CHAPTER 7: OVERALL UNIT CONTROL

MODULE 3: UNIT STARTUP

MODULE OBJECTIVES:

At the end of this module, you will be able to:

1. **State the reactor conditions, with regard to poison addition, control and safety systems availability, moderator level, which must exist prior to a start up being commenced.**
2. **List the requirements, with regard to deaerator levels and heaters, pump availability, and condensate hot well level, which must be satisfied to establish the feed water path from condenser to boilers.**
3. **Sketch a simple graph illustrating a method of raising HTS pressure and temperature between shutdown and operating state.**
4. **Briefly explain why the shutdown coolers are isolated before the main HTS circulating pumps are put into service.**
5. **Briefly describe, in writing, a method to bring the reactor to criticality using poison extraction and liquid zone control.**
6. **List the checks that should be made before, and during, turbine run up particularly before passing through the critical speed range.**

Introduction

This module is designed to highlight the major points that must be performed to restart a unit after a prolonged outage, e.g., a maintenance shutdown. An actual start-up procedure is specific to a particular station location and is too long and detailed to be described in a course of this type. The full procedures will be found in the operating manuals.

Reactor

Recall from the lessons on the Reactor Regulating System (RRS) and Shutdown Systems (SDS) that these systems must be operative before reactor criticality can be considered.

Recall that the RRS is designed to control the reactor with a Xenon load of approximately -28 mk. At the end of a maintenance outage exceeding a few days the reactor will be devoid of all Xe-135. To provide the necessary negative reactivity worth for the RRS to function correctly it will be necessary to provide an "equivalent Xenon load" of approximately -28 mk. In addition a guaranteed shutdown state must be provided. Both these requirements can be met by poisoning the moderator over and above the steady state Xenon load requirement. This poisoning is achieved by the use of either Boron or Gadolinium.

It is also important that the moderator level is at the correct height before criticality is achieved. Failure to provide this correct level would mean that the total reactor power output would not be shared by all of the available fuel bundles with a risk, particularly as power levels are increased after criticality has been achieved, that some fuel bundles and fuel channels could be overrated.

The reactor will be taken to criticality by poison removal. As the over poisoned moderator will shield the Shutdown System ion chambers, the rate log trip. will be lowered, typically to 4% power/second. The high power trip will be also set lower, typically at 10% full power. Sufficient ion exchange capacity must also be made available. If Boron is being used, at least two fresh columns and one other with removal capacity will be necessary.

Condensate/Feedwater System

During extended shutdowns decay heat from the reactor is being removed by the shutdown cooling system. Before criticality is achieved, and useful neutron power becomes available, the boilers must be established as the principal heat sink for the system. It is necessary therefore, to ensure that the condensate/feedwater, boiler and primary heat transport systems are available in an operational condition.

To make the Condensate and Feedwater systems available it is necessary to first ensure that there is a sufficient level of feedwater available in the condenser hotwell and that the low pressure feed heaters are available for use. It will be necessary, also, by operating the appropriate valves, that feed paths from the condenser hotwell to the deaerator and from the deaerator to the boiler exist.

In order to avoid exceeding the ΔT requirements (typically 150°C maximum) between boiler feedwater and HTS temperature a correct level must be established in the deaerator storage tank and the electric immersion heaters must be switched on. The capacity of these heaters is such that the heating up process will take about thirty-six hours. This time can be reduced somewhat by using-the boiler feedpumps in a recirculation mode to provide some pump heat.

The condensate extraction pumps (CEP) should be tested and the appropriate number, typically one at this stage, selected "ON" with the remainder in "AUTO" and "STANDBY". If no deaerator makeup is necessary the CEP will recirculate flow to the condenser hot well.

There must also be a sufficient level of water in the boilers and boiler feed is, at this stage, being controlled by the small feed valve. Note that as the steam and feed flows are effectively zero, boiler level control will be by either single element or manual control.

There is now a supply of feedwater from the condenser hotwell to the boilers and the boilers are now available to become the heatsink for the reactor. The boilers must first be put into the hot shutdown state using the Boiler Pressure Control System (BPC) by raising boiler temperature using heat energy from the deaerator and Boiler Feed Pumps If the Heat Transport System is available, the heatsink can be transferred from the shutdown coolers to the boilers.

HTS Cold and Depressurized to Hot and Pressurized

With the HTS in the cold and depressurized state and the shutdown cooling system operative its temperature will be typically 40°C or less.

All boiler isolating valves must be opened and if the system is fitted with a pressurizer it must be isolated. Saturation conditions will be established in the pressurizer by means of electric heaters and steam discharge valves.

Check the revel of the D_2O storage tank. Remember there must be sufficient capacity available to accommodate the large inventory swell as the system is taken to its operating state.

The bleed condenser is not required until HTS pressure exceeds approximately 2 MPa. A sufficient quantity of D_2O must be present in the Bleed Condenser to enable saturation conditions to be established by means of the built in electric heaters. The pressure control system for the bleed condenser, both reflux and spray, will not be needed at this time and can therefore, be placed in "manual," with both valves closed.

The bleed cooler is, however, still required as the inventory swell to the D_2O storage tank must be routed via the ion exchange columns and the limiting temperature of less than 50°C (to prevent resin breakdown) will still apply. The controllers should be placed in "Automatic" with the staggered setpoints at the correct settings.

Also, at this stage, ensure that the gland supply to the heat transport pumps is available and that the gland filters are in service.

Heat Transport pressure control will be in Wide Range (Solid Mode) and if the station has two HTS loops, they will normally be isolated from one another at this stage.

Initial Pressurizing

Before pressurizing, it should be remembered that the heat transport system has metallurgical constraints applied to it (particularly with respect to the zircalloy pressure tubes) and that pressure and temperature must be adjusted according to the method outlined in the operating manual. Briefly this involves raising pressure, at a constant temperature (less than 40°C) to 2.7 MPa(g) and then raising temperature at constant pressure to approximately 175°C. Pressure is then raised at this intermediate temperature until the working pressure of 8.6 MPa(g) is reached. Temperature could then be increased to the normal "hot" temperature.

At this time reactor criticality has not been achieved but the boiler and feed water system is in the hot state. The transfer of the heat sink from the coolers to the. boilers can now take place. Before transferring check that the deaerator temperature is up to the maximum which can be achieved by its built-in heaters otherwise the ΔT limit of 150°C may be exceeded.

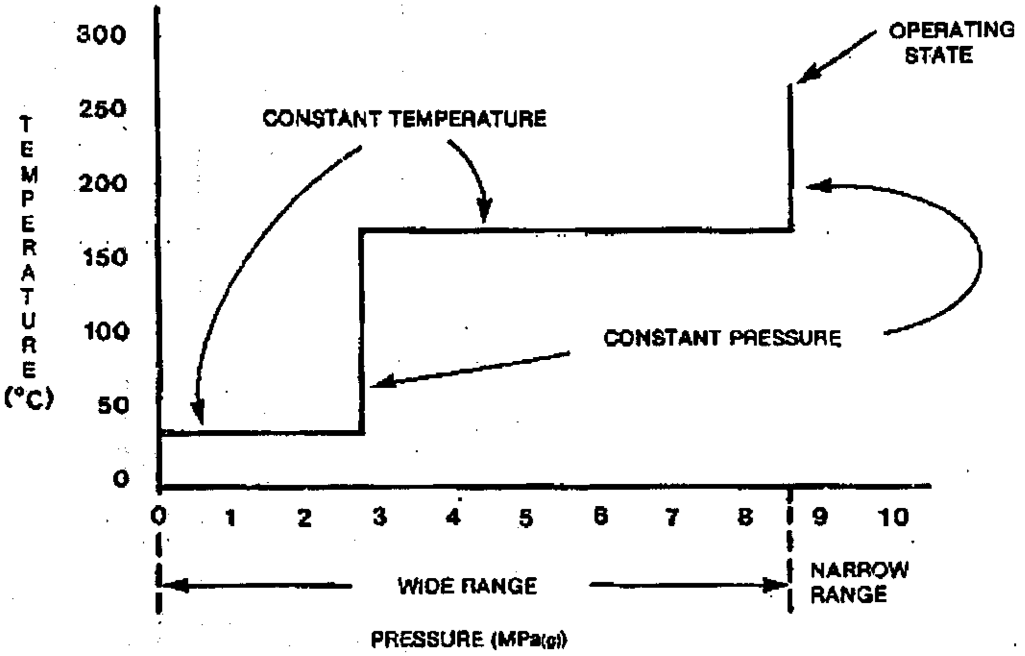

Figure 1: Typical HTS Run-Up Pressure/Temperature Profile.

The HTS temperature can now be increased by raising the setpoint of the shutdown coolers to just below 100°C. Before the whole of the heat transport system can be circulated, in order to use the boilers effectively as a heatsink (non-thermosyphoning), the main circulating pumps must be started. Before each pump is started the associated shutdown cooler in the loop must be shut off and isolated. If this was not done the main pumps would cause reverse flow through the shutdown coolers and possibly burn out the shutdown cooling pump motors due to their increased loading.

HTS Warm-up

The HTS inventory is now circulating and temperature will increase somewhat due to pump and subcritical reactor heat.

HTS temperature will now be approximately 100°C at a pressure of 2.7 MPa(g). To continue the programmed run up of temperature to 175°C before the pressure is increased the reactor must be made critical.

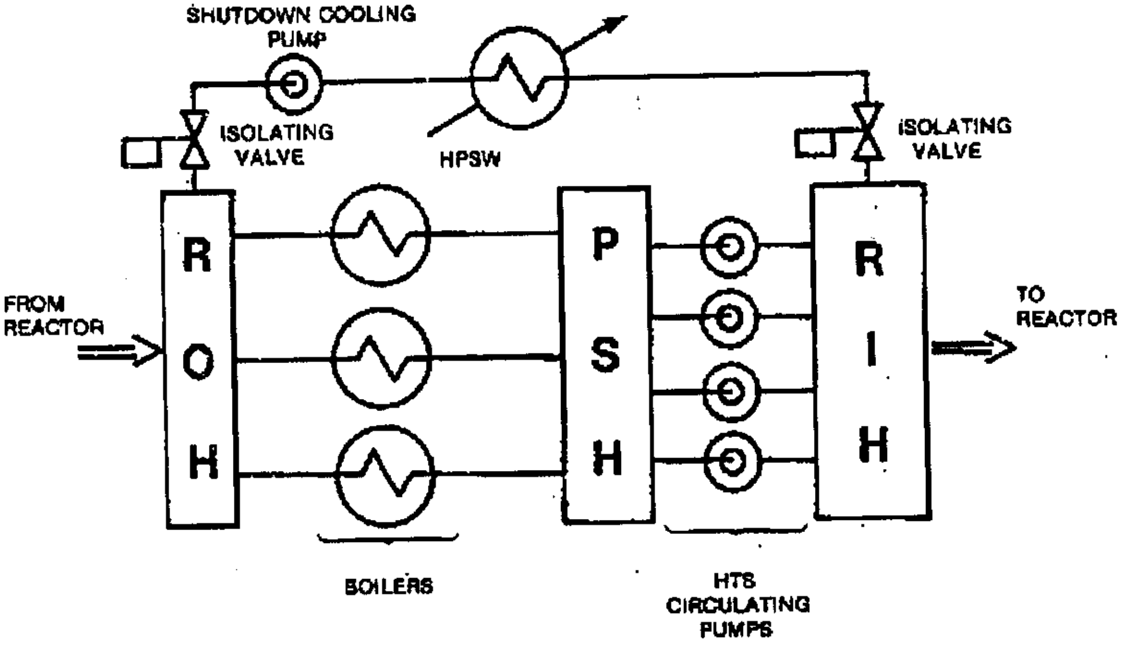

Figure 2: Typical Shutdown Cooling System Circuit.

Approach to Criticality

If all reactor parameters and control systems are correct the approach to criticality can continue. In general the method is to apply a "Hold Power" command to the control system while removing poison via the IX columns. As poison is removed reactor power will try to increase, this increase will be countered by an increase in zone level.

When the zone level reaches some predetermined figure, typically 60%, with power level still as before, an increase in power will be demanded by the operator. This will cause a lowering of zone level. When zone level reaches, about 25% a "Hold Power" command will again be input to the RRS. Poison removal continues and the foregoing procedure is repeated. Recall that if power doubles for a known increase in reactivity (change in zone level) a further, equal, increase will cause the reactor to go critical (Power Doubling Rule). Thus the approach to criticality can be carefully defined and controlled.

Once the reactor is critical power can be raised to the range of 10-4 FP with zone levels typically at 35-40%. Before power is raised further various checks will be completed to ensure that all systems are functioning correctly. Power control is in logarithmic mode and when power approaches 5% FP, Rate Log Trip settings can be set to normal operating limits, 10% power/per second, and the High Power Trip point will also be increased (typically to 45% FP).

Further Raising of HTS Temperature

The BPC can now be used to raise HTS temperature to approximately 175°C by energy banking in the boilers. Although the boiler level controller may be on automatic at this stage, since steam flow is still very low, full three element control is not yet viable. The level setpoint will therefore be set to some intermediate drum level (≈40%).

The wide range HTS pressure controller setpoints are left at 2.7 MPa(g) (the temperature is being raised at constant pressure) and at this stage the Emergency Coolant Injection (ECI) must be made available (unblocked) in case of a LOCA.

The deaerator can now be supplied with startup steam which helps maintain the boiler ΔT within limits and as feed water is now required the chemical feed system should be put into service. HTS temperature will now increase to 175°C.

Transfer to Narrow Range Pressure Control

The wide range pressure controller set points will now be steadily increased to approximately 8.5 MPa(g). When the pressure indicated on the two controllers has stabilized one of the loop interconnecting valves can be opened and, using the narrow range controller which takes its signal from both HTS loops - reject the other two by setting one setpoint high and one low - adjust the setpoint such that it matches the wide range balanced signals.

In stations fitted with a pressurizer the pressurizer can be put in service by opening its isolating valve. Saturation conditions should have been established when in wide range (solid) mode by means of its immersion heaters.

Control can now be switched to Narrow Range (Normal mode). The three pressure controller set points are staggered with the controller which looks at both loops set at the operating setpoint and the other controllers set one slightly lower and the other slightly higher than the setpoint.

Before the HTS system is taken to its full operating temperature and pressure the bleed condenser must be placed in service. Saturation conditions should have been established whilst it was isolated and the reflux and spray controllers should be set to their normal operating setpoints and placed on auto. The "through condenser" mode can now be established. Checks must also be made to ensure that bleed condenser level is also being correctly controlled at its setpoint.

HTS temperature can now be increased to its operating setpoint and at this stage the unit is functioning with the boilers as final heat sink in conjunction with SRVs or ASDVs.

Turbine Run Up

During the period of HTS warmup and achieving reactor criticality the turbine must be prepared for service. The turbine would be on turning gear and eccentricity would be carefully monitored to ensure that it is within limits.

The condenser vacuum must also be established by means of the vacuum (hogging) pumps and the CCW flow must be started. Boiler stop valves are closed.

It is important that all turbovisory parameters are carefully monitored during turbine runup and that all turbine systems are operative.

Boiler stop valves can now be opened admitting steam up to the ESVs. The turbine run up can now commence, this can either be manually or computer controlled up to 30R/S (1800 RPM) unsynchronized.

Manual Speed Control

Providing all the preliminary checks are OK (lube oil, seal oil, stator and rotor cooling, etc.) the ESVs can be opened to roll the turbine off the turning gear up to about 5R/S (300 RPM). The turning gear should have-disengaged at about 4 R/S.

Raise speed, by further opening of the ESVs, up to about 10 R/S. The exhaust steam to the condenser should have lowered condenser pressure to less than 20kPa(a). Further increase turbine speed to about, 15 R/S and once again recheck all turbovisory parameters. Hold speed until condenser pressure falls below 10kPa(a) and lube oil temperature approaches 40°C (prevents oil whip). Further open ESVs to raise speed to 20 R/S, again checking all turbovisory parameters.

The condenser vacuum unloading trip should now be armed.

Generator Synchronization

Electrical control and distribution systems for the generator must now be readied. Usually manual voltage regulation (MVR) is selected. The switchyard main breaker is opened. Rotor (hydrogen) and stator (water) cooling systems must be in service. Rotor current to the main generator can now be applied to bring rotor temperature above 30°C.

The turbine and generator must be taken through their critical speed range. The critical speed range for the turbine is 20.5 - 23 R/S, while that of the generator is 26 - 27 R/S. As a result, the ESVs must be opened steadily and without pause as speed is increased from 20 to 28 R/S. If the turbovisory parameters are not within limits (vibration > .15 mm is acceptable in critical speed range), speed must be brought back down to 20 R/S.

The ESVs should now be fully open and the governor system should have taken over turbine speed control (it is at its lower limit). The turbine can now be taken up to synchronous speed (30 R/S, 1800 RPM) by the speeder gear under manual control. If computer control had been selected the computer runup would stop at this point.

Generator excitation is now adjusted via the MVR until the generator terminal voltage is at its correct setting (typically 24 kV). Control can now be switched to automatic voltage control (AVR) using bumpless transfer techniques.

At this time reactor power would be increased, typically to about 10% FP. Any extra steam over and above the requirements of the turbine would be discharged via SRVs/ASDVs.

Synchronization of the generator to the grid can now take place. Generator voltage and frequency are matched to grid voltage and frequency by adjusting the AVR setpoint (voltage) and speeder gear setting (frequency). When the frequency, phase and voltages of the running and incoming busses are equal, the yard breaker can be closed connecting the generator to the grid.

Raise Power to Operating Limit

The unit is now supplying power to the grid. The speeder gear can now be transferred to automatic control. Reactor power and therefore unit output power can now be progressively increased. Reactor control will transfer to linear mode at about 15% FP. As power is increased the high power trip setpoint will be progressively increased. HP feedheaters usually come into operation at about 25% FP.

As reactor power increases the Xenon load will also increase. If boron was used as a moderator poison the rate of boron extraction via the IX columns must be regulated to match the rate of increase in Xenon-135. If gadolinium is used the burnout rate of gadolinium closely matches the growth rate of the Xenon so less IX column control is required.

Remember that the procedure described above is only very general and addresses only some of the major considerations in a unit re-start. Any restart will be unit specific and fully detailed in the appropriate operating manuals.

Assignments

1. **State the, major reactor conditions which must exist prior to a start up being commenced.**

2. **List the requirements which must be satisfied in order to establish the feedwater path from condenser to boilers.**

3. **At what level, and why, should the D_2O storage tank be prior to HTS warm up.**

4. **State the control methods applied to the bleed condenser and bleed cooler during HTS warmup.**

5. **Sketch a simple graph illustrating a method of raising HTS temperature and pressure between shutdown and operating state.**

6. **What could be the possible consequence, and why, of not isolating the shutdown cooler before the main HTS pumps are started.**

7. **List a sequence of control operations that could be used to achieve reactor criticality by poison removal.**

8. **List the sequence of checks made during the runup of the turbine. Detail more fully those made before, during and after passing through the critical speed range.**

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1) Sketch a block diagram to show the high level interfacing systems for boiler pressure control? What energy balance is this system maintaining? State two general functions for boiler pressure control.

2) Sketch a simplified physical system layout for one boiler to show key I&C and steam flow manipulation devices that can be used to monitor and control boiler pressure? Label these devices and give a brief description for the purpose of each device.

3) Show the relative pressure settings versus full power to indicate action points with respect to the boiler pressure setpoint and steam safety valve settings.

4) What parameters would you recommend, and why, in order to provide the boiler pressure control function.

5) Describe the performance of a boiler pressure control routine so as to provide a controlled warm-up mode.

6) Describe the concerns and considerations that must be taken into effect for a loss-of-line event for a boiler pressure control application.

7) What is the intention of a pre-steam admissions check - when should it be conducted, what sort of tests would you recommend.

8) Sketch a typical voltage regulation scheme and label key sections.

9) Describe how the voltage regulation scheme from question #8 could be used in manual mode to control the generator terminal voltage. Why is this not a desirable mode of operation?

10) Briefly describe an operational strategy that could be used to transfer boiler pressure control from an alternate pressure sink (such as ASDVs) to the turbine governor valves.

11)What is the purpose of a checkpoint in a unit warm-up such as a 'pre-warmup checklist'? What are some example checks that you would recommend.

12)What pressure and temperature (saturation) do the boilers operate at? What is the zero power hot conditions for the heat transport system? What margin (in MPa) to saturation (approximately) is there for the main heat transport pumps at zero power hot?

13)Sketch a representative shutdown cooling system circuit including a reactor outlet header, boilers, main heat transport pump and reactor inlet header. Label the direction of flow if the main circuit pumps are in operation. Also show the shutdown cooling pump, shutdown cooling heat exchanger and shutdown cooling isolation valves. What is the approximate flow rates in either mode (main pump or shutdown cooling pump)? What precaution must be taken when starting the main circuit pumps?