

53:071 Principles of Hydraulics
Laboratory Experiment #

Pelton Turbine Experiment

Principle

Turbines convert fluid energy into rotational mechanical energy.

Introduction

There are two types of turbines, reaction and the impulse, the difference being the manner of head conversion. In the reaction turbine, the fluid fills the blade passages, and the head change or pressure drop occurs within the runner. An impulse turbine first converts the water head through a nozzle into a high-velocity jet, which then strikes the buckets at one position as they pass by. The runner passages are not fully filled, and the jet flow past the buckets is essentially at constant pressure. Impulse turbines are ideally suited for high head and relatively low power. The Pelton turbine used in this experiment is an impulse turbine.

The Pelton turbine consists of three basic components as shown in Figure 1: a stationary inlet nozzle, a runner and a casing. The runner consists of multiple buckets mounted on a rotating wheel. The jet strikes the buckets and imparts momentum. The buckets are shaped in a manner to divide the flow in half and turn its relative velocity vector nearly 180°.

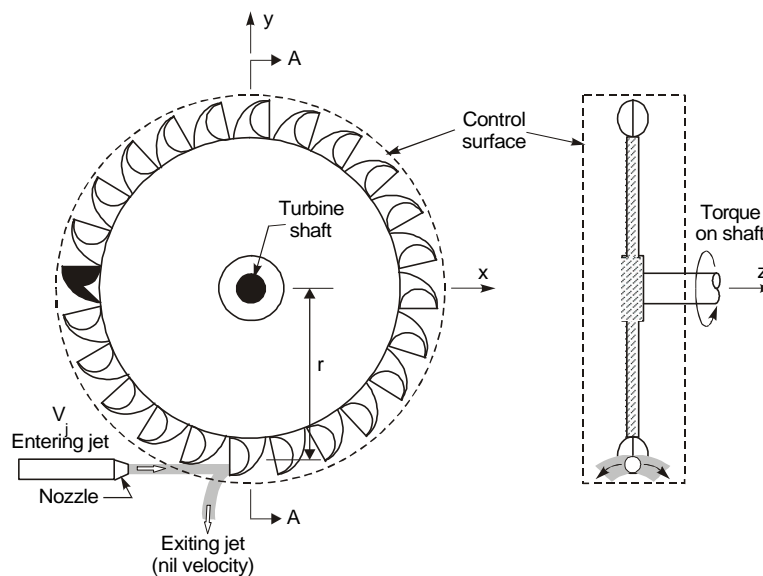


Figure 1. Schematic of an impulse turbine

The primary feature of the impulse turbine is the power production as the jet is deflected by the moving buckets. Assuming that the speed of the exiting jet is zero (all of the kinetic energy of the jet is expended in driving the buckets), negligible head loss at the nozzle and at the impact with the buckets (assuming that the entire available head is converted into jet velocity),

the energy equation applied to the control volume shown in Figure 1 provides the power extracted from the available head by the turbine

$$P_{available} = QH_{available} \quad (1)$$

where Q is the discharge of the incoming jet, and $H_{available}$ is the available pressure head on the nozzle.

By applying the angular momentum equation (assuming negligible angular momentum for the exiting jet) to the same control volume about the axis of the turbine shaft the absolute value of the power developed by the turbine can be written as

$$P = \omega T = 2pNT \quad (2)$$

where ω is the angular velocity of the runner, T is the torque acting on the turbine shaft, and N is the rotational speed of the runner.

The efficiency of the turbine is defined as the ratio between the power developed by the turbine to the available water power

$$h = \frac{P}{P_{available}} \quad (3)$$

In general the efficiency of the turbine is provided as isoefficiency curves. They show the interrelationship among Q , ω , and h . A typical isoefficiency plot is provided in Figure 2.

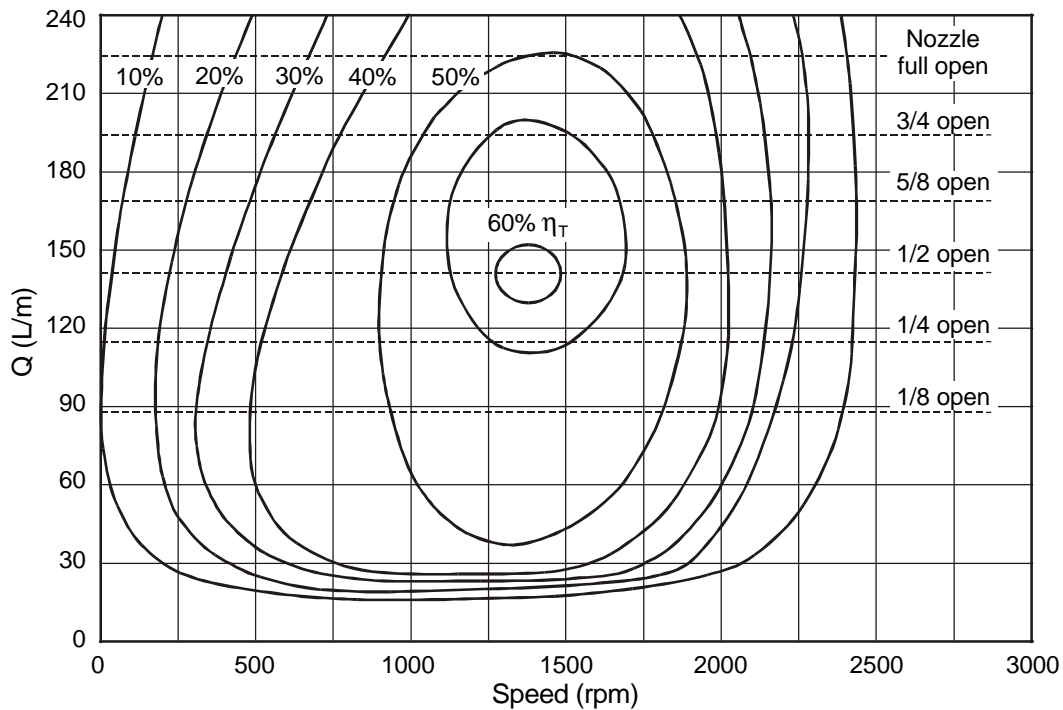


Figure 2. Isoefficiency curve for a laboratory-scale Pelton turbine

Under ideal conditions the maximum power generated is about 85%, but experimental data shows that Pelton turbine are somewhat less efficient (approximately 80%) due to windage, mechanical friction, backsplashing, and nonuniform bucket flow. The purpose of the present experiment is to determine the efficiency of a laboratory-scale Pelton turbine.

Apparatus

The Pelton turbine model is located in the Fluids Laboratory. A schematic of the experimental setup is shown in Figure 3.

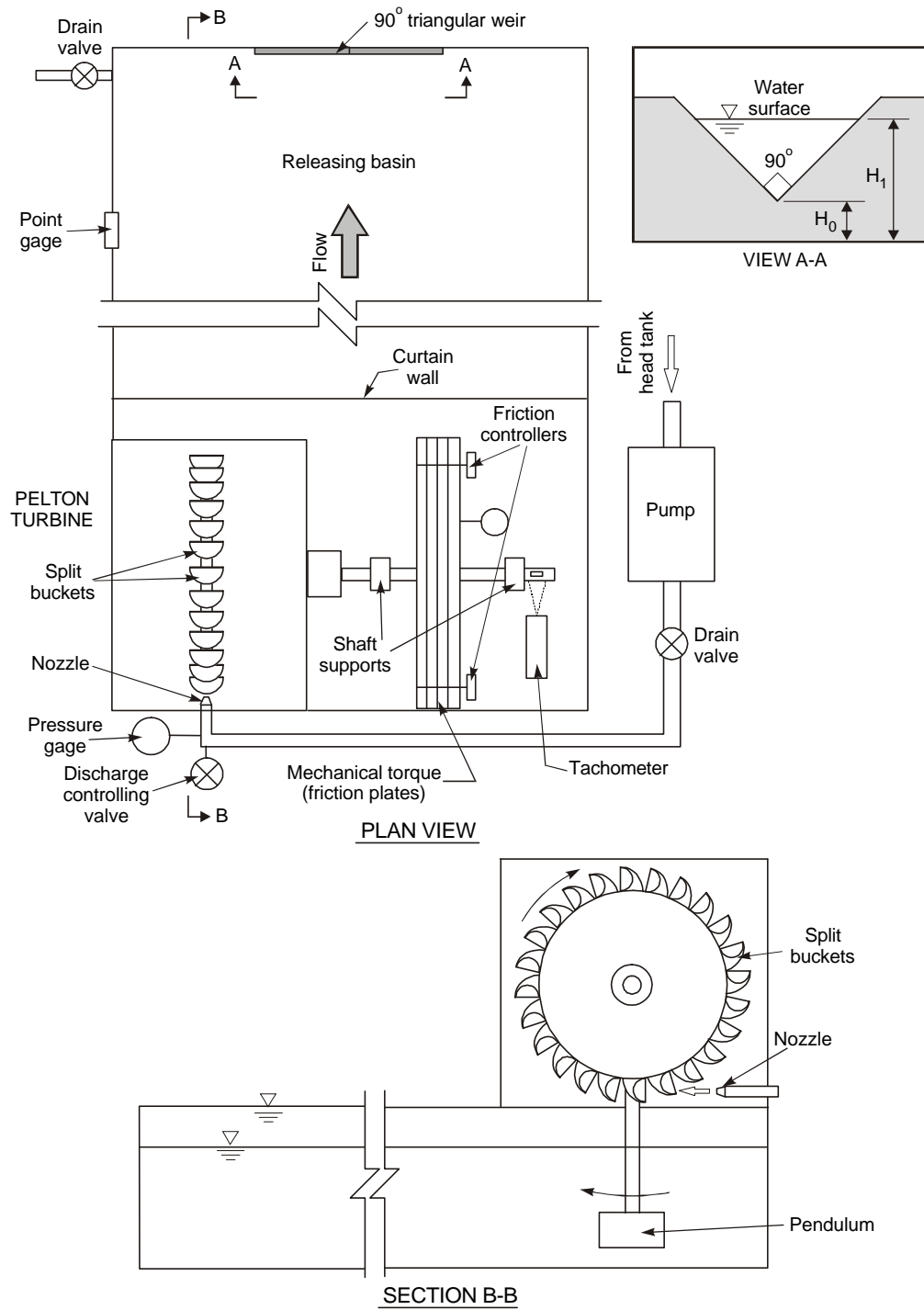


Figure 3. Layout of the experimental setup

A head tank located in the upper floors of the IIHR building maintains constant water head on the turbine. A pressure gage is attached to the water pipe entering the turbine for reading the available water head. The discharge to the setup is supplied by a pump and regulated by a discharge controlling valve. The water exiting the nozzle is collected in a releasing basin equipped with a triangular weir at the downstream end to allow measurement of the flow discharge.

Energy is extracted from the turbine using an assembly comprising friction plates centered on the turbine shaft and a pendulum attached to them. Pendulum deflection is converted in torque applied to the shaft by a mechanical system. A gage located on the mechanical brake indicates the torque applied on the turbine shaft. Water is drawn from the pipe to the turbine for cooling the friction plates. A pair of hand-wheels is used to control the friction applied on the mechanical torque. The rotational shaft speed (rpm) is determined with a photo-tachometer.

Procedures

Measurements will be taken to determine the efficiency-rotational curve for two discharges. Each group of students will proceed with the sequence described below.

1. Close the two drain valves positioned on the releasing basin.
2. Open the discharge controlling valve on the inlet pipe and record the pressure on the pressure gage.
3. Loosen the torque brake so that there is no friction applied on the turbine shaft. Adjust the torque gage display to zero reading. For this setting the tachometer should read a rotational speed of about 1800 rpm.
4. After the water level in the basin has become steady, measure the head on the weir (H_1 in Figure 3) using the point gage located on the basin.
5. Measure the rotational speed of the shaft with no torque resistance on the shaft (runaway condition) with the provided tachometer. Carefully align the tachometer reading line perpendicular to the phosphorescent tape on the shaft.
6. Tighten slightly the friction hand-wheels and record the torque displayed on the friction gage as well as the rotational speed of the shaft with the tachometer.

Note: As the hand-wheels are tightened, the mechanical torque is very sensitive to changes, in particular, for positions close to the fully stopped shaft. For these positions the torque gauge reading will oscillate by as much as 1.5 ft-lb. The best data are obtained by using gradually smaller increments on the torque as the friction applied to the torque are increased. Take the readings when the measured torque shows its maximum.

Repeat this step until approximately 10 different settings are obtained with the last setting with the turbine stopped.

7. After the shaft is fully stopped, completely loosen the torque brake and zero the friction gage.
8. Increase discharge by opening the pipe inlet valve to a runaway speed of 2000 rpm and repeat steps 2 through 7.
9. Open drain valves and allow the basin to drain until only a trickle of water flows over the weir. Wait for weir flow to stop, then measure the water depth indicated by the point gage (H_0 in Figure 3).

Measurements

Record the measured quantities in Table 1.

	Data Acquisition					Data Reduction				
	H_0 [ft]	H_1 [ft]	$H_{available}$ [psi]	T [lb-ft]	N [rpm]	Q [m ³ /s]	g [kg/m ² s ²]	$P_{available}$ [W]	P [W]	h
Run 1										
t [°C] =										
Run 2										
t [°C] =										

Data Analysis

1. Determine the discharge through the system using the weir calibration equation $Q = 2.49(H_1 - H_0)^{2.48}$ (cfs)
2. Determine the efficiency of the turbine using the data reduction equation (3).
3. Plot the rotational speed N vs. the efficiency h of the turbine for each of the applied torque. Plot $P_{available}$ on the same graph. Show the results for the both runs.
4. Compare the curves determined experimentally with those provided in the literature.

Further Considerations

1. At what speed does the efficiency peak (compare this value with data shown in Figure 2). Why does the efficiency vanish at zero rpm and again at runaway?
2. What could be done to the apparatus to increase the efficiency of the turbine?
3. Determine the value of the torque on the shaft by applying the angular momentum equation to the control volume specified in Figure 1.

References

Robertson, J.A. and Crowe, C.T. (1993). *Engineering Fluid Mechanics*, 5th edition, Houghton Mifflin, Boston, MA.
 White, F.M. (1994). *Fluid Mechanics*, 3rd edition, McGraw-Hill, Inc., New York, NY.