AE 204 FLUID MECHANICS

FRANCIS TURBINE EXPERIMENT / EXP10

2024

OBJECTIVE

The purpose of this experiment is to study the constructional details and performance parameters of Francis Turbine. Turbines are subdivided into impulse and reaction machines. In the impulse turbines, the total head available is converted into the kinetic energy. This is usually accomplished in one or more nozzles as mentioned previously in Pelton Turbine experiment (Exp7). In the reaction turbines, only some part of the available total head of the fluid is converted into kinetic energy so that the fluid entering the runner has pressure energy as well as kinetic energy. The pressure energy is then converted into kinetic energy in the runner. The Francis turbine is a type of reaction turbine that was developed by James B. Francis. Francis turbines are the most common water turbine in use today.

THEORY

The reaction turbine consists of fixed guide vanes called stay vanes, adjustable guide vanes called wicket gates, and rotating blades called runner blades. Flow enters tangentially at high pressure, is turned toward the runner by the stay vanes as it moves along the spiral casing or volute, and then passes through the wicket gates with a large tangential velocity component. Momentum is exchanged between the fluid and the runner as the runner rotates, and there is a large pressure drop.

Unlike the impulse turbine, the water completely fills the casing of a reaction turbine. For this reason, a reaction turbine generally produces more power than an impulse turbine of the same diameter, net head, and volume flow rate. The angle of the wicket gates is adjustable so as to control the volume flow rate through the runner. In most designs the wicket gates can close on each other, cutting off the flow of water into the runner. At design conditions the flow leaving the wicket gates impinges parallel to the runner blade leading edge to avoid shock losses.

In Francis turbine, a reaction turbine, there is a drop in static pressure and a drop in velocity head during energy transfer in the runner. Only part of the total head presented to the machine is converted to velocity head before entering the runner. This is achieved in the adjustable guide vanes, shown in Figure 1.

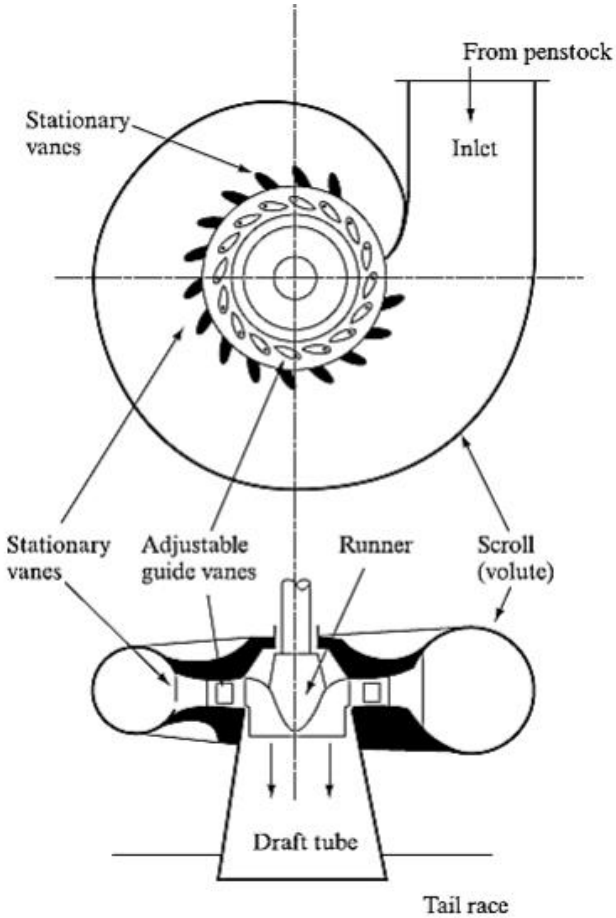

Figure 1. Configuration of a Francis Turbine.

Similarly to Pelton wheel, Francis turbine usually drives an alternator and, hence, its speed must be constant. Since the total head available is constant and dissipation of energy by throttling is undesirable, the regulation at part load is achieved by varying the guide vane angle. This is possible because there is no requirement for the speed ratio to remain constant. In Francis turbines, sudden load changes are catered for either by a bypass valve or by a surge tank.

Power and Efficiency Expressions:

Considering runner generates a torque of T with a rotational speed of N (rev/s), then power obtained from the runner can be expressed as:

$$\textit{Power Output} = \textit{(Torque)(Angular velocity)}$$

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

$$T = Fr$$

$$\omega = 2\pi N \quad [rad/s]$$

Radius of runner, r is 85 mm.

The total head available at the nozzle is equal to gross head less 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:

$$P_{in} \rightarrow \textit{power input to turbine}$$

$$H \rightarrow \textit{total available head at turbine inlet [m]}$$

$$\rho \rightarrow \textit{density of water [kg/m}^3\textit{]}$$

$$Q \rightarrow \textit{volume flow rate of water [m}^3\textit{/s]}$$

$$g \rightarrow \textit{gravitational acceleration [m/s}^2\textit{]}$$

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, seperation and leakage.

For a turbine:

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

Where:

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

Considering all losses as one term:

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

Then, overall efficiency of turbine becomes:

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

DESCRIPTION OF APPARATUS

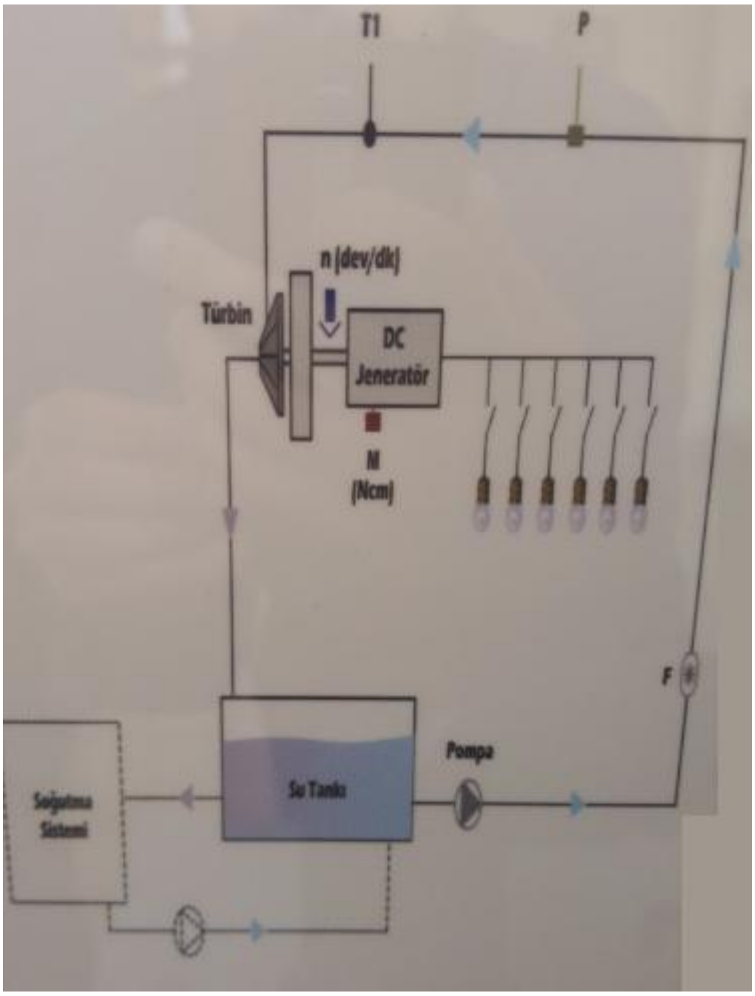

Figure 2. “Francis Turbine” Experimental Setup

PROCEDURE

1. Plug in the device to a grounded plug.
2. Make sure that the water level in the tank is appropriate.
3. Switch on the main unit and start the pump.
4. Adjust the pump rotation speed to the desired level (Start with a high value, e.g. 12 m^3/h)
5. Read and note flow rate (Q), temperature (T), Pressure (P), rotational speed (RPM), moment (M), voltage (V) and current (I) values. Repeat it for different RPM values six times by lowering Q gradually.
6. Stop the pump and switch off the main unit.

REFERENCES

1. https://www.aybu.edu.tr/bolumroot/contents/muhendislik_makina/files/MCE%20403-francis%20türbini%20deney%20föyü.pdf, Access date: May 13rd, 2022.

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

FRANCIS TURBINE EXPERIMENT / LAB 10 DATA SHEET DATE:

STUDENT NAME, SURNAME: SIGNATURE:

TABLE 1

SELECT SPEAR VALVE OPENING: MIN MAX							
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	η_{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