Steam Turbine Power Production

ENG ME 304 Energy and Thermodynamics
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1. Introduction

Most electrical power for residential and industrial use in this country is produced by steam power plants. In this laboratory exercise, you will operate a laboratory-scale system in which a steam-powered turbine is used to generate electrical power. Pressure, temperature and mass flow data recorded during steady-state operation of the system will be used to calculate some thermodynamic efficiencies of the power production process.

2. Experimental Apparatus

A schematic of the experimental system is shown in Fig. 1. The components of the system are a propane-fueled boiler to produce steam, a throttling valve to control the flow of steam from the boiler, a steam turbine that converts the thermodynamic energy of the steam into mechanical energy, a generator

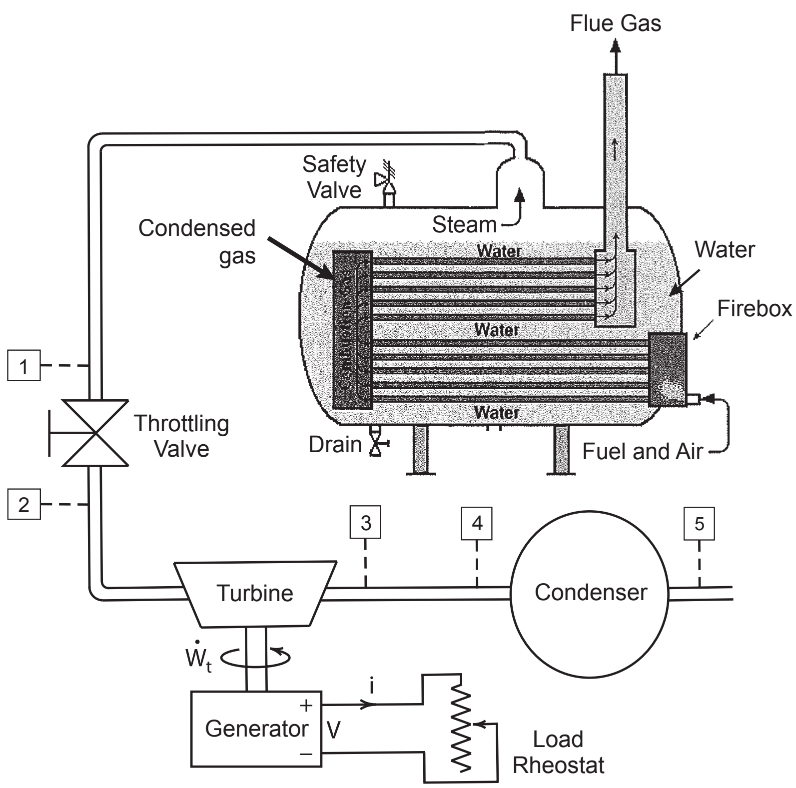

Figure 1: Components of steam turbine power system.

that converts the mechanical energy of the turbine into electrical energy, a rheostat that acts as a variable electrical load on the generator, and a condenser that collects the output steam from the turbine. Sensors are installed to measure the pressure and temperature of the water at points 1, 2, 3, 4, and 5. In addition, voltage and current meters are installed at the output of the electrical generator, and a flow meter is installed to measure the flow rate of propane into the boiler.

Guidance questions: During the start-up procedure, discuss the following issues and questions:

a.) An important goal of power plant operation is to produce a predictable and constant level of electrical power. Many factors will, however, cause the power to fluctuate. Brainstorm a list of factors that could contribute to such fluctuation, and then brainstorm a corresponding general solution to each factor.

b.) Consider this power plant and the operating conditions (the state property values) that are likely involved. Brainstorm the possible safety issues that could be involved, and the steps that could be implemented to avoid them.

c.) Discuss the role that the throttling valve (labeled as "Steam admission") plays in this operation, and how it relates to the generator voltage. If the boiler is fully pressurized and the valve is closed, what will the generator voltage read? Conversely, if the boiler is at a high steady-state pressure and the valve is slowly opened, how will the generator voltage change?

d.) The prelab asked you to brainstorm the steps that would be necessary to bring the system up to "steady state" conditions. Now that you see the equipment, discuss with your group the steps that you've already considered and compare these with the experimental apparatus that you're using.

3. Start-up Procedure

1. Turn the keyed master switch, the burner switch, the load switch, and the operator panel gas valve OFF.
2. Turn the load knob to the minimum position.
3. Drain the condenser tower.
4. OPEN the stream throttle valve.
5. Drain the boiler.
6. Fill the boiler with 5500 ml of distilled water.

7. CLOSE the steam throttle valve.
8. Turn the computer data acquisition system ON.
9. Turn the regulator on the propane tank ON.
10. Turn the operator panel gas valve ON.
11. Turn the keyed master switch ON.
12. Turn the burner switch ON. The propane burner in the boiler should light within 45 seconds, and the boiler pressure should begin to increase within an additional three minutes. If the boiler pressure does not increase within three minutes, turn the burner switch to OFF and seek help from the teaching assistant.
13. Allow the boiler pressure to rise to 120 psi (827 kPa).
14. Turn the load switch ON. Turn the steam throttle value to OPEN. Monitor the boiler pressure until it falls to 50 psi (345 kPa). While monitoring the boiler pressure, adjust the load knob so that the generator voltage does not exceed 9 volts and the turbine speed indicator does not display the red excess speed light.
15. CLOSE the steam throttle valve.
16. Turn the load knob to the minimum position and turn the load switch OFF.
17. Allow the boiler pressure to rise to 120 psi (827 kPa).

4. Steady-state Operation

After the start-up procedure is complete, steady-state operation is achieved by performing the following steps.

1. OPEN the steam throttle valve SLOWLY until the generator output is 9 volts and the boiler pressure is constant at 120 psi (827 kPa).
2. Turn the load switch ON.
3. Adjust the load knob and the steam throttle iteratively until the generator voltage is 9 volts, the generator current is 0.3 amps, and the boiler pressure is 120 psi (827 kPa). These are the desired values for steady state operation.
4. When the desired steady-state operating condition has been achieved, record the position of the water level indicator on the boiler and the time (you'll need these values to determine the mass flow rate). The boiler pressure will slowly decrease as the water level in the boiler drops. Let the system run until the boiler pressure has decreased by

10%. Record the position of the water level indicator on the boiler at this time: Clicking the 'Log data to file' icon will start the data acquisition, and clicking it again will stop and save it. Make sure to either email the data file to a member of your group or transfer it via a USB drive.

5. Shutdown

1. Record the time (again, you'll need this for the mass flow rate calculation).
2. Turn the steam throttle valve to the CLOSED position.
3. Turn the burner switch OFF.
4. Turn the operator panel gas valve OFF.
5. Turn the load knob to the minimum position,.
6. Turn the load switch OFF.
7. Turn the keyed master switch OFF.
8. SLOWLY OPEN the steam throttle valve, making sure that the generator voltage does not exceed 9 volts, until the remaining boiler pressure is exhausted.
9. Drain the condenser tower into a graduated container, and record the volume of water. Do not fill the boiler with water from the condenser tower.
10. When the boiler has cooled and the boiler pressure is atmospheric, OPEN the steam throttle valve to vent the boiler.
11. Fill the boiler until the water level indicator reaches the position noted at the beginning of the steady-state operation.
12. Drain the boiler into a graduated container until the water level indicator reaches the position noted at the end of the steady-state operation. Record the volume of the water in the graduated container.

5. Calculations

1. For an ideal throttling device that operates at steady state, the specific enthalpy at the input of the throttle is equal to the specific enthalpy at the output of the throttle. Use the experimental data for steady-state operation to compute the enthalpy at the input and output of the actual steam throttle valve.

2. The isentropic efficiency η_t of the turbine is defined as

$$\eta_t = \frac{\dot{W}_t/\dot{m}_s}{(\dot{W}_t)_s/\dot{m}_s} = \frac{h_2 - h_3}{h_2 - h_{3s}}, \tag{1}$$

where $\dot{W}_t$ is the actual turbine power output, $(\dot{W}_t)_s$ is the power output of a hypothetical turbine that operates between the actual input state 2 of the turbine and a hypothetical output state $3s$ with pressure p_3 and specific entropy $s_{3s} = s_2$, h_2 is the specific enthalpy at the actual input state 2, h_3 is the specific enthalpy at the actual output state 3, and h_{3s} is the specific enthalpy at the hypothetical output state $3s$. Use the experimental data for steady-state operation to compute the isentropic efficiency for the turbine of this system.

3. The steady-state form of the First Law for a control volume containing the turbine and generator is

$$0 = \dot{Q} - \dot{W}_e + \dot{m}_s(h_2 - h_3), \tag{2}$$

where $\dot{Q}$ is the rate of heat transfer to the turbine and generator, $\dot{W}_e$ is the electrical power out of the generator, $\dot{m}_s$ is the mass flow rate of steam through the turbine, h_2 is the specific enthalpy of the steam that enters the turbine, and h_3 is the specific enthalpy of the steam that leaves the turbine. An efficiency e_{TG} for the turbine and generator can be defined as

$$e_{TG} = \frac{\dot{W}_e}{\dot{m}_s(h_2 - h_3)}. \tag{3}$$

If the rate of heat transfer $\dot{Q}$ in equation 2 is zero, the efficiency e_{TG} is equal to one. Use the experimental data for steady-state operation to calculate the efficiency e_{TG} for the actual turbine and generator of this system.

4. The heating value[1] q_p of propane is

$$q_p = 19{,}950 \text{ Btu/lbm}. \tag{4}$$

An overall efficiency parameter e for the production of electrical power in this laboratory system may be defined as

$$e = \frac{\dot{W}_e}{\dot{m}_p q_p}, \tag{5}$$

where $\dot{W}_e$ is the electrical power output of the generator and $\dot{m}_p$ is the mass flow rate of the propane during the steady-state operation of the system. Use the experimental data for steady-state operation to compute the overall efficiency e of this experimental system.

[1] M. J. Moran et al., *Fundamentals of Engineering Thermodynamics*, 8th ed., 2014, Secs.13.1–13.2.