Introduction to Fluid Machines and Compressible Flow
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Lecture - 25
Axial Flow Compressor Part II

Good morning and welcome you all to this session of the course. Now, today will be solving some problems relating to axial compressor, last class we will discussed in brief the principle of operation and the degree of reaction of an axial compressor. Now, today we will see that how we can solve problems this use an understanding becomes much better. Now, let us concentrate on one problem.

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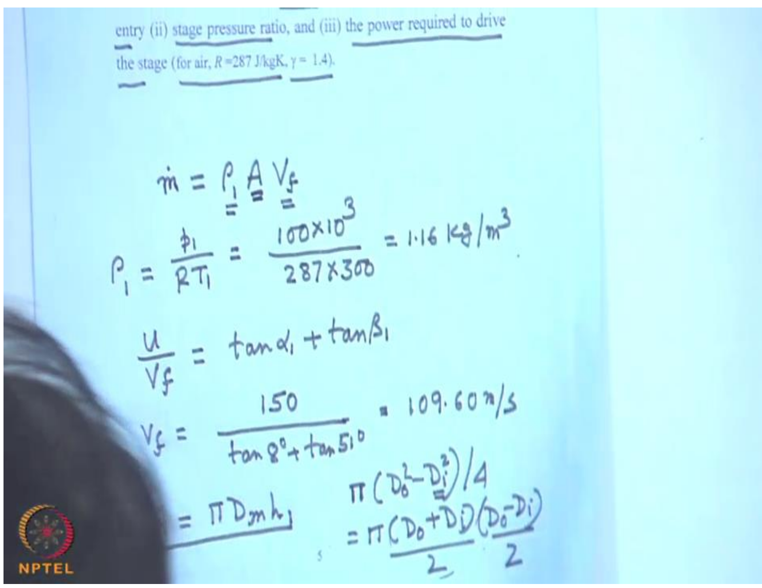

This is the problem number one, which will be solving the conditions of air, let me read out the problem first, the conditions of the air at the entry of an axial flow compressor stage are p 1 giving the inlet pressure and temperature is given. The air angles are beta 1, so these naminculture is known to us this is the blade angle at inlet and beta 2 the blade angle at the outlet that is the root of blade angles at the inlet and outlet that is 51 degree both are 51 degree. And alpha 1 is alpha 2 is 8 degree this is giving the alpha 1 at the angle the absolute velocity at the inlet and the alpha 2 is the angle of the absolute velocity at the outlet of the rooter blade. The mean diameter and peripheral speed are 0.5 meter, this is the mean diameter and this is the peripheral speed respectively, that means; the peripheral speed at the mean diameter. The mass flow rate through this stage is 30 kg per second, the work done factor is 0.95 all these things are known to us mechanical efficiency is 90 percent.

Assuming an isentropic stage efficiency of 85 percent, what have to be found out, we have to be find out blade height at entry stage pressure ratio and the power required to drive the stage this is given for air the characteristic gas constant 287 joule per kg k and the ratio of specific heat 1.4. Now, sorry, to find out the blade height at entry first of all we have to understand that it is the geometric blade height, which is basically related to the area at the inlet. So, therefore, if we write the equation of mass flow rate that think we can we have to select these equation to find this, we can right that rho 1 inlet density and the area at inlet and the velocity of flow, which is same throughout.

Now, here first of all we have to find out A rho 1, now eric with in A that is the anoles area the blade height is there, the blade height can be found out from the anoles area A. Now, let us find out rho 1, so rho 1 at the inlet can be found out from the equation of state as p 1 by R T 1 well, so p 1 is what? p 1 is given as 100 kilo Newton per meter square. So, therefore 100 into 10 Newton per meter square 100 kilo Newton into 10 to the power of 3. And if you write the value of R 287 and T is 300, we get the value of rho 1 and rho 1 comes out to be 1.16 kg per meter cube, alright, we get rho 1. How to get v f, the flow velocity is it given assuming in isentropic state air the flow velocity is not given but we can find out the flow velocity from the expression, we developed earlier that u by v f is what? Tan alpha 1 plus because, we choose this expression flow velocity is not given but beta 1 and alpha 1 is given so, that we can find out the flow velocity and u, what is u? u is given 150 meter per second so 150 divided by tan alpha 1 plus tan beta 1, that means; tan of 8 degree plus tan of 51 degree and if you solve for it, you will get a velocity 109.60 meter per second.

So, therefore, you can get the anoles area, but before that you put anoles area in terms of this blade height, anoles area is pi into the mean diameter into blade height true, where from does it come, it comes that anoles area is pi into outer diameter square minus inner diameter. If you consider the inner diameter as the diameter of the dram on disk and the outer diameter is the diameter of the casi then this is the anoles area this can be written as pi into D 0 plus D i sorry, by 4, D 0 plus D i by 2 and D 0 minus D i by 2. Now, it is this is the mean diameter D 0 plus D i by 2 and this is the blade height. So, therefore, this can be expressed in terms of the mean diameter and blade height that area.

So, therefore, now, if I substitute here, we can write m dot, m dot is given 30 kg per second is equal to rho 1 1.16 into v f, first I write v f, because I have found out v f 109.60 into pi, what is the D m? D m is given as 0.5 meter ok, 0.5 meter it is given. So, therefore, pi into 0.5 so only unknown is here blade height h, which gives h equals to rather h 1 the blade height at the inlet so I write h 1 blade height at the inlet so, h 1 is equals to 0.15 meter so, the first, but is over the h 1, blade height at entry. How to find out stage pressure ratio? Stage pressure ratio is simple to find out stage pressure ratio to find out, what you have to do? We have to find out this static temperature, the stagnation temperature ratio or this stagnation temperature difference otherwise you cannot find out the static pressure ratio.

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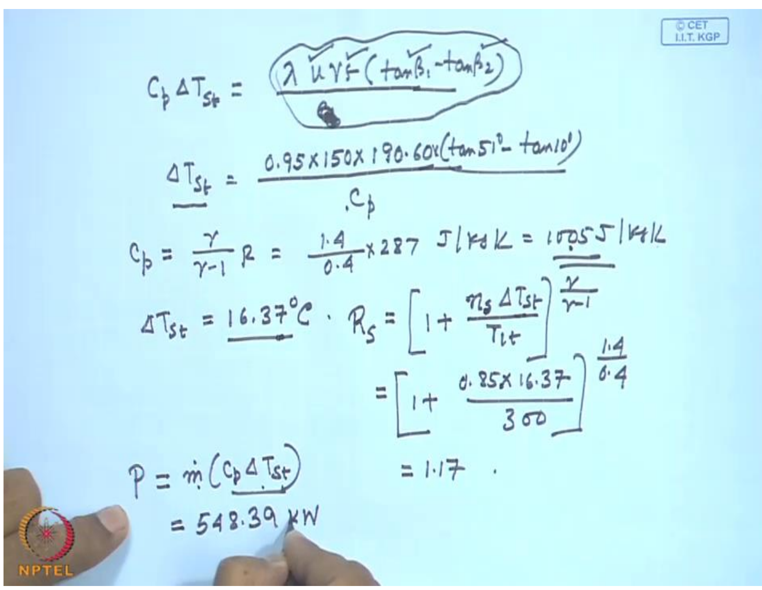

So, which one is know, now let us find out write this formula that C p into delta T s t that means; the stagnation temperature right is equal to today last class we have discussed that it is the work done factor into u v f by C p is always there, u v f into tan beta 1 minus tan, where from it comes, that this is the were done per unit mass, this equal to C p delta T s t. So, therefore, this is multiply with a work done factor, so here what we had? We have u, we have v f, we have beta 1, we have beta 2.

So, we can find out delta T s t, we can write this, what is the value of lambda here, lambda is 0.95 it is given well, then the u is 150 meter per second, v f we have calculated just now 190 I am sorry, v f is 109 know, v f is come out as 109 yes yes, v f is 109.60. So, this is lambda u into v f, v f is 190.60 that is the v f we are calculated and tan of into tan of 51 degree minus tan of 10 degree divided by C p. Now, C p value you can calculate here, here C p is not given even if it is not given you can take that in this problem gamma and characteristic gas constant is given, C p can be found out as gamma by gamma minus 1, that means; that 1.4 divided by 0.4 into 287 that is joule per k g k, that means; if you find out C p it will be 1005 joule per k g k, this is the standard value of C p for air.

So, C p then you can find out delta T s t and that becomes delta T s t becomes equals to if you calculate it, I tell you the value 16.37 degree Celsius. Then you can find out the pressure ratio or as I told that nomenclature and this is the formula again and again we tell this will be one plus the isentropic stage efficiency that is theta s with the isentropic stage efficiency delta this formula I have told in let temperature divided by gamma by gamma minus 1ok. So, this can be written as 1 plus this substituted the value substitute, which you can substitute the value delta T s t 16.37 divided by 300 and if you put the value of gamma then you get the value of the stage pressure ratio as 1.17.

Third one is that, what is the third one? The power required to drive the stage, power required is very simple, because this is the C p delta T s t, C p power required is what? Power per unit mass into the mass flow rate, mass flow rate into C p delta T s t. So, delta T s t you know this already we have found out multiply with the C p that means this part, that means actually this part, so this part we know and mass flow rate already we know 30 kg given in the problem, 30 kg per second so therefore, if you put the value C p this one delta T s t 16.37 degree Celsius and mass flow rate 30 kg per second, you get a value of 548.39 kilo vat, if you consistent in the unit final you will get this result this is the power, so this is one example.

That we can work with next another problem I will tell you, where you have some idea about the degree of reaction ok.

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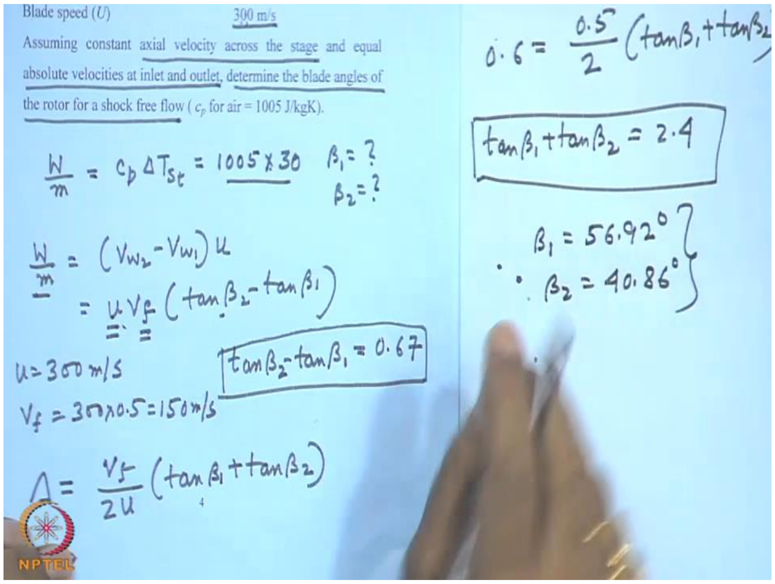

So, this problem is this, the preliminary design of an axial flow compressor is to be based upon a simplified consideration of the mean diameter conditions. Suppose that the characteristics of a repeating stage of such a design are as follows, that means; a particular stage these are repeated for different stage. Stagnation temperature rises, that means; indirectly the work done on the fluid is given, degree of reaction is given, flow efficiency is given 0.5, but this is actually not flow efficiency, I think it will be better, if you write it has flow number v f by u is actually flow number sometimes they write at flow efficiency however flow number blade speed that means, it is the ratio of flow velocity to the peripheral speed. Peripheral speed is also separately given 300 that means, we get v f multiply 0.5 with them. Then what is the problem, assuming constant axial velocity across the stage and equal absolute velocities at inlet and outlet that means, v 1 is equal to v 3 that we have already done. Determines the blade angles of the rotor for a shock free flow that means, there is no incident loss so, how to find I work out this problem. Now, this problem, if you work out, you see that the degree of reaction is given now; first of all we know the stagnation temperature rise. So, first of all we find the work per unit mass is equal to is known, that is what, that is C p into delta T s t and what is C p? Cp is 1005 joule per kg k and that is 30 and finally this becomes equal to your work per unit mass.

Now, how to find out beta 1 and beta 2? So, what we have to find out, we have to find out beta 1, we have to find out beta 2, the two angles ok, you remember that beta 1, beta 2 so, I tell you again that this one we have to find out, we have to find out beta 1 beta 2, so what we will do? We will take some of this relationship, tan beta 1 minus tan beta 2 is equal to work done, where you will get that formula that v f ok, I am coming to it again, it was done earlier, if you remember that W by m is V w 2 minus V w 1 into u and that becomes is equal to u into v f into tan beta 2 minus tan beta 1. Now, we know u, we know v f, v f is 300 into 0.5, u is 300, u is 300 meter per second well.

And you can see, I think you can see very well and v f is 300 into 0.5 that is 150 meter per second, tan beta 2 tan beta 1 beta 2 and beta 1, we have to find out. W by m we know so therefore, if we put this here and this value here we get a relationship tan beta 2 minus tan beta 1 equals to what tan beta 2 minus 0 point you get everything is known. Now, we have to get another relationship relating beta 2 and beta 1 that will come from the relationship of degree of reaction. Now, degree of reaction, if you remember is given by u by v f degree of relation is v f by u, v f by 2 u if you remember that today we have done it or last class we have done it tan beta 2 tan beta 1 plus beta 2. So, we have done these things so here also we know v f by u is 0.5 that means 0.6 that means rather I write here, I write here it will be better 0.6, 0.5 v f by u 0.5, which is given in the problem by 2 into tan beta 1 so it is a simple problem, which gives relationship tan beta 1 plus tan beta 2 is it is what 1. 2 to 2.4 it is very simple.

So, this is one relation and this is one relation so as simple as this and finally if you solve for tan beta 1 and tan beta 2 finally you get beta 1 is 56.92 degree and beta 2 is 40.86 degree so these are answers you can check. So, therefore, with a degree of reaction you can that is only that we have to deal with the equations, which equal sense will be depending upon the parameter given so these are the problems, which clear makes your concept more clear.

Now, after this I will start the fans and blowers. So, fans and blowers there is nothing much different from that of compriser the different is like that as I told earlier at the beginning of my fluid machine class that the when the output for a complexable flow for example that I have handling air at the outlet of a machine, where energy is given and we get the fluid at the outlet of the machine having higher energy aquaid stored energy, if that is mostly in the form of high pressure static pressure, but less velocity you call it has complicit, whether it is centrifugal it is axial, but when the basic purpose is to have fluid with very high velocity, where we have to deliver high rate of flow with high velocity of flow. Therefore they are the machine must deliver the fluid with higher energy by observing energy from outside mostly in the form of the kinetic energy with high velocity but relatively much less pressure static pressure those machines are known as fans and blowers. So, fans and blowers and compressor of same kind in a sense that they take energy from outside and the fluid going through it gains its internal energy but for fans and blowers this energy mostly in the form of kinetic energy rather than pressure static pressure is more of velocity then that means static pressure.

Now, among fans and blowers, fans are those machines, where the static pressure at the outlet of the machine is few millimeter of water gage, you can understand that atmosphere pressure is state meter of water gain it is so less few millimeter of water gage, where as in case of blower it is something more than thousand millimeter of water gage still is very less ten meter of water gage is the atmosphere pressure. So, this is the pressure getch pressure that means avoid the atmosphere at the outlet why this pressure is solo, why the pressure is required, first of all pressure is required, because this machines deliver air for some purpose, that means, air has to flow it may be required that to make to supply the air through a deck. So, therefore, we have to overcome the friction of the deck, that means; this flow has to take place through a deck, it has to overcome the frictional lence not only through a deck through a room. So, therefore, downstream resistance has to be frictional resistance has to be overcome to deliver that flow so this machines develop that pressure sufficient to overcome the resistance.

Now, in case of blower it handles more amount of air when less amount of air is handled and the circulated or been sent through a deck, we employee fans for which the frictional resistance is layer. So, therefore, relatively less static pressure is required at the delivery end of the machines whereas in case of blowers, which handles more air and at a high velocity it may have to be convey that transport at through a long deck the frictional resistance is much more that means; it has to overcome more frictional resistance so, that the pressure drop is more. As a consequence this static pressure at the outlet of the machines has to be higher this is the reason for which blower for blower static pressure is higher, because it handles more amount of air. So, this is the difference between blower and a fan, so fan and blowers are basically the compressor, but in this case the static pressure at the end of the machine is much lower as compare to his velocity.

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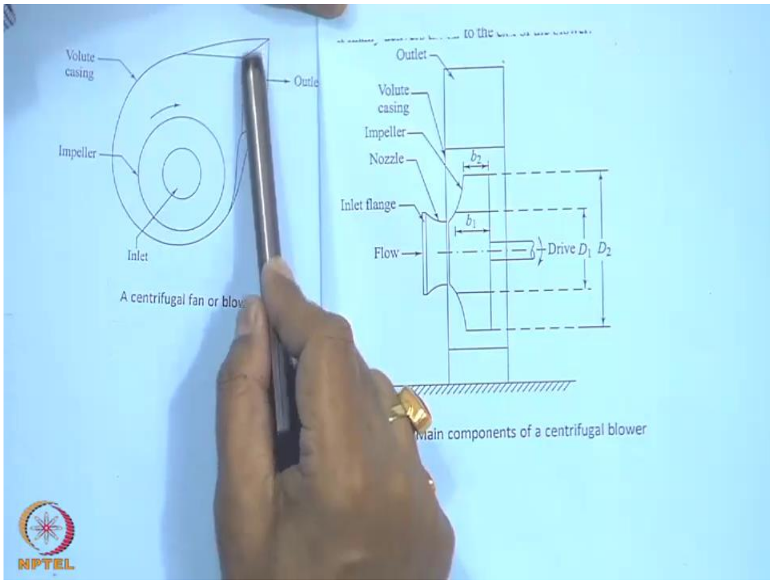

So, you see a typical centrifugal fan or blower here, I will show you simultaneously I do not know it may be a little difficult ok, I will try it yes, this is the thing. So, let me show you this is the thing, let me just a minute, let me make this things, let me show you like this, let this is a typical centrifugal fan or blower. Now, centrifugal fan air blower consist of an inlet this is the impeller the same principle impeller, which imparts the energy to the fluid then after the impeller there is a final casing knows has volute chamber, spiral or scroll casing this is the volute, where this gain the energy in term of both velocity and pressure rise at the end of the impeller high velocity and high pressure some of the velocities are then converted in the volute chamber to static pressure depending upon the requirement at the outlet of the machine.

So, this is the picture this can be shown, if we take a section like this then it is this, this is the impeller you see, so this is the inlet the flow at the inlet takes place through a nozzle that means; there is little acceleration of the flow before it enters into the impeller. Now, impeller it goes readily with same way that it happens in a centrifugal comprises that means; it is shuck or it is induced the axial direction then the flow changing the radial direction. So this is the readily outward flow then it comes out this is the volute case and this is the outlet so this is the main component of a centrifugal fan or blower.

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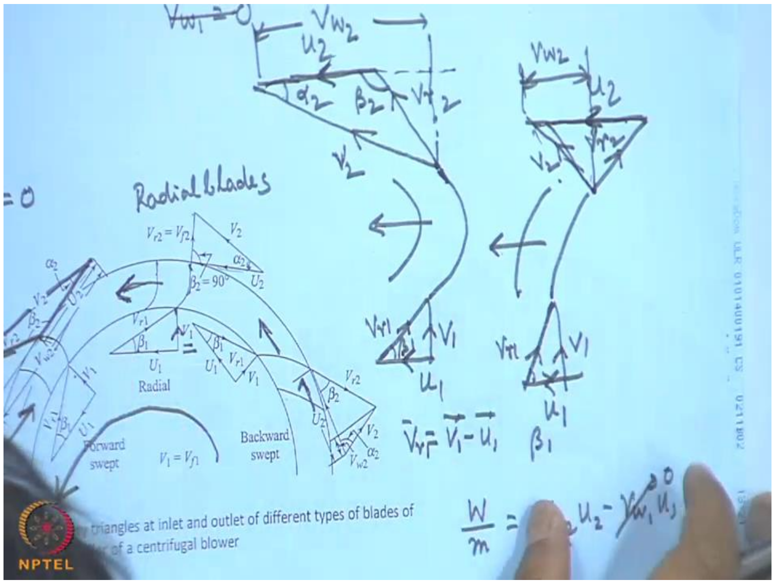

So, after this I will tell you about the as the typical type of blades in a blower or fan. Now, blower or fan both are the same machines as I have told only the static pressure rise is different for blower and fan and depending upon the florid required the fan blade shape is different. Now, three types of blade shapes from the fluid mechanical principles are used, I tell you. One is known as forward swept blade, you see this left on what is that if you consider the motion in this direction that means; this is the direction of rotation that means; the peripheral speed is in this direction the tangential. So, curvature of the blade is in the direction of the motion this is known as forward swept. Another type of blade is which is known as radial blade, this is known as, this is known as, this is forward swept blade, so this type of blade is known as radial blade what is the radial blade? Radial blade their outlet that means; at the outlet the blade is radial, but at inlet there is a curvatures and this curvature is forward swept, why? Because this is the direction of the motion the curvature in the direction of the motion, so radial blades are radial outwards plat, but this is car at the inlet which is forward. Another is the backward swept, that means is curvature this is the direction of the motion, its curvature is in the opposite direction of the motion. So, velocity triangles will defiantly change that I will tell you, you can understand, because this direction of velocity and the curvature of the blades are in the opposite direction and relative directions are changed.

Now, before that I tell you the forward swept blade are used, where large fluorides are required relatively large fluorides and higher pressure rises required as compare to backward swept. Whereas radial blades are preferred, where the fluid that is air use contest more impurities and dust, this is because of the fact that these are less turn blockage and they work more efficiently with the dust laden gas, so therefore this radial blades are preferred for that. Now, if we see the velocity triangle, so velocity triangle at the let for example in the radial you see this is same for all the blade, what is that? There is the inlet velocity is axial, absolute velocity direction this is the axial direction, axial this has got no component in the tangential direction that is V w 1 component is 0, V w 1 is zero everything that is the problem here, V w 1 is 0 ok, V w 1 is zero see that can be same V w 1 zero can be same its same V w 1 is 0.

So, radial blades entry for all blades are same that is V w 1 is axial this is the relative velocity, which matches the angle of the blade this is the peripheral velocity this makes the vector diagram that is the velocity triangle. Now, at the outlet also you see this is the peripheral p this is the direction of the flow direction of the rotation speed these velocity that is the relative velocity matches the blade angle that means it is radialy outward and this is the absolute velocity alpha 2 is the absolute velocity angle, beta 1 is the angle of the blade at the inlet and this is alpha this is 90 degree, this is the beta 2, which is radial this is alpha 2 angle of the absolute velocity.

Now, let us see the velocity triangle for the forward swept blade the velocity triangle for the forward swept blade is this one, this is the it is visible it is visible velocity diagram, let me draw the velocity diagram here, I think for you it will be forward swept I write. So, this is the inlet diagram it is already same as that, that means; there is no tangential component it is axial and this is the now here forward swept this is the u, the direction of u is this.

So, therefore, the direction of u this is V r 1 ok and this is the u and this is the V r 1 this is the beta 1 ok, V r 1 is equal to V 1 u 1 minus u 1 very good, because they differ it is a radial formation radial outward. Now, at this end what will happen this will be my radial flow so the relative velocity direction and these will be the the diagram will look like this so this will be obviously from the V r 2 this will be u 2, which will be higher than u 1 and this will be the V 2.

So, this is the simple diagram, because the velocity is in this direction so it has to be like that. In this case this is defined as the beta 2 that means in the positive sense u 2 is this direction with this is an optives angle this is the angle beta 2 with the tangent and this angle is alpha 2 so this is the velocity triangle, which is shown here like this. I think you can see, but this diagram I think is very difficult to see these things are not properly shown not legible. However now, for a backward swept this can be visible, backward swept one I again draw it here for the backward swept what will be that so these curvature is in the opposite direction that means; this is like this, this is in the opposite direction, but the direction of peripheral velocity is like this.

So, here also so this is the same thing that this is the inlet velocity triangle ok, this is the inlet velocity triangle, this is V r 1, this is V 1 let this is v 1 sorry, u 1 and this angle is beta one. So, the outlet angle for example here or here I can draw the velocity this relative velocity is this then what is this velocity, relative velocity this direction ok, that is V r 2 then these velocity is in this direction, this velocity is in this direction. So, therefore the absolute velocity will be so these looks very odd, so little more the relative this is u 2 this will be V 2.

So, this will be now, if you draw it in case for a given value of u 2 at the outlet and for a fixed value of v a we will see that for forward swipe blade the component that V 2 is more and the component that V w 2 that this one V w 2 is much more compare to these, this is V 2 this V w 2. So, therefore, you see V w 1 is 0 therefore work done per unit mass is again V w 2 u 2 since V w 1 u 1 V w 1 is 0. So, therefore in this case this is ok, understandable so in this case V w 2 is more than this and that is the reason that forward swept blade is used, where we require more work and more flow will be available and more static pressure rise will be there ok.

So, more work will be imparted to the can be imparted to the fluid flowing through it. So, three types of possible blade configuration forward swept, radial blade and backward swept blade are possible. So, with this now, other treatments I tell you in the axial flow fans and comprises are almost identical to that of the centrifugal comprises, which I have told in case of a centrifugal blowers and centrifugal fans.

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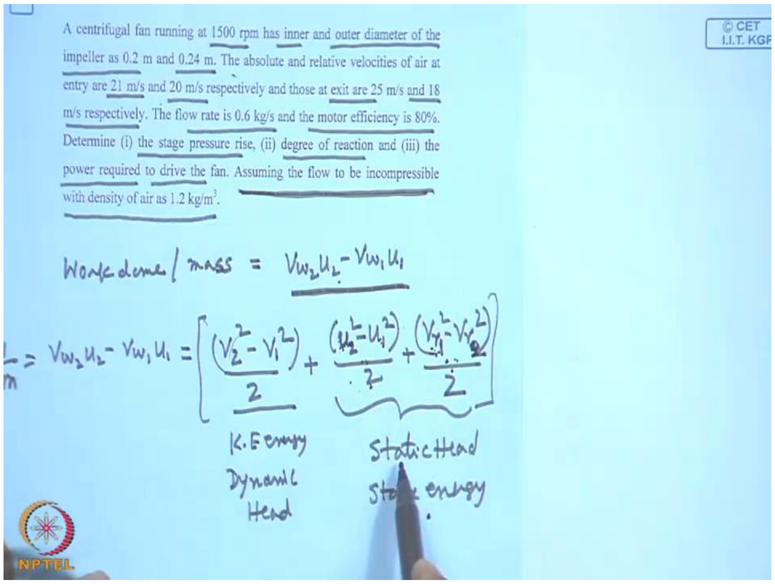

Now, with this I will go on solving a problem. Let us see this problem, a centrifugal fan ok a centrifugal fan running at 1500, that is fifteen hundred r p m, as inner and outer diameter of the impeller as 0.2 meter and 0.24 meter that is the inner diameter of the impeller, outer diameter of the impeller.

The absolute and relative velocity of air at entry are twenty so absolute and relative velocity of air at entry are these respectively and those that mean exit entry and exit absolute and relative velocities are given, the flow rate is 0.6 kg per second, the motor efficiency is 80 percent, determine the stage pressure rise degree of reaction and the power required to drive the fan, assuming flow to be incompressible with density of air as 1.2 kg per meter. Now, this particular problem I tell you, we will make here total understanding of the fan or a blower clear so let us first see that what this problem tells. Now, this problem tells that velocity absolute relative is given.

Now, if you recall this type of problem what you will do first you have to find out the stage pressure rise so how to find out the stage pressure rise so we have to find out first of all you find out the stage pressure rise by which expression we have to find out the stage pressure rise stage pressure rise means what the total pressure rise in the stage ok. So, total pressure rise in the stage depends upon the work done, total work done, if you first find out the work done per unit mass what is it work done per unit mass? Now, if you remember the work done per unit mass is V w 2 u 2 minus V w 1 u 1 without going for a change in temperature stagnation temperature so far we did this is, because this problem is told at assuming the flow to be incompressible.

So, for an incompressible float better, we do this type of analysis that this is true for any flue in incompressible of compressible. If you remember that this were done, but V w 1 u 1 that is work done that is W by m can be written as different components, if you remember that is V 2 square that is work done on the fluid minus V 1 square by 2 plus u 2 square minus u 1 square by 2 ok, plus V r 1 square minus V r 2 square by this, I explained in details in one earlier class of our fluid machines that this can be splited like this from the geometry of the velocity triangles, why it is required, because this gives very clear understanding.

This is the gain in kinetic energy, where the absolute velocity here in terms of compressor, in terms of pump, in terms of fans blowers, where the fluid gains energy V 2 is always greater than V 1. So, this is the gain in kinetic energy, this is the gain in the kinetic energy or dynamic, we sometimes tell as dynamic head, it is per unit mass, usually energy per unit mass or unit way you call it as head. And these two is the gain in the static head, why it is called static head or static energy, which is not very much used that means, this is manifested in terms of the increase in the pressure of this way. This is because of the change in this is the change in peripheral velocity at outer radius and inner radius and the fluid therefore when it reaches that outer radius from inner radius gains in static pressure and that change in the pressure energy is given by u 2 square minus u 1 square by 2.

Similarly, the change in static pressure, because of the change in the relative velocity, this is again another part of the diffusion that means, change in the relative velocity takes place, where V r 1 is more than V r 2 that means, V r 2 is less than V r 1. So, passages made in such a way that V r 2 this is a diverging passage for which the pressure is gain so this pressure is gained out of the momentum change or the change in the kinetic energy related to the blade passage. So, these two this is due to the centrifugal action the radial pressure gradient is imposed, I told many time and this is because of the diffusion from the change in the kinetic energy V r 1 is higher V r 2 is lower. So, therefore, pressure is lower and pressure is higher at the outlet so the combination of these two is the static head static energy and in these connection I like to tell you again this is a very important concept for all of you that in a radial flow machine whether it is outward or inward even if the passage is uniform there is no change in the relative velocity still there is a change in the static pressure rate, because of the change in the u the peripheral velocity in case of a turbine there is a loss in pressure in case of a pump or comprises there is a rise in pressure. So, therefore, any radial flow machine outward or inward has to have some pressure change in the rotor at least by this one but along with that, if you make a diffuse in passage in case of compressor there is an additional pressure rise ok.

So, these two sum up view this static head or static energy this is very important I want to repeat it again, so here what happens I know V 2, I know V 1, I know V r 1, I know V r 2, because all the relative velocity at inlet and outlet is given. And again I know u 2 u 1, because the impeller diameters are given and the speeds are given. I am not solving this problem I just write u 2 is pi D 2 n and u 1 is pi D 1 n, n is given rotational speed 1500 one fifteen hundred rpm. So, that we can fifteen hundred rpm so that we can do this thing better I write here, so that u 1 u 2 I found out, u 1 this way, u 2 this way we can find out and then what we do, we can find out the work done.

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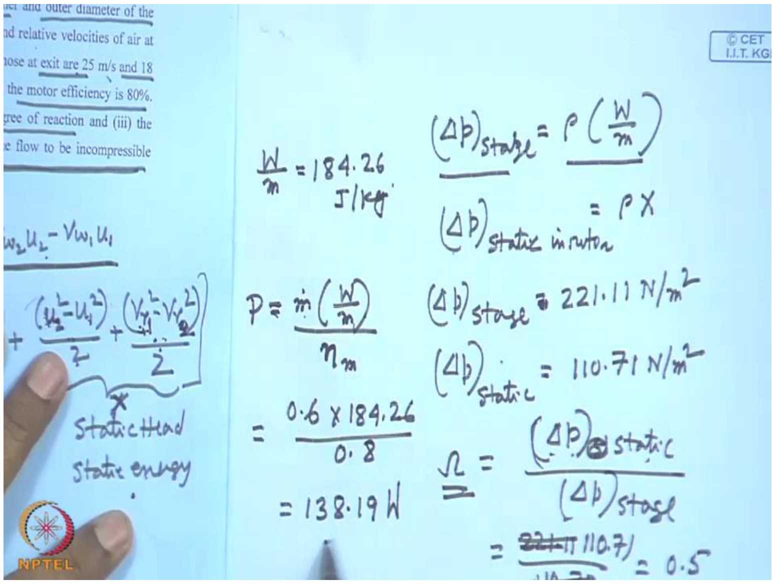

Now, if we know this work done for an incompressible situation ,we can write that delta p stage is nothing but rho times this work done per unit mass, that means; you just multiply with rho, this with rho you get the delta p per stage, total in the stage you find out the delta p ok fine. Now, static pressure rise is this one, so delta p static in the rotor, because this is in the rotor, delta p static in rotor is equal to rho into let this part I denoted at x rho into x, so this part is denoting at x rho into x. So, if you find out this by putting this value, you get delta p the total stage that means, impeller and the diffuser total delta p stage, because the work is done only in the impeller delta p total is 221.11 ok Newton per meter square and delta p in rotor or static pressure rise static ok, so that is static pressure across the stage is 110.71 Newton per meter square. Now, here this delta p static divided by total one is known as, this is the static pressure rise in the rotor and this is the total pressure rise this is the total energy given ok. So, therefore the degree of reaction in this case we define as delta p stage sorry, delta p static this already I did earlier, delta p stage now, one thing just 221.11 divided by 110.71 oh sorry, it is just reverse 110.71 by 221.11, this will roughly 0.5.

Now, here this is very simple this is numerical but thing is that what is the concept earlier also, if you recall the earlier discussion that the degree of reaction was defined in terms of the total pressure change in the machine that is change in the total pressure in the machine divided by the change sorry, change in the static head or the static pressure in the machine divided by the total head or the total energy given in the machines. And this definition holds true for every machine in case of centrifugal compriser and axial flow compriser this was manifested in terms of the enthalpy change, where you consider along with the temperature change ok, but here what happens when you consider the flow to be incompressible with the constant density of air and there is no change in temperature. So, therefore this degree of reaction is better to be estimated by that definition, which you discussed in case of hydraulic machine that delta p is static divided by delta p stage ok,

So, this is the same so therefore we find this now next is the power required, what is the next one? The and the stage pressure rise degree of reaction and the power required to drive the fan, how to find out the power required? Power required is very simple, power required you can write here, power required is the mass flow rate into work per unit mass, that means; work per unit mass is this one and you can find out the mass flow rate, what is the mass flow rate? The flow rate is 0.6 kg per second so therefore, 0.6 kg per second, you know mass flow rate W by m that divided by the mechanical efficiency probably there is a motor efficiency of 80 percent, that means; you write the motor rating speed that means; you write the motor efficiency in the denominator, that means; you there the mass flow rate is given as in this problem 0.6 kg per second.

Now, W by m, which is calculated I have only calculated here, I have told you the value of delta p stage naturally W by m here, W by m calculated will be 184.26 joule per kg this is so therefore this would be 0.6 into 184.26 divided by 0.8, which is ultimately in 138.19 what, ok. So this is the thing, that means; this problem is looked from a different angle that work done per unit mass is true that is the Euler equation this can be splited in this term for in an incompressible flow with a cost and density it is better to looked upon this way that this is the static head rise and this is the kinetic energy, sum of all these three is the energy in put to the machine and that is the total head that is raised in the fluid. So, this is the denominator their per stage and this is the numerator ok. So, therefore, the degree of reaction is this divided by this it was discussed earlier when I discussed the hydraulic machines in general this is the degree of reaction so this is bought out to be this numerically delta p stage, which is found out rho times work done per unit mass that is the total pressure change in the machine and static pressure change in the machine is rho times this part this is x again I repeat this part the static head that means, this is the energy per unit mass this into rho is the delta p static so delta p static by delta p stage is this one is 0.5 clear. Now, after this I will tell you something else that what is fan laws.

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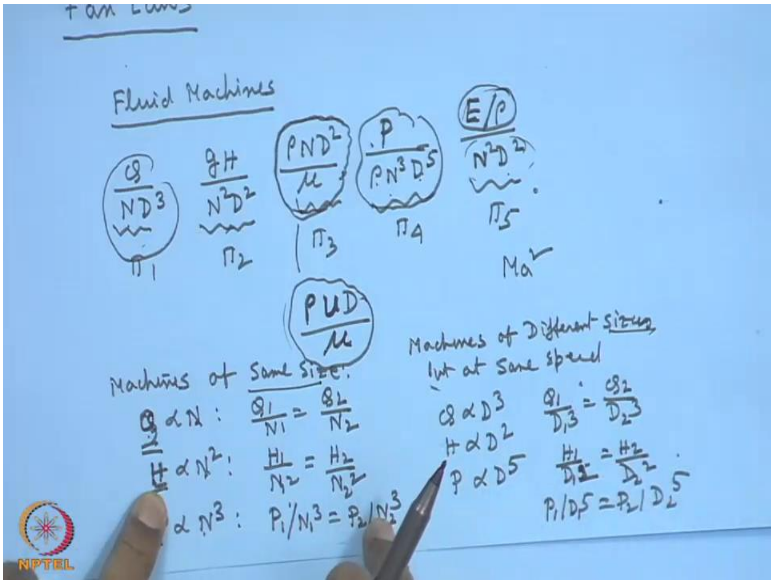

Because, sometimes you will see that people tell about fan laws, what is fan laws, this is the terminology actually. Now, in general for any fluid machines, when I discus the similarity principles one of the earlier lectures in fluid mechanics from all the variables involved in a fluid machines in the physics of fluid machines rather I will tell, we derived by application of the Bukhimcom pi theorem different pi terms as the criteria of similarity parameters.

If you recall that see my earlier lecture note then you will find this terms are like this Q by one term is like this N D cube another term is g H by there are five terms N square D square another term is rho N D square by mu another term is p by rho N cube D five another term is E by rho divided by N square D square. So, these are all pi terms, this is let pi 1 this is pi 2 this was told at length in one of the earlier class there are pi 4 and 5. Now, when we derive the pi terms for centrifugal comprise as we had four pi term this is because this term we neglected effect of viscosity we did not take in fact the viscosity as less effecting fluid machines, why I will tell you now, earlier also I told, but these four terms we got, but not in this fashion in a different fashion I told you in earlier in last classes this is an essence or corollary of pi theorem that depends upon the choice of the repeating variable you add a number of terms at semi where some pi terms, which may not match exactly the pi terms you want or the o u express that the result then a combination of the pi term is also a pi term. So, different combinations can be made by making the numbers same so that you arrive at different pi term so therefore the pi terms of centrifugal complex as which you derived can be recoupled or rearranged to get the similar type of thing. So, this an a thing where earlier explained I am not going into detailed of it but this term I tell you as you know this term represent a short of renodes numbers, because rho N D is the velocity u D by mu that means, is u is the peripheral speed that means it is the Reynolds number based on peripheral speed. So, it can be change to Reynolds number based on other flow velocity also physically it represent a short of Reynolds number.

Now, in fluid machines the flow is highly turbulent, so in those turbulent flow the Reynolds number has got very less influence on the flow parameter, mainly in the special laws or any other parameter the Reynolds number does not have much influence. So, therefore, in centrifugal comprises also we have not included the property mu to find out the dimensionless step. So, therefore, in the fluid machine earlier I also told this term is not of that relevant so only these terms are relevance. Now, if you take this term now, you see which is not only for fan for any fluid machines that, if you now this term is a non dimensional power rho into D five this term you know that E by rho is the square of the acoustic speed or speed of sound in the fluid medium related to the fluid and this is the square of the peripheral velocity.

So, therefore, this is some sort of square of the mach number, mach number square type of this. So, therefore, you see that now, if you see all this pi terms now you see that for any fluid machines, if we make the fluid machines same machines of same size then we can tell that Q is proportional to N, because D is same from this pi term, which gives Q 1 by N 1 is Q 2 by N 2 this is school level things, from the second pi term we see that head, because flow and the head is very important, what is head this is g H that means; energy per unit mass head means energy per unit quite that means this is the energy either gained by the fluid or developed by the fluid that given air by the fluid depending upon whether is a compressor pump or turbaned. H is proportional to N square that means, H 1 by N 1 square H 2 by N 2 square. Similarly, now, if we take this term then we can write power is proportional to N cube, which means that p by p 1 by N that means; this is the skilling long, p 2 by that means, we are interested in three quantity Q, H and p. And multiplication of this two is this one, so if it is proportional to N, this is N square, it has to be N cube, that means; power is proportional to N cube, head is proportional to N square, Q is proportional to N for same size and machines of different sizes, but at same speed, different sizes, but at same speed one can derive from this formula that Q is proportional to D cube, H is proportional to D square, obviously, if you know these two you do not have to see the pi term otherwise pi term is wrong, that means; it has to be D five that means, Q 1 by D 1 cube is Q 2 by D 2 cube, Q H 1 by D 1 5, H 2 D 1 square is H 2 by D 2 square.

And similarly, p 1 by D 1 5 it is p 2 this is so simple D 2 5 that means, this scaling loss with speed for the same size and with size, which is represented by the impeller diameter as a representative characteristics size for the same speed is known as this is this skilling based on the similarity parameters of fluid machines and valid for all fluid machines, but usually because this grow like this that initially fans and blowers and they were designs to make the proto type they use this type of scale so till date this scaling laws are known as fan laws in designing the fans. So, therefore, while starting the fans we must know what is fan law, fan law is nothing but this scaling law for the volumetric flow rate the head that means, energy per unit or energy per unit mass you can take g H does not matter g H is constant and the power with the speed for the same size and size for the same speed is known as fan laws.

So, I think today we will stop here and we have I like to close the lecture on this fans blowers and last class we discuss the axial flow compriser before that we discuss the centrifugal compriser and including all today I will stop or I will close my lecture series on fluid machines initially hydraulic machine basic principles of fluid machines hydraulic machines and then centrifugal compriser axial flow compriser and the fans and blower. So, next class we will start the compressor fluid.

Thank you.