**Steam and Gas Power Systems**
**Prof. Ravi Kumar**
**Department of Mechanical Industrial Engineering**

**Indian Institute of Technology - Roorkee**
**Module No # 08**
**Lecture No # 37**
**Axial Flow Compressor**

I welcome you all in this course on steam and gas power systems today we shall start with Axial Flow Compressors. In the previous lecture we discussed the centrifugal compressor.

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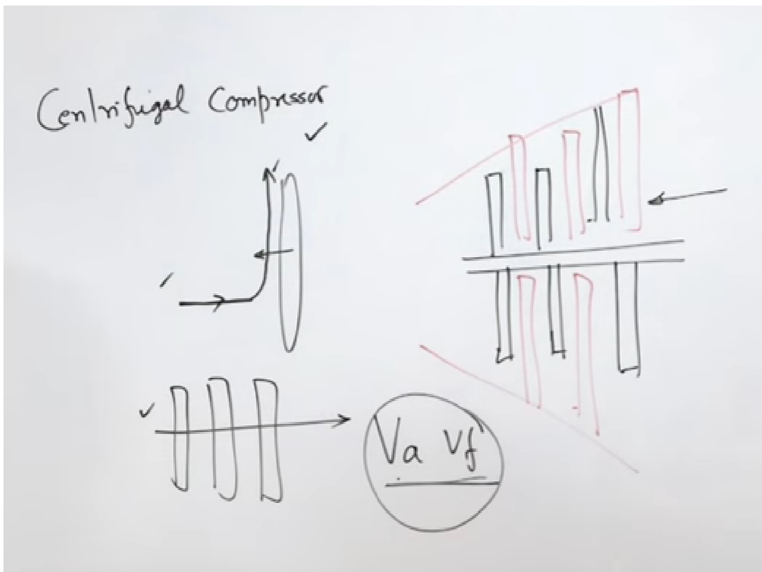


In centrifugal compressor, the fluid was entering along the shaft. There was an axial entry of the fluid or air and exit was radial. It was entering the compressor, there was an impeller, imparting energy or doing work on the incoming air and then air was compressed and finally, we got high pressure gas or air at the exit of the compressor. Now in axial flow compressor, the movement of the fluid is only in axial direction.

That is why because there is no change in direction that is why the efficiency of axial compressor is more than the centrifugal compressor. In axial compressor also like axial flow turbines, we have done the impulse turbine and impulse reaction turbine like that in axial flow compressor also there is several rings on stages each stage consists of fixed blades and moving blades.

So arrangement is like this only, there is a shaft on the blade are mounted and there are moving blades there are fixed blades also which are mounted in the casing this are fixed blades. So now in this case the energy is consumed by the compressor moves with the help of a motor the shaft rotates in a certain speed, air is sucked in and its gas compressed when it exits from the other end.

So air enters from here right, it will go from first stage, second stage, third stage it is shown converging because we have to maintain constant axial velocity. It is VA or VF, for designing the compressor. For the purpose of design of the compressor, this velocity has to remain constant. This direction the pressure is increasing, when the pressure is increasing velocity has to remain constant, will have to reduce the cross section area or size of the compressor.

That is why it is known to shown as converging passage right, it has number of the stages. Stages may go up to 18, 20, and 25. In this compressor if we look at the stages different stages, let us examine one stage of axial flow compressor.

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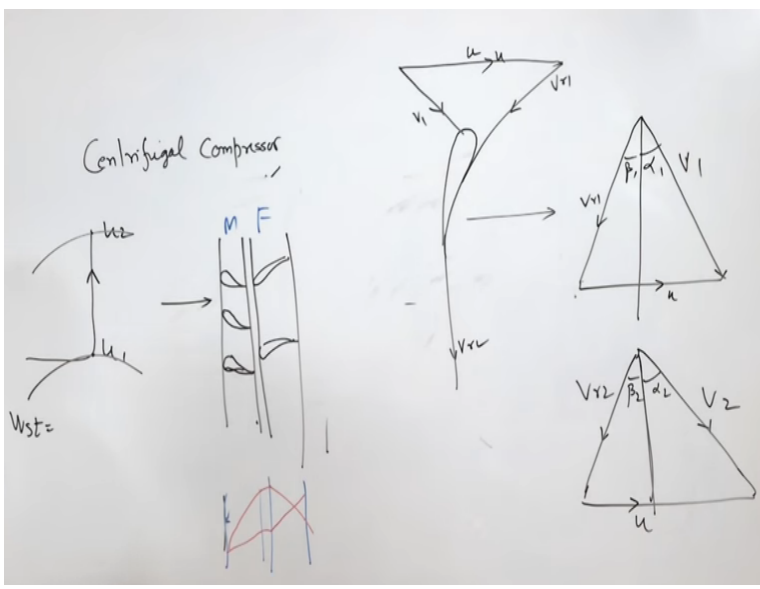


So each stage has fixed blade and the moving blades. Suppose there is a fixed blade like this and then there is small gap between these two and then there is a moving blade. So there number of fixed blades and there is a number of moving blades and they have mounted on the shaft, the shaft is parallel to this board and it rotates with a certain rotational speed. And the air moves in this direction axial flow direction.

Now in this compressor like impulse turbine, if it works as an impulse turbine then there is no pressure rise in moving blades. There is only pressure rise in fixed blades it works as a impulse turbine. That is in fix, these are fixed blades they are moving blades. Regarding velocity there will definitely increase in moving blades because the kinetic energy will be imparted to the moving air and these acts as a diffuser so velocity gets reduced.

But normally the axial flow compressors they work as reverse of impulse reaction turbine not impulse reaction turbine reverse of that. So here the pressure there is a pressure rise, if we see the pressure rise so there is pressure rise in moving blades and fixed blade as well and regarding the velocity the velocity increases in moving blades and it falls in fixed blade. Now first of all we will what will do will draw a velocity diagram for axial flow turbine then that will make things clearer.

So there is a blade in a axial compressor not turbine axial flow compressor velocity diagram for an axial flow compressor, the air is supposed to glide over the surface right. When the blade is moving in this direction, air is supposed to glide over the surface so this is VR1 right and the blade is moving with certain velocity in this direction. So it is U, here we do not have V1 and V2 in centrifugal compressor because the radial flow.

So we had U1 and U2 different peripheral velocity at the impeller. This inner diameter of the impeller and the outer diameter of the impeller because flow is taking place in axial direction. So there is only one peripheral velocity that is U and this is the absolute velocity of air through which it will be entering the blade. So in axial flow turbines the angles are the axis taken in the shaft axis is taken as a reference.

In earlier in I mean in the reaction turbine or impulse reaction turbine, the peripheral direction of the peripheral velocity was taken as a plane of reference right. Here axial flow, axial direction is taken as plane of reference. So axial direction, when we take as a plane of reference then this becomes V1 right and this is VR1 velocity U is this and is the velocity U is perpendicular to the axis of the shaft.

Now this is V1, this is VR1 this is U, so this is angle alpha 1, this is angle beta one regarding exit. Also regarding exit also the triangles are like this because this is VR2 right. So regarding axis also this is V2 and this is VR2. This is alpha 2 and this is beta 2 and this is U and this is V1, V2. Now here in axial flow compressor, there is one more thing to discuss the work in a stage, is equal to axial flow compressors.

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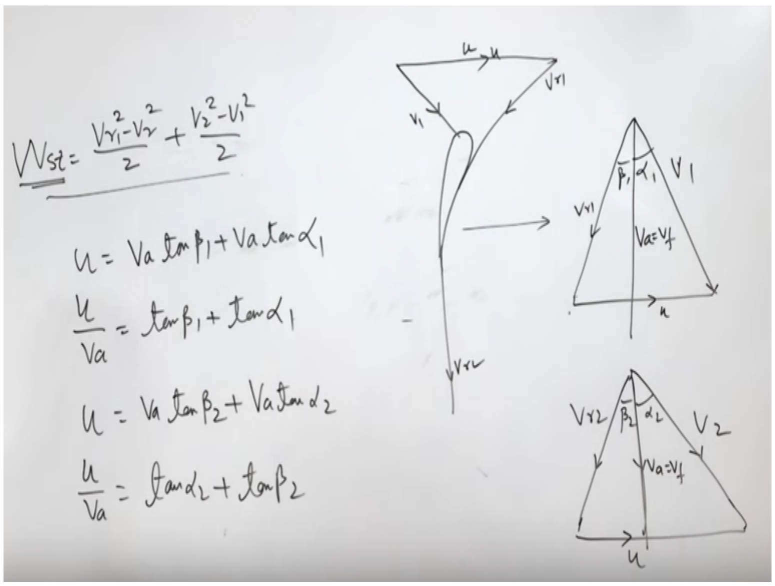

The work in a stage = VR1 square - VR2 square divide by 2 + V2 square - V1 square divide by 2, here peripheral velocity component is missing because there is nothing like U1 and U2. There is only one constant peripheral velocity so energy imparted to the fluid by virtue of changing peripheral velocity is 0. So if we look at this then per stage work in axial flow system we can say is less than the per stage work in centrifugal compressors.

Now here this is axial velocity VA or it is velocity of flow also VA velocity of flow right. So U is equal to, if we take these two triangles then U = VA Tan Beta 1 + VA Tan Beta 2 or we can say U by VA = Tan Beta 1 + Tan Beta 2. Similarly for this triangle U = Beta 1 and Alpha 1 this is Alpha 1 not Tan Alpha 1. Now in this triangle VA Tan Beta 1, Beta 2 + VA Tan Alpha 2.

So again we can take U by VA tan alpha 2 + tan beta 2 or we can say that these two if we compare these two then tan alpha 1 + tan beta 1 = tan alpha 2 + tan beta 2. So this relation is frequently used in analyses of axial flow compressors now we will calculate the tangential force required to compress the gas.

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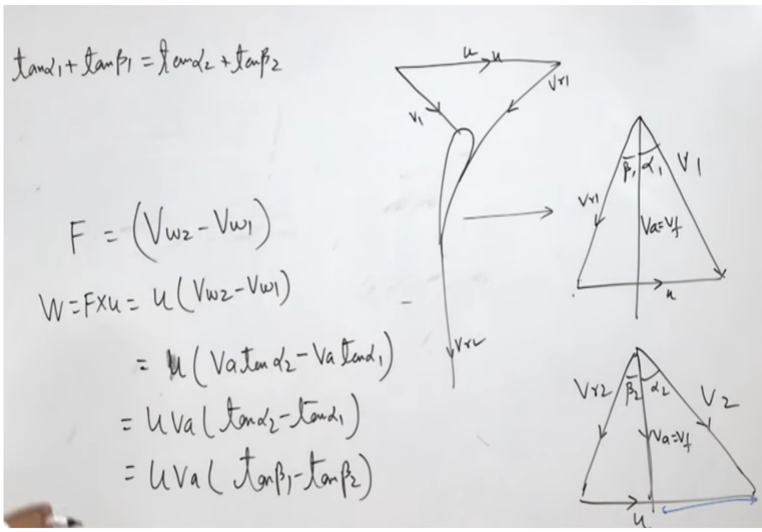


Tangential force is VW2 - VW1 for the mass flow rate of one kg per second, otherwise it will be multiplied by the mass flow rate. Also and then work is F into U = UVW 2 – VW1 and VW2 is will component at angle. This 1 VW2 = VA so U is there VA Tan Alpha 2, VA is axial velocity - VA Tan alpha 1, and then we can say it is UVA Tan Alpha 2 - Tan Alpha 1.

If we use this analyzation then work is UVA Alpha 1 - Tan Alpha 2 - Tan Alpha one Tan Beta 1 - Tan Beta 2. So either of these expressions can be used for finding out work done on the gas or air during compression in an axial flow compressor. Now temperature change in a stage because in compressor normally we have to find the temperatures and different stages.

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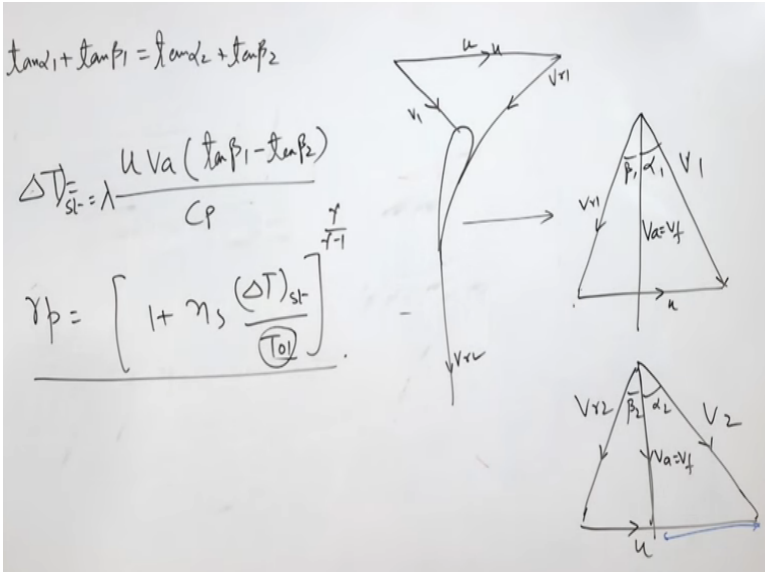

So temperature change in a stage Del T = we will take the work Tan Beta 1 -, let us say Tan Beta 2, and Delta T per stage is CP Delta T. So divided by CP that will give the change in temperature in a stage, there is a expression we will discuss it later on, that is work done factor it will be multiplied by then you want to have a actual temperature rise. It will multiplied by the work done factor and if you want to have pressure ratio in the stage that is going to be 1 + (()) (15:03) of the stage.

Delta T stage divided by TO 1 gamma over gamma - 1 T1 we have taken stagnation temperature at inlet because we have consider the kinetic energy also. So when we consider the kinetic energy is converted into the pressure energy so this will result in the raise in temperature. So this is the expression for pressure ratio in a stage now we will do the pressure raise, so what we have calculated done so far.

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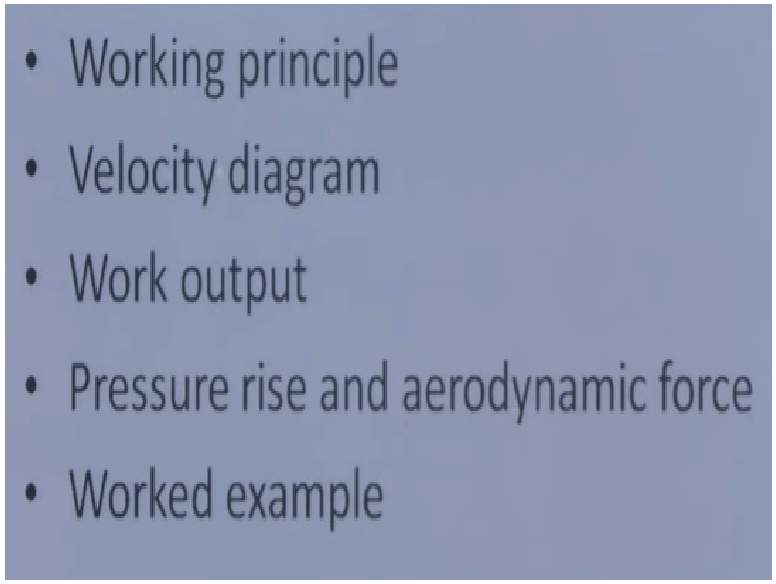


We have just discussed the working principle, we have discussed the velocity diagram, we have discussed the work output. Now pressure rise in aerodynamic force in a stage of axial flow compressor.

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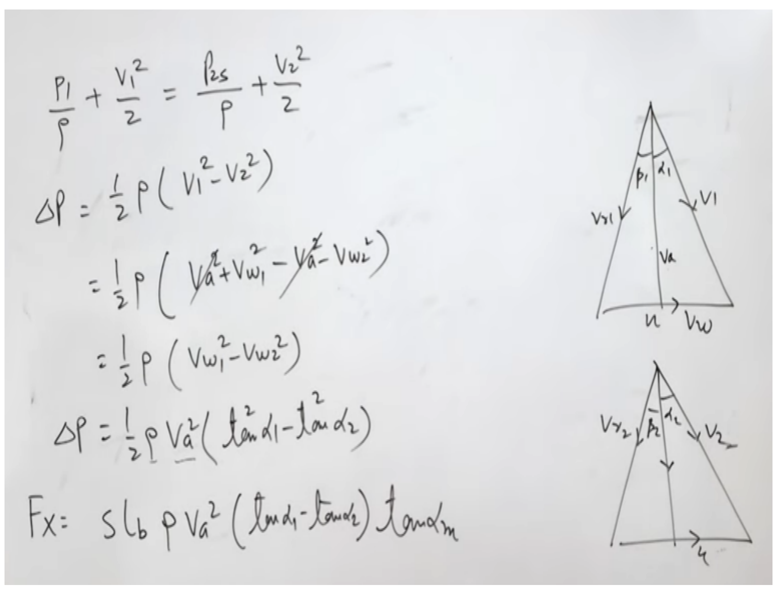


So we will start with Bernoulli's theorem, P1 by Rho = V1 square by 2 = P2 stage divided by Rho + V2 square by 2 because it is moving in horizontal direction prudentially production energy is 0. So Delta P is half Rho V1 square - V2 square Delta P.

This minus this = half Rho V1 square – V2 square = half Rho,  now if you draw again this diagram this is V1 VR 1 U Beta 1 alpha 1, So ash this is VW and this is VA. So it is V one is V A square + VW square in same fashion, if we take into account this diagram Alpha 2 Beta 2 VR2 V2 and U. Here also the V2 square is VA square - VW square and then this will be cancelled out it is going to be half Rho.

VW 1 square - VW2 square or it is half Rho VA square and the VW is nothing but VA Tan Alpha 1. So Tan square Alpha 1 - Tan square Alpha 2. So only axial velocity is with us and density is with us. We can find the pressure rise in this stage, so axial force now once we have the pressure rise pressure multiplied by area will give the force.

So axial force is SLB is the length of the blade Rho VA square Tan Alpha 1 - Tan Alpha 2 Tan Alpha 1 + Tan Alpha 2 divided by 2 or this is mean blade angle Alpha 1 Tan Alpha one plus Tan Alpha 1. So we can replace this by Tan Alpha M it is not the angle of mean of the angle but mean of the Tans of the angle so this is axial force. Now the compressor will also experience.

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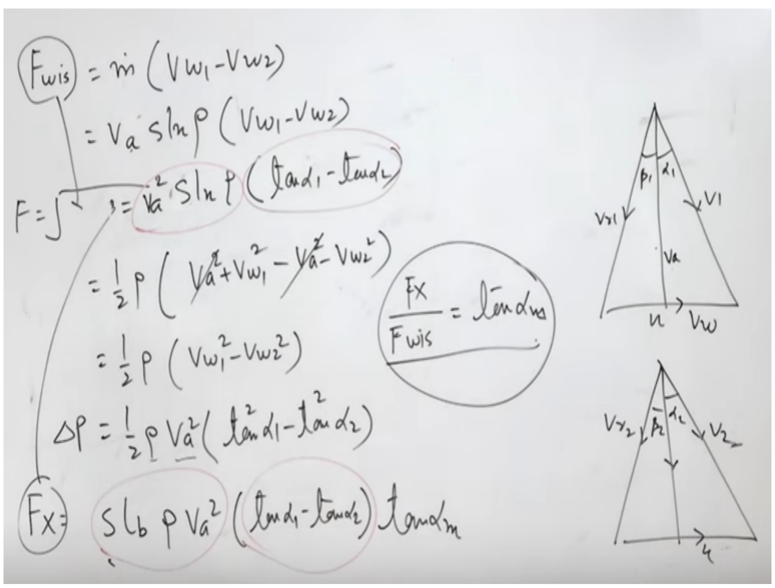

The willing force which is perpendicular to this one sorry this is an compressor, so compressor will have the force will be exerted in the axial direction force will also be exerted in willing direction and that force is mass flow rate multiplied by VW 1 – VW2 and that is V F S L N Rho. This is volume, this is density VW1 - VW2 and the net energy consumed by the axial flow compressor will be Pythagorean sum of this means net force.

It is going to be equal to under root this force square of this plus square of this and the direction of the force will be the ratio of these two and that is going to be, this FX divided by F W S I F X divided by FWIS and that is going to be = Tan Alpha M because these terms will be cancelled out this is VA. So these terms will be cancelled out and we will be getting the ratio of these two as Tan Alpha M.

Now before dividing it we can write VF or VA square S length of the blade, Rho VW 1 is the V1 that is why square has come here. This is Tan alpha 1 - Tan Alpha 2 now they will be cancelled, now if we take the ratio of this and in order to find the direction then we will get all this terms. They will be cancelled out and this will also be cancelled out and what we are going to get is Tan Alpha M.

So we have calculated work force required in a axial direction to compress the gas force required in the peripheral direction. This is the force in axial direction, this is the force in peripheral direction and then Pythagorean sum of these two forces will give the net force required for compressing the gas and there ratio will give the direction right. Now we will solve one worked example of axial flow compressors.

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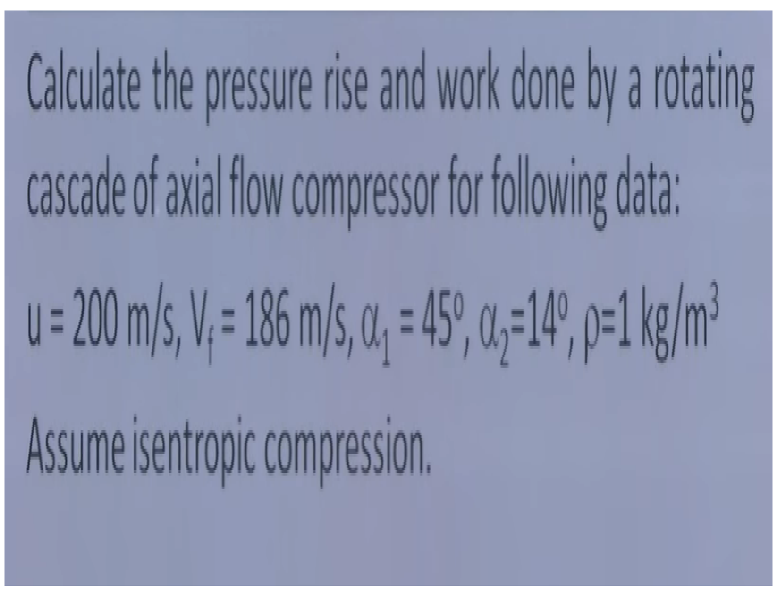


Calculate the pressure rise and work done by rotating cascade of axial flow compressor for following data peripheral velocity 200 meters per second flow, velocity is or V A axial velocity is

186 meter per second and Alpha 1 and Alpha 2 are given Rho = 1, that is density of air or working fluid assume isentropic compression.

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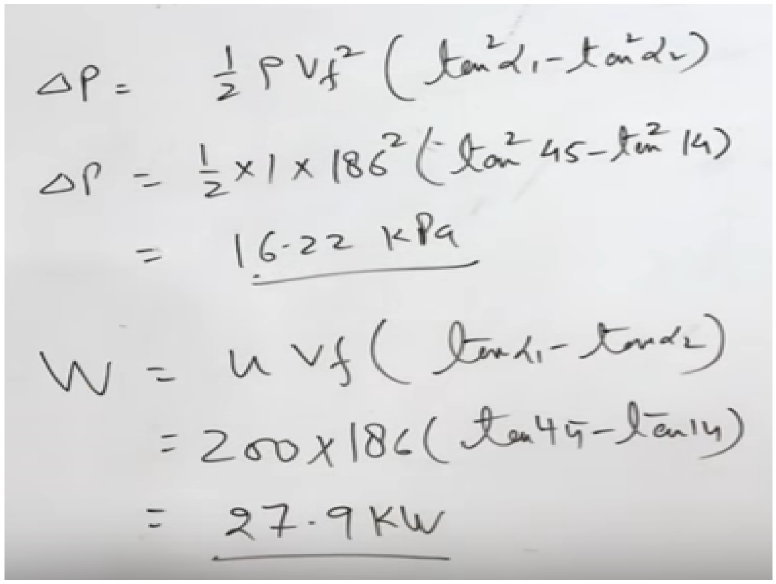


So Delta T pressure rise is half Rho PF square Tan square Alpha 1 - Tan square Alpha two we have already done that. Now here Delta P = half Rho is given here one velocity of flow is 186 square Tan square Alpha 1 is 45 - Tan square Alpha 2 is fourteen and this case the pressure rise as 16.22 kilopascal that is the pressure rise.

Calculate the pressure rise at work done by rotating so work done is UVF tan alpha 1 - Tan Alpha 2. Simply we will put the values U is 200 meters per second, 200 - VF1 8645 - Tan 14 and this give will the work done as 25.9 kilowatt. This is the work or energy consumed by compressor in for the movement of air or for the compression of air and after this we will take another numerical which is a little lengthier.

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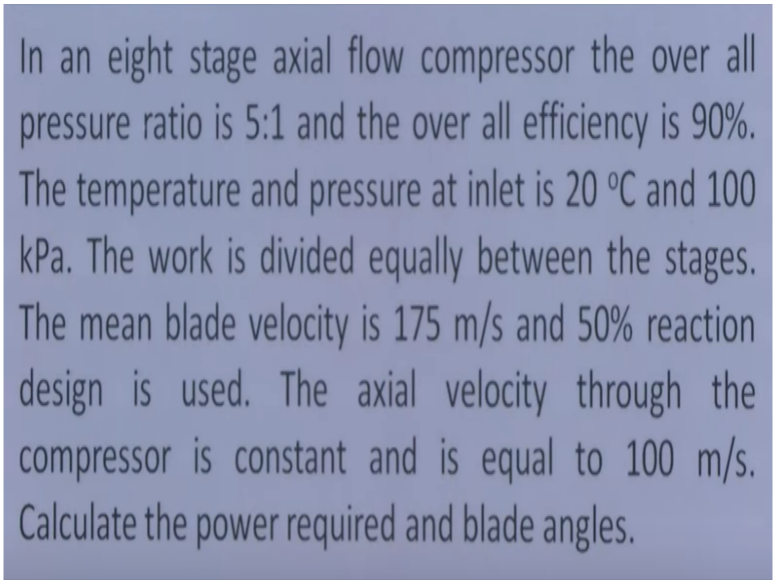


In eight stage axial flow compressor, so there is a axial flow compressor consisting of eight stages the overall pressure ratio is 5 is to 1. So compressor has number of stages right and cumulative effect of pressure rise is 5 is to 1 and the overall efficiency of the compressor is 90% the temperature and pressure at inlet will write down here. So that later on time is saved, so the temperature and pressure at the inlet.

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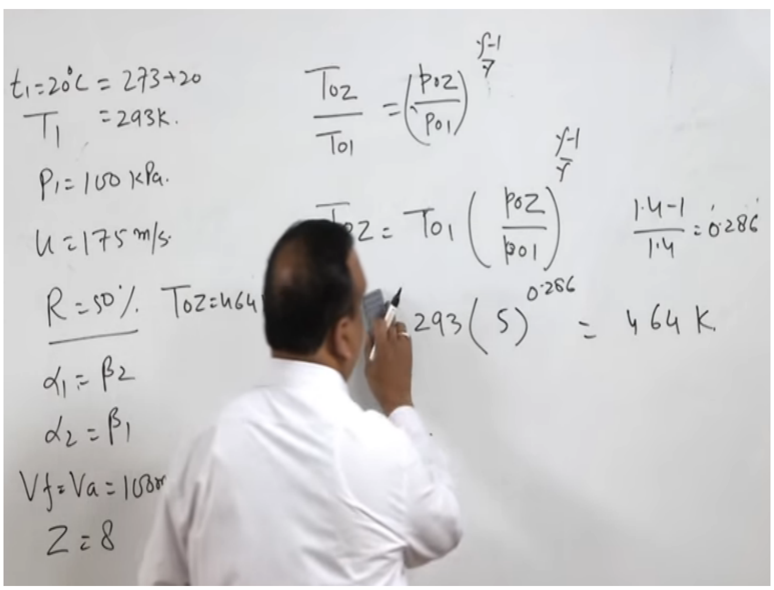


So T1 = 20 degree or 293 Kelvin we will just add 273, here 273 + 20 = 293 Kelvin that is T1 and 100 kilopascal pressure P1 = 100 kilopascal. The work is divided equally between the stage, so each stage on each stage same amount of work is being done on the gas. The mean blade velocity is 175 meters per second and 50%reaction design is used.

When there is a reaction is 50% then Alpha 1 = Beta 2 and Alpha 2 = Beta 1 as we did in the case of turbine, same thing will be done here. Also in axial flow compressor, if the degree of reaction is 50%. Then this nozzle inlet angle is equal to blade outlet angle and nozzle outlet angle is equal to blade inlet angle.

The axial velocity throughout the compressor is constant is equal to or VF = VA = 100 meters per second okay. So we assume that eight how many stages are there eight stages though Z is denoted by this stage. So Z = 8 there is a pressure rise in each stage and the temperature at the outlet of the compressor T O Z by TO 1 to Z means after the eighth stage that is POZ by PO 1 raise to power gamma - 1 over gamma.

If the compression index is not given we assume it to be Gamma. So T O Z = T O 1 P O Z by P O 1 raise to power Gamma minus over Gamma because index of compression is not given. We will assume it to be gamma = TO1 is 293 POZ by PO1 is 50.986 this Gamma = 1.41 - 1 divided by 1.4 = 0.286.

So directly we have put the values and the T O Z, we are getting 464 Kelvin. So T O Z 464 Kelvin and the compression is not isentropic because the efficiency is given is 90% overall efficiency is 90%.

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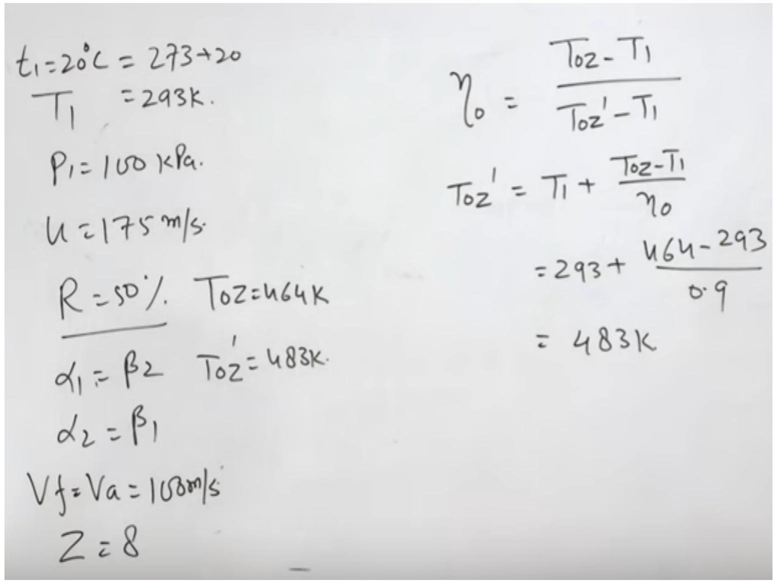


So = T OZ - T1 divided by TOZ dash – T1 TOZ dash = T1+ TOZ – T1 divided by T1 is 293 + TOZ. We have taken as 464 -293 divided by .9 and that gives TOZ as 483 Kelvin. So TOZ dash is 483 Kelvin same thing. We have done as we did earlier also.

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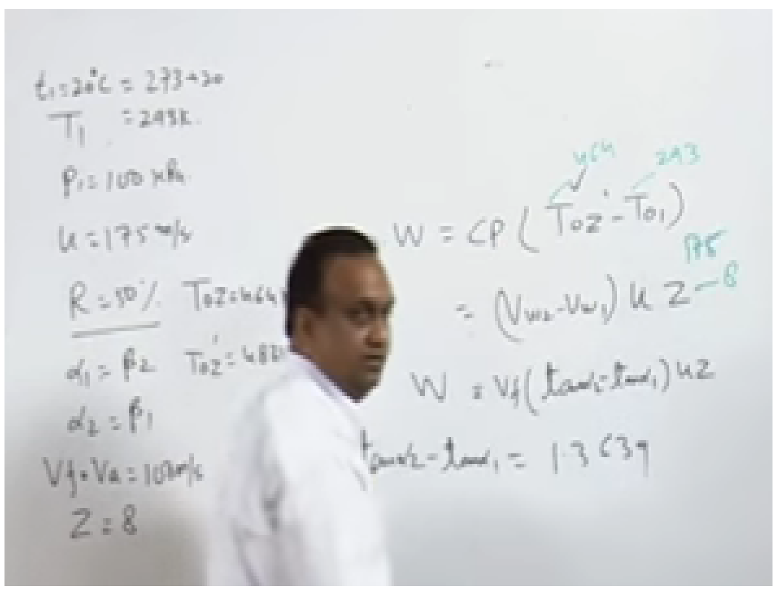


Now work is if we take as a thermodynamic process then work = CP, TOZ dash - TO1. This is the work done on the gas and this is equal to V W2 – VW1 multiplied by U that is one in one stage multiplied by number of stages. This is the work, this is not the work in the entire compressor because this will component is only for one stage. So this work multiplied by the peripheral velocity multiplied by the work number of stages.

This will give VF Tan Alpha1 - Tan Alpha 1 UZ okay. Now here we can get the value of Tan Alpha 2 - Tan Alpha 1 because this is = W. Now here we have the value of TOZ dash 483 Kelvin to 1293 Kelvin and U is also given 175 meters per second.

So this is 175 and this one is 474 and TO1 is 293 and this is equal to this one both are equal from here we will get the value of Tan Alpha 2 - Tan Alpha 1 and Tan Alpha 2 - Tan Alpha  is 1.3639 okay. That is equation one, and second and second third second one.

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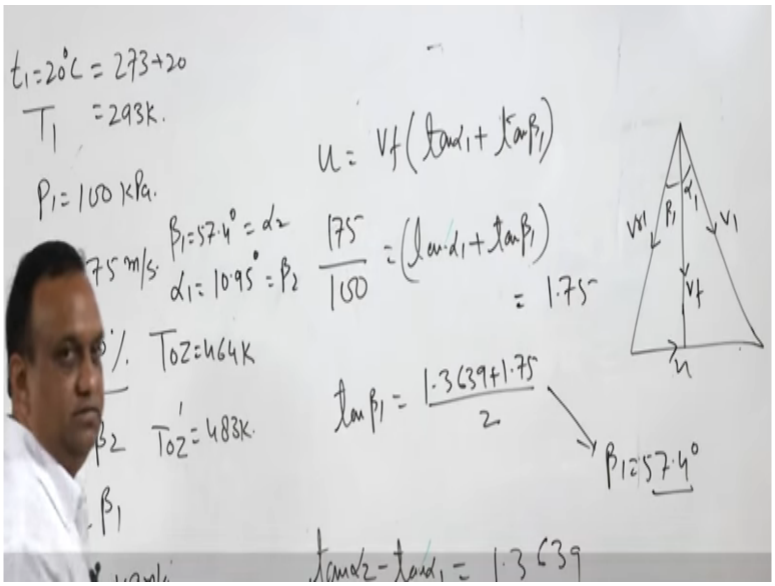

We know that U = VF Tan Alpha 1 + Tan Beta if you look at the velocity triangle Alpha 1 and this is Beta 1 and this is V1 VR1 and this is U. So U = this is VF. So U = VF Tan Alpha 1 + Tan Alpha 2 or U = 175 and VF is 100 = Tan Alpha 1 + Tan Beta 1 and this = Tan Alpha 1 + Tan Beta 1 = 1.75 by 100.

Now add these two you will get Tan Alpha 2 minus plus Tan Beta 1. So if you add these two this will be cancelled out if you add these two, then this will be cancelled out then Tan Beta 1 + Tan Alpha 2 and Beta 2 = Beta 1 = Alpha 2. So we can comfortably say that Tan Beta 1 = 1.3639 + 1.75 divided by 2 and from here we will get the value of Beta 1 and the Beta 1 is 57.4 degree. So Beta 1 is 57.4 degree.

Now once we have the value of Beta 1, we can either take the equation from either of the equation. We can calculate the value of which angle is required Kelvin power required blade angles. So Beta 1 is with us, we can calculate the value of Alpha 1 and once Alpha 1 Beta 1 are with us. We can find the value of Alpha 2 and Beta 2. So here the Alpha 1 is 10.95 degree it is = Beta 2 and this is equal to Alpha 2.

So all blade angles are known here that is all for today and in the next class we will start with the characteristics of axial flow compressors.