The Losses of Turbomachines

1. ***Internal Losses:*** Losses which ***take place in the inner passages*** of the machine and directly connected with rotor or flow of the medium and which are ***adding heat to the flow medium***

2. ***External losses:*** Losses which ***appear outside of the inner passages*** of the casing and which ***do not transfer the generated heat directly into the flow medium***

Internal Losses

- Due to the inner losses, the total energy exchange between the rotor and the flow medium is altered.
- In the case of the ***working machine more energy has to be exchanged***
- In the case of the ***power machine less energy is exchanged*** than by a machine under the same condition but without losses.

- The losses can be :
  - Specific Energy Losses
  - Volume/mass-flow losses

A. Hydraulic Loss Z_h

- Is a ***specific Energy Loss due to friction, separation, contraction, diffucion, eddy formation*** etc. while the flow passes through the main flow passages from entrance to discharge flange of the machine

- ***In case of turbines*** the needed energy to overcome the hydraulic loss Z_h is taken from the available spec. energy Y.

$$Y_{blade} = Y - Z_h \left[\frac{Nm}{kg} \right]$$

- ***In case of working machines***, the impeller has to transfer in addition to the spec. energy Y a spec. energy Z_h

$$Y_{blade} = Y + Z_h \left[\frac{Nm}{kg} \right]$$

B. Disc Friction Loss Z_r

- The surface of the rotor which does not form the main flow passage is surrounded by a fluid medium

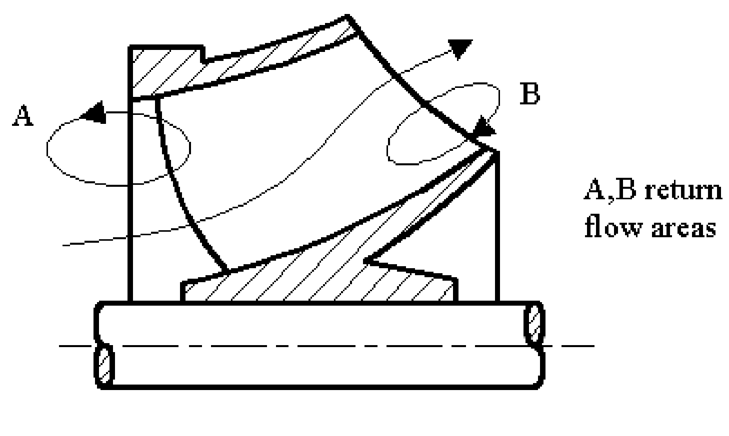
- While the rotor rotates, ***a friction is generated between this rotor surface and its surrounding fluid medium***. The needed power to overcome this friction can be written as:

$$N_r = \rho V Z_r$$

Where: Z_r = disc friction spec. energy loss and is involved with ρV

C. Return-Flow Loss Z_a

- A return flow of already energy loaded medium may be noted in pumps. Especially by those of the axial-flow type.



MIXED-FLOW PUMP

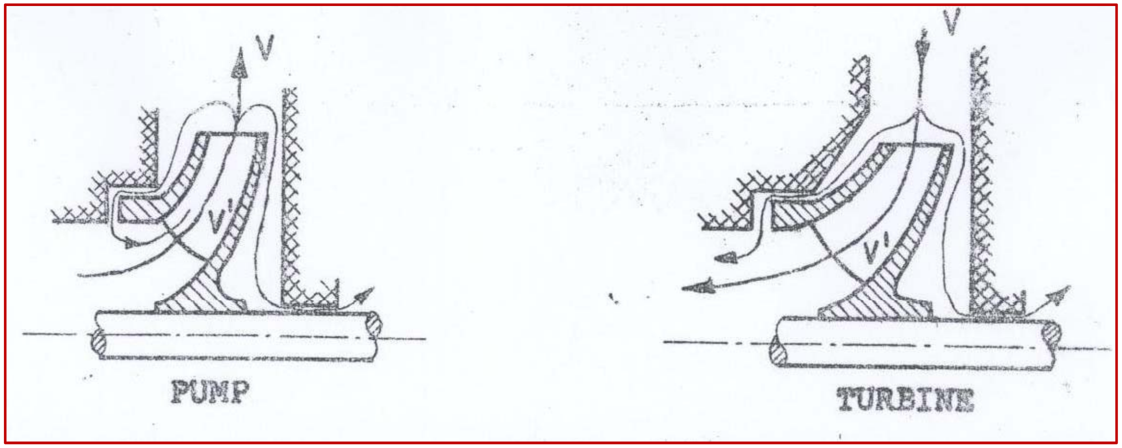
$$N_a = \rho V Z_a$$

Where Z_a = the spec. energy loss involved and related to ρV.

❖ Na is very small for the design point and, thus it is normally neglected. But it may increase greatly when discharge V_x is less that the design point discharge V.

D. Leakage Loss ΔV (Loss of Volume or mass-flow

- Due to possible leakage, ***the volume V passing through the pressure flange*** of the machine differs from ***the volume V' passing through the rotor vane channels.***



If ΔV is the total leakage, the volume flowing through the rotor channels is:

$$V' = V + \Delta V \qquad \textit{In working machines}$$
$$V' = V - \Delta V \qquad \textit{In power machines}$$

The specific energy loss due to leakage:

$$Z_l = \frac{\Delta V}{V} Y_{blade}$$

Internal Power

- The total internal loss, Z_i

$$Z_i = Z_h + Z_r + Z_a + Z_l$$

- Accounting for all internal losses, the power transferred between the rotor and the flow is defined as:

$$N_i = \rho(V \pm \Delta V)Y_{blade} \pm (N_r + N_a) = \rho V Y_i$$

- Where ***Y_i is internal specific work*** defined as:

$$Y_i = \frac{N_i}{\rho V} = \left(1 \pm \frac{\Delta V}{V}\right)Y_{blade} \pm (Z_r + Z_a)$$

$$Y_i = Y - Z_i \qquad \textit{For power machines}$$

$$Y_i = Y + Z_i \qquad \textit{For working machines}$$

External Losses

- All external losses due to ***friction in the bearings, sealings and due to fluid friction at the outside rotating surfaces*** of the machine can be counted together as a power loss: $N_m \left[\frac{Nm}{kg}\right]$

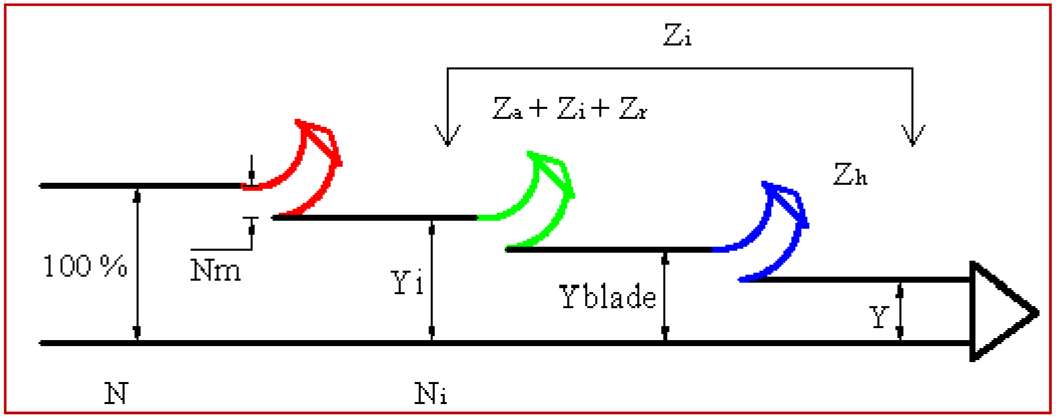
- External losses also include ***losses from auxiliary equipments (oil pump, bearing lubrication speed regulators)*** since they are mostly driven directly by the shaft of the turbomachine

- The coupling power N which considers all internal and external losses is

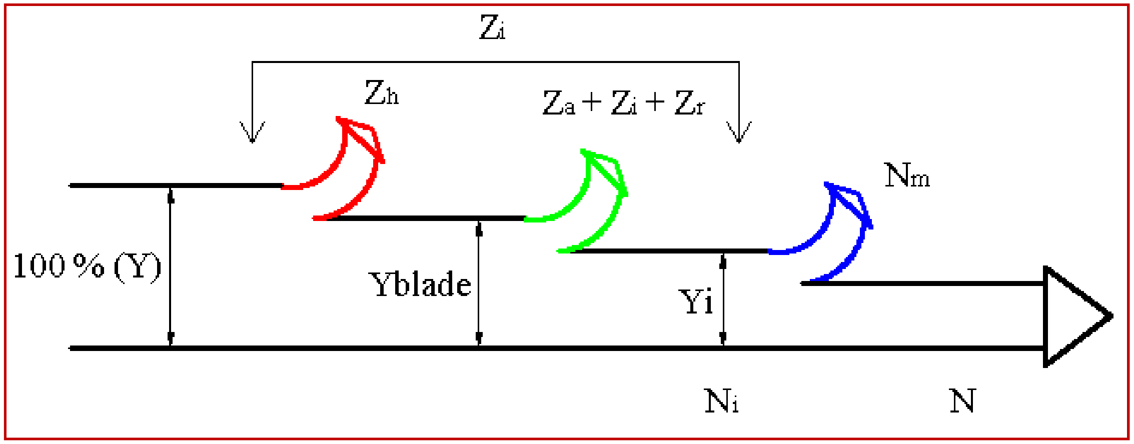
$$N = N_i \pm N_m = \rho\left(V \pm \Delta V\right)Y_{blade} \pm \left(N_r + N_a + N_m\right)$$

Sankey diagram

- For working Machines



- For Power Machines



The Efficiency of the Turbomachine

- Definition of Efficiency: $$\eta = \frac{energy\ \ output}{energy\ \ input} = \frac{power\ \ output}{power\ \ input}$$

- Different efficiencies can be defined considering different losses:

A. <u>Hydraulic Efficiency:</u>

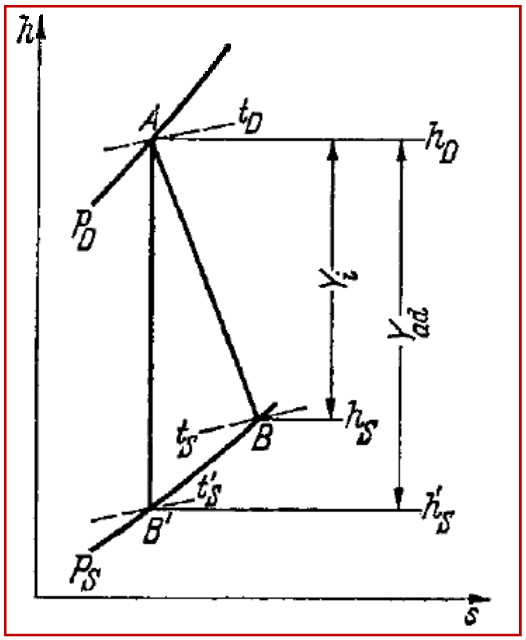
$$\eta_h = \left(\frac{Y}{Y_{blade}} \right)^{\pm 1} = \left(\frac{Y}{Y \pm Z_h} \right)^{\pm 1}$$

- Hydraulic efficiency cannot be measured directly by test because N_r and N_a are also involved in the flow through and around the rotor.

B. Internal Efficiency:

$$\eta_i = \left(\frac{Y}{Y_i}\right)^{\pm 1} = \left(\frac{\rho V Y}{N_i}\right)^{\pm 1}$$

- Considers all internal losses including the hydraulic losses.
- For steam or a gas turbines the velocity and geodetic energy can be neglected:
- the internal efficiency can be determined by measuring temperatures or enthalpies



$$compression \quad \eta_i = \frac{\Delta t_{ad}}{\Delta t} = \frac{T'_D - T_S}{T_D - T_S} = \frac{\Delta i_{ad}}{\Delta i} = \frac{i'_D - i_S}{i_D - i_S}$$

$$expansion \quad \eta_i = \frac{\Delta t_{ad}}{\Delta t} = \frac{T_D - T_S}{T_D - T'_S} = \frac{\Delta i_{ad}}{\Delta i} = \frac{i_D - i_S}{i_D - i'_S}$$

C. Mechanical Efficiency:

$$\eta_m = \left(\frac{N_i}{N}\right)^{\pm 1} = \left(\frac{N_i}{N_i \pm N_m}\right)^{\pm 1}$$

- The mechanical efficiency considers only the external losses.

D. Overall Efficiency: (Often referred to as 'efficiency'):

$$For \ \ working \ \ machines \ \ :$$

$$\eta = \frac{\rho VY}{N} = \frac{\rho VY}{N_i}\frac{N_i}{N} = \eta_i \eta_m$$

$$For \ \ power \ \ machines \ \ :$$

$$\eta = \frac{N}{\rho VY} = \frac{N_i}{\rho VY}\frac{N}{N_i} = \eta_i \eta_m$$

- The overall efficiency which includes all internal and external losses can be determined by test.