FRANCIS TURBINE EXPERIMENT

1. OBJECT

The purpose of this experiment is to study the constructional details and performance parameters of Francis Turbine.

2. INTRODUCTION

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 Wheel experiment.

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. They operate in a water head from 40 to 600 m and are primarily used for electrical power production. The electric generators which most often use this type of turbine have a power output which generally ranges just a few kilowatts up to 800 MW.

3. 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 Fig.1.
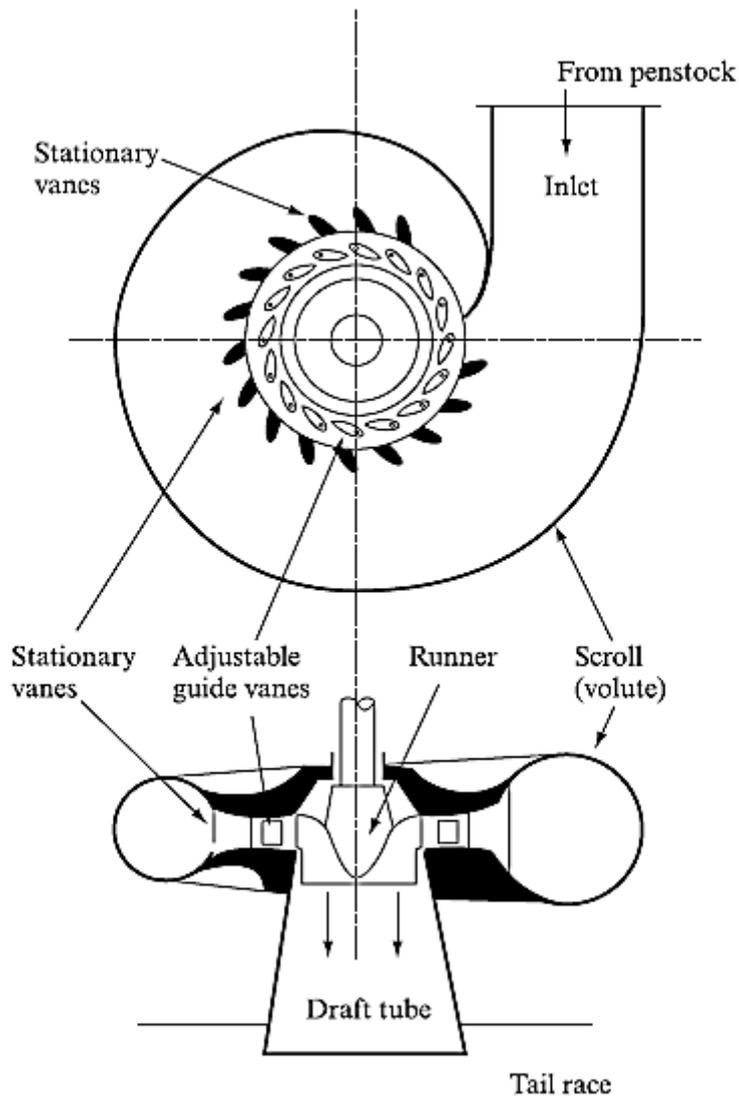
Figure 1: Configuration of a Francis Turbine

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.

Components of the Francis Turbine:

Spiral Casing: Most of these machines have vertical shafts although some smaller machines of this type have horizontal shaft. The fluid enters from the penstock (pipeline leading to the turbine from the reservoir at high altitude) to a spiral casing which completely surrounds the runner. This casing is known as scroll casing or volute. The cross-sectional area of this casing decreases uniformly along the circumference to keep the fluid velocity constant in magnitude along its path towards the stay vane. This is so because the rate of flow along the fluid path in the volute decreases due to continuous entry of the fluid to the runner through the openings of the stay vanes.

Stay Vanes and Wicket Gates: Water flow is directed toward the runner by the stay vanes as it moves along the spiral casing, and then it passes through the wicket gates. The basic purpose of the wicket gate is to convert a part of pressure energy of the fluid to the kinetic energy and then to direct the fluid on to the runner blades at the angle appropriate to the design. Moreover, they are pivoted and can be turned by a suitable governing mechanism to regulate the flow while the load changes. The wicket gates impart a tangential velocity and hence an angular momentum to the water before its entry to the runner.

Runner: It is the main part of the turbine that has blades on its periphery. During operation, runner rotates and produces power. For a mixed flow type Francis Turbine, the flow in the runner is not purely radial but a combination of radial and axial. The flow is inward, i.e. from the periphery towards the centre. The main direction of flow changes as water passes through the runner and is finally turned into the axial direction while entering the draft tube.

Draft Tube: After passing through the turbine runner, the exiting fluid still has appreciable kinetic energy. To recover some of this kinetic energy the flow enters an expanding area (diffuser) called draft tube, which slows down the flow speed, while increasing the pressure prior to discharge into the downstream water. Therefore, the primary function of the draft tube is to reduce the velocity of the discharged water to minimize the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without any appreciable drop of available head. Moreover careful design of draft tube is vital, otherwise cavitation can occur inside the tube.

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:

$$Power\ Output = (Torque)(Angular\ velocity)$$

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

$$T = Fr$$

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

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:

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

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

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

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

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

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:

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

4. EXPERIMENTS

4.1 Calculation of Francis Turbine Efficiency

Aim of the Experiment: To comprehend how to calculate Francis Turbine efficiency

The necessary data for calculations will be recorded to the table given below.

Measurement No:	1	2
Rotational speed, N [rev/sec]		
Force, F [N]		
Water flow rate, Q [m³/h]		
Water inlet pressure, P_1 [bar]		

Calculations: Using the appropriate equations, calculate the overall efficiency.

4.2 Change in Francis Turbine Efficiency with respect to Flow Rate

Aim of the Experiment: To understand how Francis Turbine efficiency alters when the flow rate is varied.

The necessary data for calculations will be recorded to the table given below.

Measurement No:	1	2	3
Rotational speed, N [rev/sec]			
Force, F [N]			
Water flow rate, Q [m³/h]	4	5	6
Water inlet pressure, P_1 [bar]			

Calculations: Using the appropriate equations, calculate the efficiency of turbine and draw the graph of efficiency versus flow rate.

4.3 Change in Francis Turbine Efficiency with respect to Guide Vane Position

Aim of the Experiment: To understand how Francis Turbine efficiency alters with guide vane position.

The necessary data for calculations will be recorded to the table given below.

Measurement No:	1	2	3
Rotational speed, N [rev/sec]			
Force, F [N]			
Water flow rate, Q [m^3/h]			
Water inlet pressure, P_1 [bar]			
Guide vane position	Closed	Semi-Open	Fully Open

Calculations: Using the appropriate equations, calculate the efficiency of turbine and draw the graph of efficiency versus guide vane position.

5. REPORT

In your laboratory reports must have the followings;

a) Cover

b) A short introduction

c) All the necessary calculations using measured data.

d) Discussion of your results and a conclusion.

References

John F. Douglas, Fluid Mechanics, 5th ed., Pearson.

Yunus A. Çengel, John M. Cimbala, Fluid Mechanics: Fundamentals and Applications, 1st ed., McGraw-Hill