PEMP RMD 2501

Hydraulic Turbines

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Session Objectives

This session is intended to introduce the following:

- □ Different types of Hydraulic Turbines
- □ Operation of Hydraulic turbines
- □ Draft tubes
- Design concepts related to hydraulic turbines

Introduction

- Hydraulic turbines may be defined as prime movers that transform the kinetic energy of the falling water into mechanical energy of rotation and whose primary function is to drive a electric generator.
- A cubic meter of water can give about 9800 Joules of mechanical energy for every meter it descends and a flow of a cubic meter per second in a fall of 1 meter can provide 9800 W of power
- Hydro-power is essentially a controlled method of water descent usefully utilised to generate power.
- Hydroelectric plants utilise the energy of water falling through a head that may vary from a few meters to ~1500 or even 2000 m. To manage this wide range of heads, many different kinds of turbines are employed, which differ in their working components.
- The main components of a hydroelectric system may be classified into two groups:
 - the hydraulic system components that include the turbine, the associated conduits-like penstocks, tunnel and surge tank-and its control system, and
 - the electric system components formed by the synchronous generator and its control system.

Layout of a Hydro-Electric Power Plant RMD 2501



13. Tale race canal

Layout of a Hydro-Electric Power Plant RMD 2501



Schematic layout of a hydro-electric plant with surge tank

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Necessity of Surge Tank

- The performance of hydraulic turbines is strongly influenced by the characteristics of water conduit that feeds the turbine. These characteristics include the effect of water inertia, water compressibility and pipe wall elasticity in the penstock.
- Hydroelectric turbines present non-minimal phase characteristics due to water inertia; this means that a change in the gate produces an initial change in mechanical power, which is opposite to the one requested.
- The water compressibility effect produces traveling waves of pressure and is usually called water hammer.
- The water hammer is characterised by a sudden high-pressure rise caused by stopping the flow too rapidly. The wave propagation speed is around 1200 m/s.
- In those plants where distance between the forebay or reservoir and the turbine is quite large, a surge tank is usually utilised.
- The function of this tank is to hydraulically isolate the turbine from deviations in the head produced by the wave effects in the conduits.
- Some surge tanks include an orifice whose function is to dampen and absorb the energy of the hydraulic oscillations.

History of Hydraulic Turbines

- ➢ Water wheels China and Egypt thousands of years ago.
- $\blacktriangleright \quad \text{Reaction runner} J \text{ A Segnar} 1950.$
- Euler turbine theory Leonard Euler valid till today
- Turbine is a designation that was introduced in 1824 in a dissertation of the French engineer Burdin.
- Fourneyron designed a radial turbine and put to operation the first real turbine in 1827 – power 20-30kW and runner diameter of 500 mm
- Henschel and Jonval in 1840 independently developed turbine with axial water flow through it. They were the first ones to apply draft tube and in that way to utilize the water head between runner outlet and tail water level.
- ➢ Francis in 1849 developed the radial turbine, named Francis turbine.
- In 1870 professor Fink introduced an important improvement in Francis turbine by making the guide vanes turning on a pivot in order to regulate the flow discharge.
- In 1890 American engineer Pelton developed impulse turbine, named Pelton turbine
- ➢ In 1913 Kaplan designed a propeller turbine, named Kaplan turbine
- Subsequent developments were made on Francis, Pelton and Kaplan turbines.

Classification of Hydraulic Turbines RMD 2501

Hydraulic turbines are generally classified as

□ Impulse Turbine – Pelton, Turgo turbine

□ Reaction Turbine – Francis, Kaplan and Propeller turbine

Based on flow direction, they are further classified as:

- □ Tangential Flow
- □ Radial Flow
- □ Axial Flow
- □ Mixed Flow

Impulse and Reaction Turbines

- The flow energy to the impulse turbines is completely converted to kinetic energy before transformation in the runner.
- The impulse forces being transferred by the direction changes of the flow velocity vectors when passing the buckets create the energy converted to mechanical energy on the turbine shaft.
- The flow enters the runner from jets spaced around the rim of the runners. The jet hits momentarily only a part of the circumference of the runner.
- ➢ In the reaction turbines two effects cause the energy transfer from the flow to the mechanical energy on the turbine shaft:
 - Firstly, it follows from a drop in pressure from inlet to outlet of the runner. This is denoted as the *reaction part* of the energy conversion.
 - Secondly, the changes in the directions of the flow velocity vectors through the runner blade channels transfer impulse forces. This is denoted as the *impulse part* of the energy conversion.
- The pressure drop from inlet to outlet of the runners is obtained because the runners are completely filled with water.

Hydro-Electric Power Plants

		Rated capacity (MW)		Year of
Name of dam	Location	Present	Ultimate	operation
Itaipu	Brazil/Paraguay	12,600	14,000	1983
Guri	Venezuela	10,000	10,000	1986
Grand Coulee	Washington	6,494	6,494	1942
Sayano-Shushensk	Russia	6,400	6,400	1989
Krasnoyarsk	Russia	6,000	6,000	1968
Churchill Falls	Canada	5,428	5,428	1971
La Grande 2	Canada	5,328	5,328	1979
Bratsk	Russia	4,500	4,500	1961
Moxoto	Brazil	4,328	4,328	n.a.
Ust-Ilim	Russia	4,320	4,320	1977
Tucurui	Brazil	4,245	8,370	1984

A few of the large hydro-electric installations globally

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Hydraulic Turbines



Pelton turbine





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Francis Turbine



Kaplan turbine

Hydraulic Turbines (...contd.)



Turgo impulse turbine





Pump turbine



Tubular turbine

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Pelton Turbine

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- ➢ Invented by Pelton in 1890.
- The Pelton turbine is a tangential flow impulse turbine.
- The Pelton wheel is most efficient in high head applications.
- Power plants with net heads ranging from 200 to 1,500 m.

- ➤ The largest units can be up to 200 Megawatts.
- Pelton turbines are best suited for high head and low flow sites.
- Depending on water flow and design, Pelton wheels can operate with heads as small as 15 meters and as high as 1800 meters.
- ➢ As the height of fall increases, less volume of water can generate same power.

Horizontal Arrangement of a Pelton Turbine 2501



Horizontal arrangement is found only in medium and small sized turbines with usually one or two jets. In some designs, up to four jets have been used. The flow passes through the inlet bend to the nozzle outlet, where it flows out as a compact jet through atmospheric air on to the wheel buckets. From the outlet of the buckets the water falls through the pit down into the tail water canal.

Vertical Arrangement of a Pelton Turbine^{RMD 2501}



Large Pelton turbines with many jets are normally arranged with vertical shaft. The jets are symmetrically distributed around the runner to balance the jet forces. The figure shows the vertical and horizontal sections of the arrangement of a six jet vertical Pelton turbine.

Parts of a Pelton Turbine



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Parts of a Pelton Turbine

- The Pelton runners may be designed either for casting of the disc and buckets in one piece, i.e. monocast, or the disc and each of the buckets are casted in separate pieces.
- The shape of the buckets is decisive for the efficiency of the turbines.
 Limitations however are that bucket shape always will be a compromise between a hydraulically ideal and a structural optimum design.
- \succ The runner disc is fastened to the shaft by bolts and nuts.
- The turbine shaft of vertical Pelton turbines is made of forged steel with an integral flange at both ends. A hole is drilled centrally through the whole length of the shaft. An oil reservoir is a rotating member bolted to the shaft flange.
- ➢ Journal and thrust bearings are provided with circulating oil to carry the heat dissipated by the shaft and bearings.
- The distributor pipe is designed to provide an acceleration of the water flow through the bifurcation towards each of the main injectors. This design is advantageous, because it by contributes in keeping a uniform velocity profile of the flow.
- > The injector is operated hydraulically by servo motors.

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Material of Pelton Turbine

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Case	: fabricated carbon steel to BS EN 10025:1993 S275JR
Runner:	: cast Stainless BS3100 Grade 425 C11
Shaft seal:	: cast gunmetal labyrinth type seal
Bearings:	: rolling element or sleeve type
Spear / Needle valve	: stainless steel internal components housed in a carbon steel fabricated or cast branch pipe
Deflector	: stainless steel plate

The material of the runner and buckets are chosen according to the head, stresses, content of sand in the water and other strain factors. For the large turbines the main strain factors are cavitation, sand erosion and cycle fatigue

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Pelton Turbine Specifications

Dixence, Switzerland

Gross head	: 1748 m
Net head	: 1625 m
Jet velocity	: 177 m/s
Power	: 18.6 MW
Speed	: 500
Jet diameter	: 94.2 mm
Pitch diameter of the wheel:	: 3.319m

Turgo Impulse Turbine

- Turgo impulse turbine design was developed by Gilkes in 1919 to provide a simple impulse type machine with considerably higher specific speed than a single jet Pelton. The design allows larger jet of water to be directed at an angle onto the runner face.
- The Turgo turbine is an impulse water turbine designed for medium head applications.
- \blacktriangleright Turgo runners may have an efficiency of over 90%.



- A Turgo runner looks like a Pelton runner split in half. For the same power, the Turgo runner is one half the diameter of the Pelton runner and so twice the specific speed.
- The Turgo can handle a greater water flow than the Pelton because exiting water does not interfere with adjacent buckets.

Parts of Turgo Impulse Turbine RMD 2501



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Material of Turgo Impulse Turbine RMD 2501

Case: fabricated carbon steel to BS EN 10025:1993 S275JRRunner: cast Stainless BS3100 Grade 425 C11 or Aluminium
bronze Gr. AB2CShaft seal: cast gunmetal labyrinth type seal

Bearings : rolling element or sleeve type

Spear /: stainless steel internal components housed in a carbonneedle valvesteel fabricated or cast branch pipe

Deflector : stainless steel plate

Year of Rated capacity (MW) initial Name of dam Location Present Ultimate operation Itaipu Brazil/Paraguay 12,600 14,000 1983 Guri Venezuela 10,000 10,000 1986 Grand Coulee Washington 6,494 6,494 1942 Sayano-Shushensk Russia 6,400 6,400 1989 Krasnoyarsk Russia 6,000 6,000 1968 Churchill Falls Canada 5,428 5,428 1971 5,328 La Grande 2 Canada 5,328 1979 Bratsk Russia 4,500 4,500 1961 Moxoto Brazil 4,328 4,328 n.a. Ust-Ilim Russia 4,320 4,320 1977 Tucurui Brazil 4,245 8,370 1984



- The Francis turbine is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy.
- The inlet is spiral shaped. The guide vanes direct the water tangentially to the runner causing the runner to spin.
- The guide vanes (or wicket gate) may be adjustable to allow efficient turbine operation for a range of water flow conditions.
- Power plants with net heads ranging from 20 to 750 m.

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Vertical Shaft Francis Turbine

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- The water from the penstock is conducted through the scroll casing and distributed around the stay ring and the complete circumference of the guide vane cascade. The scroll casings are normally welded steel plate constructions for turbines at low, medium as well as high heads.
- The openings of the guide vanes are adjustable by the regulating ring, the links and levers. The vanes are shaped according to hydraulic design specifications and given a smooth surface finish. The bearings of the guide vane shafts are lubricated with oil or grease.
- Casing covers are bolted to the stay ring of the scroll casing. They are designed for high stiffness to keep the deformations caused by the water pressure at a minimum. This is of great importance for achieving a minimal clearance gap between the guide vane ends and the facing plates of the covers. Between the runner and the covers the clearance is also made as small as possible.
- The turbine shaft is steel forged and has forged flanges at both ends. The turbine and generator shafts are connected by a flanged joint. This joint may be a bolted reamed or friction coupling where the torque is transferred by means of shear or friction.

Regulating Mechanism for Francis Turbine^{PEMP}



- The guide vane mechanism along with the governors provides the regulation of the turbine output.
- The turbine governor controls the servomotor which transfers its force through a rod to the regulating ring. This ring transfers the movement to the guide vanes through a rod, lever and link construction.
- ➤ The guide vane exit area in flow direction is varied by an equal rotation of each of the guide vanes.

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Material of Francis Turbine

Fabricated carbon steel to BS EN 10025.1993 S275IR
Cast Stainless BS3100 Grade 425 C11 or Aluminium Bronze BS 1400 Gr. AB2C
Fabricated carbon steel
Rolling element or sleeve type
Stainless steel or Aluminium Bronze
Fabricated steel BS 10025:1993 S275 JR
Stainless steel plate

Francis Turbine-Specification

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Fionnay, Switzerland

Head:	: 454 m
Power:	: 47.1 MW
Speed	: 750 rpm

Propeller Turbine

The **propeller turbines** have the following favourable characteristics:

- \checkmark relatively small dimensions combined with high rotational speed
- \checkmark a favourable efficiency curve
- ✓ large overloading capacity
- The runner has only a few blades radially oriented on the hub and without an outer rim.
- \succ The water flows axially through the runner.
- The runner blades have a slight curvature and cause relatively low flow losses. This allows for higher flow velocities without great loss of efficiency.
- Accordingly, the runner diameter becomes relatively smaller and the rotational speed more than twice than that for a Francis turbine of the corresponding head and discharge.
- The comparatively high efficiencies at partial loads and the ability of overloading is obtained by a coordinated regulation of the guide vanes and the runner blades to obtain optimal efficiency for all operations.

Kaplan Turbine

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- The Kaplan turbine is a propeller-type water turbine that has adjustable blades. It was developed in 1913 by the Austrian professor, Viktor Kaplan.
- The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low head applications that was not possible with Francis turbines.
- Kaplan turbines are now widely used throughout the world in high-flow, low-head power production.
- \blacktriangleright Power plants with net heads ranging from 10 to 70 m.

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Kaplan Turbine



Sectional view of Kaplan turbine

- Kaplan turbines have adjustable runner
 blades, that offers significant advantage
 to give high efficiency even in the range
 of partial load, and there is little drop in
 efficiency due to head variation or load.
- The runner blade operating mechanism consists of a pressure oil head, a runner servomotor and the blade operating rod inside the shaft, etc.
- The runner blades are operated to smoothly adjust their blade angles by a link mechanism installed inside the runner hub.

Diagonal Flow Turbine



- The Diagonal flow turbine is an improvement of Kaplan turbine with better performance for high head.
- The Diagonal flow turbine, as a result of using adjustable runner blades, has high efficiency over a wide range of head and load. Thus, it is suitable for a power station with wide variation of head or large variation of discharge.
- The Diagonal flow turbine has runner blade-stems constructed at a certain diagonal angle to the vertical center line of the machine.

Tubular or Bulb Turbine

Tubular turbine is a reaction turbine of Kaplan type which is used for the lowest head.



- In a Bulb turbine, the water flows with a mixed axial-radial direction into the guide vane cascade and not through a scroll casing. The guide vane spindles are inclined (normally 60°) in relation to the turbine shaft. Contrary to other turbine types, this results in a conical guide vane cascade. The Bulb turbine runner is of the same design as the Kaplan turbine runner.
- The tubular turbine is equipped with adjustable wicket gates and adjustable runner blades.
- This arrangement provides the greatest possible flexibility in adapting to changing net head and changing demands for power output, because the gates and blades can be adjusted to their optimum openings.

Parts of a Bulb Turbine



- 1. Bulb nose
- 2. Access arm to upstream compartment
- 3. Removable cover for generator dismantling
- 4. Oil distribution head
- 5. Generator
- 6. Upper stay vane for access to downstream compartment
- 7. Upstream thrust and counter thrust bearing
- 8. Lower stay vane
- 9. Downstream bearing
- 10. Adjustable distributor
- 11. Blade
- 12. Turbine pit

Kaplan Turbine Specification

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St. Lawrence Power Dam

Head	: 24.7 m
Speed	: 94.7 rpm
Power	: 59 MW

Pump Turbine



- When water enters the rotor at the periphery and flows inward the machine acts as a turbine
- With water entering at the center and flowing outward, the machine acts as a pump
- The pump turbine is connected to a motor generator, which acts as either a motor or generator depending on the direction of rotation.
- The pump turbine is used at pumped storage hydroelectric plants, which pump water from a lower reservoir to an upper reservoir during off-peak load periods so that water is available to drive the machine as a turbine during the peak power generation needs.

Pump Turbine

Pump turbines are classified into three principal types analogous to reaction turbines and pumps.

Radial flow – Francis	23-800 m
Mixed flow or diagonal flow	11-76 m
Axial flow or propeller	1-14 m

- ➢ As a turbine
 - Develops 240 MW at a maximum head of 220 m
 - Develops 177 MW at minimum net head of 185 m.
- ➢ As a Pump
 - Delivers 110 m³/s at a minimum net head of 198 m
 - Delivers $86m^3/s$ at minimum net head of 185 m
- To reduce the head loss at submerged discharge and thereby to increase the net head available to the turbine runner. This is accomplished by using a gradually diverging tube whose cross-sectional area at discharge is considerably larger than the cross-sectional area at entrance to the tube.

Pump Turbine Specification

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	Turbine	Pump
Туре	: Vertical Francis	Centrifugal
Rated horse power	: 59656 kW	76061 kW
Rated head	: 58 m	62.5 m
Rated discharge	: 118.3 m ³ /s	110 m ³ /s
Rated speed	: 106 rpm	106 rpm
Maximum runaway speed	: 161 rpm	121 rpm
Direction of rotation	: clockwise	counterclockwise
Specific speed at rating	: 42.1	121

Hydraulic Turbine Selection



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Gross head: It is the difference between the head race and tail race level when there is no flow. As such it is termed as static head and is denoted as H_s or H_g

Effective head: It is the head available at the inlet of the turbine. It is obtained by considering all losses. If h_f is the total loss then the effective head above the turbine is $H = H_g - H_f$

Reaction Turbine- Head



Specific Energy of Hydraulic Turbine

The specific energy of a hydro power plant is the quantity of potential and kinetic energy which 1 kilogram of the water delivers when passing through the plant from an upper to a lower reservoir. The expression of the specific energy is Nm/kg or J/kg and is designated as $[m^2/s^2]$.

In a hydro power plant as outlined in the figure, the difference between the level of the upper reservoir z_{res} and the level of the tail water z_{tw} is defined as the gross head

$$H_g = z_{res} - z_{tw}$$
(a)

The corresponding gross specific hydraulic energy

$$E_g = gH_g \tag{b}$$

where *g* is the acceleration of gravity.

When a water discharge Q [m³/s] passes through the plant, the delivered power is

$$P_{gr} = \rho Q_g H_g \tag{c}$$

where P_g is the gross power of the plant

 ρ is the density of the water

Q is the discharge

Specific Energy of Hydraulic Turbine RMD 2501

The specific hydraulic energy between section B and C is available for the turbine.

This specific energy is defined as net specific energy and is expressed by

 $E_n = gH_n$

And the net head of the turbine $H_n = E_n/g$

$$H_n = h_p + \frac{V^2}{2g}$$
$$H_n = H_g - \frac{E_L}{g} = H_g - H_L$$

where h_p is the piezometric head above tail water level (P_B/γ) $V^2/2g$ is the velocity head

 E_L/g is specific hydraulic energy loss H_L

Velocity Triangle for Pelton Turbine RMD 2501



- (a) Ideal fluid velocities for Pelton wheel turbine
- (b) Relative velocities for Pelton wheel turbine
- (c) Inlet and exit velocity triangles for Pelton wheel turbine



Work Done for Pelton Turbine

Tangential velocity at inlet of Pelton wheel

$$V_{\theta 1} = V_1 = W_1 + U$$
 (1)

Tangential velocity at outlet of Pelton wheel

$$V_{\theta 2} = W_2 \cos\beta + U$$
⁽²⁾

Assuming $W_1 = W_2$ (i.e., the relative speed of the fluid does not change as it is deflected by the buckets, we can combine equation (1) and (2) to obtain

$$V_{\theta 2} - V_{\theta 1} = \left(U - V_1\right) \left(1 - \cos\beta\right)$$
⁽⁵⁾

This change in tangential component of velocity combined with torque and power equation gives

$$T_{shaft} = m r_m (U - V_1)(1 - \cos \beta)$$
⁽⁴⁾

and since
$$U = \omega r_m$$

 $W_{shaft} = T_{shaft} \omega = m U (U - V_1) (1 - \cos \beta)$
(5)

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$P = \rho Q (U_1 V_{\mu 1} - U_2 V_{\mu 2})$

Power,

Power and Torque for Pelton Turbine

Since $U_1 = U_2$,

$$P = \rho Q (V_{u1} - V_{u2})$$

When runner is at standstill (U=0), P=0When $U = 0.5V_1$, power is maximum When $U = V_1$, power = 0 (corresponds to $\frac{1}{1.0}$ v₁ run away speed)

Typical theoretical and experimental power and torque relation for a Pelton turbine as a function of bucket speed









Figure shows an axial section through a Francis turbine with the guide vane cascade (G) and the runner (R). The runner is fastened to the turbine shaft (S).

Velocity Triangle for Francis Turbine RMD 2501



Velocity triangle for three angular velocities

The absolute velocity at exit of the runner is such that there is no whirl at the outlet i.e., $V_{u2} = 0$.

Work done per kg of water

$$W_{shaft} = (U_1 - V_{\theta 1} - U_2 - V_{\theta 2})$$

Power,

$$P = \rho Q (U_1 V_{u1} - U_2 V_{u2})$$

 $\omega = \omega_{normal}$ means the rotational speed for which the turbine gives the lowest energy loss at outlet represented mainly by $V_2^2/2$ and highest hydraulic efficiency for the given angle α_0 of the guide vane canal.

Guide Vane Setting for Francis Turbine RMD 2501

- ✓ For regulating discharge Q of the turbine, the width of the guide vane canals must be varied.
- ✓ An increase in Q requires adjusting the guide vanes to a larger angle α_0 and a decrease of Q requires an adjustment in the opposite direction. This regulation causes corresponding changes in the direction of the absolute velocity V_1 . Accordingly, the velocity diagrams change.
- ✓ Both, the variation of the angular velocity ω and the regulation of the discharge Q, involve changes in the direction and magnitude of the relative velocity W_1 . The relative velocity W_2 varies accordingly in magnitude with the regulation of Q. Moreover the difference $(U_1V_{u1} U_2V_{u2})$, and thereby the power transfer, is entirely dependent on these changes.
- ✓ The most efficient power transfer, however, is obtained for the operating condition when the relative velocity W_1 coincides with blade angle β_1 at the runner inlet and simultaneously the rotational component $V_{u2} \approx 0$.
- ✓ Therefore, the hydraulic layouts of all reaction turbine runners are based on the data of rotational speed *n*, discharge *Q* and net head H_n , at which the optimal efficiency is desired.

Components of Kaplan Turbine

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Figure shows an axial section through a Kaplan turbine with the guide vane cascade (G) and the runner (R). The runner is fastened to the turbine shaft (S).

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W_2 Work done per kg of water $\omega = \omega_{normal} V_{u2}$ V_{u1}

 U_2

 $W_{shaft} = (U_1 - V_{\theta 1} - U_2 - V_{\theta 12})$ Power.

The absolute velocity at exit leaves

the runner such that there is no whirl

$$P = \rho O(U V) -$$

at the outlet i.e., $V_{\mu 2} = 0$.

 $\omega = \omega_{normal}$ means the rotational speed for which the turbine gives the lowest energy loss at outlet represented mainly by $V_2^2/2$ and highest hydraulic efficiency for the given angle α_0 of the guide vane canal.

 $V_{\underline{u}\underline{1}}$

 $\overline{\alpha_1}$ V₁

U.

U_2 U_1 W_1 W_2 V_1 $\omega < \omega_{normal} V_{u2}$ V_{u1} U_2 U. V_2 V_1 W_2 $\omega > \omega_{normal}$ Velocity triangle for three angular velocities

X Velocity Triangle for Kaplan Turbine

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Velocity Triangle for Kaplan Turbine RMD 2501



Draft Tube

- 1. In a reaction turbine, water leaves the runner with remaining kinetic energy. To recover as much of this energy as possible, the runner outlet is connected to a diffuser, called draft tube. The draft tube *converts* the dynamic pressure (kinetic energy) into static pressure.
- 2. Draft tube permits a suction head to be established at the runner exit, thus making it possible for placing the wheel and connecting machinery at a level above that of water in the tail race under high water flow conditions of river, without loss of head.
- 3. To operate properly, reaction turbines must have a submerged discharge.
- 4. The water after passing through the runner enters the draft tube, which directs the water to the point of discharge.
- 5. The aim of the draft tube is also to convert the main part of the kinetic energy at the runner outlet to pressure energy at the draft tube outlet.
- 6. This is achieved by increasing the cross section area of the draft tube in the flow direction.
- 7. In an intermediate part of the bend, however, the draft tube cross sections are decreased in the flow direction to prevent separation and loss of efficiency.

Types of Draft Tube



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Draft Tube

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Energy Equation Applied to Draft Tube RMD 2501

$$\frac{P_B}{\gamma} + Z_B + \frac{V_B^2}{2g} + h_I$$

- The velocity V_2 can be reduced by having a diverging passage.
- To prevent cavitation, the vertical distance z_1 from the tail water to the draft tube inlet should be limited so that at no point within the draft tube or turbine will the absolute pressure drop to the vapour pressure of water.

Cavitation in Turbines

- **Cavitation** is a term used to describe a process, which includes nucleation, growth and implosion of vapour or gas filled cavities. These cavities are formed into a liquid when the static pressure of the liquid for one reason or another is reduced below its vapour pressure at the prevailing temperature. When cavities are carried to high-pressure region, they implode violently.
- Cavitation is an undesirable effect that results in pitting, mechanical vibration and loss of efficiency.
- If the nozzle and buckets are not properly shaped in impulse turbines, flow separation from the boundaries may occur at some operating conditions that may cause regions of low pressure and result in cavitation.
- The turbine parts exposed to cavitation are the runners, draft tube cones for the Francis and Kaplan turbines and the needles, nozzles and the runner buckets of the Pelton turbines.
- Measures for combating erosion and damage under cavitation conditions include improvements in hydraulic design and production of components with erosion resistant materials and arrangement of the turbines for operations within good range of acceptable cavitation conditions.

Cavitation Process

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Cavitation in Turbines

Traveling bubble cavitation in Francis turbine

Inlet edge cavitation in Francis turbine

Leading edge cavitation damage in Francis turbine

Critical Value of Cavitation Parameter RMD 2501

- The value of σ , at which cavitation will occur, is the critical value.
- Typical values of the critical cavitation parameter for reaction turbine are shown.

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Efficiencies of Hydraulic Turbines RMD 2501

Efficiencies:

Various efficiencies of hydraulic turbines are:

- Hydraulic efficiency
- Volumetric efficiency
- Mechanical Efficiency
- Overall Efficiency

Efficiency in general is defined as the ratio of power delivered to the shaft (brake Power) to the power taken from water.

Hydraulic efficiency :

It is the ratio of the power developed by the runner to the water power available at the inlet of turbine.

Total available power of a plant is given by

 $P_{available} = \rho Q g H_n$

Power transfer from the fluid to the turbine runner is given by

$$P_{shaft} = \rho Q \left(U_1 V_{u1} - U_2 V_{u2} \right)$$

Efficiencies of Hydraulic Turbines RMD 2501

The ratio of these two powers is given by

$$\eta_{hydraulic} = \frac{Power_{shaft}}{Power_{available}}$$
$$\eta_{hydraulic} = \frac{\rho Q (U_1 V_{u1} - U_2 V_{u2})}{\rho Q g H_n}$$
$$\eta_{hydraulic} = \frac{(U_1 V_{u1} - U_2 V_{u2})}{g H_n}$$

The rearrangement of this equation gives the main turbine equation

$$\eta_{hydraulic}H_n = \frac{\left(U_1V_{u1} - U_2V_{u2}\right)}{g}$$

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Efficiency vs Load for Turbines RMD 2501

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Specific Speed

- It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc., with the actual turbine but of such a size that it will develop unit power when working under unit head
- This is the speed at which the runner of a particular diameter will develop 1 kW (1 hp) power under 1 m (1 ft) head.

$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$$

• The specific speed is an important factor governing the selection of the type of runner best suited for a given operating range. The impulse (Pelton) turbines have very low specific speeds relative to Kaplan turbines. The specific speed of a Francis turbine lies between the impulse and Kaplan turbine.

Efficiency vs Specific Speed

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Selection of Turbines

Turbine	Head	Specific Speed (SI)
Pelton Wheel	>300 m	8.5-30 (Single Jet) 30-51 (2 or More)
Francis Turbine	50-450 m	51-255
Kaplan Turbine	Up to 60 m	255-860

Session Summary

In this session the following aspects of hydraulic turbines have been discussed:

- □ Working principle
- □ Classification and types
- □ Operation of hydro turbines
- □ Materials and construction
- □ Importance and types of draft tubes
- □ The main turbine equation and various efficiencies
- □ Cavitation phenomenon in hydraulic turbines

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Thank you

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