5/4/19

MODULE - 4.

CENTRIFUGAL COMPRESSOR

In the centrifugal compressor energy is transfered by dynamic means from a rotating member [impeller] to the continuously flowing working fluid. The main feauture of the centrifugal compressor is that, the angular momentum of the fluid flowing through the impeller is increased partly by virtue of the impeller outlet diameter which is significantly larger than its inlet diameter.

The centrifugal compressors are not generally used in gas turbain powerplants, this is because the specific fuel consumption [SFC] is a majour criteria. The advantages of centrifugal compressor include;

(i) It occupy a smaller length than the equivalent ~~(ii)~~ axial flow compressor.

(ii) It is not so liable to loss of perform by build up of deposites on the surface of air channels.

(iii) It can work reasonably well in a contaminated atmosphere compared to axial flow compressor.

(iv) It is able to operate efficiently over a wide range of mass flow rate at any perticular rotational speed.

The wide range of mass flow rate matches a wide range of operating conditions of the turbine which makes the centrifugal compressor more attractive than the axial flow compressors. A pressure ratio of the order of 4:1 can be obtained from a single stage centrifugal compressor. The centrifugal compressor is less suitable when the cycle pressure ratio requires the use of the more the one stage in series because of the path the air must flow between the stages.

* Parts of a Centrifugal Compressor:

The essential parts of a centrifugal compressor is as listed below

6/9/19

(1) The inlet casing with converging nozzle:-

The function is to accelarate the fluid to the impeller inlet, the outlet of the inlet casing is refered as 'eye'

(2) The impeller:-

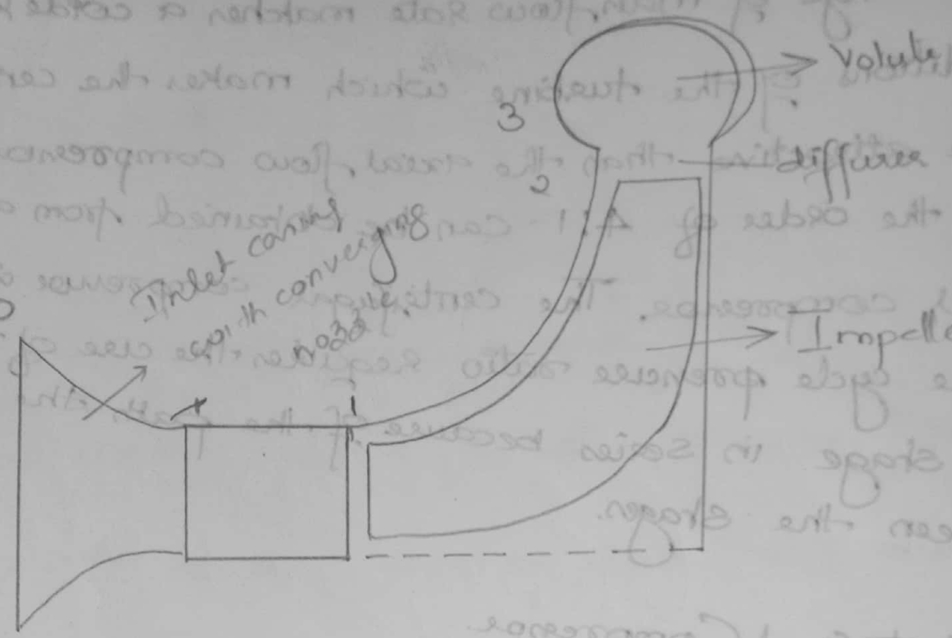
In the impeller the energy transfer takes place which results in an increase in kinetic energy.

(3) The diffuser:-

Whose function is to transform the high kinetic energy of the fluid at the impeller outlet into static pressure rise.

(4) The outlet Casing:-

Which consists of a fluid collector which is refered as 'volute'



The centrifugal compressor has two parts of energy transformt?

(i) The rotating impeller which imparts a high velocity to the fluid and at the same time increases its static pressure. The impellers are housed inside a stationary casing.

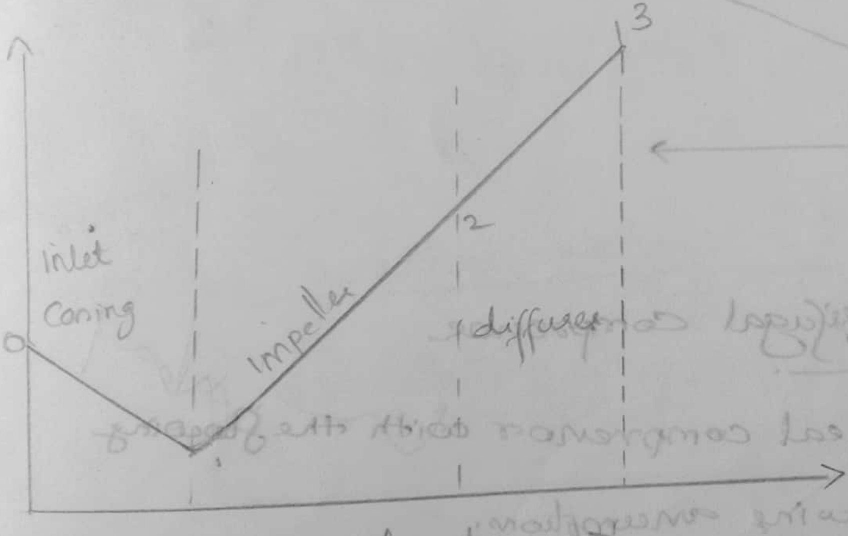
(2) A number of fixed diverging passages in which the air is deccelarated which futher increases the static pressure.

* Principle of Operation of Centrifugal compressor

The air is sucked into the impeller eye through an accelarating nozzle and is whirled at high speed by the vanes on the impeller ~~blade~~ disc. At any point the flow experiences a centripetal accelaration. Hence the static pressure of the air increases from impeller eye to the tip, the reminder of the static pressure rise is obtained in the diffuser.

It may be noted that air enters the impeller eye with a very high velocity. The friction in the diffuser will cause some losses in stagnation pressure. Generally the compressor is designed such that 50% of the pressure rise occurs in the impeller and the balance 50% occurs in the diffuser. On the impeller there will be slightly higher static pressure rise in the forward face of the vane than at the trailing phase, this pressure differential will make the air to flow around the space between the impeller and the casing. This naturally results in a loss of efficiency, therefore the clearance must be kept as small as possible to reduce such losses.

As far as possible the pre-whirl should be avoided in order to achieve maximum energy transfer. The contribution of each component of the centrifugal compressor in producing the pressure rise in a stage is as shown in the figure.



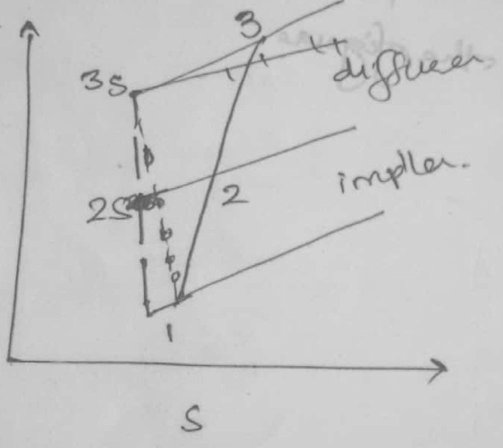
The inlet casing with accelerating nozzle directs the airflow into the impeller eye or inducer. Since the velocity of the air increases as it approaches the eye, as seen in the figure from 0 to 1. In the impeller the vanes imparts a swirling motion to the air which leaves the impeller tip at a high velocity. The energy transfer takesplace in the impeller and the static pressure

of the air also increases as shown in the graph from 1→2.
The purpose of the diffuser (vaned or vaneless) is to convert the high velocity of the air leaving the impeller into static pressure rise, it can be seen in the graph 2→3. The collector or the volute collects the air from the circumference of the diffuser and delivers the air to a single or multi exit ducts.
Sometimes a small amount of further diffusion may occur in the collector (hence it is referred as a volute).

8/08/19

* Enthalpy - Entropy (h-s) diagram of a CFC :

T-s also same fig



* Work input in a centrifugal compressor

Let us consider an ideal compressor ~~with the flowing~~ ~~assumptions~~ with the following assumptions.

1) Losses due to friction are negligible.

2) Energy loss or gain due to heat transfer is considered small.

3) The fluid leaves the impeller with a tangential velocity equal to that of impeller velocity (u) ie no slip condition

assumed

(4) The air enters the impeller from the atmosphere without any tangential component [$C_{T_1} = 0$]

The maximum work capacity of a radial vaned centrifugal compressor for an ideal operation is expressed below,

$$W = h_{02} - h_{01}.$$

the above equation is represented in term of stagnation enthalpy difference. In term of static enthalpy we can write,

$$W = h_2 - h_1$$

$$h = C_p T$$

$$W = C_p (T_2 - T_1)$$

$$W = C_p T_1 (T_2/T_1 - 1)$$

~~In term of~~ From isentropic relation we've, $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$

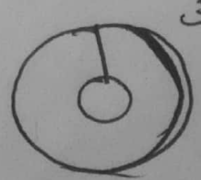
$$\boxed{W = C_p T_1 \left[\left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} - 1\right]}$$

* Vane shape & Velocity triangles.

The impeller in a centrifugal compressor can have 3 arrangements as shown in the figure;

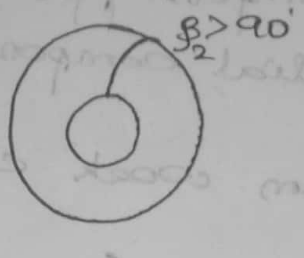
1) Radially curved ~~blade~~ vane

$\beta_2 = 90$

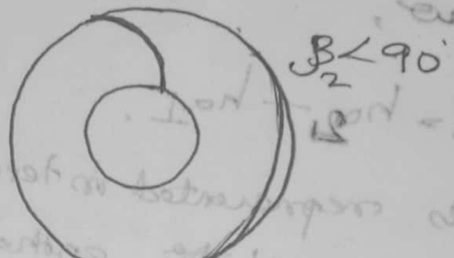


(2)

(2) forward curved vane

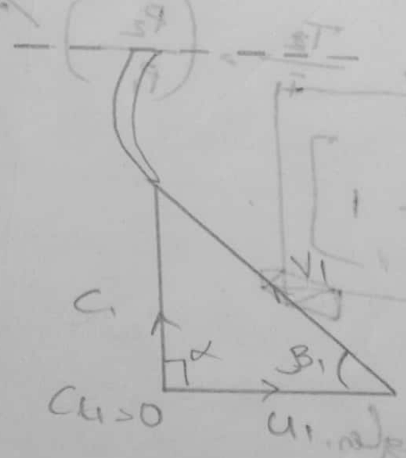


(3) Backward curved vane

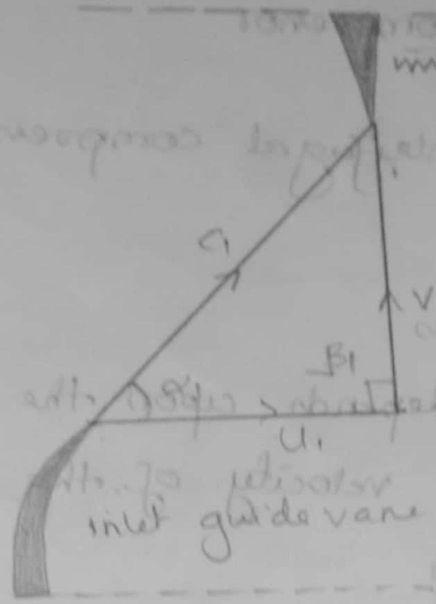


$\Longrightarrow$ Entry velocity triangle

The figure (a) shows the flow at the entry impeller without inlet guide vanes. The figure (b) shows the flow at the entry of the impeller with inlet guide vanes

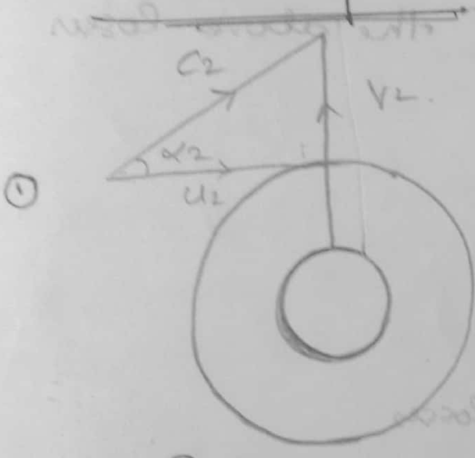


(a) without IGV

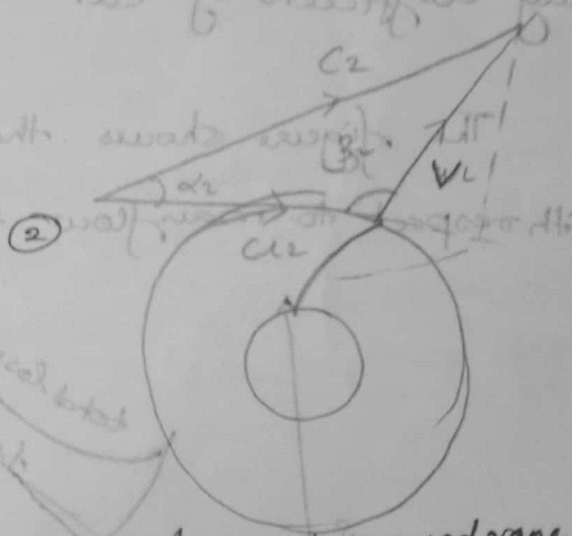


(b) with IGV

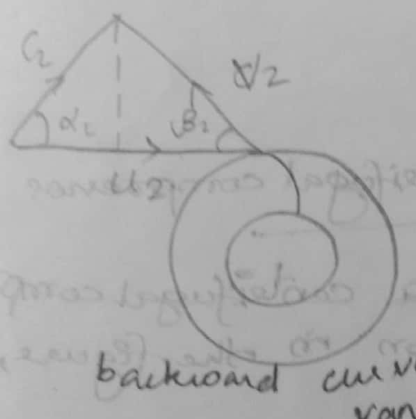
⇒ Exit velocity triangle

① 

Radial vane

② 

forward curved vane



backward curved vane

1/7/19

* Losses in centrifugal compressor

The total losses in a centrifugal compressor can be divided into two groups,

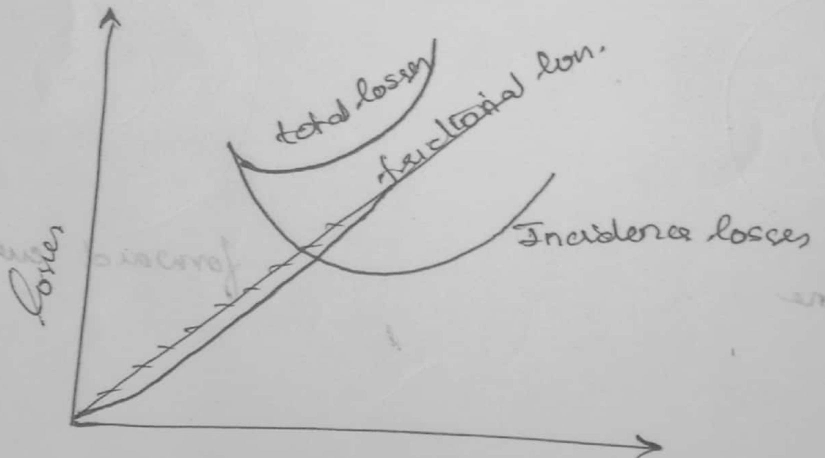
(1) Frictional losses

This losses depends upon the mass flow rate and the ~~op~~ absolute velocity of the flow.

(2) Incidence losses

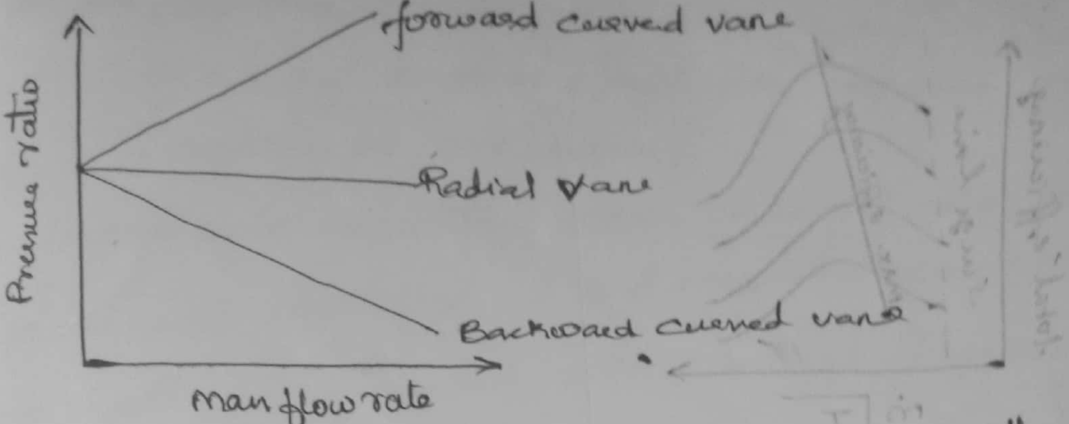
This losses are generally expressed in terms of drag coefficient of Cd.

The figure shows the variation of the above losses with respect to mass flow rate.

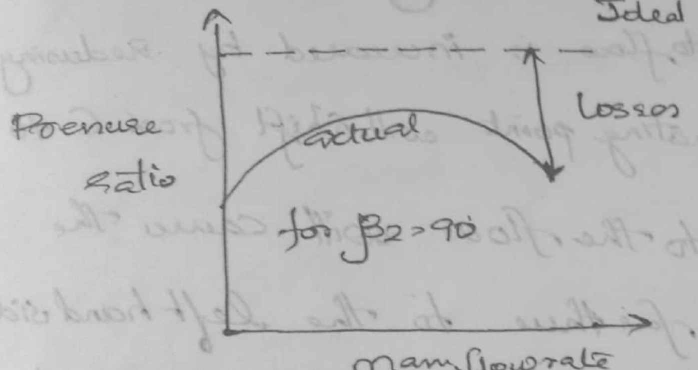


* Performance characteristics of a centrifugal compressor

The ideal performance characteristics of a centrifugal compressor for a radial vane impeller is as shown in the figure,



Now considering the losses in a centrifugal compressor the ideal and actual performance curve of can be shown as below

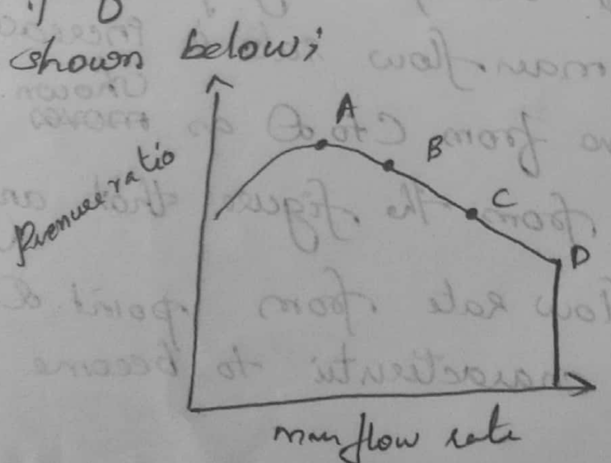


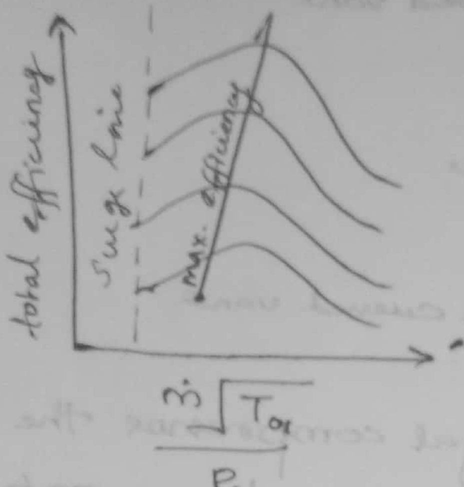
It can be seen from the figure that, the actual performance characteristic of a centrifugal compressor (radial vaned impeller) becomes curved, due to the losses present in the machined and the maximum pressure ratio is obtained, for a particular mass flow rate.

➡ Surging & Choking

The performance characteristics of a centrifugal compressor for at a particular speed is shown below.

Now the performance characteristics can be drawn, for various speeds as shown below;





If the centrifugal compressor is running at point C as shown in the figure, if the resistance to flow is increased by reducing the mass flow rate then, the operating point will shift from C to B. Any further restriction to the flow will cause the operating point to shift further to the left hand side & will attain a point A as shown in the figure. At this point the maximum pressure ratio is obtained. If the flow is further reduced from this point, then the compressor cannot increase the pressure ratio and therefore it starts to reduce the pressure ratio.

At this moment, it may result in a complete reduction of the flow and the flow may reverse its direction. After a short interval of time the compressor again starts to deliver the fluid and the operating point shift to point C again. If the mass flow rate is increased the point of operation will move from C to D as shown in the figure. It can be seen from the figure that any further increase in the mass flow rate from point D will cause the compressor characteristic to become vertical.

The point ~~B~~ D on the characteristic curve is defined as ~~chocking~~ chocking point. Thus the chocking keeps a limitation in the mass flow rate of the ~~ce~~ centrifugal compressor.

If the downstream conditions are changed then the operation point will shift from B and moves towards A. and then cycle will be repeated with a high frequency. The This phenomenon is refered as surging or pumping.

Other graph shows the variation of total head efficiency V/s mass flow rate (non dimensional mass flow rate) for various operations speeds. The locus of all the point representing the surging is refered as surgeline. The locus of all the points having maximum efficiency for different speeds are joined to obtain a line of maximum efficiency line.

Scanned by CamScanner

10-4-2019. Module-4

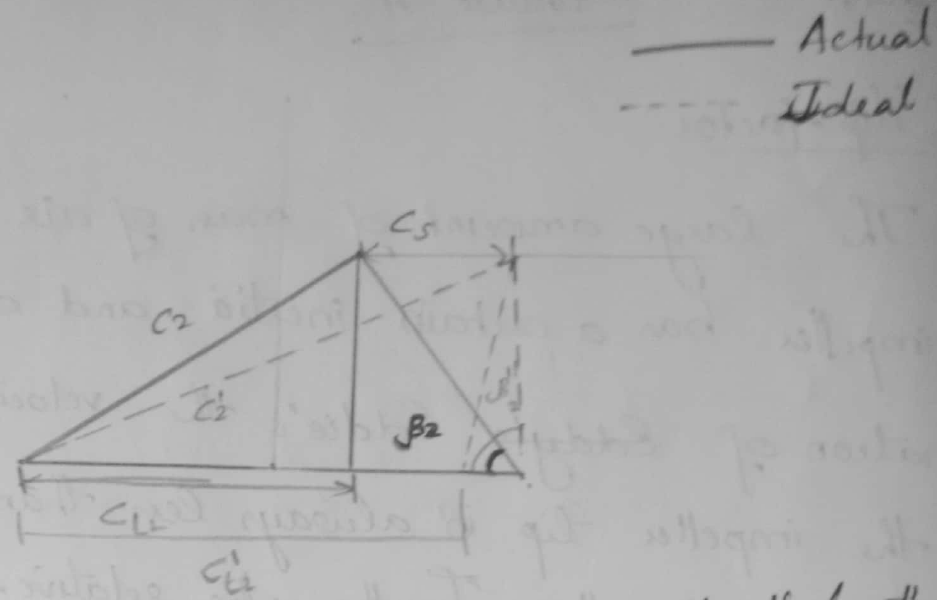
* Slip factor

The large amount of mass of air flowing through the impeller has a certain inertia and due to the formation of ~~Eddy's~~ Eddie's the velocity of the air at the impeller lip is always less than the rotational speed of the impeller. Further the relative flow through the impeller is not perfectly guide and is deflected away from the direction of rotation of the impeller.

The resultant velocity triangle at the impeller outlet is as shown in the figure. It can be seen that the actual tangential component of the absolute velocity (C_{t2}) of the fluid is less than that of the ideal value (C'_{t2}). The ideal value will be obtained if the fluid leaves the impeller at an angle β'_2. The difference between the values of ideal and actual tangential components is refered as slip velocity (C_s) and it can be given by the expression

$$C_s = C'_{t2} - C_{t2}$$

Thus it can be seen that the actual energy transfer in the impeller is less than the ideal value, this is because the fluid is not perfectly guided by the impeller vanes.

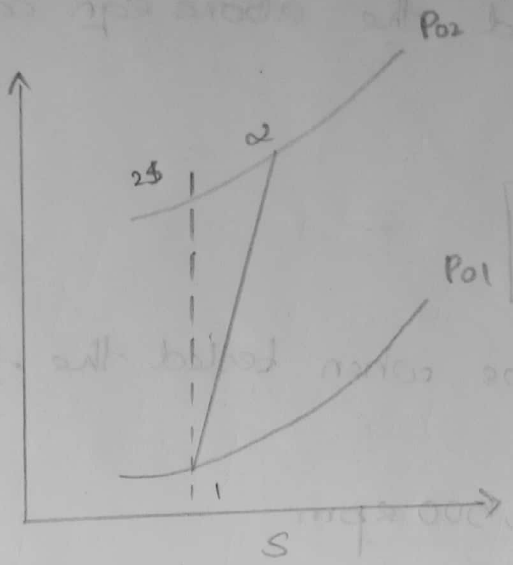


It can be seen from the velocity triangle that the ~~effects~~ apex of the actual velocity triangle at the impeller exit is shifted away from the apex of the ideal velocity triangle. This phenomenon is refered as **slip** and the shift of the apex is slip velocity 'C_s'. The ratio of the actual and ideal values of the tangential compoent of absolute velocity at the impeller exit is refered as slip factor and it is given by,

$$\boxed{\mu = \frac{C_{t2}}{C_{t2}'}}$$

* Efficiency of a centrifugal compressor.

The efficiency of a centrifugal compressor can be expressed in terms of the ideal and actual enthalpy changes.



$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$\eta_c = \frac{T_1\left(\frac{T_2}{T_1} - 1\right)}{T_2 - T_1}$$

from isentropic relation,

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma - 1/\gamma}$$

$r_p \rightarrow$ is the pressure ratio.

$$\frac{P_2}{P_1} = r_p$$

$$\boxed{\eta_c = \frac{T_1\left[r_p^{\gamma - 1/\gamma} - 1\right]}{T_2 - T_1}}$$

* Relation between work input and rotational speed of the impeller

$$\boxed{W = u^2}$$

If the slip factor mentioned the above eqn can be written as,

$$\boxed{W = \mu u^2}$$

(1) A centrifugal compressor when tested the following datas are obtained,

Speed = 11,500 rpm

inlet total head temperature

= 21°C

outlet and inlet total head pressure

= 4 bar & 1 bar respectively

Impeller diameter = 75cm

If the slip factor is 0.92 what is the compressor efficiency