
Steam Turbines

Types of steam turbines

- Impulse type
- Reaction type
    - The chapter is intended to formulate the general theory of axial turbines.
    - The chapter discusses the role of degree of reaction (DOR).

Applications of steam turbines

- A special feature of steam turbines is their ability for very high power, due to the big enthalpy drop realizable per steam mass unit.

- The working principles of steam turbines practically realized by Gustaf de Laval (Sweden) in 1883 and by Charles Parsons (UK) in 1884.

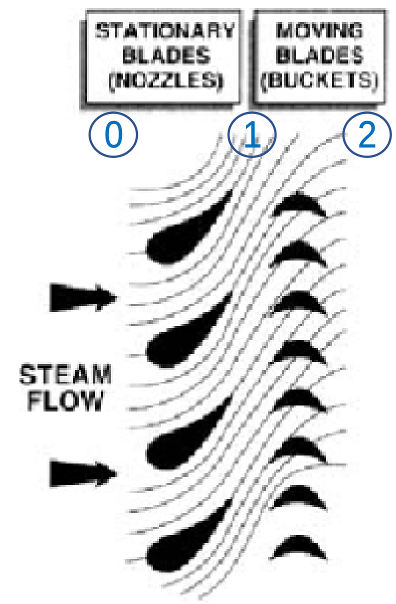
- Steam turbines are only applied to drive machines requiring high power and turning at high rotational speed.

Working principles of steam turbines

- Present steam turbines are almost exclusively built in the axial form.
- A flow is generated in stator components by converting static enthalpy into kinetic energy.
- Mechanical work is produced by change of flow direction in the downstream rotor by using the kinetic energy.
- Static enthalpy can be converted into kinetic energy during work in the rotor. A degree of reaction is then present.
- From a historical point of view, there are two steam turbine types: the impulse turbine and the reaction turbine.

Working principles of steam turbines

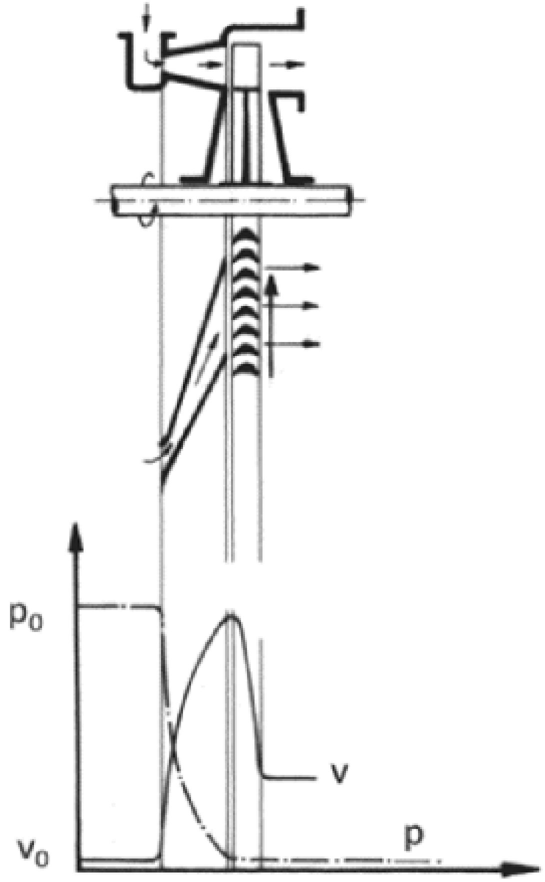
- From a historical point of view, there are two steam turbine types: the impulse turbine and the reaction turbine.
- The impulse turbine was introduced by G. de Laval in 1883. It is a machine with no pressure drop in the rotor.
- As a principle, the degree of reaction thus equals zero.
- The enthalpy relations in stator and rotor are:



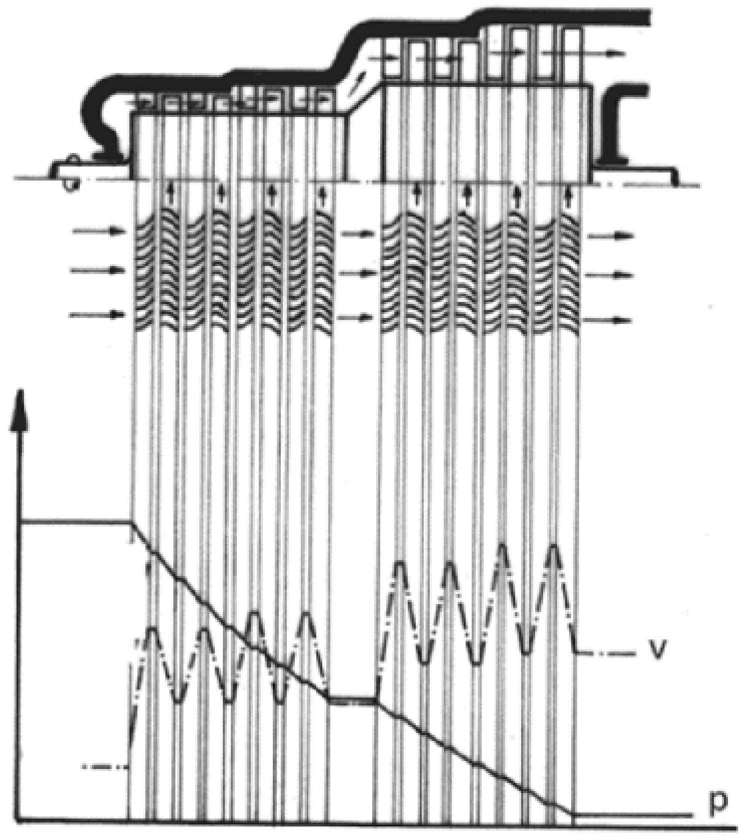
- For Stator $$h_{00} = h_1 + \frac{v_1^2}{2} = h_{01}$$

- For rotor $$h_{0r} = h_1 + \frac{w_1^2}{2} = h_2 + \frac{w_2^2}{2}; \quad h_1 - h_2 = \frac{w_2^2 - w_1^2}{2}$$

Working principles of steam turbines



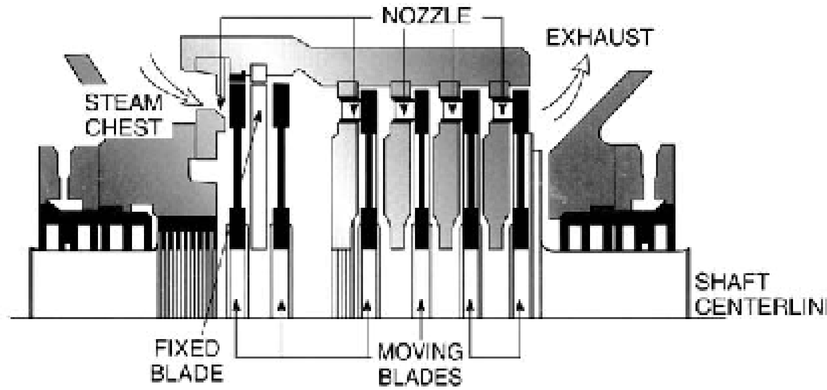
Simple Impulse



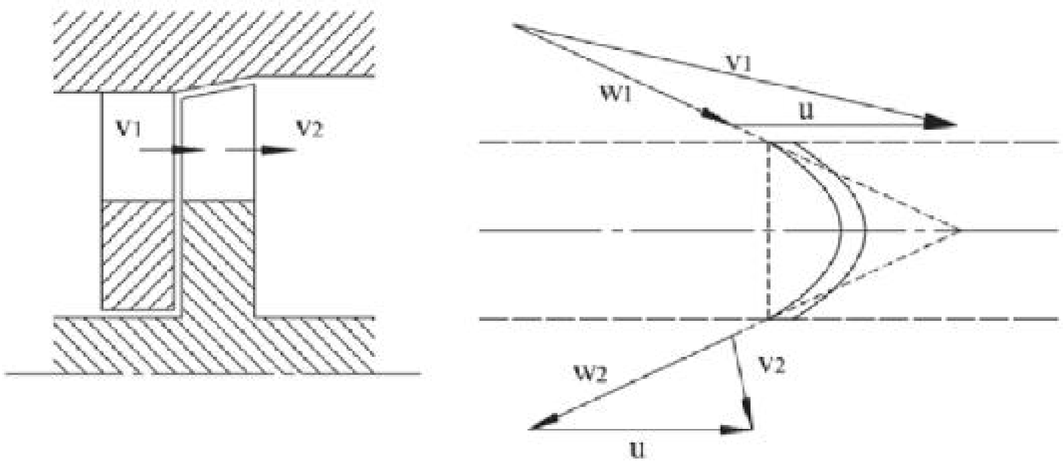
Reaction Stages

The Single Impulse Stage or Laval Stage

- For simplicity reasons, we discuss a single-stage impulse turbine at first, its analysis being the simplest one.

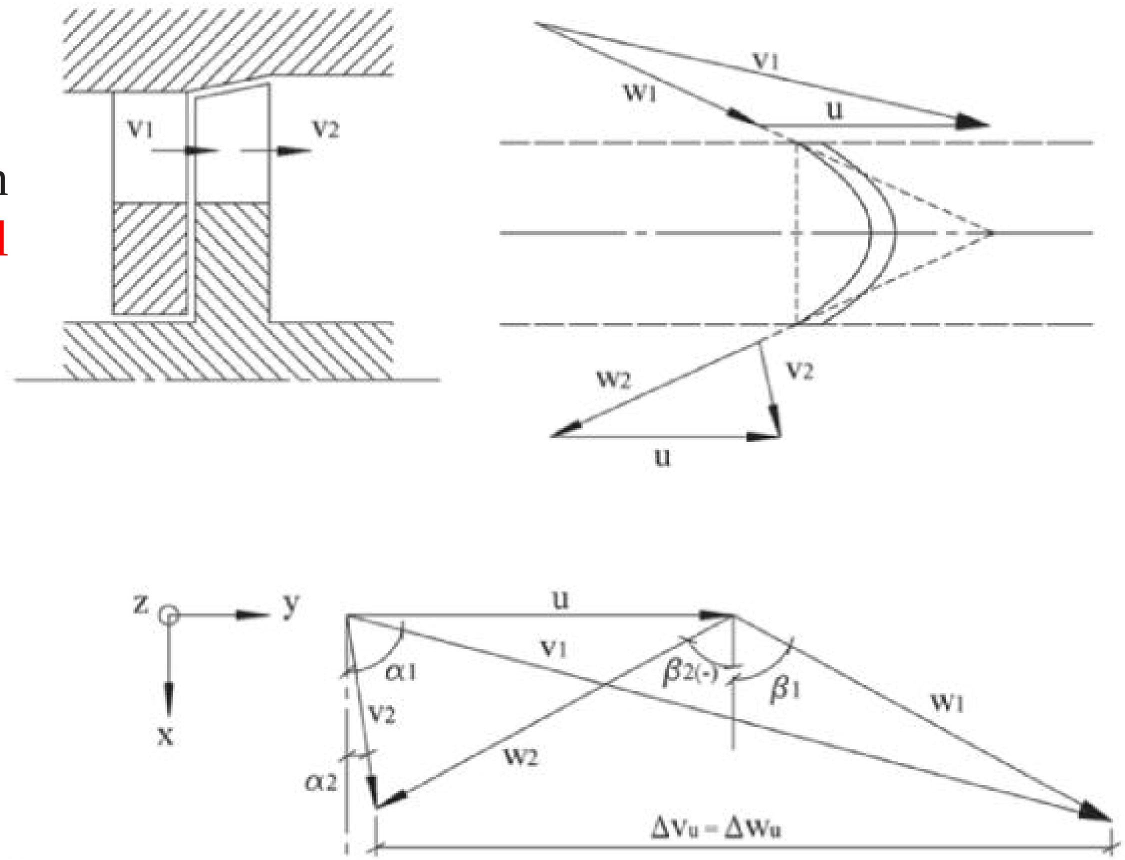


Velocity Triangles



The Single Impulse Stage or Laval Stage

- Angles are counted with respect to the axial direction.

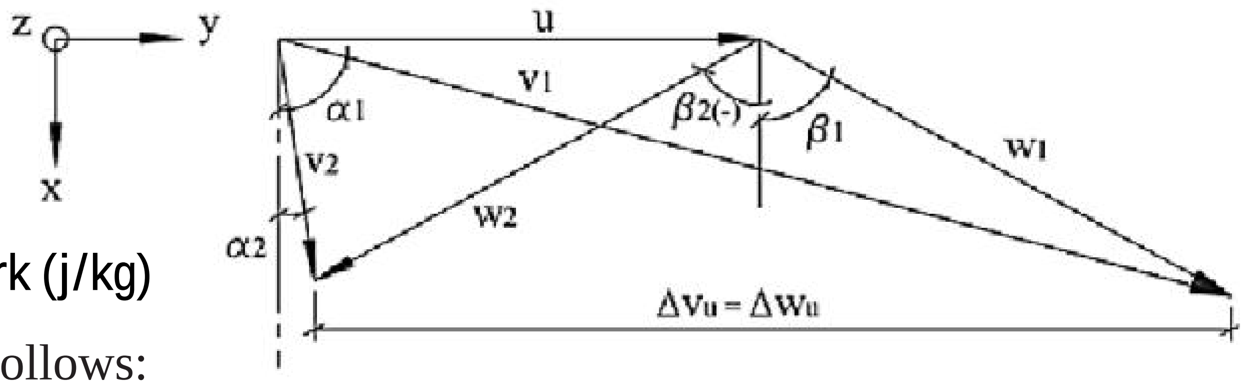


Work and Energy Relations

Rotor work (Euler):

$$\Delta W = u(v_{2u} - v_{1u}).$$

Specific work (j/kg)



Through velocity triangles it follows:

By using Cosine rule

$$w_1^2 = u^2 + v_1^2 - 2uv_{1u}$$

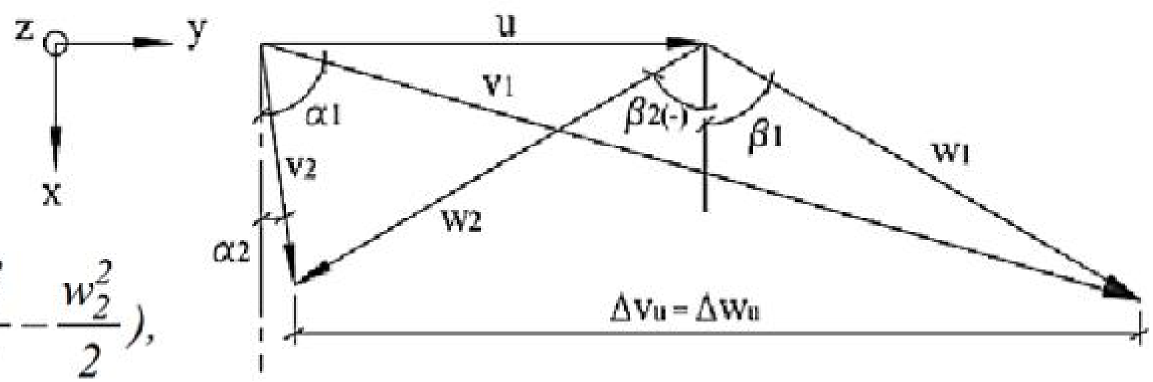
$$w_2^2 = u^2 + v_2^2 - 2uv_{2u}$$

$$w_1^2 - w_2^2 = v_1^2 - v_2^2 - 2u(v_{1u} - v_{2u}),$$

$$\Rightarrow -\Delta W = u(v_{1u} - v_{2u}) = \frac{v_1^2}{2} - \frac{v_2^2}{2} - \left(\frac{w_1^2}{2} - \frac{w_2^2}{2}\right).$$

Work and Energy Relations

- For a turbine, we conventionally consider delivered work as positive and write:



therefore,

$$\Delta W = u(v_{1u} - v_{2u}) = \frac{v_1^2}{2} - \frac{v_2^2}{2} - (\frac{w_1^2}{2} - \frac{w_2^2}{2}),$$

$$\Delta W = \Delta h_0 = h_{01} - h_{02}.$$

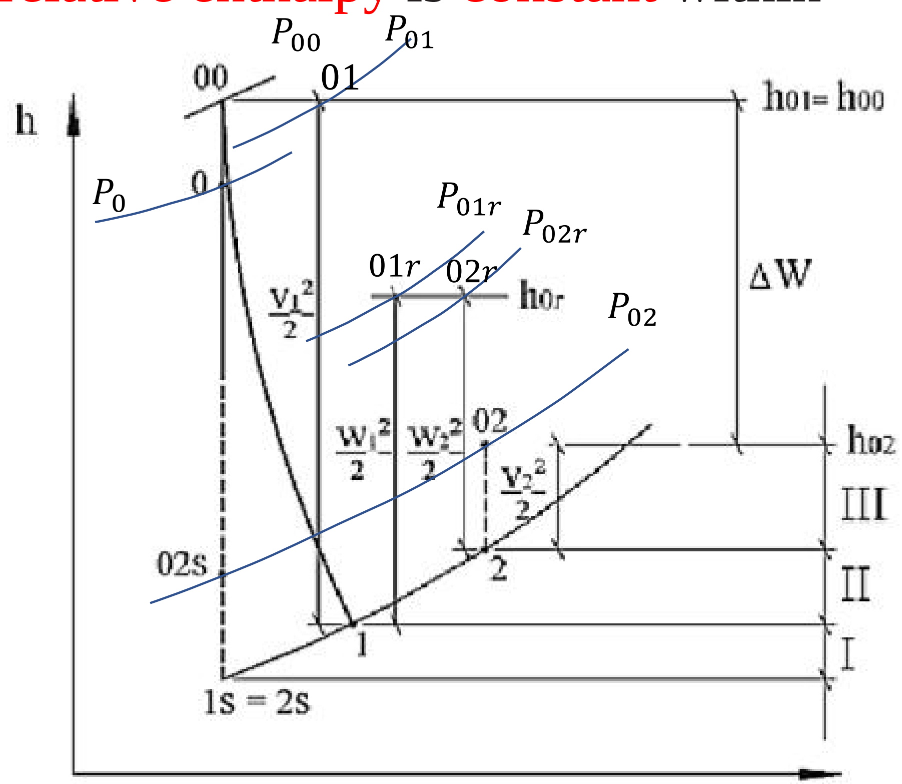
Since Δh_0 represents the total enthalpy drop. From rotor work and energy it follows

$$h_1 + \frac{v_1^2}{2} - h_2 - \frac{v_2^2}{2} = \frac{v_1^2}{2} - \frac{v_2^2}{2} - (\frac{w_1^2}{2} - \frac{w_2^2}{2}),$$

$$h_1 + \frac{w_1^2}{2} = h_2 + \frac{w_2^2}{2} = h_{0r} = \text{constant}.$$

Work and Energy Relations

- We recover the result that the total relative enthalpy is constant within the rotor.



h-s diagram of an impulse turbine stage

- The Figure demonstrates the processes with an impulse turbine in the h-s diagram, taking the obtained relations into account.
- The diagram is drawn for constant pressure in the rotor.
- Efficiency is therefore defined by comparing the result of the real expansion to that of a loss-free expansion.

Isentropic nozzle efficiency

$$\eta_{ss} = \frac{v_1^2 / 2}{v_{1s}^2 / 2},$$

$$\frac{v_1^2}{2} = h_{00} - h_1; \quad \frac{v_{1s}^2}{2} = h_{00} - h_{1s}.$$

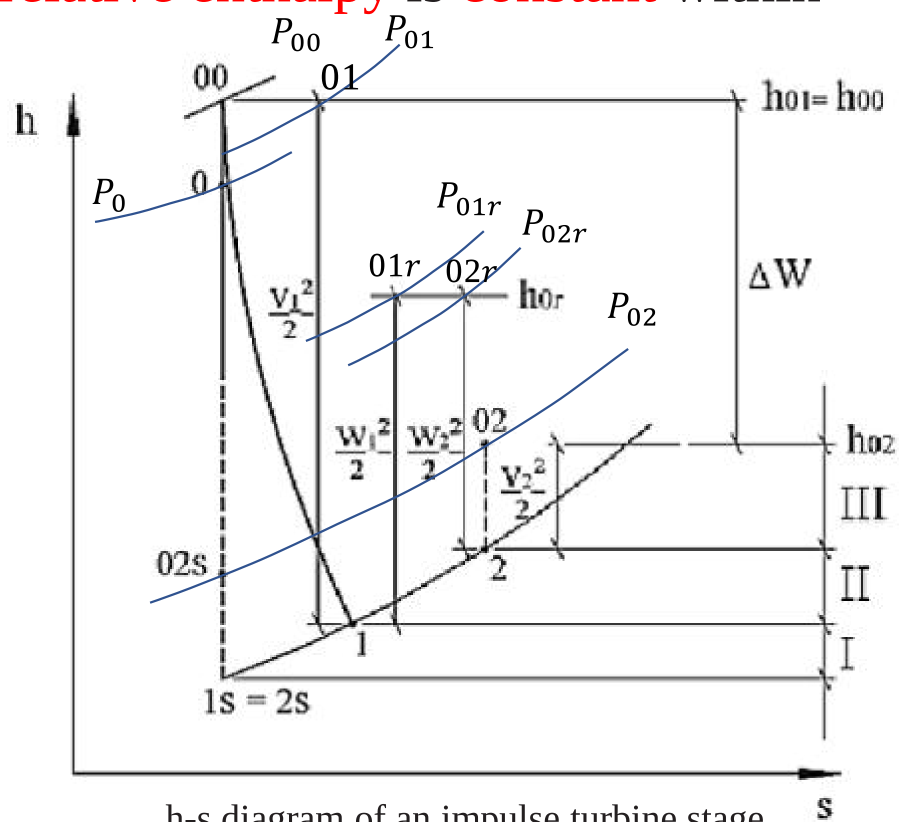
Work and Energy Relations

- We recover the result that the total relative enthalpy is constant within the rotor.

I: nozzle loss

II: rotor loss

III: outlet kinetic energy



h-s diagram of an impulse turbine stage

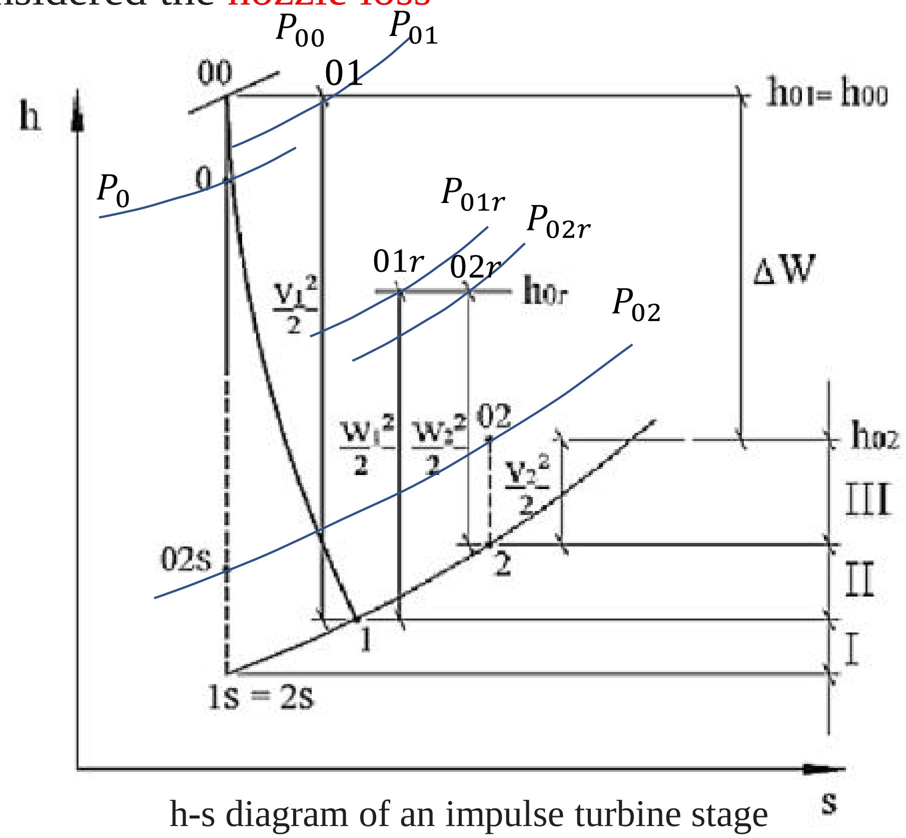
Work and Energy Relations

- Conventionally, the difference $\frac{v_{1s}^2}{2} - \frac{v_1^2}{2}$ is considered the nozzle loss
- This difference does not correspond exactly to the integral of dq_{irr} in the work equation.
- Since q_{irr} is the dissipated heat inside flow path.
- As the real loss is practically undeterminable, because it depends on the details of the expansion path, the conventional nozzle loss is applied in the further analysis.

Velocity coefficient $\emptyset_s$

$$v_1 = \phi_s v_{1s}$$

$$\eta_{ss} = \phi_s^2 .$$



h-s diagram of an impulse turbine stage

Work and Energy Relations

Energy: $dW = dh + \frac{1}{2}dv^2 = dh_0$;

Work: $dW = \frac{1}{\rho}dp + d\frac{1}{2}v^2 + dq_{irr}$,

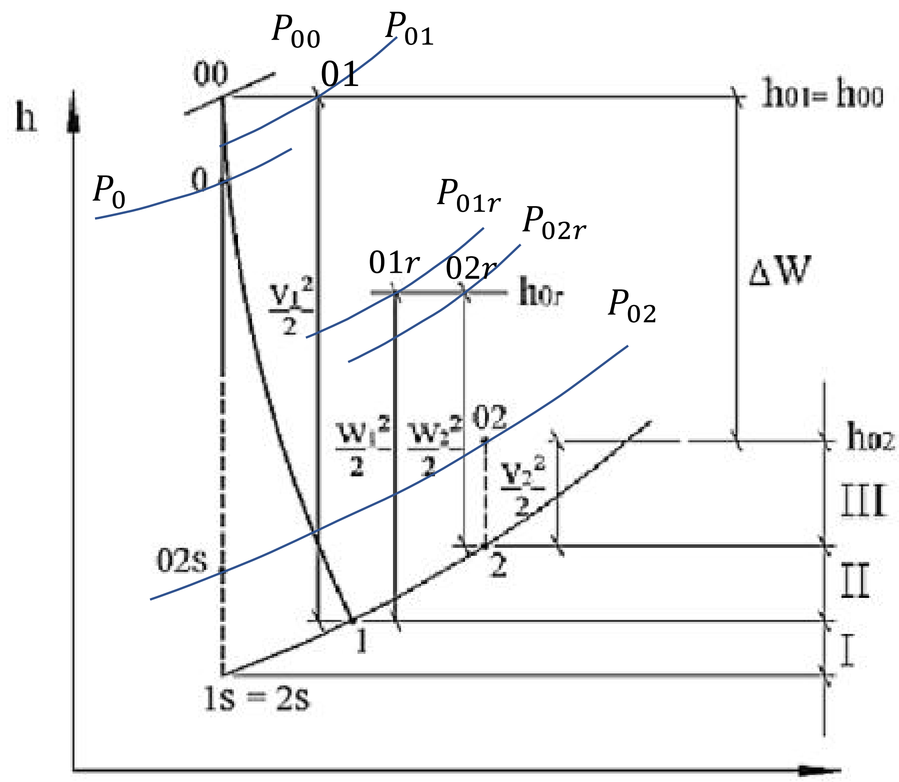
In the rotor of an impulse turbine, $dp = 0$. So the work equation can be integrated.

$$0 = 0 + d\frac{1}{2}w^2 + dq_{irr},$$

$$q_{irr} = \frac{w_1^2}{2} - \frac{w_2^2}{2}.$$

Therefore,

The decrease of the kinetic energy in the relative system thus is the loss.



h-s diagram of an impulse turbine stage

Work and Energy Relations

- Since, rotor work relation is $\Delta W = u(v_{1u} - v_{2u}) = \frac{v_1^2}{2} - \frac{v_2^2}{2} - (\frac{w_1^2}{2} - \frac{w_2^2}{2})$

- It can be written as $\Delta W = \frac{v_1^2}{2} - \left(\frac{w_1^2}{2} - \frac{w_2^2}{2}\right) - \frac{v_2^2}{2}$

$\frac{v_1^2}{2}$: Kinetic energy supplied to the rotor

$\left(\frac{w_1^2}{2} - \frac{w_2^2}{2}\right)$: Rotor loss

$\frac{v_2^2}{2}$: Outlet kinetic energy

It seems appropriate to define rotor efficiency by $\eta_r = \frac{\Delta W}{v_1^2 / 2}$

Work and Energy Relations

- As there is no pressure drop, the kinetic energy supplied to the rotor is the only source of work.

We define a ***rotor velocity coefficient*** *by*

$$w_2 = \phi_r . w_{2s}$$

Since, the optimum case for the rotor by making $w_1 = w_{2s}$

$$w_2 = \phi_r . w_{2s} = \phi_r . w_1$$

$\emptyset_r$: Rotor velocity coefficient