10-11 ⇔

b) i) State two actions which minimize two of these consequences.

ii) Explain how these actions achieve it.

4.4 For a reheater tube leak:

Pages 12-13 ⇔

a) Describe four adverse consequences/operating concerns caused by a large leak;

Page 13 ⇔

b) State three operator actions to minimize or prevent these consequences;

Pages 13-14 ⇔

c) Describe one method of detecting a small leak and two additional indications of a large leak.

Page 14 ⇔

4.5 State two operating practices used in the reheat system to prevent water hammer.

Pages 15-16 ⇔

4.6 State three reasons why attemperating sprays must be valved in when the gland exhaust condenser is unavailable.

Pages 17-18 ⇔

4.7 a) Describe two adverse consequences/operating concerns caused by overheating of the LP turbine exhaust.

Pages 18-19 ⇔

b) i) List four important operating parameters that should be carefully monitored while operating in a condition that promotes overheating of the LP turbine exhaust.

ii) Explain why each of these parameters should be monitored.

Page 19 ⇔

c) State two general operator actions that can be taken if heating of the LP turbine has reached a point such that lack of action could result in turbine damage.

Pages 19-20 ⇔

d) State the operating concern caused by excessive use of the LP turbine exhaust hood sprays.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

In this module, the following auxiliary steam systems are discussed:

- The reheat system;
- The gland steam sealing system*;
- The LP turbine exhaust cooling system.

* In some stations, the name of this system is slightly different. Examples: the turbine gland steam system, the gland steam system or the gland sealing system.

The previous turbine courses describe the major functions and the layout of these systems, as well as the functions of their major components. Based on this general knowledge, this module discusses operation of these systems. In the discussion, emphasis is placed on operational upsets.

For your convenience, simplified flowsheets of these systems are attached to the module end. The appropriate flowsheet can be pulled out and kept in sight for easy reference.

Due to inherent station specific differences, the information presented in this module is only generic and does not cover all variations.

THE REHEAT SYSTEM

Recall that two different types of this system are used in CANDU stations:

- Live steam reheat systems where boiler steam is the only heat input;
- Two-stage reheat systems where two different heat inputs are used: HP turbine extraction steam in the first stage, and boiler steam in the second stage.

The first pullout diagram (on page 29) shows both these systems. For simplicity, part a) of this diagram shows steam supply to only one reheater. Likewise, part b) illustrates only one two-stage reheater with its steam supply and drainage equipment. The remaining reheaters are equipped identically.

In this module, you will learn about the following aspects of reheater operation:

- Reheating steam flow control;
- Drains level control;
- Effects of loss of reheat on unit operation;
- Reheater tube leak;
- Water hammer.

Reheating steam flow control

⇔ Obj. 4.1 a)

In both types of reheat system, the **reheating steam flow changes with turbine load.**

1. **In live steam reheat systems and the second stage of the two-stage reheat systems**, this happens as follows.

   At high turbine loads*, the reheating steam flow is self-regulating. What it means is that the flow adjusts itself to turbine load. No control

* Typically, above 50-60% FP.

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valve takes part in this process, ie. all valves in the steam supply piping stay fully open. Here is how this self-regulation happens.

At any steady load, only as much steam enters the reheater as condenses inside the tubes. The rate of condensation depends on, among other factors, the turbine steam flow rate. In the extreme case, where no steam flows through the turbine, the rate of condensation is, in principle, zero and hence no reheating steam is taken. When the turbine load increases, so does the rate of heat transfer through the reheater tubes because more turbine steam flows through this heat exchanger. If the rate of condensation exceeds the flow of incoming reheating steam, the pressure inside the reheater tubes drops. As a result, more steam is drawn through the reheater steam supply piping until a new equilibrium is established.

* Pressure losses in the piping are only about 3-5% of boiler pressure at full power, and less at partial loads.

The pressure drop that is necessary to increase the reheating steam flow is very small* because the reheater steam piping has a very small resistance to flow. This is achieved by proper sizing of the piping such that steam velocity is kept reasonably low.

The opposite changes in the reheating steam flow occur when the turbine load decreases.

* A more detailed description is given in module 234-6.

The above description is somewhat simplified*. In reality, any factor that influences heat transfer across the reheater tubes (eg. tube flooding), changes the rate of condensation of the reheating steam, and hence its flow. Note that some other heat exchangers (eg. feedheaters) exhibit this self-regulating feature, too.

Obj. 4.1 b) ⇔

* Typically, below 20-30% FP.

At light turbine loads*, the reheating steam flow is isolated (except for startup, when a small flow of steam is admitted to prewarm the reheaters). This is done **to prevent overheating of the LP turbine exhaust**. Recall from the previous turbine courses that during turbine startup and at very light loads, the LP turbine exhaust steam can be superheated, even if no reheat is used. As steam wetness is not a problem during these operating states, there is no need to use the reheat. Its use would only aggravate the LP turbine exhaust overheating which, if excessive, could damage the turbine*.

* Details are on pages 17-18.

As to the reheat operation **at medium turbine loads, the reheating steam flow is throttled**. The opening of the control valves gradually increases with rising load*. During turbine unloading, the valves close over a similar range of turbine load. Depending on the station, the valves are controlled either by the operator or automatically. In the latter case, a turbine steam pressure (eg. at the HP turbine exhaust) is used as a measure of turbine load.

* Usually, the control valves are fully closed at about 20-30% FP, and fully open at 50-60% FP.

NOTES & REFERENCES

Because the control valve position is linked to turbine load – whose rate of changing is limited during turbine startup and power manoeuvres – the **reheaters are valved in/out gradually**. ⇔ *Obj. 4.1 c)*

This has the following **advantages**:

- Thermal stresses in the reheaters and LP turbines are minimized:
- Abrupt changes in reheater drains flow are avoided, which facilitates drains level control;
- As the reheater steam and drains flows change gradually, their disturbing effect on boiler pressure and level control is minimized.

2. **In the first stage of two-stage reheat systems, the reheating steam flow is self-regulating over the whole range of turbine load.** Note that the stage is supplied with HP turbine extraction steam whose pressure and temperature rise with turbine load. Therefore, the stage can be valved in at all turbine loads.

In both types of the reheat system, more than one reheater is used. As they are not perfectly identical, the **temperature of the superheated steam produced by individual reheaters is not exactly the same**. This creates a **side-to-side temperature difference** (ΔT) at the LP turbine inlet. If excessive, the ΔT **can produce thermal deformations in the LP turbine casing sufficient to cause blade and/or seal rubbing as well as increased vibrations**. To prevent this, a limit is imposed on the ΔT. Proper actions (eg. valving out of some reheater tube bundles), as specified in the appropriate operating manual, must be taken when this limit is approached or exceeded. ⇔ *Obj. 4.1 d)*

SUMMARY OF THE KEY CONCEPTS

- Typically, the reheating steam flow is isolated during turbine startup and operation at light turbine loads, throttled at medium turbine loads, and self-regulating at high loads.
- During turbine startup and at light loads, reheating must be limited in order to prevent overheating of the LP turbine exhaust.
- Reheaters should be valved in (out) slowly to minimize thermal stresses in the reheaters and LP turbines. Also, gradual changes of the reheater steam and drains flow facilitates reheater drains level control and boiler pressure and level control.
- Exceeding the limit on side-to-side ΔT at the LP turbine inlet can result in large thermal deformations of the LP turbine casing. The deformations can cause rubbing in the turbine, as well as increased vibration.

NOTES & REFERENCES

REHEATER DRAINS LEVEL CONTROL

Obj. 4.2 a) ⇔

Normal control

In both types of reheat system, condensate of the reheating steam is collected in one or more drain tanks. **In live steam reheat systems** (see Fig. 4.5 a) on page 29), there is only one tank which is shared by both reheaters. Their drains are pumped to the boilers, and **the drains level in the tank is normally maintained by a control valve which adjusts the drains flow to the boilers**. When the level rises, the valve opens more, increasing the outflow from the tank. A recirculation line back to the tank is provided to prevent overheating of the drains pump due to too small a flow. The recirculation line operates when the drains flow to the boiler is below a certain limit. This happens when the control valve opening is small in response to a low level in the drains tank.

Note in Fig 4.5 a) that some water is supplied from the discharge of the boiler feed pumps to the suction of the reheater drains pumps. The purpose of this water – whose temperature is well below the drains temperature – is to subcool the drains, thereby preventing pump cavitation/vapourlocking. If not isolated when necessary, this water may, however, flood the reheaters and their steam piping. Such an incident has happened in a CANDU unit.

In two-stage reheat systems (see Fig. 4.5 b) on page 28), separate drain tanks are used for each stage because of their different operating pressures and temperatures. Typically, each individual reheater has its own set of two drain tanks. The first stage drains cascade to the HP feedheaters, whereas the second stage drains are pumped to the boilers. The **drains levels are normally maintained** in the same way as described above, ie. **by adjusting the drains outflow**.

Obj. 4.2 b) ⇔

Automatic actions in response to improper drains level

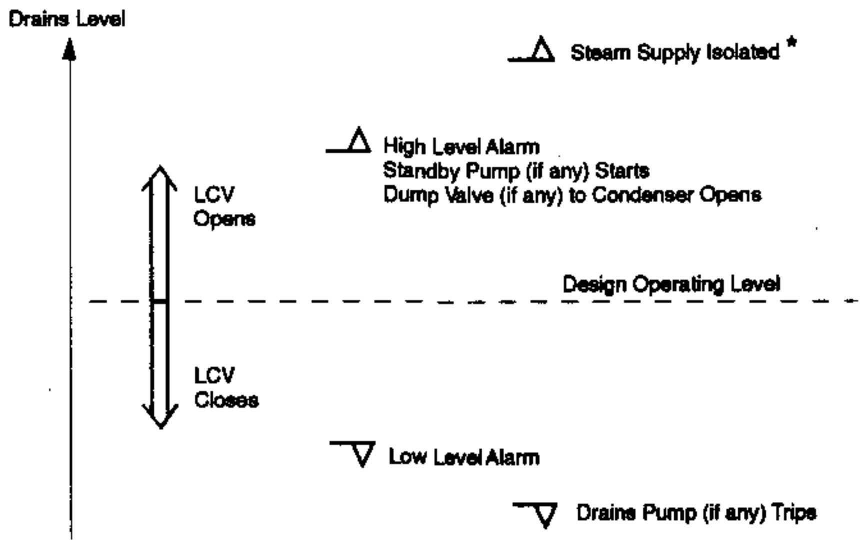
The above description covers the normal control action performed when the level error is relatively small. When the error is too large, other actions are carried out to protect the equipment. The most typical of these actions are depicted in Fig. 4.1.

Obj. 4.2 c) ⇔

Adverse consequences and operating concerns caused by improper drains level

Improper reheater drains level can have serious operating implications. Let us first consider the adverse consequences/operating concerns caused by **too high a drains level**. They are listed below in order of rising level.

NOTES & REFERENCES



* Applies only to some stations.

Fig. 4.1. Major automatic responses to reheater drains level:
LCV = Level control valve.

1. **Reduced overall thermal efficiency.**

   Even when the reheater tubes are still not flooded, the typical protective action on too high a drains level is to dump the drains to the condenser. Usually, this action can quickly restore the normal level. However, dumping hot drains to the condenser reduces the overall thermal efficiency which can be of concern when such operation is continued.

2. Flooding of the reheater tubes would result in a **partial or total loss of reheat**. Its adverse consequences are described on page 10.

Once the reheater tubes are flooded with drains, condensation of reheating steam in the flooded reheater(s) is stopped (for all practical purposes). Therefore, in the stations where no attemperating water is supplied from the boiler feed pump discharge to the reheater drains pump suction, the reheater drains level also stops rising. But in the stations where attemperating water is used (see Fig. 4.5 a) on page 28), failure to isolate its supply on a very high drains level may cause the additional adverse consequences described below.

3. **Flooding of the reheat steam piping** could cause the following problems:

   a) **Large thermal stresses in the piping** if the drains are much cooler than the piping.

      Note that attemperating water temperature* is far below the reheat steam piping temperature. When this water is allowed to reach the

* 125-150°C, depending on the station.

resultant quenching of the hot pipes could overstress them, possibly causing their failure. Welds in the live steam piping are particularly susceptible and, in the extreme case, could crack.

b) **Water hammer in the piping.**

For example, this can happen in the main steam lines to the HP turbine when the reheat drains have reached the main balance header from where slugs of water can be driven by the main steam flow. The presence of large quantities of water in the reheater steam pipes also promotes water hammer during system restartup if pipeline drainage is inadequate.

c) **Water induction to the HP turbine.**

This can happen through the main steam lines after the drains have reached the main balance header. The resultant damage can be very serious.

Too low a reheater drains level is of much less concern. However, it causes the following adverse consequences/operating concerns:

1. **Possible cavitation/vapourlocking** of the reheater drains pump due to an excessive reduction of their suction head.

   In most installations, a drop in the drains level would have to be substantial (ie. the tank would have to be nearly completely drained) to cause these problems.

2. **If the low level is caused by the drains dump valve stuck open,** the following consequences would occur:

   a) **The overall thermal efficiency would be reduced** due to dumping hot drains to the condenser;

   b) **Water hammer** in the drain lines would occur if the level dropped enough for steam to enter the drain piping and drive slugs of water.

Obj. 4.2 d) ⇔

Causes of reheater drains level problems

Some of the possible causes of reheater drains level problems are as follows:

1. **Too high a drains level** can be caused by:

   a) Control or mechanical problems with the level control valve resulting in too small opening of the valve;

   b) Tripping of the reheater drains pump combined with failure of the standby pump (if any) to start up.

NOTES & REFERENCES

2. **Too low a drains level** can result from:

   a) Control or mechanical problems with the level control valve or the drains dump valve resulting in excessive opening of either one;

   b) A large leak in the system (eg. a pipeline break).

SUMMARY OF THE KEY CONCEPTS

- The normal drains level is controlled by adjusting the drains outflow.
- When reheater drains level is abnormally high, an alarm is given and the dump valve (if any) to the condenser opens. The standby drains pump (if applicable) starts up as well. In some stations, the steam supply is automatically isolated when the drains level reaches a very high limit.
- Too low a reheater drains level gives an alarm. When applicable, the drains pump trips as well.
- Too high a reheater drains level can result in the following adverse consequences, listed in the order of rising level. First, the overall thermal efficiency is reduced when hot drains are dumped to the condenser. Second, flooding of the reheater tubes results in a partial or total loss of reheat – with all attendant consequences. Finally, flooding of the reheater steam piping can damage the piping due to water hammer or quenching. Water induction to the HP turbine can also occur.
- Too low a reheater drains level can cause reheater drains pump cavitation/vapourlocking. The overall thermal efficiency would be reduced if hot drains were dumped to the condenser due to the dump valve stuck open. In the extreme case, water hammer in the drains piping can result if the level has dropped enough to cause steam to drive slugs of water through the piping.
- Typical causes of improper reheater drains level are control/mechanical problems with the drains LCV or the dump valve. A large leak in the reheat system and failure of the reheater drains pump are other causes.

You can now do **assignment questions 1-9**.

⇔ *Pages 21-23*

LOSS OF REHEAT

Adverse consequences/operating concerns

⇔ *Obj. 4.3 a)*

Any serious operational problem (eg. loss of drains level control or a large steam leak) may require some or all of the reheater tube bundles to be isolated. This forced action causes the following major adverse consequences and operating concerns:

1. **Increased thermal stresses in:**

   a) **The LP turbine casing.**

   If the loss of reheat is rapid, the LP turbine inlet is subjected to fast cooling, and thus increased thermal stresses. The stresses can be particularly high if the loss of reheat is asymmetrical with respect to the turbine, eg. when only one reheater is experiencing tube flooding. In such a case, an excessive side-to-side ΔT is produced at the LP turbine inlet. The resultant thermal deformation of the turbine casing can cause **high turbine vibration and possible blade and/ or seal rubbing.**

   b) **The affected reheater(s).**

   A rapid loss of the reheating steam subjects the reheater tubes to fast cooling by the turbine steam. The resultant thermal stresses, if repeated a sufficient number of times, can eventually cause a **reheater tube or gasket failure.**

2. **Increased steam wetness in the LP turbine.**

   Recall from module 234-1 that this results in accelerated erosion and corrosion, increased overspeed potential and reduced LP turbine efficiency. Because of these consequences, and particularly due to drastically increased erosion rate in the latter stages of the turbine, prolonged operation with no reheat should be avoided.

   As for the reduced LP turbine efficiency, it decreases the additional MW output produced by the increased turbine steam flow. The latter happens because less boiler steam (or none, in the extreme case of a total loss of reheat) is used for reheating. Note that the MW gain is conditional upon maintaining reactor power, and the GVs being able to accommodate the increased turbine steam flow (see also point 3 below for more information).

3. **Disturbed boiler pressure and level control** due to loss of reheater steam and drains.

   At full power, the reheaters take about 5-7% of the total boiler steam output, depending on the type of the reheat system. Loss of this flow disturbs a thermal equilibrium in the boilers, causing their pressure to rise. BPC counteracts it as described in the preceding module and summarized in the sidenote*. Note that this action **may result in some loss of the generator MW output.**

   In turn, loss of the reheater drains tends to lower the boiler level. If the level control is ineffective for whatever reason, a low boiler level – with its attendant adverse consequences as described in module 234-2 – will result.

* In the reactor leading mode, BPC raises the setpoint to the turbine governing system. The GVs open more. If they can accommodate the extra flow, the MW output increases. But if they cannot, the small SRVs open, forcing a manual reduction in reactor power to conserve makeup water. This action, combined with decreased LP turbine efficiency, may reduce the generator MW output somewhat.

  In the reactor lagging mode, BPC lowers the setpoint to the reactor regulating system. Reduced reactor power, combined with decreased LP turbine efficiency, leads to some loss of the generator MW output. But because in this mode of unit operation the output is maintained automatically, the GVs open more. This action tends to reduce boiler pressure, and BPC responds by adjusting reactor power. If the GV opening can be increased enough, the normal output is restored. Otherwise, the output is somewhat reduced due to the limited flow capacity of the fully open GVs.

Mitigating actions

⇔ *Obj. 4.3 b)*

Some of the above consequences and concerns can be minimized if the operator takes proper actions. First, thermal stresses in the LP turbine can be kept at a safe level if the side-to-side ΔT at the turbine inlet is within its limit. To ensure this, **loss of reheat on one side of the turbine must be accompanied by valving out a proper number of reheater tube bundles on the other side of the turbine.**

Second, **a substantial loss of reheat should be followed by a proper reduction in turbine load** as specified in the appropriate operating manual. Operation at full load can be continued only when absolutely necessary (to supply the grid load at the time when other sources of generation are unavailable), and then only over a limited period of time (usually, up to 12 hours).

When the turbine is unloaded, following a substantial loss of reheat, **the excessive steam wetness in the LP turbine is reduced back to the acceptable level**. This effect is shown in Fig. 4.2, where sample values of steam pressure, temperature and wetness are plotted, and turbine unloading is assumed to reduce load to about 60% FP*.

* Recall that turbine interstage pressures change proportionally to turbine load. In this example, 480 kPa / 800 kPa = 0.6 = 60% FP.

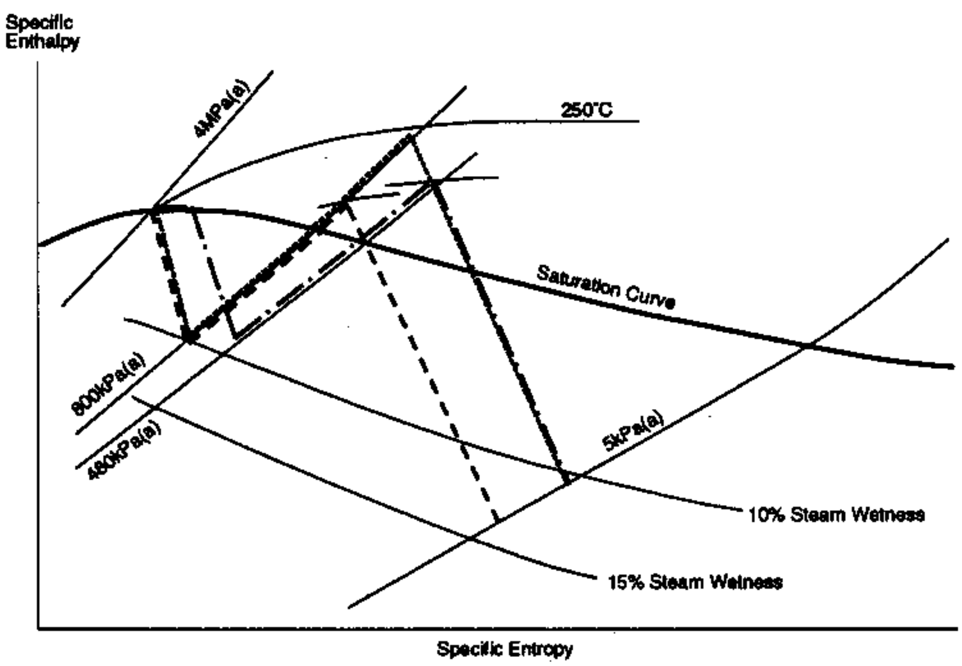


Fig. 4.2. Effects of loss of reheat on a simplified turbine steam expansion line:
·········· Operation at full power with full reheat available;
– – – – Operation at full power with reheat capacity substantially reduced;
— · — Operation at partial load with the same reduction in the reheat capacity.

NOTES & REFERENCES

Notice in Fig. 4.2 that turbine unloading is effective in reducing the LP turbine exhaust steam wetness for two reasons:

1. Reduced LP turbine inlet pressure (and hence, the pressure ratio) causes the turbine to extract less heat from the steam;
2. In the case of partial loss of reheat, the remaining reheat capacity can superheat the reduced flow of turbine steam to a higher temperature. Naturally, this effect does not apply to the total loss of reheat.

REHEATER TUBE LEAK

Obj. 4.4 a) ⇔

Adverse consequences and operating concerns

During turbine operation, the reheating steam pressure is higher than the turbine steam pressure. In fact, during startup and at low loads, the pressure difference can approach 4-5 MPa. Hence, a reheater internal leak (through a faulty tube or gasket) causes the **reheating steam** to leak into the reheater shell where it **mixes with the turbine steam.**

The leak, if large enough, **can raise the HP turbine exhaust pressure and lower the LP turbine inlet steam temperature.** The latter effect – perhaps a bit surprising – stems from the throttling process that the leaking steam undergoes*. During this process, steam temperature drops substantially: from about 250-255°C (assuming that the leaking reheater is supplied with boiler steam) to about 170-180°C, depending on the station. Note that the latter temperature is well below the normal LP turbine inlet steam temperature (225-240°C at full power, depending on the station). This is why the leak tends to lower this temperature. Of course, the leak rate must be large enough for this temperature reduction to be measurable.

* Recall from the 225 course that during throttling enthalpy is assumed to stay constant. You can easily verify the temperatures quoted below in the text if you plot a line showing this process in a Mollier diagram. By the way, you are not required to memorize these temperatures – they are quoted only to help you understand the problem.

This brings us to **adverse consequences/operating concerns caused by a large internal leak:**

1. **Reduced steam temperature on one side of the LP turbine** (it is assumed here that a large tube leak appears only in one tube bundle at a time) **may result in an excessive side-to-side ΔT at the turbine inlet.**

   You will recall that the ΔT limit would force valving out a similar tube bundle on the other side of the turbine in order to prevent damage due to excessive deformations of the turbine casing.

2. **Increased moisture content of the LP turbine steam due to reduced inlet temperature.**

   Accelerated erosion and corrosion, reduced overall thermal efficiency, and increased overspeed potential result from it.

NOTES & REFERENCES

3. **Increased HP turbine exhaust pressure.**

   In the extreme case (which would require a very large leak), the following **operational concerns** could arise:

   a) **Overloading of the LP turbine stages** due to an excessive steam flow.

      Recall from module 234-1 that turbine load is essentially proportional to the turbine inlet pressure. Hence, when a large reheater internal leak results in the LP turbine inlet pressure exceeding its full power level, the load on the LP turbine stages exceeds its full power value. This can eventually lead to overstressing of some of the turbine components.

   b) Reduced overall thermal efficiency and loss of generator output due to the following **automatic protective actions** which intend to prevent overpressure of the moisture separators, reheaters and interconnecting piping:

      – Opening of the release valves* (if there are any);

      – Tripping the turbine – in early CANDU stations, this feature may be absent;

      – Operation of the reheater safety valves or bursting discs (depending on the station) as the last line of defence.

   c) **Overpressure of the moisture separators, reheaters and the interconnecting pipelines** if the protective actions listed in point b) above have failed.

4. **Turbine speed control problems and possible overspeed if a large reheater tube leak occurred during while unsynchronized.**

* In some stations, this action is not performed.

Operator actions

⇔ *Obj. 4.4 b)*

While a small tube leak creates no acute problem, a large leak requires the following operator actions to prevent further equipment damage:

1. **Identification and isolation of the leaking tube bundle.**

   Note that in some stations equipped with a two-stage reheat system, isolation of the first stage bundle may force valving out the second stage. This action may be necessary to prevent excessive thermal stresses in the second stage of the reheater.

2. **Isolation of another tube bundle(s) on the other side of the turbine.**

   This action may be necessary to prevent an excessive side-to-side ΔT at the LP turbine inlet.

3. **If necessary, turbine unloading** as described on pages 11-12.

NOTES & REFERENCES

Obj. 4.4 c) ⇔

Detection of a reheater internal leak

Recall that **a large leak** in one of the reheaters is indicated by **reduced LP turbine inlet temperature and increased HP turbine exhaust pressure.** What about detecting a leak which is too small to cause any measurable change in these parameters?

A **classic method** used for this purpose relies on isolating the suspected tube bundle and monitoring the rate at which the pressure inside decays. An excessive rate indicates a leak. However, the leak may or may not be located in the tube bundle; for example, an isolating valve may be leaking. This uncertainty about the leak location is the main drawback of this method. This testing can be performed both on load as well as during a shutdown; in the latter case, instrument air – and not reheating steam – is used to pressurize the tube bundle.

In some stations, **another method** is used where dedicated reheater tube leak detecting instrumentation measures the reheating steam flow rate to individual tube bundles. The measured flow is compared with its expected value for a given turbine load. A sufficiently large difference between the two implies a tube leak. This method is believed to be capable of detecting a single tube leak.

Obj. 4.5 ⇔

WATER HAMMER PREVENTION

To prevent water hammer in the reheat system, the following major general operating practices are necessary:

1. **Proper drainage, particularly when prewarming the system during startup and at light loads.**

   Recall from module 234-3 that the above operating conditions cause increased rate of steam condensation in the piping. To prevent an excessive accumulation of condensate, that could lead to the formation of water slugs, the **drain valves must be open** during these operating conditions. At medium and high turbine loads, drainage is provided by steam traps.

2. **After having isolated the faulty reheater(s) upon a very high drains level, the reheat steam piping must be properly drained prior to steam admission.**

   This precaution is taken because some drains might enter the steam piping during the drains level excursion. To remove this water, drain valves in the piping must be open for a sufficiently long period of time.

You will recall that prevention of a very low drains level (such that steam could enter the drains dump piping to the condenser and drive slugs of water) is also important to prevent water hammer in the reheat system.

NOTES & REFERENCES

SUMMARY OF THE KEY CONCEPTS

- A loss of reheat increases thermal stresses in the LP turbine and the affected reheater(s), raises the steam wetness in the LP turbine and disturbs boiler pressure and level control.
- To minimize thermal stresses in the LP turbine, the operator must ensure that the loss of reheat is symmetrical with respect to the turbine such that the LP turbine inlet side-to-side ΔT is within its limit.
- A substantial loss of reheat should be followed by an appropriate turbine unloading to avoid prolonged operation with excessive wetness of the LP turbine steam.
- A large internal leak in a reheater can result in an excessive side-to-side ΔT at the turbine inlet, increased moisture content of the LP turbine steam, and increased HP turbine exhaust pressure.
- Major indications of a large leak include reduced LP turbine inlet steam temperature and increased HP turbine exhaust pressure.
- To prevent equipment damage in the event of a large internal leak in a reheater, the leaking bundle, as well as another tube bundle on the other side of the turbine, must be isolated. The turbine may have to be unloaded, depending on the extent of the loss of reheat.
- Detection of a small internal leak requires isolating the suspected bundle and monitoring the rate of pressure decay. In the alternate method, no isolation is performed, and the actual reheating steam flow rate is measured and compared with the expected value for a given turbine load.
- To prevent water hammer, the reheat steam piping must be properly drained during system warming, at light loads, and after any reheater has been isolated on a very high drains level.

You can now do **assignment questions 10-13.** ⇔ ***Pages 23-25***

THE GLAND STEAM SEALING SYSTEM

⇔ ***Obj. 4.6***

Most of the information about this system is provided in the previous turbine courses. The only topic that is left over is the use of **attemperating sprays**. Fig. 4.3 on the next page shows the part of the system where the sprays are installed, whereas the whole system is shown in a pullout diagram at the module end (Fig. 4.6 on page 29).

NOTES & REFERENCES

* Other names of this equipment, that are used in some stations, are listed on page 29 (Fig. 4.6).

**Not installed in some units.

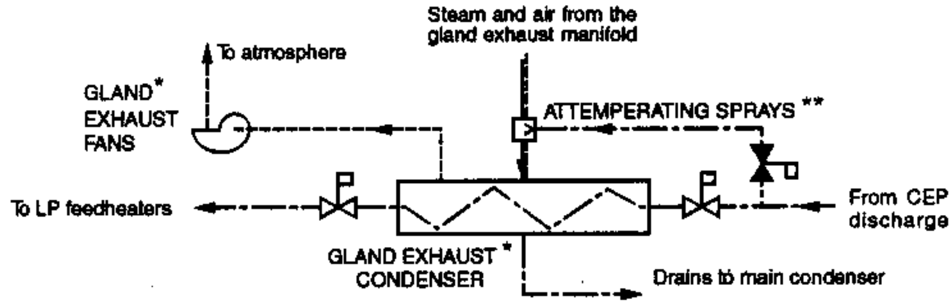


Fig. 4.3. The exhaust part of the gland steam sealing system:
Steam Air Condensate

Normally inoperative, the attemperating sprays must be valved in whenever temperature of the air flowing to the gland exhaust fans reaches an alarm level. The **sprays must** also **be valved in before the gland exhaust condenser is isolated** (eg. due to tube leaks)*, while steam supply to the gland steam sealing system is continued. The sprays condense the gland steam leakoff, thereby compensating for the loss of cooling in the gland exhaust condenser.

* In the units where no attemperating sprays are fitted, the gland exhaust condenser has an overflow sized to handle the condensate from a tube leak. Therefore, the gland exhaust condenser with a tube leak does not have to be valved out, and operation can be continued.

Failure to use the sprays in these circumstances would mean a total loss of cooling of the steam leakoff from various seals. As a result, the steam would flow through the gland exhaust fans which normally handle only air evacuated from the seals. **The following adverse consequences/operating concerns would result:**

1. **Possible damage to the gland exhaust fans due to overheating.**
2. **Release of steam from the turbine and steam valve gland seals** which are connected to the gland exhaust condenser.

   Note that the greatly increased flow rate would exceed the capacity of the fans, causing their suction pressure to rise. As a result, the pressure in the gland exhaust manifold would rise enough to cause steam outleakage from the gland seals connected to this manifold*. Recall that the manifold pressure must be maintained a few kPa below atmospheric in order for the gland seals to function properly.

* The adverse consequences of such leakage are outlined in module 234-1.

3. **Possible steam hammer in the condensate system.**

   The flow of hot steam through the gland exhaust condenser, combined with a loss of condensate flow, would cause the condensate inside the tubes to boil. The relief valve installed on the condensate line should open, preventing overpressure of the tubes. But the steam pockets formed inside the tubes would implode when the condensate flow is restored. The resultant collisions of water columns previously separated by the pockets would produce steam hammer*.

* Also discussed in module 234-6.

NOTES & REFERENCES

SUMMARY OF THE KEY CONCEPTS

- The attemperating sprays in the gland steam sealing system must be valved in to compensate for loss of normal cooling in the gland exhaust condenser.
- Failure to do this would result in steam flowing through the gland exhaust fans which normally handle air only. The fans could suffer damage due to overheating. In addition, their suction pressure would rise because the actual flow would greatly exceed their flow capacity. As a result, steam egress from the turbine and steam valve gland seals would occur. Finally, water hammer in the condensate system could occur due to implosion of the steam pockets created (due to heat input from the gland leakoff steam) inside the gland exhaust condenser tubes.

THE LP TURBINE EXHAUST COOLING SYSTEM

In the previous turbine courses, the purpose, major components and operation of the LP turbine exhaust cooling system were described. In this module, you will learn about:

- Possible LP turbine damage due to overheating of its exhaust if the system failed to provide adequate cooling;
- Operating parameters that should be monitored to prevent such damage;
- Operator actions that should be taken when the turbine exhaust heating is excessive;
- Operating concern caused by excessive use of the LP turbine exhaust hood cooling sprays.

For easy reference, the system is shown in a pullout diagram (Fig. 4.7) on page 29.

LP turbine exhaust overheating

⇔ *Obj. 4.7 a)*

You will recall that prolonged motoring* or operation at very light load promotes overheating of the LP turbine exhaust. During these operating conditions, large windage losses occur in the turbine last stage(s), and the small steam flow cannot provide adequate cooling. As a result, the moving blades and (to a smaller extent) the shaft, diaphragms, casing and exhaust cover become hotter. The transient heating produces increased thermal stresses. It also results in reduced radial and axial clearances in the turbine due to the rotating and stationary components expanding at different rates.

* Motoring is discussed in detail in module 234-13.

If proper condenser vacuum is maintained and the LP turbine exhaust cooling system operates satisfactorily, LP turbine exhaust temperature – while elevated as compared with normal operation – stays at a safe level. Otherwise, overheating of the LP turbine exhaust may develop, causing the following **adverse consequences/operating concerns:**

NOTES & REFERENCES

1. If no protective action were taken, the **turbine** could suffer **damage** due to:

   - **Rubbing** of turbine internals, eg. seals;
   - **Increased rotor vibration*** caused by rubbing and/or increased bearing misalignment due to the thermal distortion of the LP turbine casing and exhaust cover;
   - **Permanent distortion** (in the extreme case, **cracking**) of turbine parts, eg. the exhaust cover.

2. Forced **turbine trip** for turbine protection. As necessary as this action is, it would cause loss of production for which poor condenser vacuum and/or malfunction of the LP turbine exhaust cooling system may be responsible.

* Turbine generator damage due to excessive vibration is described in module 234-14.

Obj. 4.7 b) ⇔

Monitored parameters

To prevent turbine damage, the following parameters must be carefully monitored:

1. **LP turbine exhaust temperatures.**

   Several temperature sensors are installed in the six LP turbine exhausts. The indicated temperatures should be checked against the operating limits (as specified in the appropriate operating manual) to make sure the turbine trip limit has not been exceeded and that the cooling water sprays in the LP turbine exhaust hood operate properly.

2. **LP turbine bearing vibrations.**

   They are monitored to ensure that heating of the LP turbine exhaust has not resulted in excessive bearing misalignment and/or internal rubbing in the turbine.

3. **LP turbine axial differential expansions.**

   These parameters (typically, one for each LP turbine) are monitored to make sure that the axial clearances in the turbine have not been reduced excessively.

4. **Condenser vacuum.**

   Efforts should be made to keep condenser vacuum as high as possible during the turbine operating states when LP turbine exhaust overheating is a potential problem. Note that high condenser vacuum results in a low density of the LP turbine exhaust steam, thereby reducing the windage losses in the turbine last stage(s).

In addition to these parameters, a **proper supply of condensate to the LP turbine exhaust cooling sprays must be ensured** by checking the

NOTES & REFERENCES

status of the isolating valves (should be open) and the pressure drop across the strainer (should not be excessively high). During motoring, similar checks should be made to **ensure proper supply of motoring cooling steam and its attemperating sprays** (if installed).

Operator actions

⇔ *Obj. 4.7 c)*

If the LP turbine exhaust overheating has become excessive (as indicated by some of the monitored parameters), prevention of turbine damage requires the operator to take either of **the following actions**:

1. **Load the turbine.**

   This action reduces the windage losses in the turbine last stage(s) and improves cooling of the turbine internals by the increased steam flow. To minimize thermal stresses caused by the cooling, the initial loading should be performed slowly.

2. **Trip the turbine** (if loading is impossible, eg. due to reactor problems).

Excessive use of the LP turbine exhaust cooling sprays

⇔ *Obj. 4.7 d)*

The major operating concern caused by excessive use of the LP turbine exhaust cooling sprays is that it can result in **erosion of the last stage blades.** Recall that at no/light loads – not to mention motoring – intensive steam recirculation occurs in the exhaust hood and the last stage blading. This was already described in module 234-1, but for your convenience is also shown below in Fig. 4.4.

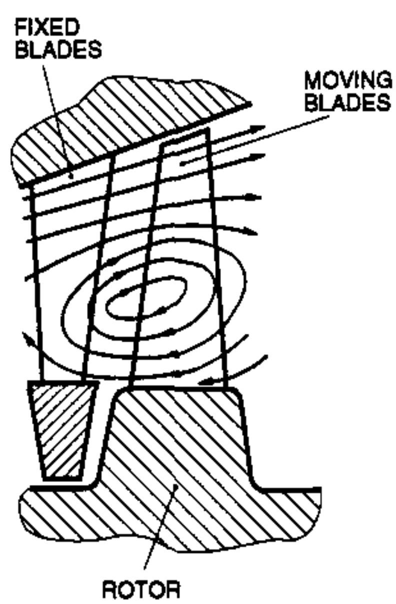


Fig. 4.4. Steam recirculation in the last stage at no/light turbine load.

NOTES & REFERENCES

Note in Fig. 4.4 that the recirculating steam enters the moving blades at their trailing edge close to the blade root. The steam carries the sprayed water droplets that have not been fully evaporated. Collisions between these droplets and the trailing edge of the blades eventually cause blade erosion. To minimize this erosion, it is important not to use the sprays when they are not necessary for turbine protection from overheating.

SUMMARY OF THE KEY CONCEPTS

- If no action is taken, overheating of the LP turbine exhaust can result in severe damage to the turbine.
- LP turbine exhaust temperatures, bearing vibrations, axial differential expansions and condenser vacuum should be carefully monitored while operating in a condition that promotes overheating of the LP turbine exhaust.
- If any safe limit has been reached, turbine load should be slowly increased. When loading is impossible, the turbine should be tripped in order to prevent damage.
- Excessive use of the LP turbine exhaust cooling sprays can result in erosion of the trailing edge of the moving blades in the last stage.

Pages 25-27 ⇔

You can now do **assignment questions 14-17.**

NOTES & REFERENCES

ASSIGNMENT

1. a) In a typical live steam reheat system and the second stage of a two-stage reheat system, the reheating steam flow is controlled as follows:

    i) At high turbine loads:

    ____

    ii) At medium turbine loads:

    ____

    iii) At low turbine loads:

    ____

   b) In the first stage of a two-stage reheat system, the reheating steam flow is ______________ over the whole range of turbine bine load.

2. a) Reheating must be limited during turbine startup and operation at light loads in order to ______________________

   ____

   b) Valving out the reheat during turbine startup and operation at light loads (does / does not) result in excessive steam wetness in the LP turbine.

3. Reheaters should be valved in/out slowly in order to:

   a) ______________________________

   ____

   b) ______________________________

   ____

   c) ______________________________

   ____

4. An excessive side-to-side ΔT at the LP turbine inlet can result in

   ____

   ____

5. The normal reheater drains level is controlled by ______________

   ____

NOTES & REFERENCES

6. The following actions (other than the normal control) are carried out in response to:

   a) Too high a reheater drains level:

      i) ______________________________

      ii) ______________________________

      iii) ______________________________

      iv) ______________________________

   b) Too low a reheater drains level:

      i) ______________________________

      ii) ______________________________

7. a) Even when the reheater tubes are still not flooded, too high a drains level reduces the overall thermal efficiency due to

   ____

   b) Flooding of the reheater tubes results in ______________________________

   ____

   c) Flooding of the reheat steam piping could cause:

      i) ______________________________

      ii) ______________________________

      iii) ______________________________

8. Too low a reheater drains level can cause the following adverse consequences/operating concerns:

   a) ______________________________

   ____

   ____

   b) ______________________________

   ____

   ____

9. a) Too high a reheater drains level can be caused by:

      i) ______________________________

      ____

NOTES & REFERENCES

ii) ______________________________

____

b) Too low a reheater drains level can be caused by:

i) ______________________________

ii) ______________________________

10. a) Valving out some or all of the reheater tube bundles while operating at a high load can cause the following adverse consequences/ operating concerns:

i) ______________________________

____

____

ii) ______________________________

____

____

iii) ______________________________

____

____

b) Reducing turbine load can alleviate excessive wetness of the LP turbine steam due to the following two effects:

i) ______________________________

____

ii) ______________________________

____

11. a) A reheater internal leak causes the (reheating / turbine) steam to leak into the reheater (shell / tubes).

b) A large leak can (decrease / increase) the temperature of the superheated steam supplied to the LP turbines.

c) A reheater leak detection instrumentation enables detection of a small leak by ______________________________

____

____

NOTES & REFERENCES

d) A classic method of leak detection relies on ________________

____

____

12\. a) A large reheater internal leak is indicated by:

i) ______________________________

ii) ______________________________

b) The adverse consequences/operating concerns caused by a large reheater internal leak are:

i) ______________________________

____

____

ii) ______________________________

____

____

iii) ______________________________

____

____

iv) ______________________________

____

____

c) When a large reheater internal leak results in increased HP turbine exhaust pressure, the following operating concerns arise:

i) ______________________________

____

____

ii) ______________________________

____

____

iii) ______________________________

____

____

NOTES & REFERENCES

d) A large reheater internal leak requires the following operator actions to prevent further equipment damage:

i) ____

____

ii) ____

______________________________ ____________

iii) ____

____

13. Water hammer in the reheat system is prevented by the following general operating practices:

a) ____

____

____

b) ____

____

____

14. a) Attemperating sprays in the gland sealing steam system must be valved in when ______________________________

____

b) Failure to do this would result in the following adverse consequences/operating concerns:

i) ____

____

ii) ____

____

iii) ____

____

15. a) Overheating of the LP turbine exhaust is promoted during the following turbine operating states:

i) ____

ii) ____

NOTES & REFERENCES

b) Excessive heating of the turbine during these operating states causes the following adverse consequences/operating concerns:

i) ______________________________

____

____

ii) ______________________________

____

____

16. a) The following parameters should be carefully monitored while operating in a state that promotes overheating of the LP turbine exhaust:

i) Parameter: ______________________________

Reason why it is monitored: ______________________________

____

____

____

ii) Parameter: ______________________________

Reason why it is monitored: ______________________________

____

____

____

iii) Parameter: ______________________________

Reason why it is monitored: ______________________________

____

____

____

iv) Parameter: ______________________________

Reason why it is monitored: ______________________________

____

____

____

NOTES & REFERENCES

b) In addition to the above, the following checks should also be made: ____

____

____

____

c) If any of the monitored parameters listed in point a) has reached its safe limit, the operator can take either of the following actions:

i) ____

ii) ____

17. The major operating concern caused by excessive use of the LP turbine exhaust cooling sprays is ______________________________________

____

____

Before you move on to the next module, **review the objectives** and make sure that you can meet their requirements.

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Revision date: May, 1994

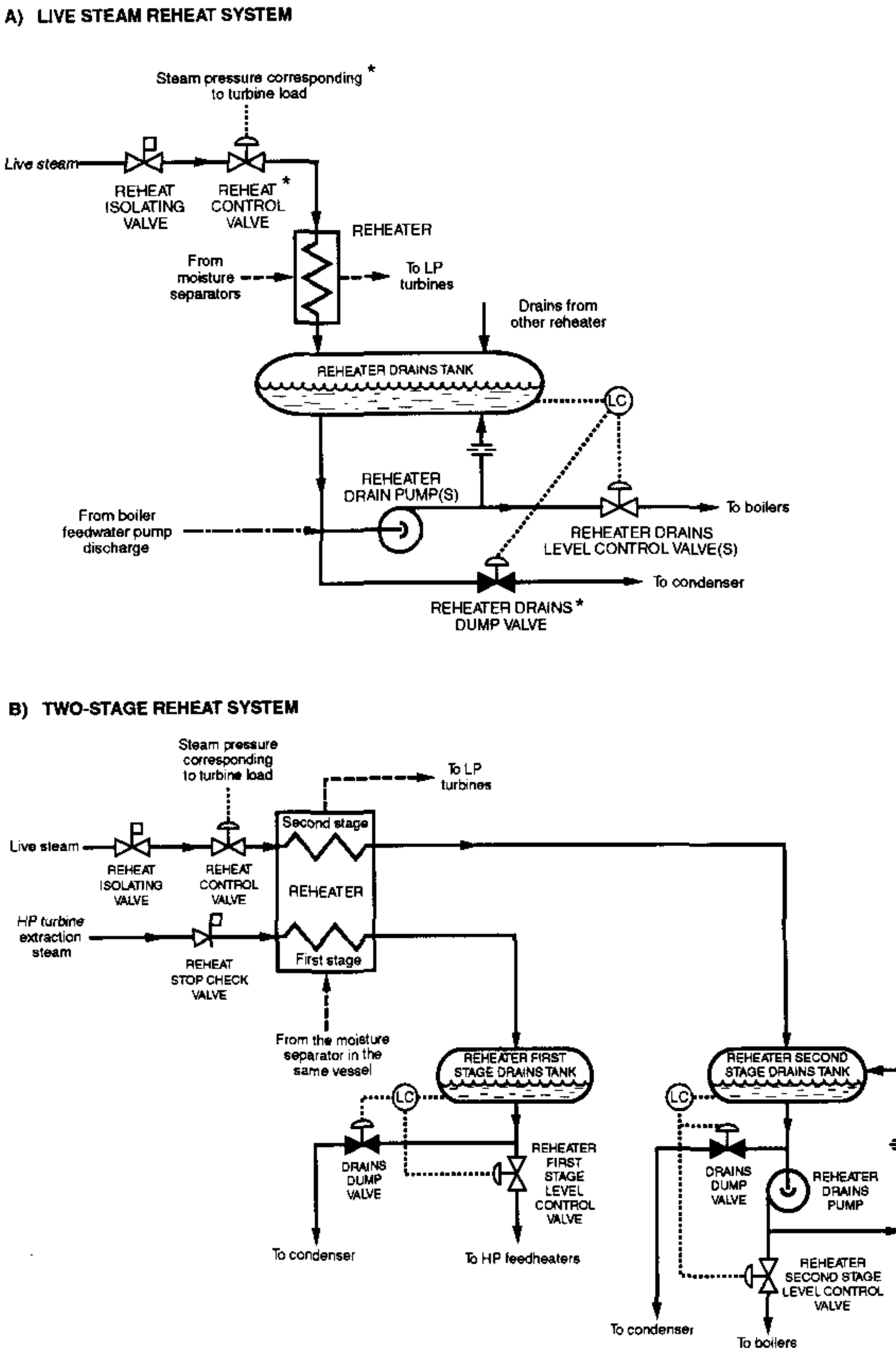

Fig. 4.5. Reheat systems in CANDU stations:

------ Turbine process steam, ——— Reheater steam and drains,
—·—·— Attemperating water, ··········· Control signals.

* Not in all stations.

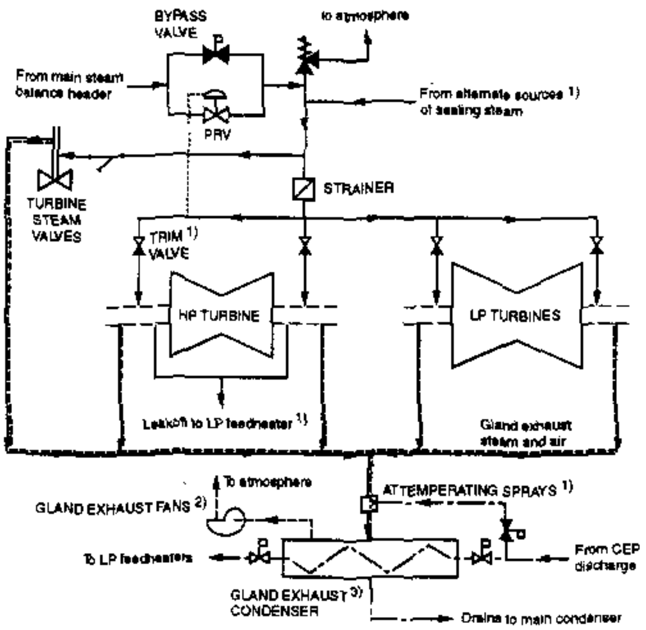

Fig. 4.6. Simplified gland steam sealing system:

——— Steam ------ Air ——— Condensate ········· Control signal

Notes:

1) *Not in all stations.*
2) *Also known under other names such as vapour extraction fans, turbine gland steam vapour extractors, or gland steam exhaust fans.*
3) *A few other names are also in use. Examples: the gland steam condenser or the steam packing exhauster.*

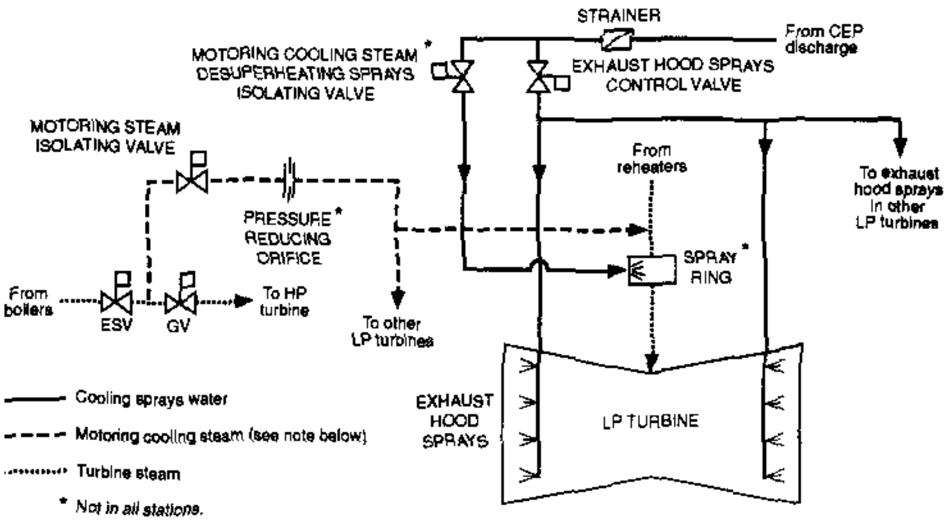

Fig. 4.7. Simplified LP turbine exhaust cooling system:

CEP = Condensate extraction pump; ESV = Emergency stop valve.
GV = Governor valve.

Note:
In some stations, motoring cooling steam is not used at all or is supplied to the HP turbine, bypassing the closed GVs. In the latter case, the steam follows the normal flow path through the turbine set.