TURBO MACHINES

BME IV/I

Chapter Two: Velocity Vector Diagram

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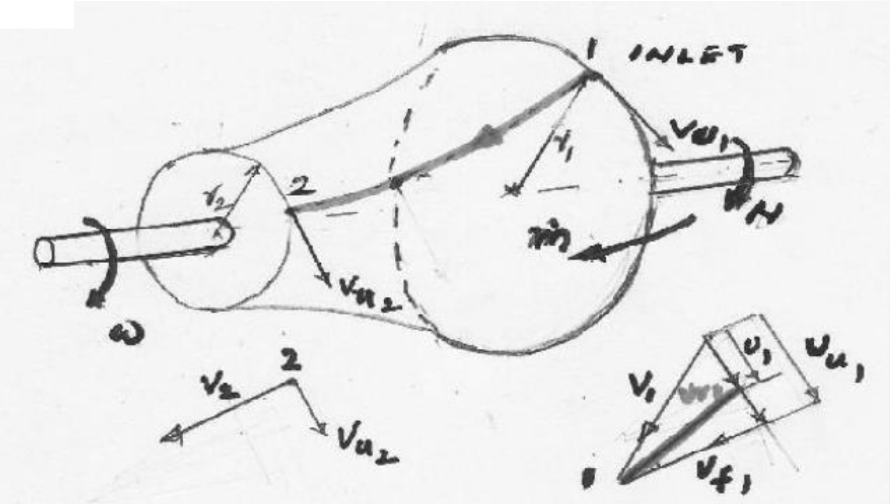
Chapter overview

- Analysis of Work Done
- Typical Turbine Blade Profile
- Staging of turbo machines
- Efficiency in Impulse Turbine
- Efficiency in Reaction Turbine

Analysis of Work Done

Referring to figure,
1 is inlet; 2 is outlet of rotor

V =	Absolute velocity of fluid (m/s)
R =	Radius of the wheel (m)
ω =	Angular velocity of rotor (rad/s)
N =	Speed of rotor (rpm)
U =	Linear velocity of vane (m/s)
□ =	Mass flow rate of fluid (kg/s)



CONTD…

Tangential momentum of fluid at inlet

$\square\ V_{u1}$ (N)

Momentum of momentum OR

Angular momentum of fluid at inlet

$\square\ .\ V_{u1}\ .\ r_1$ (Nm)

Angular momentum of fluid at outlet

$\square\ .\ V_{u2}\ .\ r_2$ (Nm)

Torque on the wheel

= Change in angular momentum

$\therefore\ T = \square\ (V_{u1}\, r_1 - V_{u2}\, r_2)$ (Nm)

$\therefore$ Work done/sec = Torque x angular velocity = $T \times \omega$

Taking $\omega\, r_1 = 2\pi\, r_1/N = U_1$

$\omega\, r_2 = 2\pi\, r_2/N = U_2$

Work done/sec = $\square\ [V_{u1}U_1 - V_{u2}U_2]$ Nm/s or Watts

Work done/Unit mass when m = 1kg

WD/kg = Energy transfer

$= [V_{u1}U_1 - V_{u2}U_2]$ ...[$Nm/kg = m^2/sec^2$]

This is known as Euler's Turbine equation.

CONTD…

If $V_{u1}U_1 >> V_{u2}U_2$

Then, $[V_{u1}U_1 - V_{u2}U_2]$ is +ve
It is applicable to Power Generating Turbo Machines or Turbines.

If $V_{u1}U_1 << V_{u2}U_2$

Then, $[V_{u1}U_1 - V_{u2}U_2]$ is –ve
It is applicable to Power Absorbing Turbo Machines like pump, fans, blowers and compressors.

CONTD…

In a turbine if $V_{u1}U_1 >> V_{u2}U_2$ and

V_{u2} is in opposite direction to rotation of wheel, then work done will be greater.

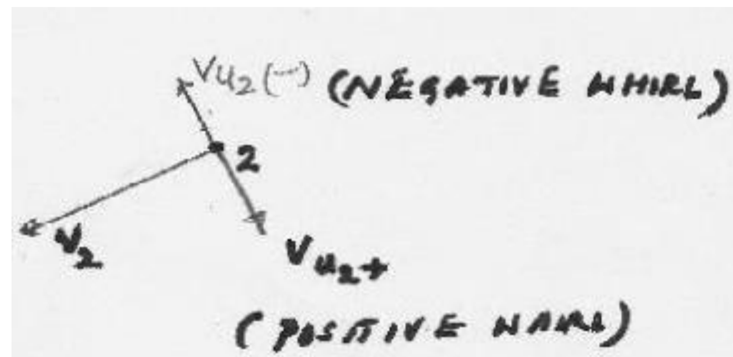
Work done/kg

$$WD/kg = [V_{u1}U_1 - (-V_{u2})\,U_2]$$
$$= V_{u1}U_1 + V_{u2}U_2 \qquad \text{(Nm/kg)}$$

Generally, for a turbine,

work done/kg

$$WD/kg = [V_{u1}U_1 \pm V_{u2}U_2] \text{ (Nm/kg)}$$
where, $V_{u1}U_1 > V_{u2}U_2$



For pumps, fans, blowers and compressors

$$\text{Work done/kg} = [V_{u2}U_2 - V_{u1}U_1]$$
where $V_{u2}U_2 > V_{u1}U_1$

If □ = mass rate of flow in kgs/s

Power developed in a turbine

$$\mathbf{P = \square\, [V_{u1}U_1 \pm V_{u2}U_2]}$$
Watts or Nm/s or J/s

Power given to fluid in pumps, fans, blowers and compressors

$$\mathbf{P = \square\, [V_{u2}U_2 - V_{u1}U_1]}$$
Watts or Nm/s or J/s

Blade Profile and staging of turbine

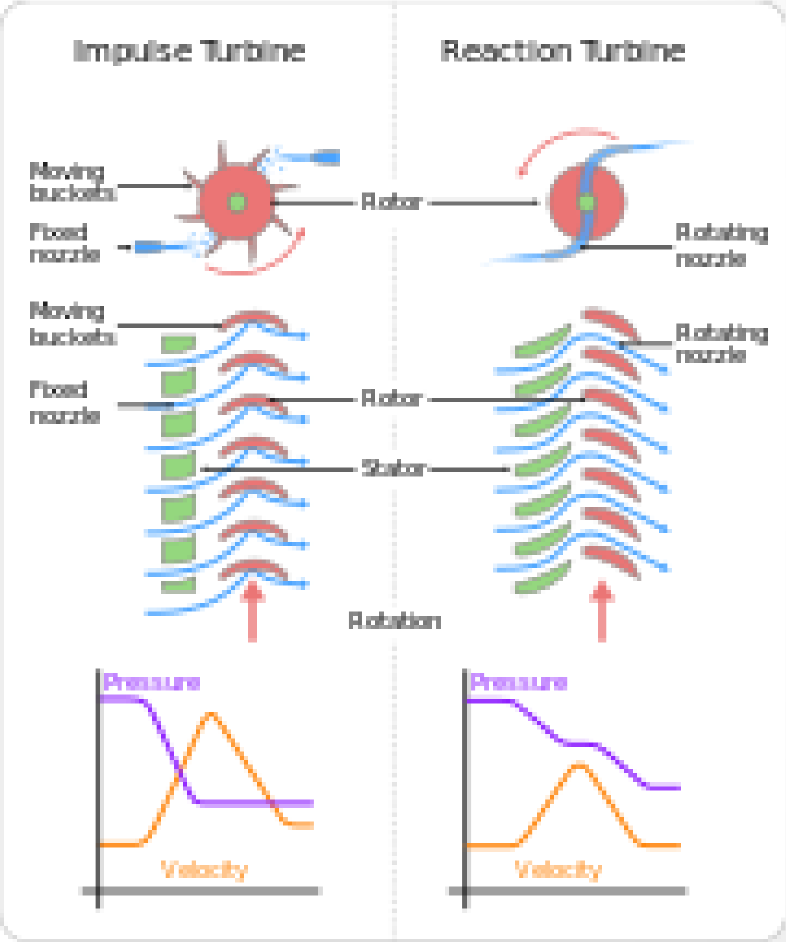
- Steam turbines are usually impulse or a mixture of impulse and reaction stages whereas gas turbines tend to be always of the reaction type.
- Pressure ratio of steam turbines can be of the order 1000:1, whereas it’s within the order of 10:1 for gas turbines.
- To reduce the number of stages, pressure drop per stage should be large, but in doing so blade losses and efficiency costs rise.
- Therefore, reaction stages are used where pressure drop per stage is low and also where the overall pressure ratio of the turbine is relatively low.
- Shape and size of the blades can vary with different types of stages.

CONTD…

- Turbine blades are of two basic types:
- A turbine composed of blades alternating with fixed nozzles is called an impulse turbine, Curtis turbine, Rateau turbine.
- Nozzles appear similar to blades, but their profiles converge near the exit. This results in a steam pressure drop and velocity increase as steam moves through the nozzles.
- Nozzles move due to both the impact of steam on them and the reaction due to the high-velocity steam at the exit.
- A turbine composed of moving nozzles alternating with fixed nozzles is called a reaction turbine or Parsons turbine.

CONTD…

- Except for low-power applications, turbine blades are arranged in multiple stages in series, called compounding, which greatly improves efficiency at low speeds.
- A reaction stage is a row of fixed nozzles followed by a row of moving nozzles.
- Schematic diagram outlining the difference between an impulse and a 50% reaction turbine



CONTD…

- Multiple reaction stages divide the pressure drop between the steam inlet and exhaust into numerous small drops, resulting in a **pressure-compounded** turbine.
- Impulse stages may be either pressure-compounded, velocity-compounded, or pressure-velocity compounded.
- A pressure-compounded impulse stage is a row of fixed nozzles followed by a row of moving blades, with multiple stages for compounding. This is also known as a Rateau turbine, after its inventor.
- A **velocity-compounded** impulse stage (invented by Curtis and also called a "Curtis wheel") is a row of fixed nozzles followed by two or more rows of moving blades alternating with rows of fixed blades. This divides the velocity drop across the stage into several smaller drops.
- A series of velocity-compounded impulse stages is called a **pressure-velocity compounded** turbine.

CONTD…

- Staging of axial-flow compressor-turbine assembly is done in combination of rotor and stators.
- For centrifugal compressors, the staging are the same as spools, for e.g. one compressor-turbine coupled stage is linked through a single ‘spool’ hence also called a ‘single spool compressor/turbine’.
- For axial compressors, the staging is defined in terms of rows of stator-rotor assembly, with a single such assembly referred to as a compressor stage. Each stage can have a compression ratio in the range of 1.05~2 with an efficiency of around 0.94.
- Hence, for axial compressors a single spool can contain several stages. And spools (up to three) in combination can provide compression in the range of 5-40.

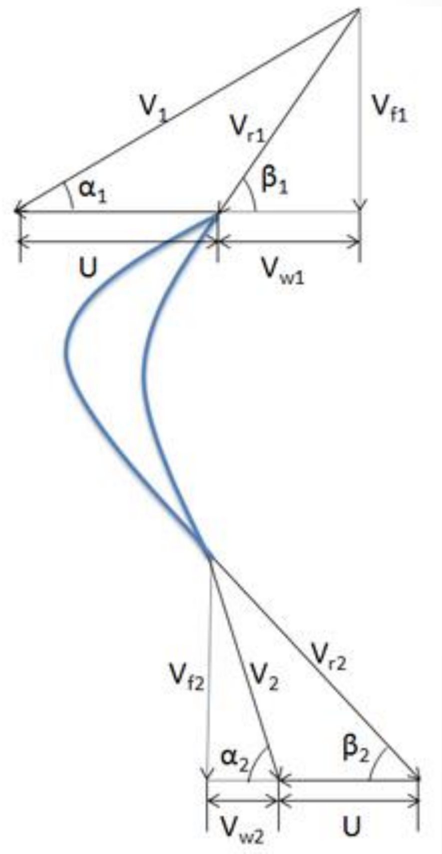
Efficiency in Impulse Turbine

- Then by the law of moment of momentum, the torque on the fluid is given by:

$$T = \dot{m}(r_2 V_{w2} - r_1 V_{w1})$$

- For an impulse steam turbine: r2=r1=r
- Therefore, the tangential force on the blades is $F_u = \dot{m}(V_{w1} - V_{w2})$
- The work done per unit time or power developed: W= T. ω
- When ω is the angular velocity of the turbine, then the blade speed is U= ω.r
- The power developed is then .

$$W = \dot{m}U(\Delta V_w)$$



CONTD…

Blade efficiency

- Blade efficiency can be defined as the ratio of the work done on the blades to kinetic energy supplied to the fluid, and is given by

$$\eta_b = \frac{Work\ Done}{Kinetic\ Energy\ Supplied} = \frac{2UV_w}{V_1^2}$$

Stage efficiency

- A stage of an impulse turbine consists of a nozzle set and a moving wheel. The stage efficiency defines a relationship between enthalpy drop in the nozzle and work done in the stage.

$$\eta_{stage} = \frac{Work\ done\ on\ blade}{Energy\ supplied\ per\ stage} = \frac{U\Delta V_w}{\Delta h}$$

- Nozzle efficiency is given by, $\eta_N = \frac{V_2^2}{2(h_1 - h_2)}$

where the enthalpy (in J/Kg) of steam at the entrance of the nozzle is h1 and the enthalpy of steam at the exit of the nozzle is h2.

CONTD…

$$\eta_{stage} = \eta_b * \eta_N$$

- **Condition for maximum efficiency,**

$$(\eta_b)_{max} = \cos^2 \alpha_1$$

- For a given steam velocity work done per kg of steam would be maximum when alpha1 =0
- As alpha1 increases, the work done on the blades reduces, but at the same time surface area of the blade reduces, therefore there are less frictional losses.

Efficiency in Reaction Turbine

THANK YOU !!!