Steam Turbines

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Session Objectives

This session is intended to discuss the following:

- ☐ Classification of steam turbines
- ☐ Compounding of steam turbines
- ☐ Forces, work done and efficiency of steam turbine
- ☐ Numerical examples

Steam

Steam is a vapour used as a working substance in the operation of steam turbine.

Is steam a perfect gas?

Steam possess properties like those of gases: namely pressure, volume, temperature, internal energy, enthalpy and entropy. But the pressure volume and temperature of steam as a vapour are not connected by any simple relationship such as is expressed by the characteristic equation for a perfect gas.

Sensible heat – The heat absorbed by water in attaining its boiling point.

Latent heat – The heat absorbed to convert boiling water into steam.

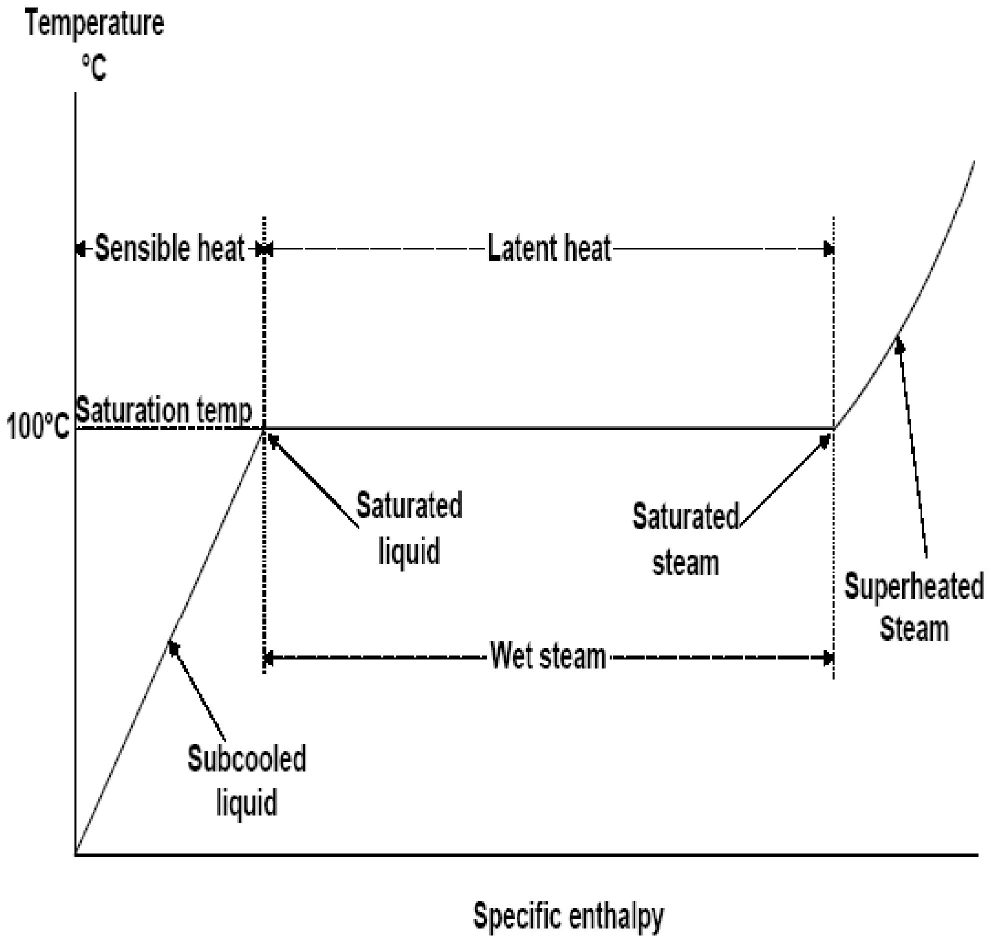
Wet steam – Steam containing some quantity of moisture.

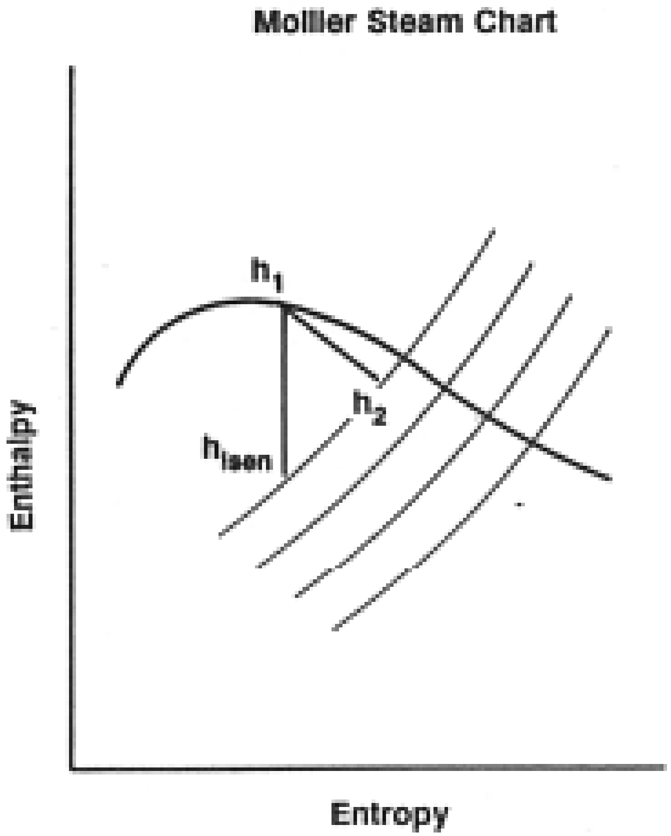
Dry steam – Steam that has no moisture content.

Superheated steam – Dry steam, when heated at constant pressure, attains superheat

The properties of steam are dependent on its pressure.

Steam Properties





Enthalpy (H) kJ/kg

Internal energy (U) kJ/kg

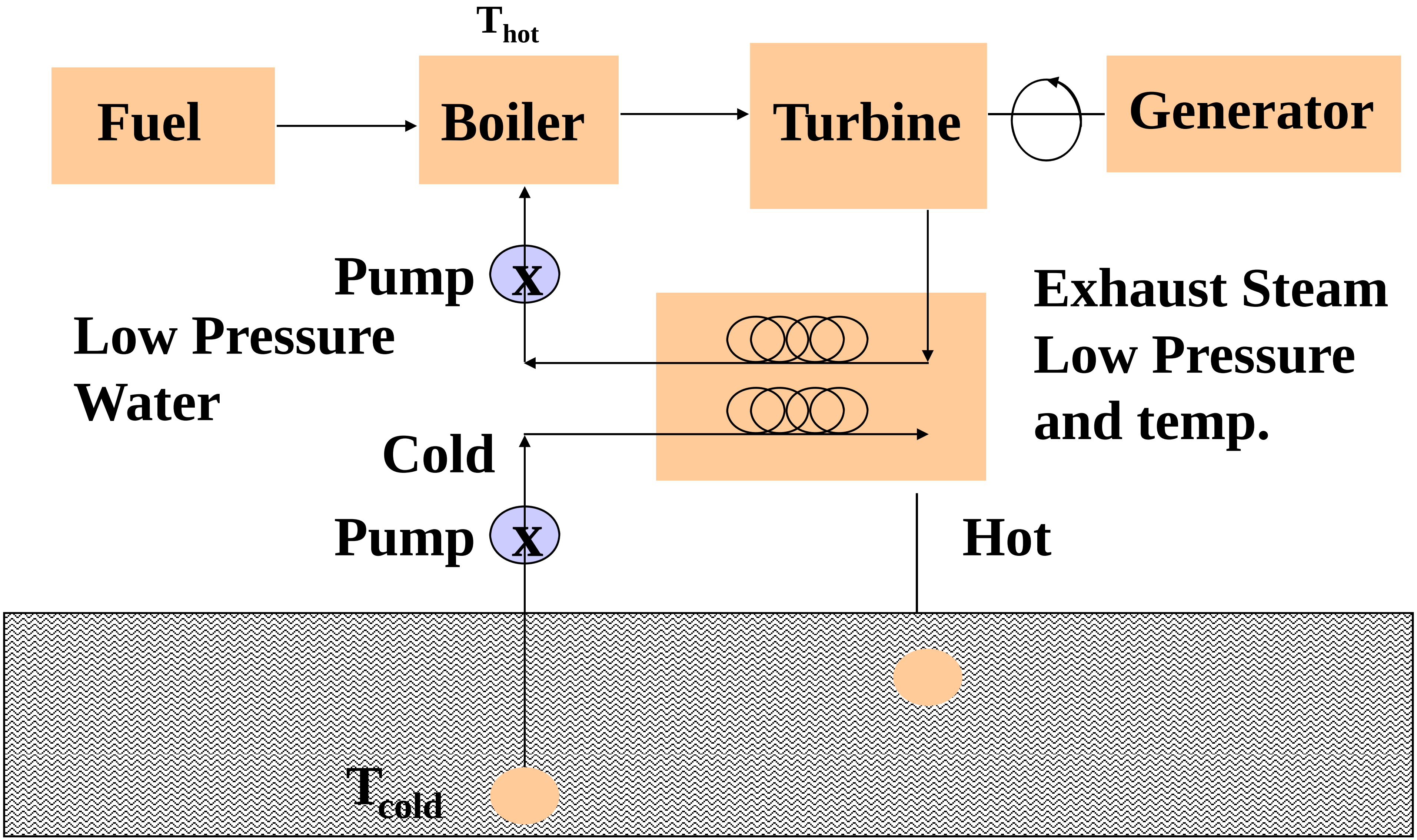
Entropy (S) kJ/kg-K

Specific volume (v) m^3/kg

Density (ρ) kg/m^3

Isobaric heat capacity (C_p) kJ/kg-K

Steam Power Plant Process



T_{hot}

Fuel

Boiler

Turbine

Generator

Pump

Low Pressure Water

Exhaust Steam Low Pressure and temp.

Cold

Pump

Hot

T_{cold}

Steam Turbine

- Steam turbine convert a part of the energy of the steam evidenced by high temperature and pressure into mechanical power-in turn electrical power
- The steam from the boiler is expanded in a nozzle, resulting in the emission of a high velocity jet. This jet of steam impinges on the moving vanes or blades, mounted on a shaft. Here it undergoes a change of direction of motion which gives rise to a change in momentum and therefore a force.
- The motive power in a steam turbine is obtained by the rate of change in momentum of a high velocity jet of steam impinging on a curved blade which is free to rotate.
- The conversion of energy in the blades takes place by impulse, reaction or impulse reaction principle.
- Steam turbines are available in a few kW (as prime mover) to 1500 MW
- Impulse turbine are used for capacity up to
- Reaction turbines are used for capacity up to

Steam, Gas and Hydraulic Turbines

- ✓ The working substance differs for different types of turbines.
- ✓ Steam turbines are axial flow machines (radial steam turbines are rarely used) whereas gas turbines and hydraulic turbines of both axial and radial flow type are used based on applications.
- ✓ The pressure of working medium used in steam turbines is very high, whereas the temperature of working medium used is gas turbine is high comparatively.
- ✓ The pressure and temperature of working medium in hydraulic turbines is lower than steam turbines.
- ✓ Steam turbines of 1300 MW single units are available whereas largest gas turbines unit is 530 MW and 815 MW

Merits and Demerits of Steam Turbine

Merits:

- Ability to utilize high pressure and high temperature steam.
- High component efficiency.
- High rotational speed.
- High capacity/weight ratio.
- Smooth, nearly vibration-free operation.
- No internal lubrication.
- Oil free exhaust steam.
- Can be built in small or very large units (up to 1200 MW).

Demerits:

- For slow speed application reduction gears are required.
- The steam turbine cannot be made reversible.
- The efficiency of small simple steam turbines is poor.

Application

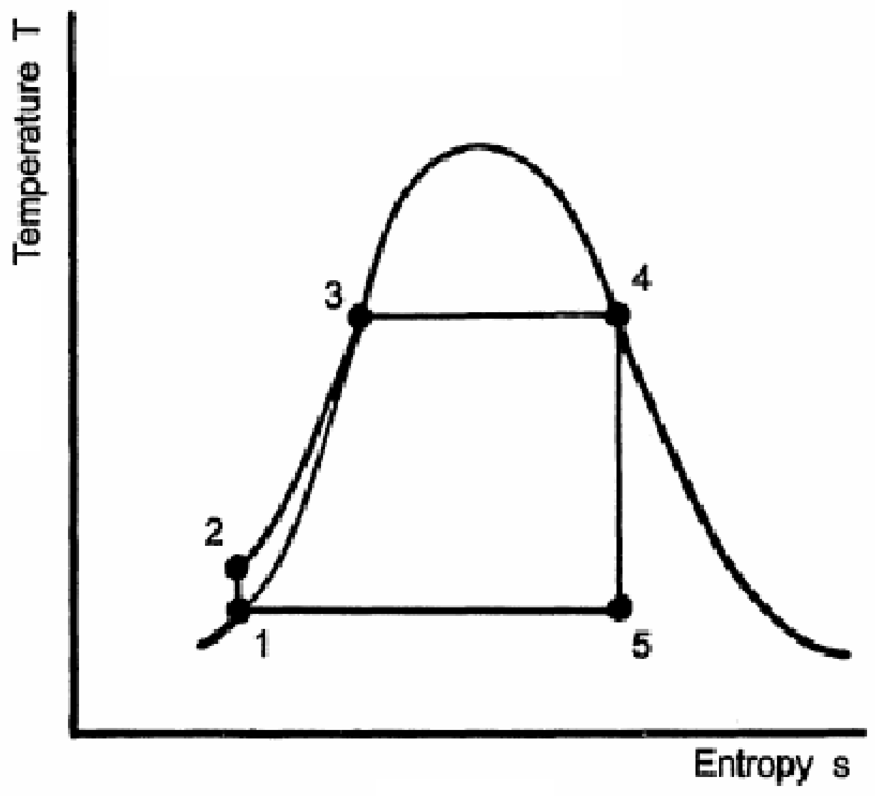
- Power generation
- Refinery, Petrochemical,
- Pharmaceuticals,
- Food processing,
- Petroleum/Gas processing,
- Pulp & Paper mills,
- Waste-to-energy

Turbine Selection

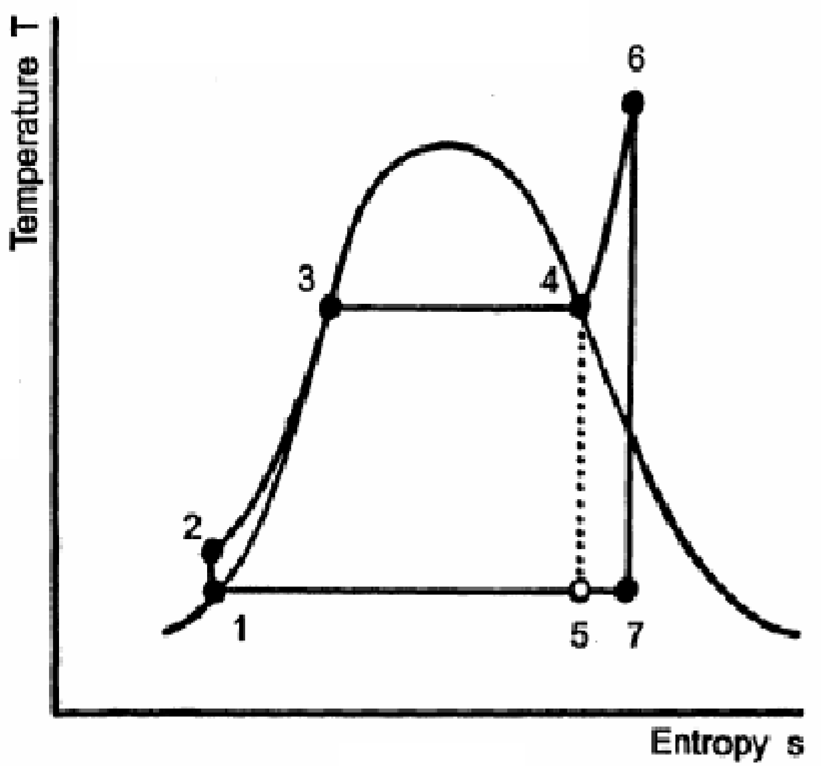
In all fields of application the competitiveness of a turbine is a combination of several factors:

- Efficiency
- Life
- Power density (power to weight ratio)
- Direct operation cost
- Manufacturing and maintenance costs

Rankine Cycle

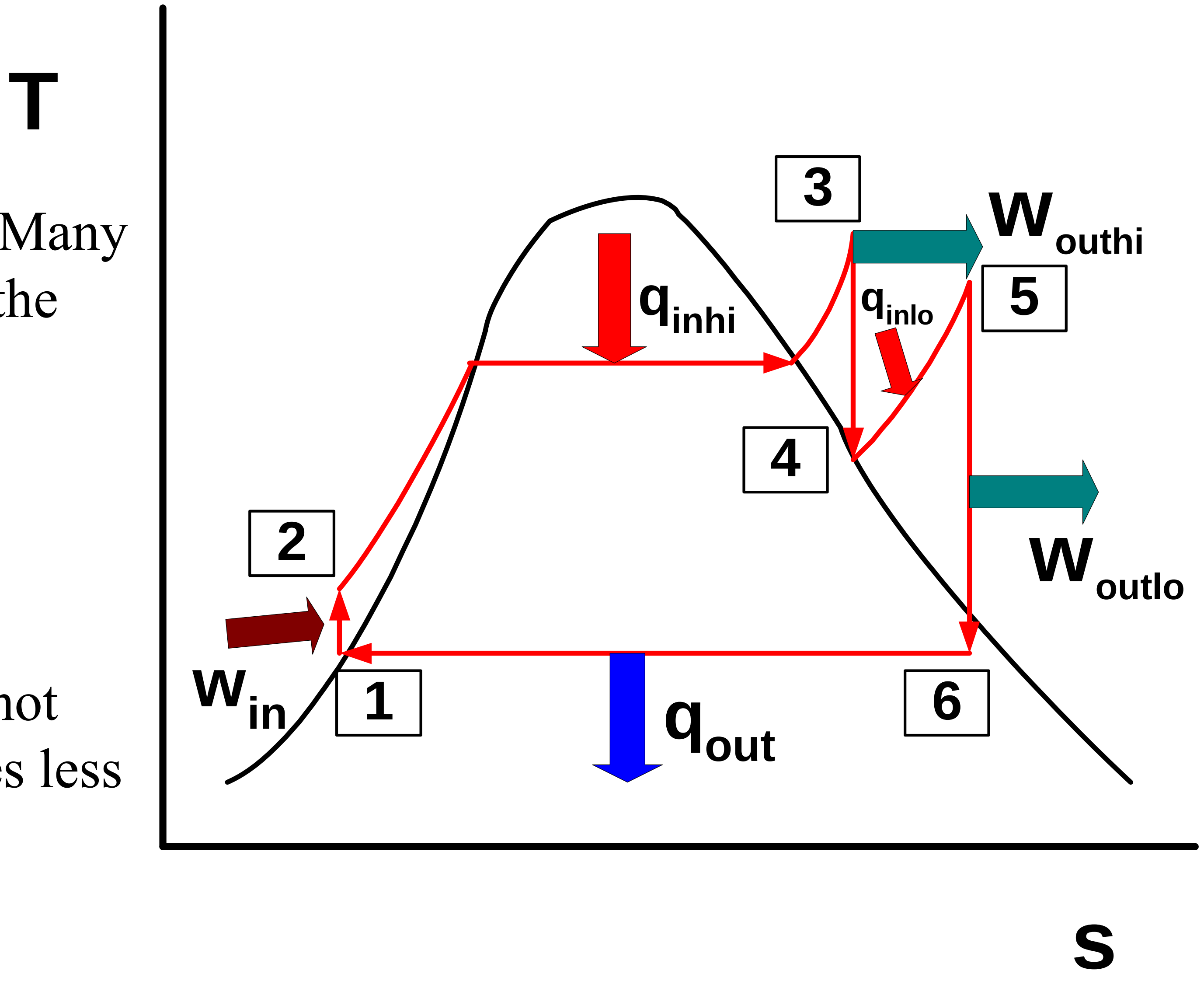


Saturated Rankine cycle



Superheated Rankine cycle

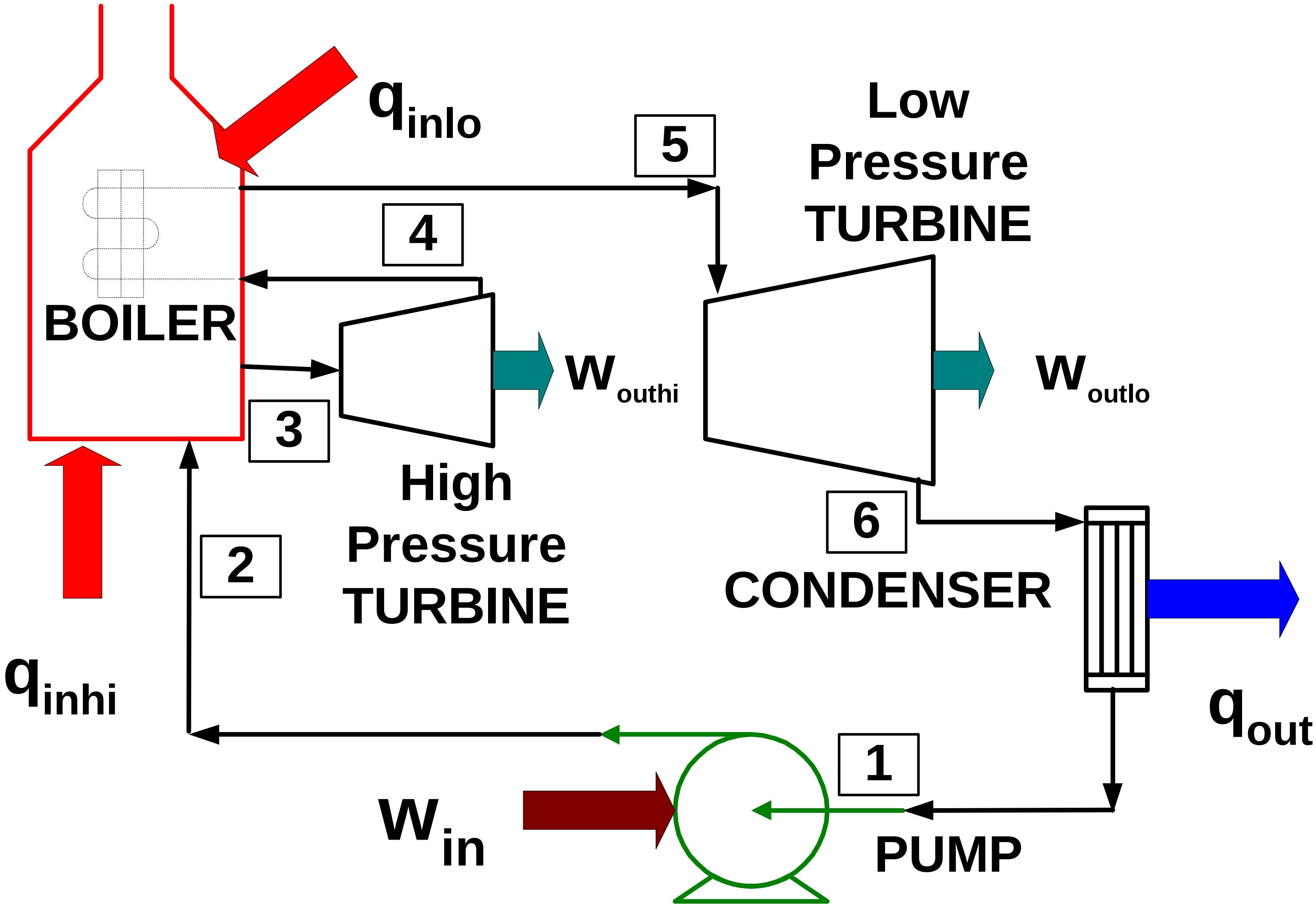
Reheat on *T-s* diagram



Note that $T_5 < T_3$. Many systems reheat to the same temperature (T_3=T_5).

Reheat is usually not offered for turbines less than 50 MW

Schematic of Rankine Reheat Cycle

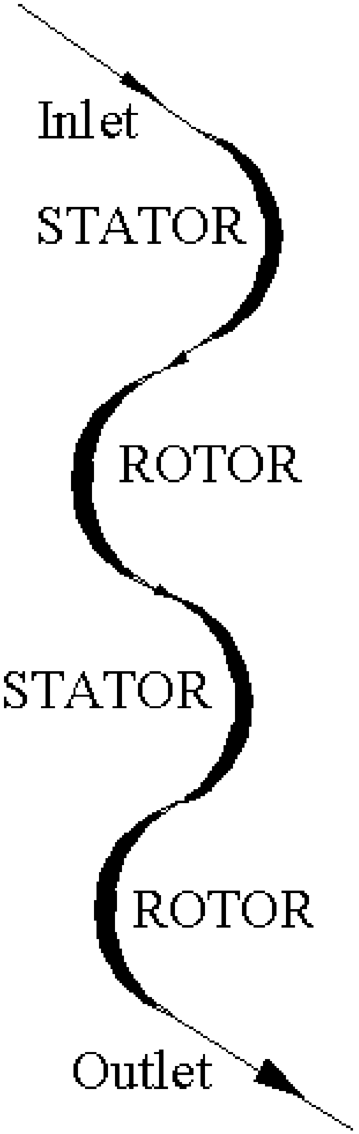


Steam Turbine Classification

Steam turbines can be classified in several different ways:

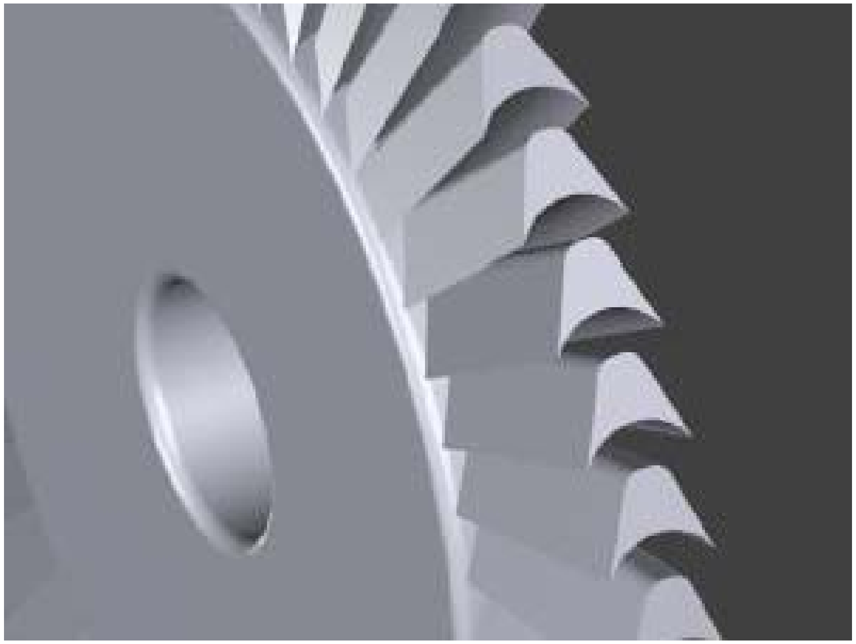
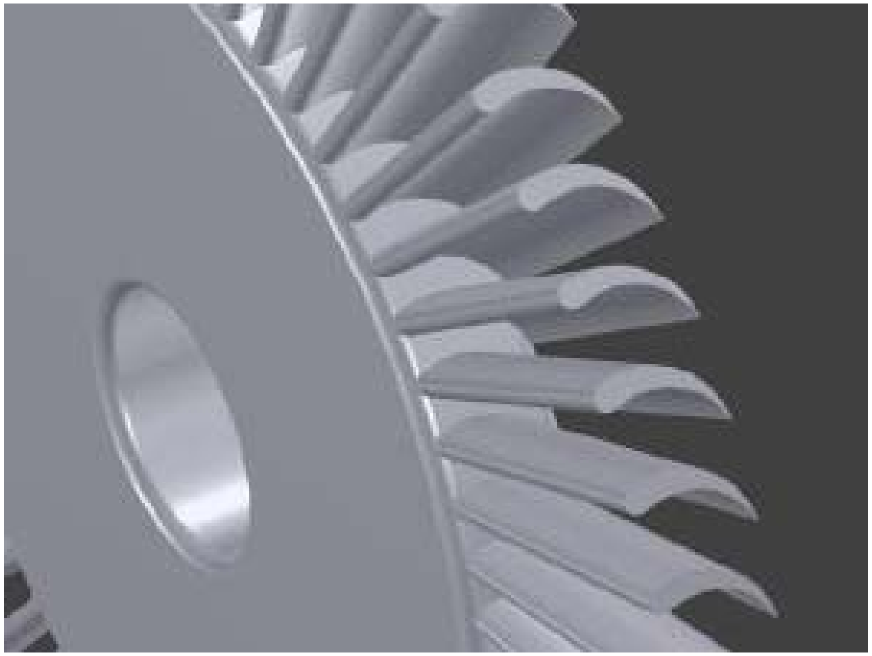
1. By details of stage design
   - Impulse or reaction.
2. By steam supply and exhaust conditions
   - Condensing, or Non-condensing (back pressure),
   - Automatic or controlled extraction,
   - Mixed pressure
   - Reheat
3. By casing or shaft arrangement
   - Single casing, Tandem compound or Cross compound
4. By number of exhaust stages in parallel:
   - Two flow, Four flow or Six flow.
5. By direction of steam flow:
   - Axial flow, Radial flow or Tangential flow
6. Single or multi-stage
7. By steam supply
   - Superheat or Saturated

Steam Turbine Stage

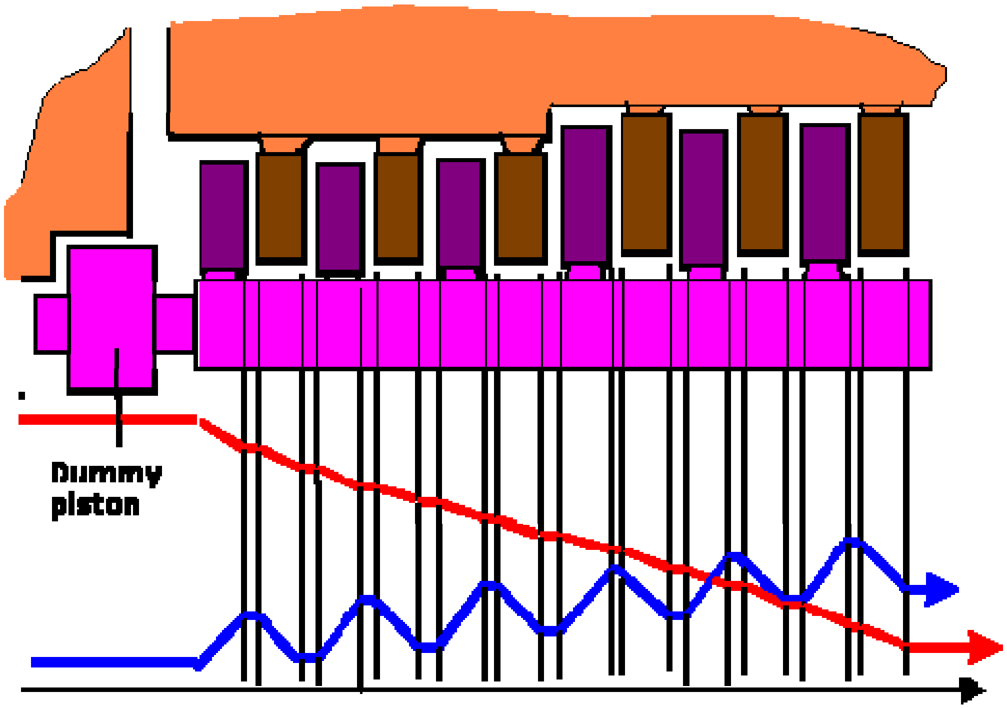


- ✓ A turbine stage consists of stationary stator row (guide vanes or nozzle ring) and rotating rotor row.
- ✓ In the guide vanes high pressure, high temperature steam is expanded resulting in high velocity.
- ✓ The guide vanes direct the flow to the rotor blades at an appropriate angle.
- ✓ In the rotor, the flow direction is changed and kinetic energy of the working fluid is absorbed by the rotor shaft producing mechanical energy

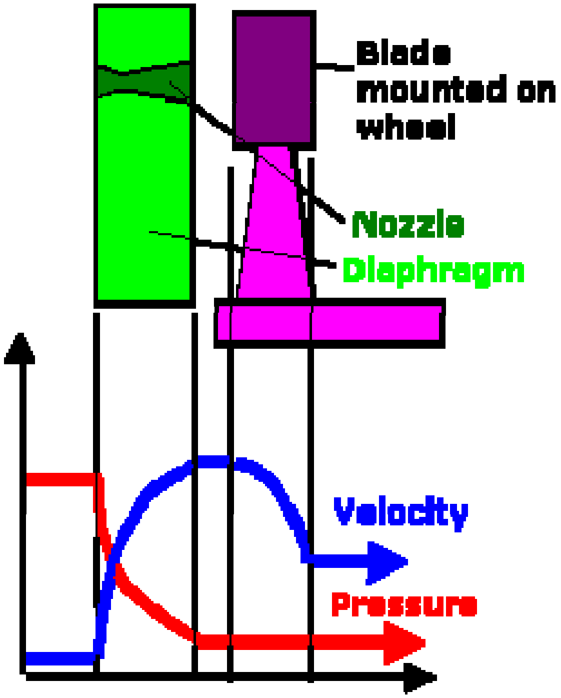
Types of Steam Turbine

Impulse Turbine	**Reaction Turbine**
	
Process of complete expansion of steam takes place in stationary nozzle and the velocity energy is converted into mechanical work on the turbine blades.	Pressure drop with expansion and generation of kinetic energy takes place in the moving blades.

Types of Steam Turbine



Parsons Reaction Turbine

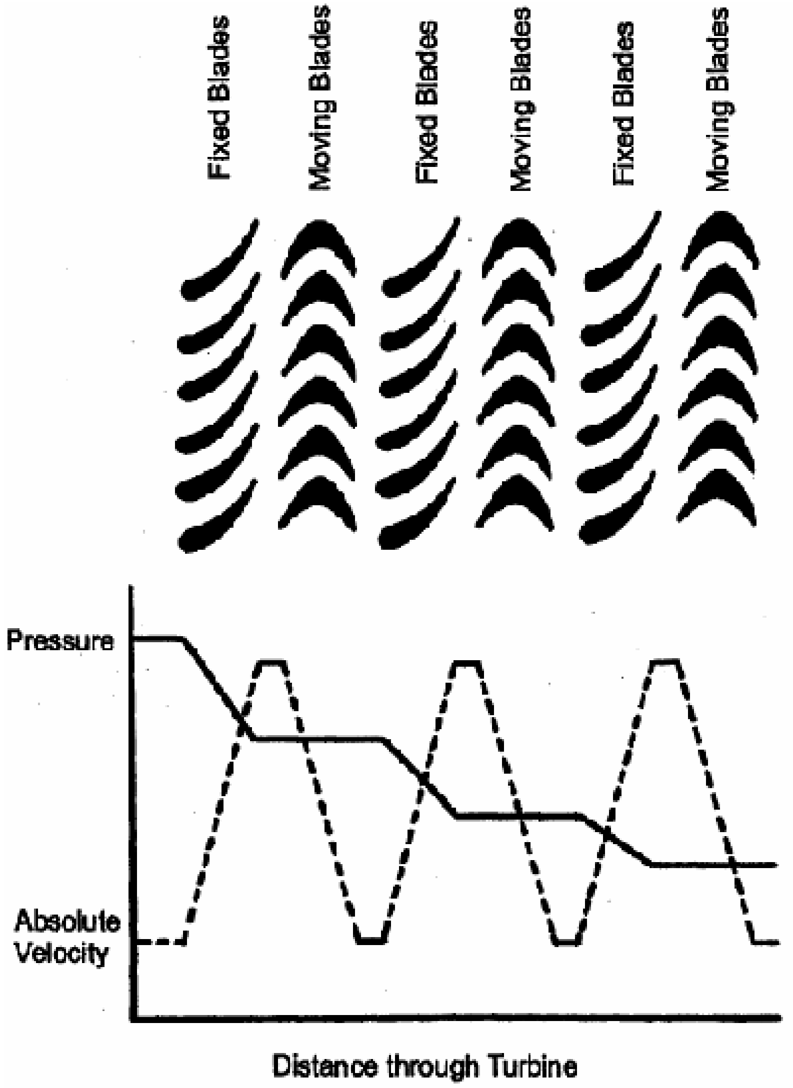


De Laval Impulse Turbine.

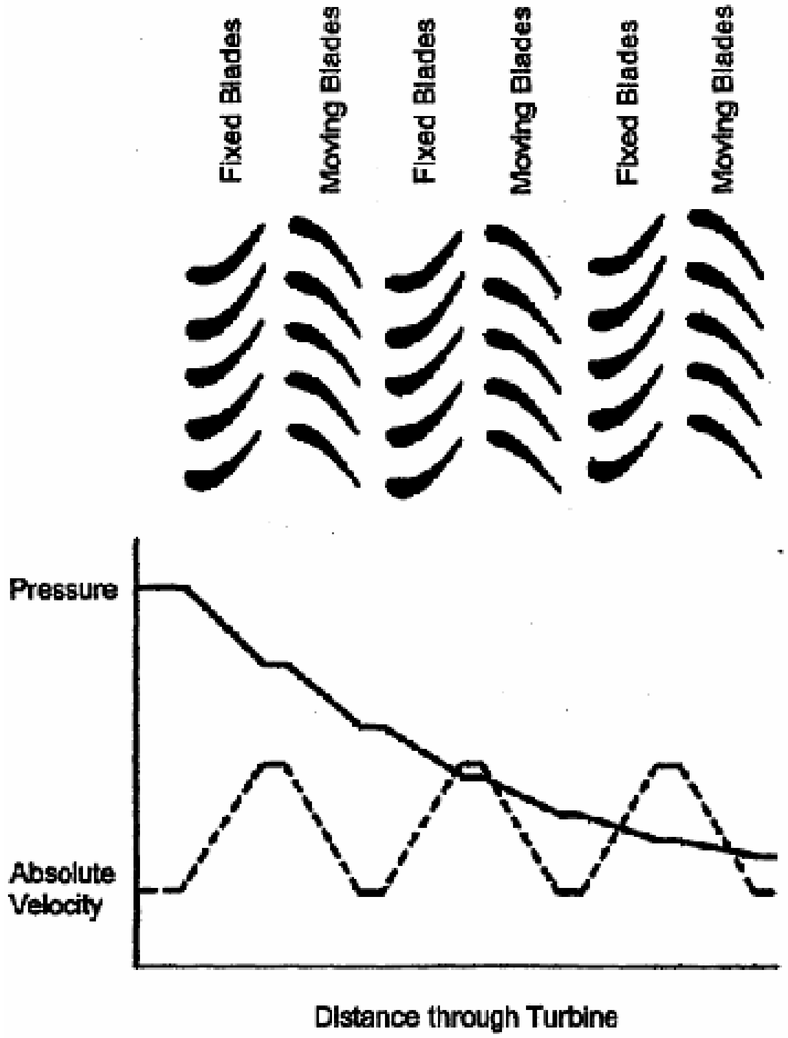
Impulse Reaction Turbine

- Modern turbines are neither purely impulse or reaction but a combination of both.
- Pressure drop is effected partly in nozzles and partly in moving blades which are so designed that expansion of steam takes place in them.
- High velocity jet from nozzles produce an impulse on the moving blade and jet coming out from still higher velocity from moving blades produces a reaction.
- Impulse turbine began employing reaction of upto 20% at the root of the moving blades in order to counteract the poor efficiency incurred from zero or even negative reaction.
- Reaction at the root of reaction turbines has come down to as little as 30% to 40% resulting in the reduction of the number of stages required and the sustaining of 50% reaction at mid point.
- It may be more accurate to describe the two design as
  - ✓ Disc and diaphragm turbine using low reaction blading
  - ✓ Drum rotor turbine using high reaction blading

Flow Through Steam Turbine Stage



Impulse turbine blading and conditions



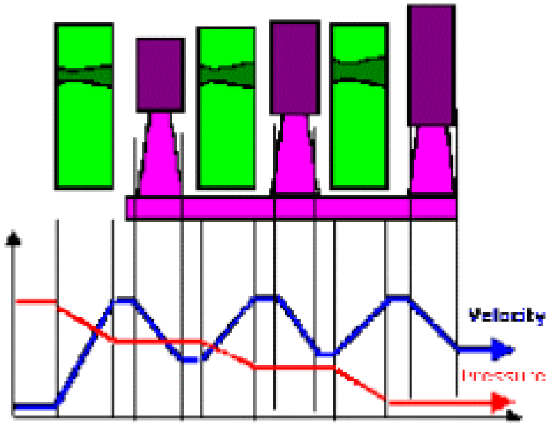
Reaction turbine blading and conditions

Compounding of Steam Turbines

- This is done to reduce the rotational speed of the impulse turbine to practical limits.
- Compounding is achieved by using more than one set of nozzles, blades, rotors, in a series, keyed to a common shaft; so that either the steam pressure or the jet velocity is absorbed by the turbine in stages.

Three main types of compounded impulse turbines are:

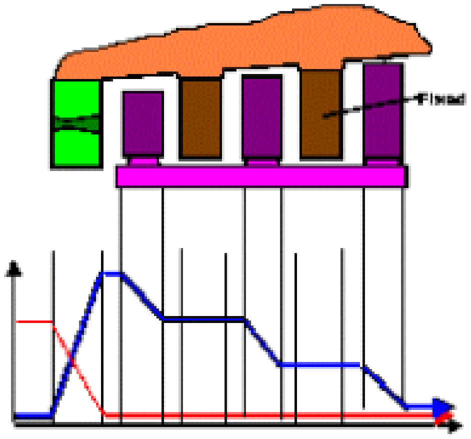
a. Pressure compounded
b. Velocity compounded
c. Pressure and velocity compounded impulse turbines.



Pressure Compounding

Involves splitting up of the whole pressure drop into a series of smaller pressure drops across several stages of impulse turbine.
The nozzles are fitted into a diaphragm locked in the casing that separates one wheel chamber from another. All rotors are mounted on the same shaft.

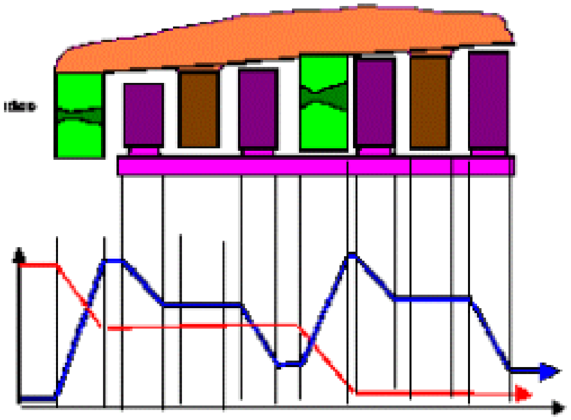
Compounding of Steam Turbines



Velocity Compounded

Velocity drop is acheived through many moving rows of blades instead of a single row of moving blades.

It consists of a nozzle or a set of nozzles and rows of moving blades attached to the rotor or the wheel and rows of fixed blades attached to the casing.



Pressure-Velocity Compound

Pressure velocity compounding gives the advantage of producing a shortened rotor compared to pure velocity compounding.

In this design steam velocity at exit to the nozzles is kept reasonable and thus the blade speed (hence rotor rpm) reduced.

Comparison between Impulse & Reaction Turbines

Impulse Turbines

- An impulse turbine has fixed nozzles that orient the steam flow into high speed jets.
- Blade profile is symmetrical as no pressure drop takes place in the rotor blades.
- Suitable for efficiently absorbing the high velocity and high pressure.
- Steam pressure is constant across the blades and therefore fine tip clearances are not necessary.
- Efficiency is not maintained in the lower pressure stages (high velocity cannot be achieved in steam for the lower pressure stages).

Reaction Turbines

- Reaction turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor
- Blades have aerofoil profile (convergent passage) since pressure drop occurs partly in the rotor blades.
- Efficient at the lower pressure stages
- Fine blade tip clearances are necessary due to the pressure leakages.
- Inefficient at the high pressure stages due to the pressure leakages around the blade tips.
- Fine tip clearances can cause damage to the tips of the blades.

Losses in Steam Turbine

Profile loss: Due to formation of boundary layer on blade surfaces. Profile loss is a boundary layer phenomenon and therefore subject to factors that influence boundary layer development. These factors are Reynolds number, surface roughness, exit Mach number and trailing edge thickness.

Secondary loss: Due to friction on the casing wall and on the blade root and tip. It is a boundary layer effect and dependent upon the same considerations as those of profile loss.

Tip leakage loss: Due to steam passing through the small clearances required between the moving tip and casing or between the moving blade tip and rotating shaft. The extend of leakage depends on the whether the turbine is impulse or reaction. Due to pressure drop in moving blades of reaction turbine they are more prone to leakages.

Disc windage loss: Due to surface friction created on the discs of an impulse turbine as the disc rotates in steam atmosphere. The result is the forfeiture of shaft power for an increase in kinetic energy and heat energy of steam.

Losses in Steam Turbine

Lacing wire loss: Due to passage blockage created by the presence of lacing wires in long blade of LP Stages.

Wetness loss: Due to moisture entrained in the low pressure steam at the exit of LP turbine. The loss is a combination of two effects; firstly, reduction in efficiency due to absorption of energy by the water droplets and secondly, erosion of final moving blades leading edges.

Annulus loss: Due to significant amount of diffusion between adjacent stages or where wall cavities occur between the fixed and moving blades. The extent of loss is greatly reduced at high annulus area ratios (inlet/outlet) if the expansion of the steam is controlled by a flared casing wall.

Leaving loss: Due to kinetic energy available at the steam leaving from the last stage of LP turbine. In practice steam does slow down after leaving the last blade, but through the conversion of its kinetic energy to flow friction losses.

Partial admission loss: Due to partial filling of steam, flow between the blades is considerably accelerated causing a loss in power.

Nomenclature

V	Absolute velocity of steam
U	Blade velocity
W	Relative velocity of steam
$V_a = V_f = V_m$	Axial component or flow velocity
V_w	Whirl or tangential component
α	Nozzle angle
β	Blade angle
h	enthalpy

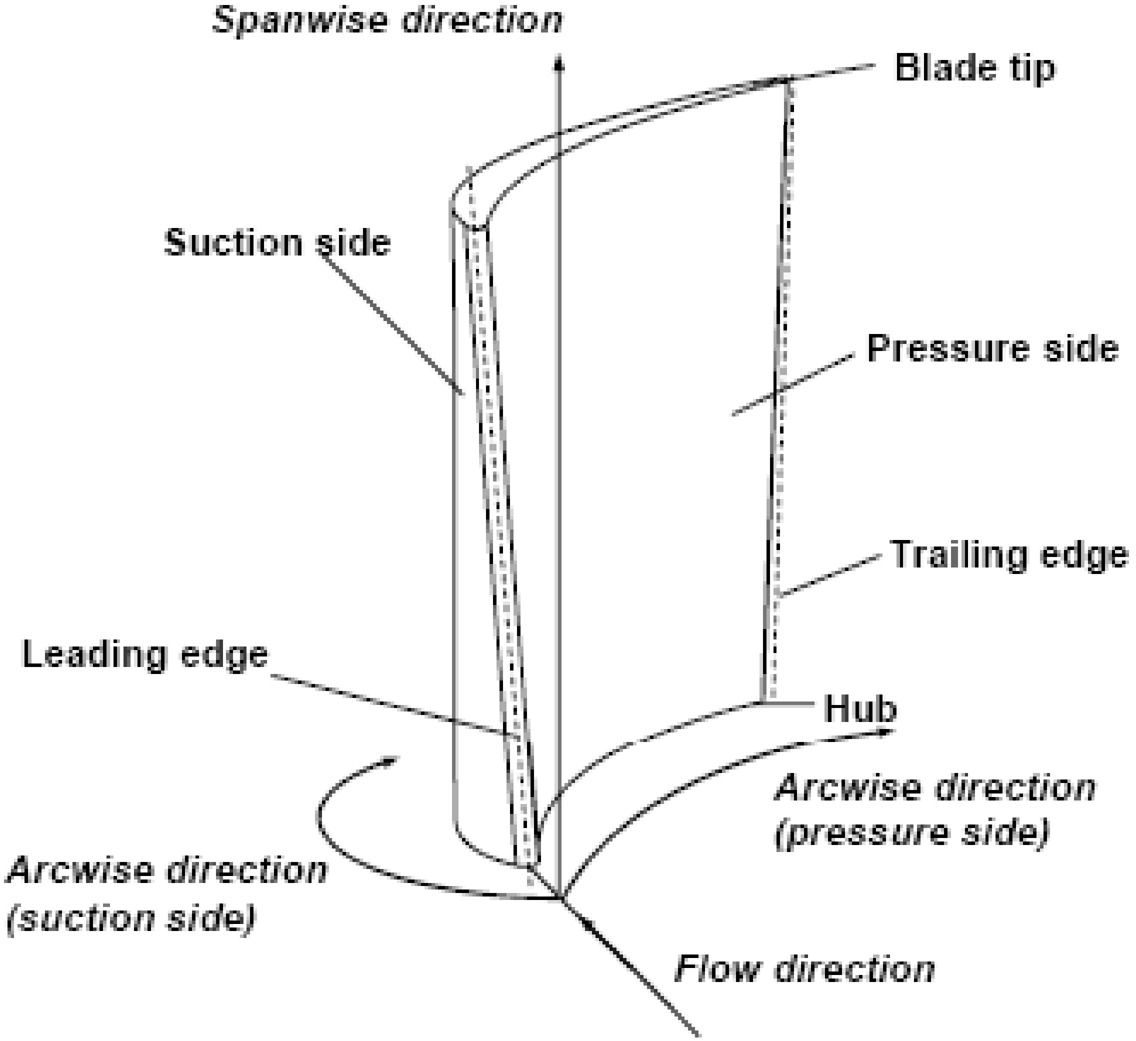
Suffix

1	Inlet
2	Outlet

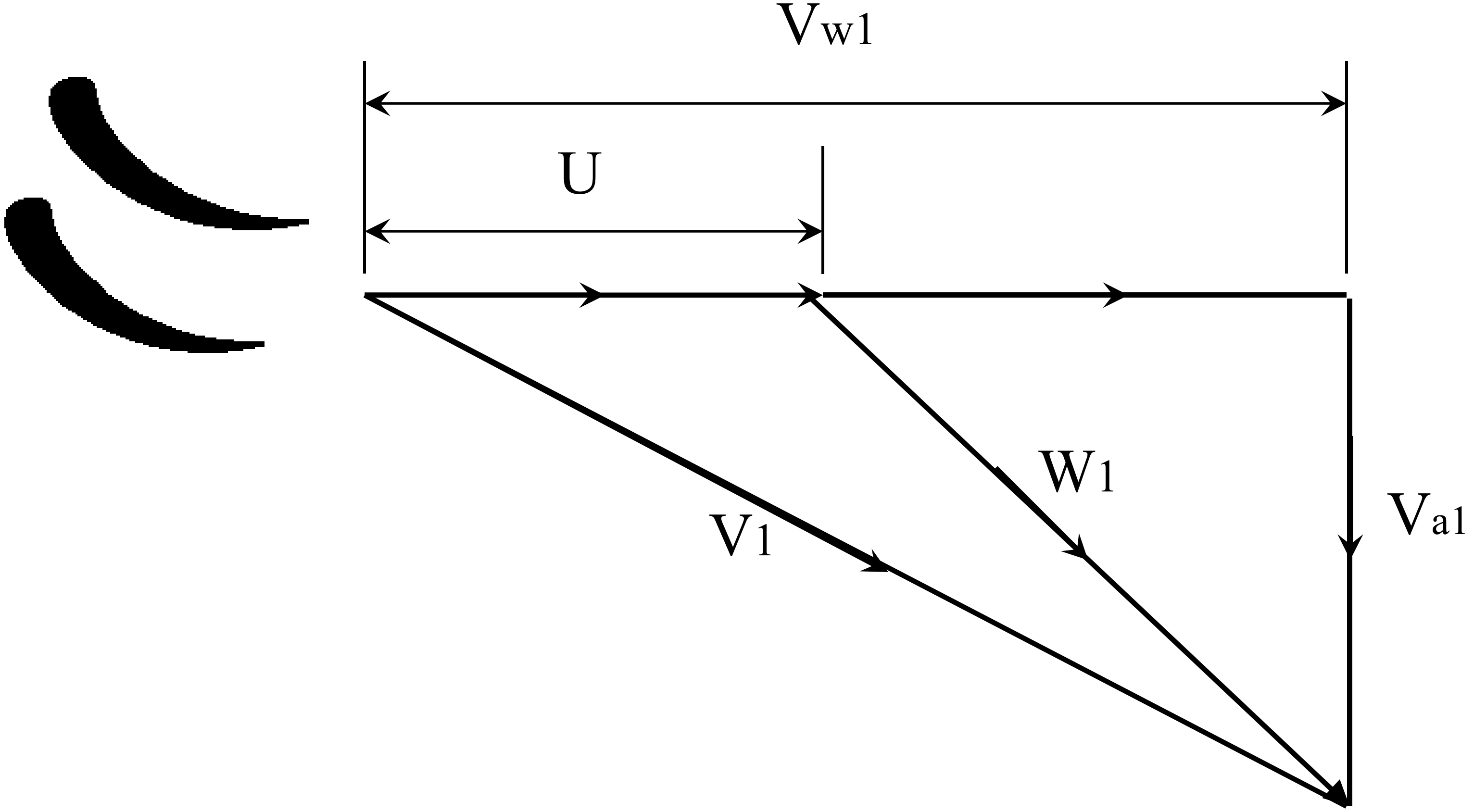
Velocity Triangles

- ✓ The three velocity vectors namely, blade speed, absolute velocity and relative velocity in relation to the rotor are used to form a triangle called velocity triangle.
- ✓ Velocity triangles are used to illustrate the flow in the bladings of turbomachinery.
- ✓ Changes in the flow direction and velocity are easy to understand with the help of the velocity triangles.
- ✓ Note that the velocity triangles are drawn for the inlet and outlet of the rotor at certain radii.

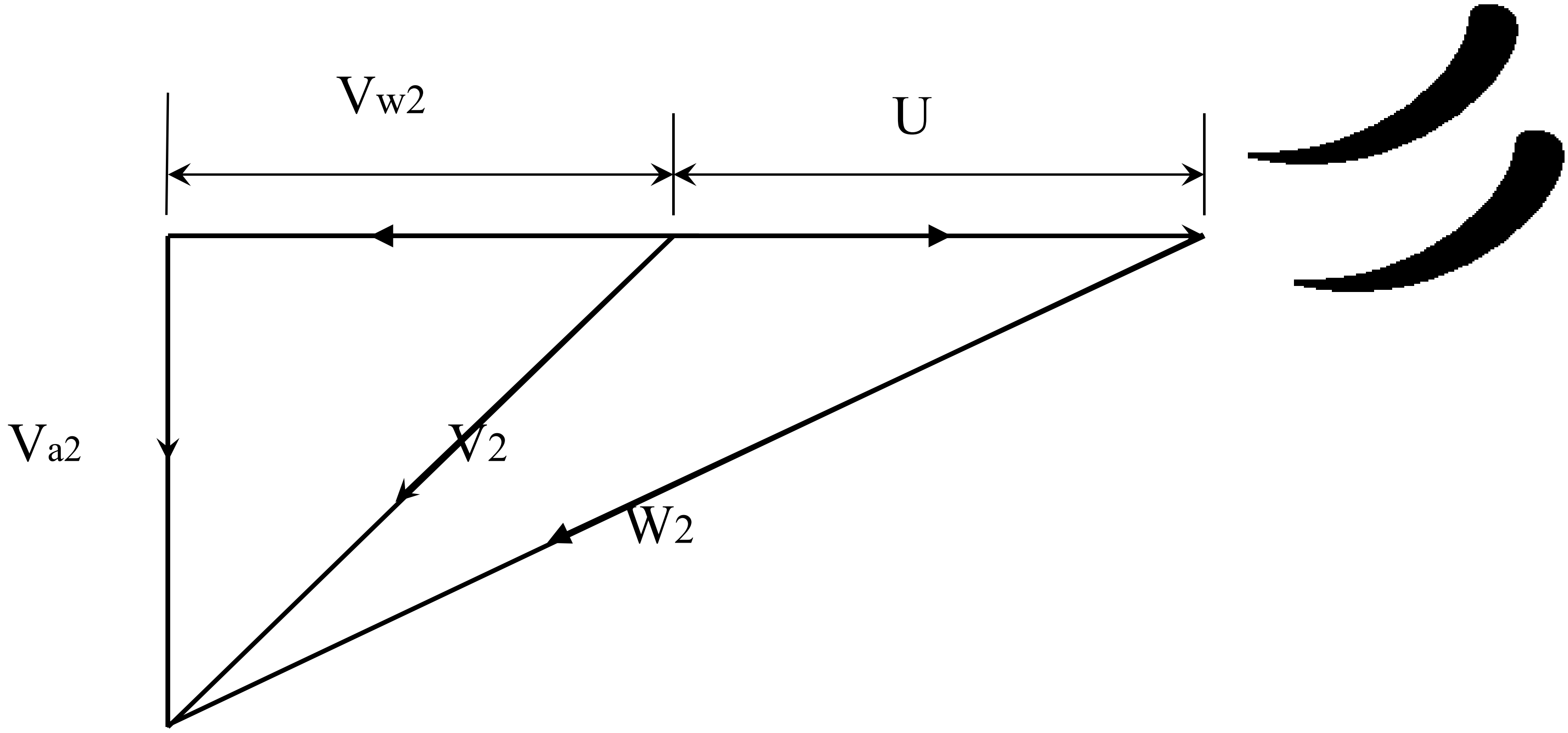
Steam Turbine Blade Terminology



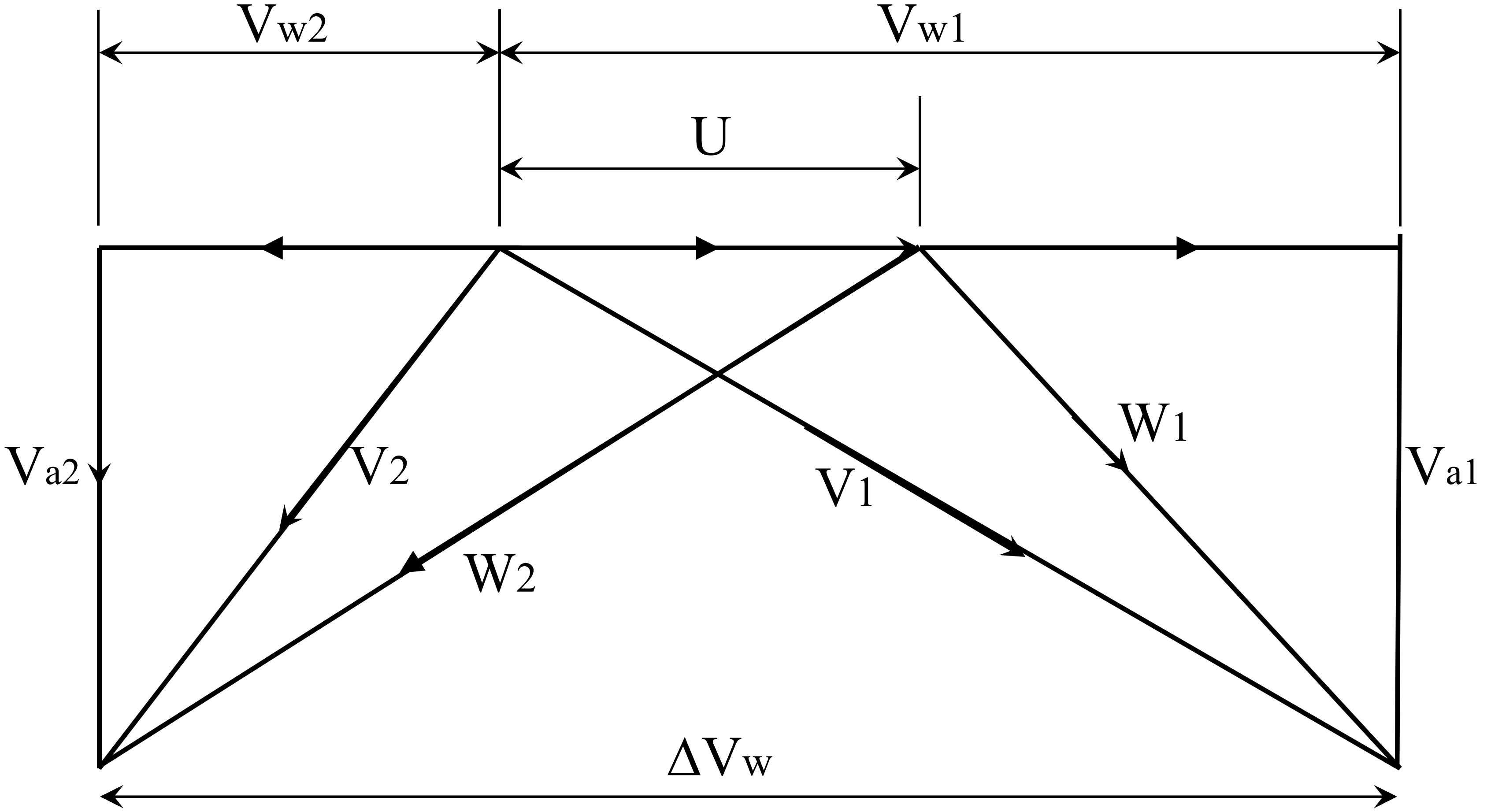
Inlet Velocity Triangle



Outlet Velocity Triangles



Combined Velocity Triangles



For 50% reaction design

Work Done – Impulse Steam Turbine

If the blade is symmetrical then $\beta_1 = \beta_2$ and neglecting frictional effects of the blades on the steam, $W_1 = W_2$.

In actual case, the relative velocity is reduced by friction and expressed by a blade velocity coefficient k.

Thus $k = W_2/W^1$

From Euler's equation, work done by the steam is given by;

$W_t = U(V_{w1} \pm V_{w2})$ (1)

Since V_{w2} is in the negative r direction, the work done per unit mass flow is given by,

$W_t = U(V_{w1}+V_{w2})$ (2)

If $V_{a1} \neq V_{a2}$, there will an axial thrust in the flow direction. Assume that Va is constant then,

$Wt = UVa\ (\tan\alpha_1 + \tan\alpha_2)$ (3)

$Wt = UV_a\ (\tan\beta_1 + \tan\beta_2)$ (4)

Equation (4) is often referred to as the diagram work per unit mass flow and hence the diagram efficiency is defined as

Work Done – Impulse Steam Turbine

$$\eta_d = \frac{\text{Diagram work done per unit mass flow}}{\text{Work available per unit mass flow}} \qquad (5)$$

Referring to the combined diagram ΔV_w is the change in the velocity of whirl. Therefore:

The driving force on the wheel = mV_w (6)

The product of the driving force and the blade velocity gives the rate at which work is done on the wheel. From equation (6)

Power output = $mU\Delta V_w$ (7)

If $V_{a1}-V_{a2} = \Delta V_a$, the axial thrust is given by;

Axial thrust = $m\Delta V_a$ (8)

The maximum velocity of the steam striking the blades

$$V_1 = \sqrt{\{2(h_0-h_1)\}} \qquad (9)$$

Where h_0 is the enthalpy at the entry to the nozzle and h_1 is the enthalpy at the exit, neglecting the velocity at the inlet to the nozzle. The energy supplied to the blades is the kinetic energy of the jet $V_1^2/2$ and the blading or diagram efficiency;

Work Done – Impulse Steam Turbine

$$\eta_d = \frac{\text{Rate of work performed per unit mass flow}}{\text{Energy supplied per unit mass of steam}}$$

$$\eta_d = (U\Delta V_w)x\frac{2}{V_1^2} = \frac{2U\Delta V_w}{V_1^2} \qquad (10)$$

Using the blade velocity coefficient (k=W_2/W_1) and symmetrical blades (β_1= β_2),

then; $\Delta V_w = 2V_1\cos\alpha_1 - U$

Hence $\Delta V_w = 2(V_1\cos\alpha_1 - U)U$ (11)

And the rate of work performed per unit mass $= 2(V_1\cos\alpha_1 - U)U$

Therefore; $\eta_d = 2(V_1\cos\alpha_1 - U)U \times {}^{2}\!/\!{}_{V_1^2}$

$$\eta_d = \frac{4(V_1\cos\alpha_1 - U)U}{V_1^2} = \frac{4U}{V_1}\left(\cos\alpha_1\frac{U}{V_1}\right)$$

where $\dfrac{U}{V_1}$ is called the blade speed ratio

(12)

Work Done – Impulse Steam Turbine

Differentiating equation (12) and equating it to zero provides the maximum diagram efficiency;

$$\frac{d(\eta d)}{d\left(U/V_1\right)} = 4\cos\alpha_1 - 8U/V_1 = 0$$

or $$\frac{U}{V_1} = \frac{\cos\alpha_1}{2} \tag{13}$$

i.e., maximum diagram efficiency

$$= \frac{4\cos\alpha_1}{2}\left(\cos\alpha_1 - \frac{\cos\alpha_1}{2}\right)$$

or $$\eta_d = 4\cos^2\alpha_1 \tag{14}$$

Substituting this value in equation (7), the power output per unit mass flow rate at the maximum diagram efficiency

$$P = 2U^2 \tag{15}$$

Degree of Reaction

- **Degree of reaction** is a parameter that describes the relation between the energy transfer due to the static pressure change and the energy transfer due to dynamic pressure change.
- **Degree of reaction** is defined as the ratio of static pressure drop in the rotor to the static pressure drop in the stage. It is also defined as the ratio of static enthalpy drop in the rotor to the static enthalpy drop in the stage

$$\Lambda = \text{Degree of reaction} = \frac{\text{Static enthalpy change in rotor}}{\text{Total enthalpy change in stage}} = \frac{h_1 - h_2}{h_0 - h_2} \qquad (16)$$

The static enthalpy at the inlet to the fixed blade in terms of stagnation enthalpy and velocity at the inlet to the fixed blades is given by

$$h_0 = h_{00} - \frac{V_0^2}{2C_p} \quad \text{similarly} \quad h_2 = h_{02} - \frac{V_2^2}{2C_p}$$

Substituting

$$\Lambda = \frac{(h_1 - h_2)}{\left(h_{00} - \frac{V_0^2}{2C_p}\right) - \left(h_{02} - \frac{V_2^2}{2C_p}\right)}$$

Degree of Reaction

But for a normal stage, $V_0 = V_2$ and since $h_{00} = h_{01}$ in the nozzle, then;

$$\Lambda = \frac{(h_1 - h_2)}{(h_{01} - h_{02})} \tag{17}$$

We know that $(h_{01} - h_{02}) = \quad (h_1 - h_2) + \frac{(V_{w1}^2 - V_{w2}^2)}{2} = 0$

Substituting for $(h_1 - h_2)$ in equation (17),

$$\Lambda = \frac{(V_{w2}^2 - V_{w1}^2)}{[2(h_{01} - h_{02})]} \quad = \frac{(V_{w2}^2 - V_{w1}^2)}{[2U(V_{w1} - V_{w2})]} \tag{18}$$

Assuming the axial velocity is constant through out the stage, then

$$\Lambda = \frac{(V_{w2}^2 - V_{w1}^2)}{[2U(U + V_{w1} + V_{w2} - U)]}$$

$$\Lambda = \frac{(V_{w2} - V_{w1})(V_{w2} + V_{w1})}{[2U(V_{w1} + V_{w2})]} \tag{19}$$

Degree of Reaction

(20)

$$\Lambda = \frac{V_a\left(\tan\beta_2 + \tan\beta_1\right)}{2U}$$

From the velocity triangles it is seen that

$$V_{w1} = U + V_{w1} \qquad V_{w2} = V_{w2} - U$$

Therefore equation (20) can be arranged into a second form:

$$\Lambda = \frac{1}{2} + \frac{V_a}{2U}\left(\tan\beta_2 + \tan\alpha_2\right) \tag{21}$$

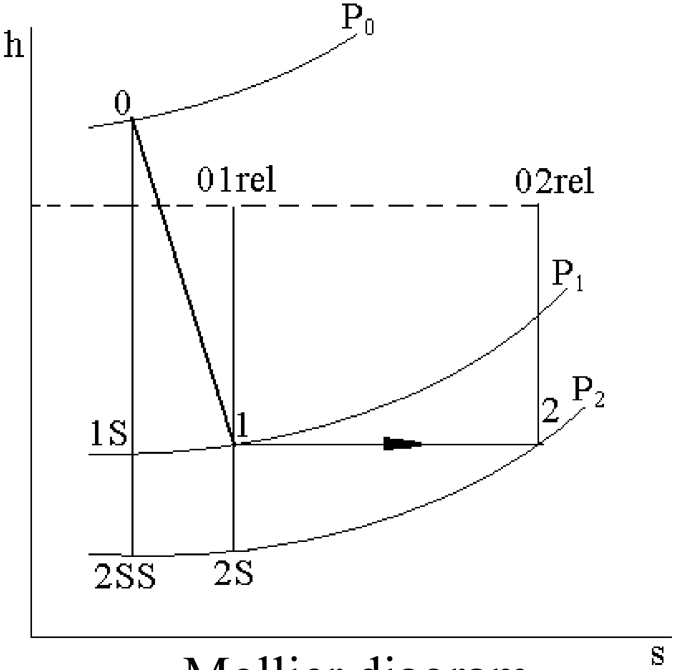
Putting Λ = 0 in equation (20), we get

$\left(\beta_2 = \beta_1\right)$ And $V_1 = V_2$ and for Λ = 0.5, $\left(\beta_2 = \alpha_1\right)$

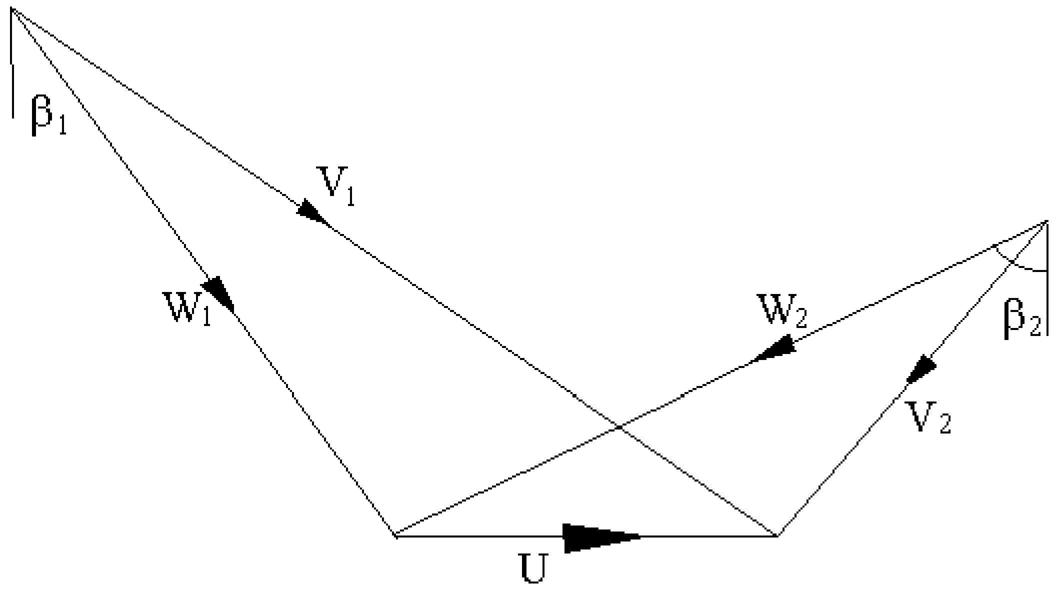
Zero reaction stage

Let us first discuss the special case of zero reaction. According to the definition of reaction, When Λ = 0, equation (16) reveals that $h_1 = h_2$ and equation (20) that $\beta_1 = \beta_2$.

Degree of Reaction



Mollier diagram



Velocity Diagram

Now $h_{01r01} = h_{02r02}$ and $h_1 = h_2$ for $\Lambda = 0$. Then $W_1 = W_2$. In the ideal case, there is no pressure drop in the rotor and points 1 2 and 2s on the mollier chart should coincide. But due to irreversibility, there is a pressure drop through the rotor. The zero reaction in the impulse stage by definition, means there is no pressure drop through the rotor. The Mollier diagram for an impulse stage is shown in Fig. 1.a, where it can be observed that the enthalpy increases through the rotor.

Degree of Reaction

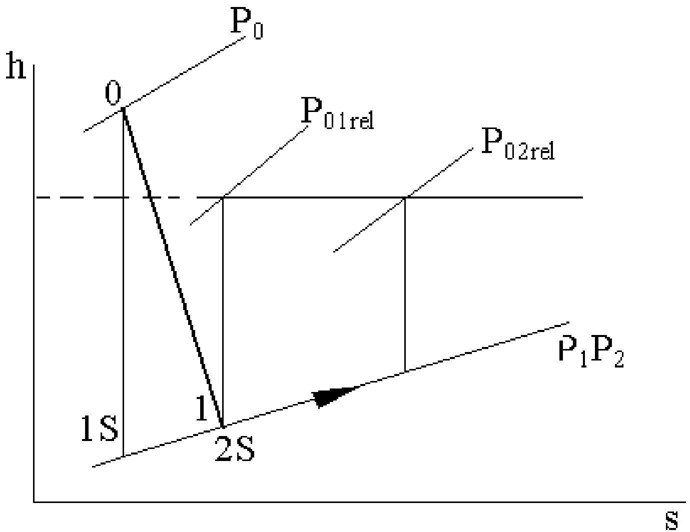
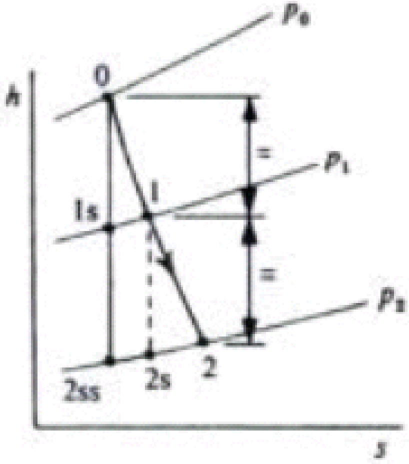


Fig.1.a

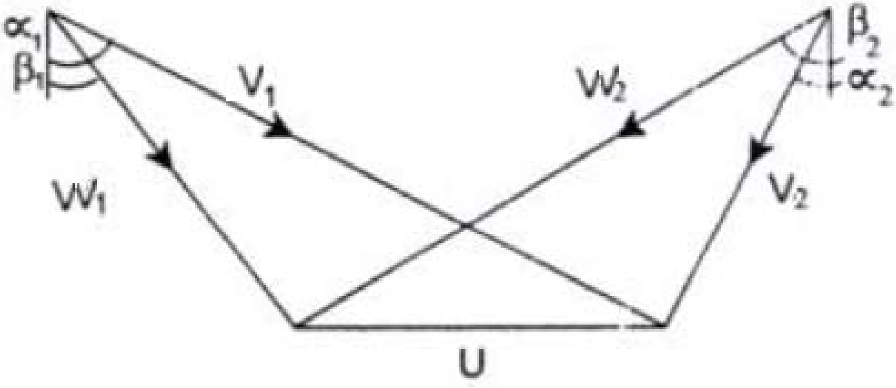


From equation (16) it is clear that the reaction is negative for the impulse turbine stage when irreversibility is taken into account.

Fifty percent reaction stage

From equation (16) for $\Lambda = 0.5$ $\alpha_1 = \beta_2$ and the velocity diagram is symmetrical. Because of symmetry, it is also clear that $\alpha_2 = \beta_1$. For $\Lambda=1/2$, the enthalpy drop in the nozzle row equals the enthalpy drop in the rotor. That is

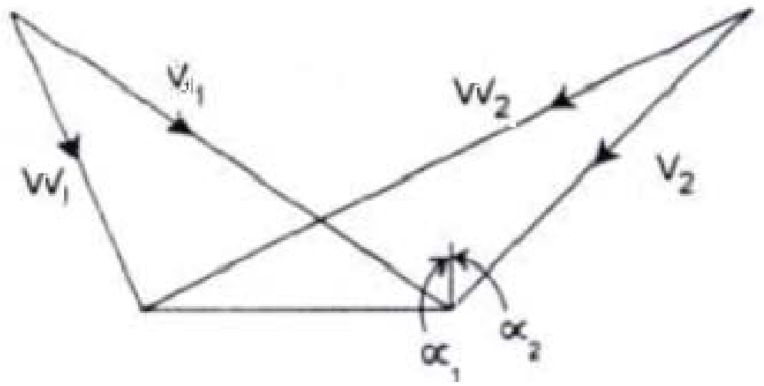
$h_0 - h_1 = h_1 - h_2$



Degree of Reaction

Substituting $\beta_2 = \tan\alpha_2 + \frac{U}{V_a}$ into equation (21)

$$\Lambda = 1 + \frac{V_a}{2U}\left(\tan\alpha_2 - \tan\alpha_1\right) \qquad (22)$$



Thus when $\alpha_2 = \alpha_1$, the reaction is unity (also $V_1 = V_2$). The velocity diagram for $\Lambda = 1$ is shown in Fig. with the same values of V_a, U and W used for $\Lambda = 0$ and $\Lambda = ½$. It is obvious that if Λ exceeds unity, then $V_1 < V_0$ (i.e., nozzle flow diffusion).

Choice of Reaction and Effect on Efficiency

Equation (17) can be rewritten as $\Lambda = 1 + \frac{V_{w2} - V_{w1}}{2U}$

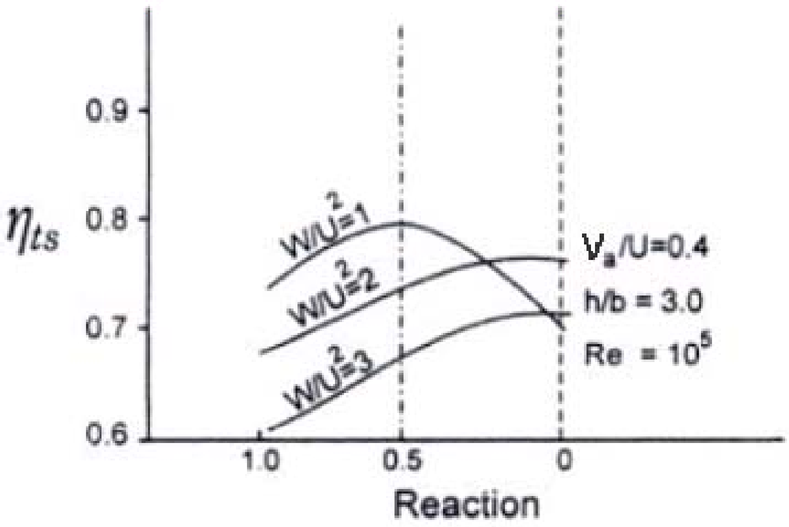
Cw2 can be eliminated by using this equation

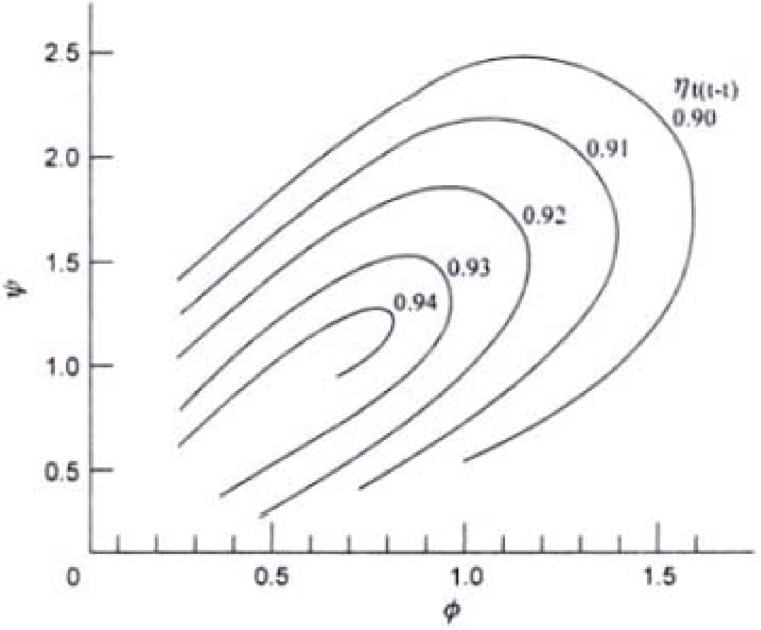
$V_{w2} = \frac{W}{U} - V_{w1}$ yielding $\Lambda = 1 + \frac{W}{2U^2} - \frac{V_{w1}}{U}$

Degree of Reaction

In Fig. the total to static efficiencies are shown plotted against the degree of reaction.

When $W/U^2 = 2$, η_{ts} is maximum at $\Lambda = 0$. With higher loading, the optimum η_{ts} is obtained with higher reaction ratios. As shown in Fig. for a high total to total efficiency, the blade loading factor should be as small as possible, which implies the highest possible value of blade speed is consistent with blade stress limitations. It means that the total to static efficiency is heavily dependent upon the reaction ratio and η_{ts} can be optimized by choosing a suitable value of reaction.





Blade Height in Axial Flow Machines

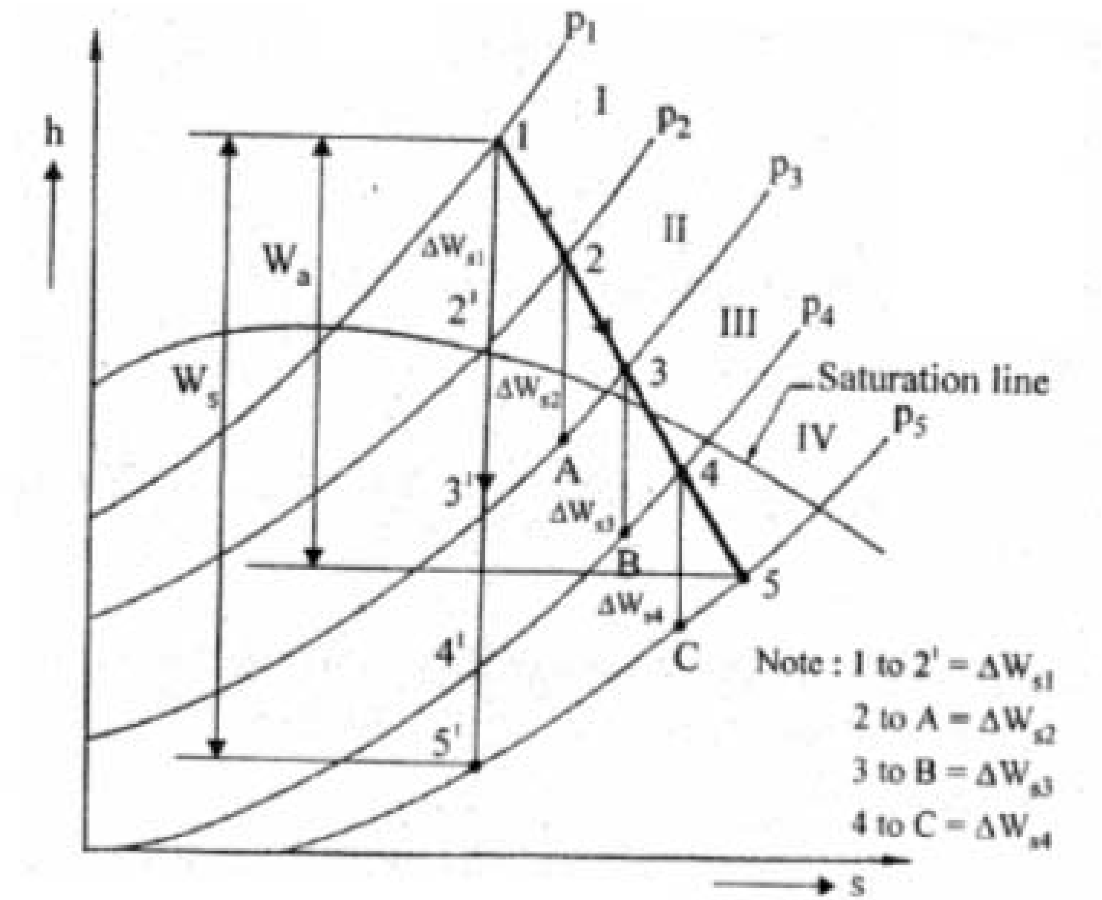
The continuity equation $\dot{m} = \rho A V$ may be used to find the blade height ‘h’. The annular area of flow = πDh. Thus the mass flow rate through an axial flow turbine is

$$\dot{m} = \rho \pi D h V_a$$

$$h = \frac{\dot{m}}{\rho \pi D V_a}$$

Blade height will increase in the direction of flow in a turbine and decrease in the direction of flow in a compressor.

Effect of Reheat Factor & Stage Efficiency



The thermodynamic effect on the turbine efficiency can be best understood by considering a number of stages, say 4, between states 1 and 5 as shown in Fig. Total expansion is divided into four stages of the same stage efficiency and pressure ratio

Effect of Reheat Factor & Stage Efficiency

$$i.e., \frac{P_1}{P_2} = \frac{P_2}{P_3} = \frac{P_3}{P_4} = \frac{P_4}{P_5}$$

Let η_0 is the overall efficiency of expansion and is defined as the ratio of actual work done per kg of steam to the isentropic work done per kg of steam between 1 and 5.

$$i.e., \eta_0 = \left(\frac{W_a}{W_s}\right) \quad i.e., \eta_0 = \frac{h_1 - h_5}{h_1 - h_5^{'}}$$

(22)

The actual work done per kg of steam $W_a = \eta_0 W_s$

Isentropic or ideal values in each stages are ΔW_{s1}, ΔW_{s2}, ΔW_{s3}, ΔW_{s4}.

Therefore the total value of the actual work done in these stages is,

$W_a = \Sigma(1\text{-}2)+(2\text{-}3)+(3\text{-}4)+(4\text{-}5)$

Also stage efficiency for each stage is given by

$$\eta_s = \frac{\text{actual work done/kg of steam}}{\text{Isentropic work done in stage}} = \frac{W_{a1}}{W_{s1}}$$

Effect of Reheat Factor & Stage Efficiency

For stage 1

$$i.e., \eta_{s1} = \frac{W_{a1}}{W_{s1}} = \frac{h_1 - h_2}{h_1 - h_2^{'}} = \frac{W_{a1}}{\Delta W_{s1}} or \Delta W_{a1} = \eta_{s1} \Delta W_{s1}$$

$$\therefore \Delta W_a = \Sigma \Delta W_a = \Sigma \left[\eta_{s1} \Delta W_{s1} + \eta_{s2} \Delta W_{s2} + \eta_{s3} \Delta W_{s3} + \eta_{s4} \Delta W_{s4} \right]$$

For same stage efficiency in each stage $\eta_{s1} = \eta_{s2} = \eta_{s3} = \eta_{s4}$

$$W_a = \eta_s \Sigma \left[\Delta W_{s1} + \Delta W_{s2} + \Delta W_{s3} + \Delta W_{s4} \right] = \eta_s \Sigma \Delta W_s \qquad (23)$$

From equation (22) and (23),

$$\eta_0 W_0 = \eta_s \Sigma \Delta W_s$$

$$\therefore \eta_0 = \eta_s \frac{\Sigma \Delta W_s}{W_s} \qquad (24)$$

The slope of constant pressure lines on h-s plane is given by

$$\left(\frac{\partial h}{\partial s} \right)_p = T$$

Effect of Reheat Factor & Stage Efficiency

This shows that the constant pressure lines must diverge towards the right. Therefore $\frac{\Sigma\Delta W_s}{W_s} > 1$

.

For expansion process. It is obvious that the enthalpy increases when we move towards right along the constant pressure line. Hence the summation of ΔWs1 ΔWs1 etc., is more than the total isentropic enthalpy drop Ws

The ratio of summation of isentropic enthalpy drop for individual stage to the total isentropic enthalpy drop as a whole is called Reheat factor. Thus

$$RF = \frac{\Sigma\left[\Delta W_{s1} + \Delta W_{s2} + \Delta W_{s3} + \Delta W_{s4}\right]}{W_s} = \frac{\Sigma\left[(1-2') + (2-a') + (3-b') + (4-c')\right]}{(1-5)}$$

$$RF = \frac{\Sigma\Delta W_s}{W_s} \qquad (25)$$

Therefore the overall efficiency of the expansion process,

$$\eta_0 = \eta_{stage} \times RF \qquad (26)$$

As $RF = (\Sigma\Delta W_s / W_s) > 1$

the overall efficiency of the turbine η0 is greater than than stage efficiencies ηs

$i.e., \eta_0 > \eta_s$ for turbines (27)

Merits and Demerits of Reheating

Advantages of Reheating

1. There is an increase in output of turbine.
2. Erosion and corrosion problems in steam turbine are reduced.
3. There is an improvement in overall thermal efficiency of the turbine.
4. Condition of steam in last stage are improved.

Demerits

1. Capital cost required for Reheating
2. The increase in thermal efficiency is not appreciable compared to expenditure incurred in reheating for smaller capacity turbines.

Materials of Steam Turbine

Part name	Material Code/Composition
Casing	IS:2063
Inner casing	GS 22Mo4 Shaft
Shaft	30CrMoV121
Blade high pressure	X22CrMoV121
Blade Low pressure	X20Cr3
Casing joint bolt	21CrMoV57
Crossover pipe	ASTM 533 Gr.70
Valve spindle	X22CrMoV121
Valve body	GS17crmov511
Valve seat	21CrMo57

Source BHEL Hyderabad

Session Summary

In this session the students would have learnt about

- Working principle of steam turbine
- Classification of turbines
- Types of compounding
- Work done and efficiency of Impulse steam turbine stage
- Work done and efficiency of reaction steam turbine stage
- Solution of some numerical examples related to steam turbines

Thank you