STEAM TURBINE LABORATORY

Objective

The objective of this laboratory experience is to demonstrate how mechanical power can be generated using a steam turbine and how the conservation laws and thermodynamic properties of water can be used to analyze the performance of the system.

Background

Many manufacturing and chemical processes require low-pressure steam for heating or mechanical power. In many situations, however, the installed boiler capacity is greater than the normal usage because of changing production schedules. When this imbalance occurs the plant engineer is faced with either reducing the firing rate of the boiler or just dumping the waste steam. One popular solution is to install low-pressure steam turbines with an attached generator set to produce electrical energy. This energy can be used internally or sold back to the local electric utility. In Terre Haute, electrical energy has a value of approximately $0.08 per kilowatt-hour.

The steam turbine installed in Room DL-205 in Moench Hall is a typical low-pressure turbine that could be used to recover mechanical power from waste steam. A picture of the turbine is shown in Figure 5. Specifications for the turbine are shown below:

DESCRIPTION

Model: Terry GLT-360 Manufacturer: Dresser-Rand Cost: $15,060

Type: Single-stage, radial inflow, non-condensing steam turbine

Speed Control Governor: Woodward TG-13 (hydraulic type)

Load: Pohl 90-hp water-brake type dynamometer Weight: 2000 lbs

OPERATING CONDITIONS

Rated Performance: Power Output = 10 hp @ 3600 rpm

Steam Conditions: Inlet @ 80 psig (324°F); Outlet @ -9.7 psig (165°F)

Steam Rate: 50.1 lbm/(hour·hp)

Speed Range: 3060 - 3780 rpm

1st Critical Speed: 7200 rpm Trip Speed: 4572 rpm

Sentinel Warning Valve Setting: 5 psig

Exhaust Full Flow Relief Valve Set Pressures: Begin to open @ 10 psig; Full relief @ 20 psig

CONSTRUCTION

Inlet connection: Size 2.0” Rating 600#

Exhaust connection: Size 4.0” Rating 150#

Steam nozzle throat diameter: 0.287”

Steam to power the turbine is supplied by the Rose-Hulman boiler. The Rose-Hulman boiler typically supplies saturated steam at 125 psig. By the time steam reaches DL-205, heat loss from the steam lines will cause condensation producing a steam quality slightly less than 100% and pressure losses will reduce the pressure. Exhaust steam from the turbine is condensed in a shell-and-tube heat exchanger, and the steam condensate is dumped to a drain.

Instead of using the turbine to generate electricity in the laboratory, a water-brake dynamometer is used to provide a known load for the turbine. The brake horsepower absorbed by the water brake can be calculated directly knowing the turbine speed and the dynamometer reading. The brake horsepower equals the actual mechanical power (shaft power) that is available to drive a device attached to the turbine shaft.

A schematic diagram showing the major components of the steam boiler and turbine system is presented in Figure 1. The corresponding states and processes are shown on a temperature-entropy (T-s) process diagram in Figure 2. A detailed description of the individual states and connecting processes is provided in Figure 3. A piping and instrumentation diagram for steam turbine installation in Room DL-205 is presented in Figure 4. This diagram begins with State 3, the outlet of the Boiler / Steam Line / Separator process, and shows almost all of the piping and instrumentation.

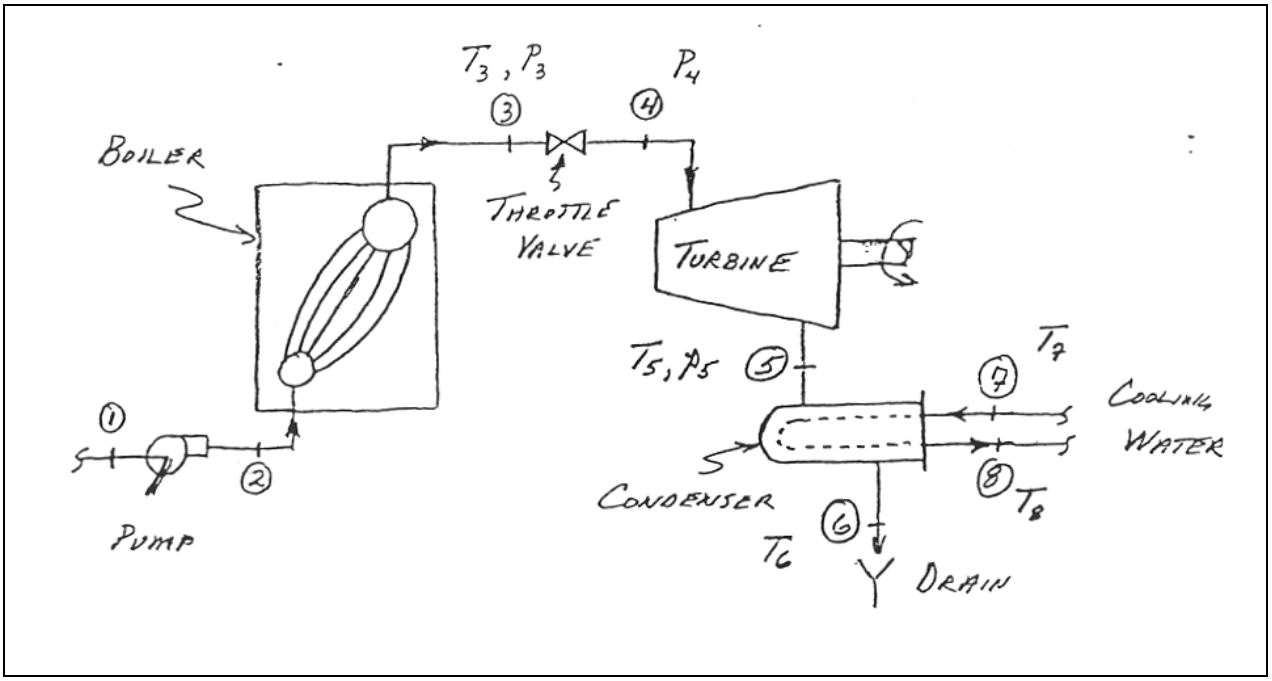

Figure 1 - Schematic of the Steam Boiler / Turbine System

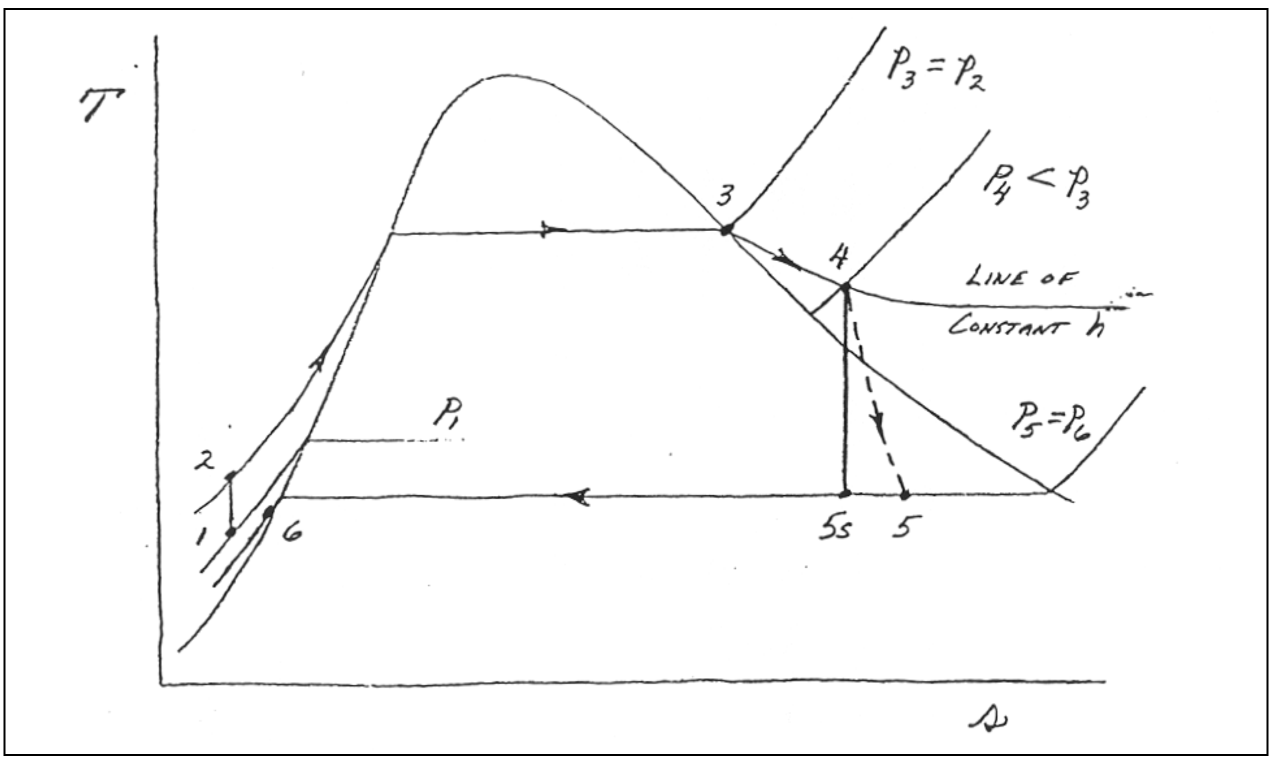

Figure 2 - Process T-s Diagram for Steam Boiler / Turbine System
(See Fig. 1 for Schematic Diagram)

STEAM LOOP

State 1 – Water Supply to Boiler Feed Pump [$p_1 \approx 60$ psig ; $T_1 = T_7$]

Process 1 → 2 Boiler Feed Pump [model as reversible and adiabatic compression, i.e. $s_2 = s_1$]

State 2 – Boiler Inlet [$p_2 \approx p_3$]

Process 2 → 3 Boiler / Steam Line / Steam Separator [model as isobaric process]
Note: The steam separator located immediately upstream of the turbine is used to keep liquid from entering the turbine. By design, a saturated liquid-vapor mixture entering the separator is separated into a saturated liquid and a saturated vapor stream. If superheated vapor enters the separator, then superheated vapor will leave the separator. Depending upon the steam conditions, temperature and pressure may not be independent variables. If your measurements indicate that State 3 should be a compressed liquid, you should assume that the state is really a saturated vapor and use either the temperature or pressure alone to determine the state.

State 3 – Throttle Valve Inlet [**measure T_3 and p_3**]

Process 3 → 4 Throttling Valve [model as throttling process, i.e. $h_3 = h_2$]
Note: The throttling valve is controlled by the Woodward hydraulic speed control governor (a completely mechanical feedback control system) and within a range of loads and flow rates will keep a constant turbine speed of 3600 rpm regardless of the applied load.

State 4 – Steam Turbine Nozzle Inlet (Bowl Conditions) [**measure p_4**]

Process 4 → 5 Single-stage, Radial-inflow Turbine

State 5 – Turbine Exhaust [**measure p_5 and T_5**]
Note: The turbine exhaust will be either a superheated vapor or a saturated liquid-vapor mixture. Depending upon what steam conditions exist, temperature and pressure may not be independent variables. If your measurements indicate that State 5 should be a compressed liquid, assume that the state is really a saturated liquid-vapor mixture and use either the temperature or pressure alone to determine the state. (Typically you should rely on the measurement you feel is most accurate.) Under these conditions, the outlet enthalpy can only be determined by performing an energy balance on the condenser.

Process 5 → 6 Condenser (Shell-side of tube-in-shell heat exchanger) [model as isobaric cooling]
Note: This heat exchanger is a shell-and-tube heat exchanger and represents one of the most common types of heat exchangers used in industry. The condensing steam is passed over the outside of round tubes. As the steam is cooled, liquid water condenses on the tubes and drips to the bottom of the heat exchanger. Only liquid water (condensate) should leave the heat exchanger if it is operating correctly. City water used as cooling water flows through the inside of the round tubes.

State 6 – Condenser Outlet (Condensate) [**measure T_6 and p_6]**

COOLING WATER LOOP

State 7 – Cooling Water Inlet to Condenser (Tubeside) [**measure T_7 and p_3, typically $p_3 \approx 60$ psig**]

Process 7 → 8 Condenser (Tube-side of tube-in-shell heat exchanger) [model as isobaric heating]

State 8 – Cooling Water to Drain [**measure T_8 and p_8**]

Figure 3 - Description of Steam Boiler / Turbine System
(See Fig. 1 for Schematic and Fig. 2 for T-s Diagram)

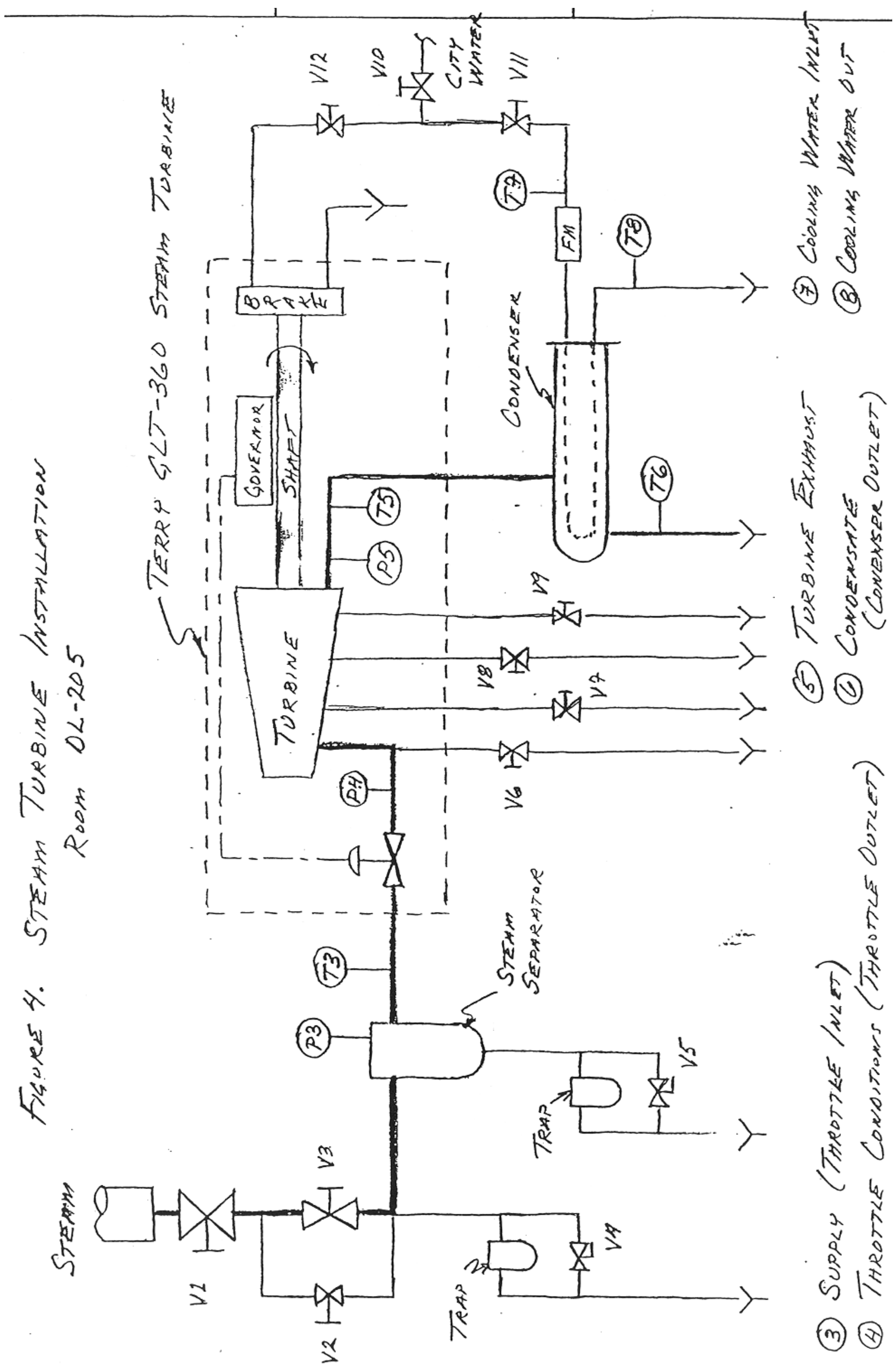

Figure 4 – Piping & Instrumentation (P-I) Diagram for Steam Turbine in DL-205

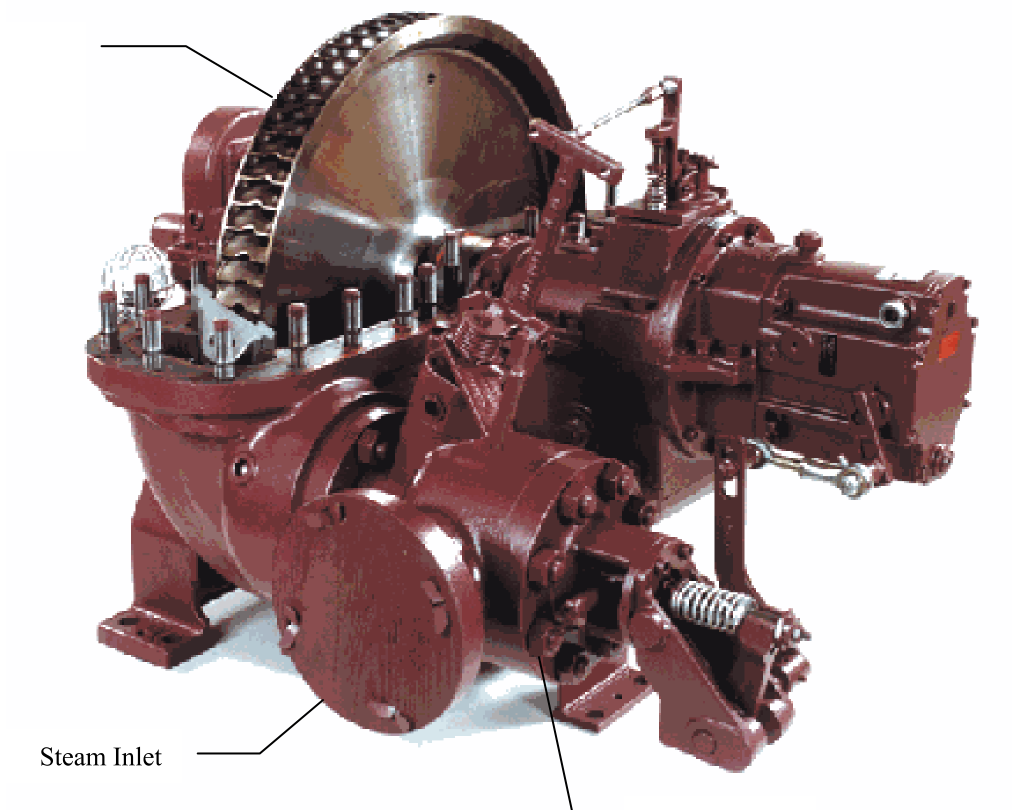

Figure 5 – Picture of a Terry GLT turbine with the top half of the rotor casing removed.

Laboratory Procedure

1. Review and explore the steam turbine installation and instrumentation. Refer to the background section of this laboratory, especially Figures 1, 2, 3 and 4.
2. As instructed, help the instructor start up the turbine following the attached starting procedures.
3. Once the turbine is online take data for two different operating points. Operating points are selected by varying load on the water-brake dynamometer using the control valve (#14) on the dynamometer panel.
   - Before taking data, observe the pressure and temperature readings to be sure the system is at steady state.
   - Record all measurements on the attached data sheets. Use a unique ID number that combines the course section (ES202A), the data (month/day/year), and the time on a 24-hour clock, e.g. ES202A-1/8/96-14:00.
   - You should make a note of the smallest scale increment for all of the measurements; however you do not have to consider uncertainties in your calculations for this lab.
   - BEWARE! All pressures measured using gages, except the barometer, are gage pressures. You must convert these to absolute pressures when determining thermodynamic properties.
   - Cooling water flow rate information is obtained by counting the volume of water flowing through the condenser in a measured time interval.
   - Condensate flow rate is obtained by weighing the amount of condensate that flows into a tank in a measured time interval.
4. If instructed by the instructor, shut down the steam turbine.
5. Once you have measured the performance of the steam turbine by recording the pertinent data, follow the instructions given in class to complete the laboratory.

STEAM TURBINE OPERATING PROCEDURES

Safety Considerations: Before beginning work with the turbine you should be wearing hard hats and have heat resistant gloves readily available (steam is HOT!).

STARTING TURBINE

Notify Boiler Room Operator

Notify the boiler operator in the boiler room (Ext 8240) that the turbine is to be operated BEFORE any steam valves are opened.

Check Valve Positions

1. Check to be sure that STEAM VALVE #1 IS CLOSED.
2. Check to be sure that STEAM VALVES #2 AND #3 ARE CLOSED.
3. Check to be sure that TRAP DRAIN VALVES #4 AND #5 ARE OPEN.
4. Check to be sure that THROTTLE DRAIN VALVE #6 IS OPEN.
5. Check to be sure that the TURBINE THROTTLE VALVE IS IN THE OPEN POSITION. This is usually the case unless the turbine over-speed trip has been activated previously. The throttle valve rod connected to the governor should be fully extended. LOCATE THE MANUAL TRIP FOR THE THROTTLE VALVE.
6. Check to be sure that TURBINE DRAIN VALVES #7, #8, AND #9 ARE OPEN.
7. Check to be sure that WATER SUPPLY VALVES #10, #11, AND #12 ARE CLOSED.
8. Check to be sure that CONDENSATE DRAIN VALVE #13 IS OPEN.
9. Check to be sure that the VALVE #14 ON THE WATERBRAKE CONTROL PANEL IS CLOSED.

Establish Cooling Water Flow through the Condenser

1. Open city-water supply valve #10 fully.
2. Gradually open condenser supply valve #11 and observe the water flow rate shown on the nutating-disk type flow meter. Adjust valve #11 until the flow rate through the condenser is approximately 4 gpm (gallons per minute).

Establish Water Flow to Water-Brake Dynamometer

1. Fully open valve #12 which supplies water to the water brake control valve.
2. Partially open control valve #14 on the water brake control panel to apply small load to the turbine.

Preheat Turbine

1. With valves #1 and #2 closed, GRADUALLY OPEN VALVE #1. As you open valve listen for unusual noises and look for steam leaks. Should you observe problems, close valve #1 and check with the instructor.
2. GRADUALLY OPEN VALVE #2 and observe trap drain (valve #4), separator drain (valve #5) and throttle valve drain (valve #6).
3. Close valves #4, #5, and #6 when steam appears at the floor outlets near the drain. The Turbine Inlet Pressure Gage (State 3) attached to the separator outlet (turbine throttle valve inlet) should begin to indicate gage pressure values above zero and the turbine may begin to rotate.
4. When steam begins to come from the drains attached to valves #7, #8, and #9, close them.

Bring Turbine Online

Open valve #3. Turbine should pick up speed and the throttle valve should move as the governor adjusts the steam flow rate to stabilize the turbine at the governor set point (rated @ 3600 rpm). ***Should the turbine overspeed, press the manual throttle trip and close valve #1.***

SHUTTING DOWN TURBINE

1. Reduce the load applied to the turbine by adjusting valve #14 on the water-brake control panel. Do not completely remove the load applied to the turbine.
2. Close the steam inlet valves (#1, #2, and #3).
3. LET TURBINE COAST DOWN BEFORE PROCEEDING to close water supply valves (#10, #11, and #12).
4. Open all drain valves (#4, #5, #6, #7, #8, and #9)
5. Check to be sure that the condensate drain valve (#13) is open.
6. Turn off power to the thermocouple board and the condensate pump.