AE 204 FLUID MECHANICS

PELTON TURBINE EXPERIMENT / EXP7

2024

OBJECTIVE

Pelton turbines are impulse turbines and are generally used in hydroelectric power plants since they operate according to the “high water supply input-low flow rate output” principle. The speed of the impeller can be adjusted from the inlet valve that is placed on the hydraulic main unit. The total head of the incoming fluid (the sum of the pressure head, velocity head, and elevation head) is converted into a large-velocity head at the exit of the supply nozzle (or nozzles if a multiple nozzle configuration is used). Both the pressure drop across the bucket (blade) and the change in relative speed (i.e., fluid speed relative to the moving bucket) of the fluid across the bucket are negligible. The space surrounding the rotor is not completely filled with fluid. It is the impulse of the individual jets of fluid striking the buckets that generates the torque. Mechanical movement in the turbine is absorbed by a simple friction dynamometer. The pressure coming out of the nozzle (with special production spear valve) is measured by a pressure transmitter. The speed of the turbine is read by the speed sensor.

THEORY

A high-speed jet of water strikes the Pelton wheel buckets and is deflected. The water enters and leaves the control volume surrounding the wheel as free jets (atmospheric pressure). In addition, a person riding on the bucket would note that the speed of the water does not change as it slides across the buckets (assuming viscous effects are negligible). That is, the magnitude of the relative velocity does not change, but its direction does. The change in direction of the velocity of the fluid jet causes a torque on the rotor, resulting in a power output from the turbine.

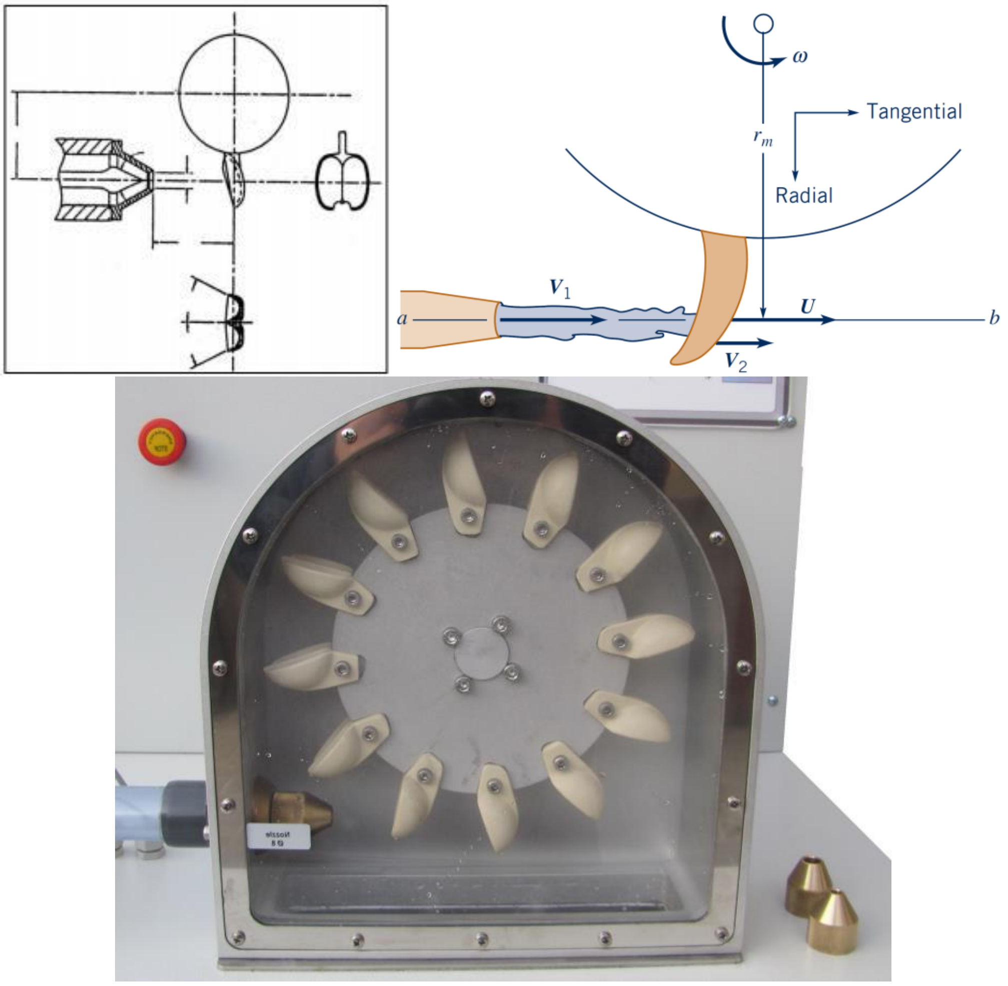

Figure 1. Cross-sectional view of a Pelton wheel (top left), ideal fluid velocities for a Pelton wheel turbine (top right) and the snapshot of the Pelton turbine used in this experiment (bottom).

Design of the optimum, complex shape of the buckets to obtain maximum power output is a very difficult matter. Ideally, the fluid enters and leaves the control volume shown in Figure 1 with no radial component of velocity (In practice there often is a small but negligible radial component). In addition, the buckets would ideally turn the relative velocity vector through a 180° turn, but physical constraints dictate that β, the angle of the exit edge of the blade, is less than 180°. Thus, the fluid leaves with an axial component of velocity as shown in Figure 2.

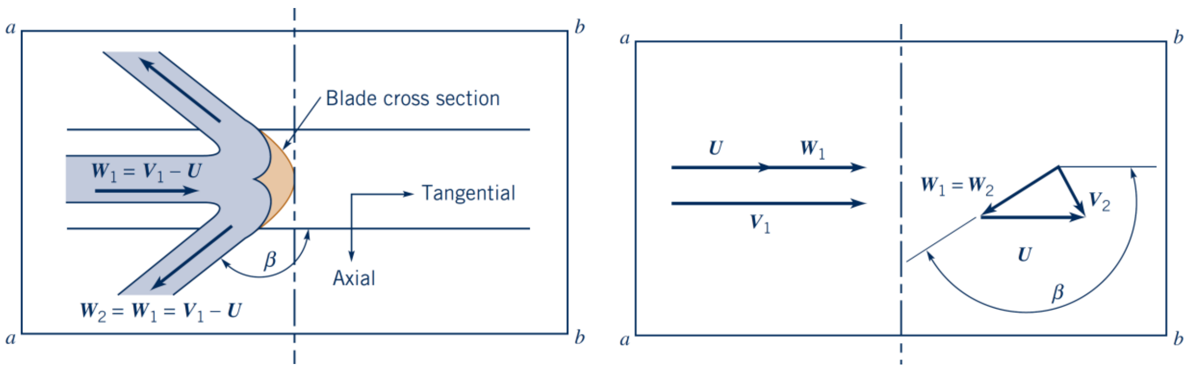

Figure 2. Flow as viewed by an observer riding on the Pelton wheel—relative velocities (left) and inlet and exit velocity triangles for a Pelton wheel turbine (right).

Power, Efficiency and Specific Speed Expressions:

From Newton's second law applied to angular motion,

Angular momentum = (Mass) (Tangential velocity) (Radius)

Torque = Rate of change of angular momentum

Power = (Torque) (Angular velocity)

Considering the water jet striking the runner generates a torque of and rotates the runner with (rev/m), then power obtained from the runner can be expressed as:

$$P_{out} = T\omega \ [W]$$

$$\omega = \frac{2\pi N}{60} \ [rad/s]$$

The total head available at the nozzle is equal to gross head minus losses in the pipeline leading to the nozzle (in the penstock) and denoted by H . Then available power input to the turbine becomes:

$$P_{in} = \rho g Q H$$

where:

$P_{in} \rightarrow$ Power input to turbine

$H \rightarrow$ Total available head [m]

$\rho \rightarrow$ density of water [kg/m³]

$Q \rightarrow$ volume flow rate of water [m³/s]

$g \rightarrow$ gravitational acceleration [m/s²]

During conversion of energy (hydraulic energy to mechanic energy or vice versa) there occur some losses. They can be in many form and main causes of them are friction, separation and leakage.

For a turbine:

Fluid Input Power = (Mechanical loss) + (Hydraulic losses) + (Useful shaft power output)

where:

Hydraulic Losses = (Runner loss) + (Casing loss) + (Leakage loss)

Considering all losses as one term:

$$P_{in} = P_{lost} + P_{out}$$

Then, overall efficiency of turbine becomes:

$$\eta_o = \frac{P_{out}}{P_{in}} = \frac{T\omega}{\rho g H \dot{V}}$$

Pelton wheel is directly coupled to a generator to produce electricity. Therefore, another efficiency term, namely generator efficiency is used to show how efficiently the mechanical energy is converted to electricity.

$$\eta_{gen.} = \frac{P_e}{P_{out}} = \frac{VI}{T\omega}$$

where:

$V \rightarrow$ Generator voltage [V]

$I \rightarrow$ Generator current [A]

DESCRIPTION OF APPARATUS

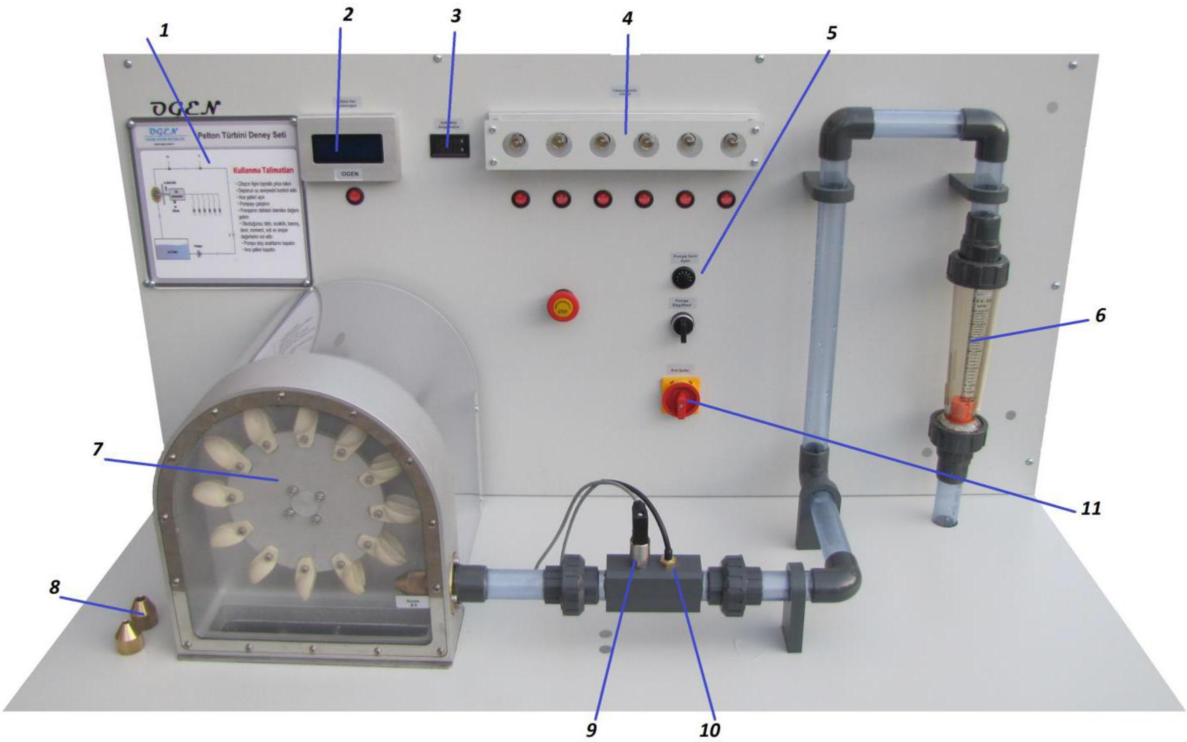

Figure 3. The "Pelton Turbine" experimental setup.

1- Experiment Information 2- Pressure Reading Screen 3- Current Reading Screen

4- Loading Unit 5- Pump revolution rate adjusting potentiometer 6- Rotameter

7- Pelton turbine 8- Nozzles 9- Pressure transducers 10- Temperature sensor 11- Switch

PROCEDURE

1. After plugging in the device, switch on the main unit.

2. Start the pump to fill in the pipe till the nozzle.

3. Select a spear valve opening (1/2, 3/4 or 4/4).

4. Nozzle will issue water to the cups of Pelton wheel. Read the temperature (T), pressure (P), revolution (RPM), flow rate (Q), moment (M), voltage (V) and current (I) values from the digital indicator screen.

5. Change the RPM value and note P, Q, M, V and I values again.

6. Repeat procedures 4 and 5 six times and the experiment is over when you reach the “shut off” of the pump.

REFERENCES

1. https://www.aybu.edu.tr/bolumroot/contents/muhendislik_makina/files/MCE%20403-pelton%20t%C3%BCrbini%20deney%20f%C3%B6y%C3%BC-%C3%B6grenci-17_11_2016.pdf, Access date: 17.04.2024.

2. Munson, B.R. et al., Fundamentals of Fluid Mechanics, 7th Ed., 2013.

THE PELTON TURBINE EXPERIMENT / LAB 7 DATA SHEET DATE:

STUDENT NAME, SURNAME: SIGNATURE:

TABLE 1

SELECT SPEAR VALVE OPENING: 1/4 2/4 3/4 4/4							
Data No	N, Rotational Speed, (rev/min)	Temperature (°C)	P, Pressure (bar)	Q, Volumetric flow rate (m^3/s)	Moment, M (N-cm)	I, Current (A)	V, Voltage (V)
1							
2							
3							
4							
5							
6							

TABLE 2

Data No	P_{out} , Power obtained(W)	P_{in} , Fluid input power (W)	P_e , electricity power (W)	η_o , overall efficiency	$\eta_{gen.}$, generator efficiency
1					
2					
3					
4					
5					
6					

Calculation steps:

1. Select the spear valve opening.
2. The necessary data for calculations will be recorded to the table 1. Start from the maximum flow rate and finish at the “shut-off” of the pump.
3. Using the appropriate equations, calculate the efficiency of the generator. Fill in table 2.
4. FIRST GRAPH: Plot flowrate (m^3/s) versus generator power, $P_{out}(W)$.
5. SECOND GRAPH: Plot flowrate (m^3/s) versus overall efficiency, η_o.

LAB RULES:

•Each group should submit one report.

•Each group should write each part by their own and get together with their group members to merge all of them.

•Reports are due to next Monday. They must be submitted to the corresponding assistant **till 17:00** on the next Monday.

•Students must sign the data sheet from the lab assistant at the end of each experiment and the signed sheet must be attached with the report. Reports without the signed data sheet will not be graded.

•Students are advised to read the detail of each experiment sheet before coming to the corresponding lab class.

LAB REPORT FORMAT (HANDWRITTEN EXCEPT COVER PAGE, TABLES AND PLOTS):

The lab report (no longer than 15 pages – all included –) should include the followings (unless otherwise specified):

1. Objective	2. Theory	3. Procedure	4. Results
5. Sample calculation	6. Necessary plots	7. Discussion on results, errors and graphs	8. Conclusion