Fluid Machines.
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Lecture-39.
Fans and Blowers Part II.

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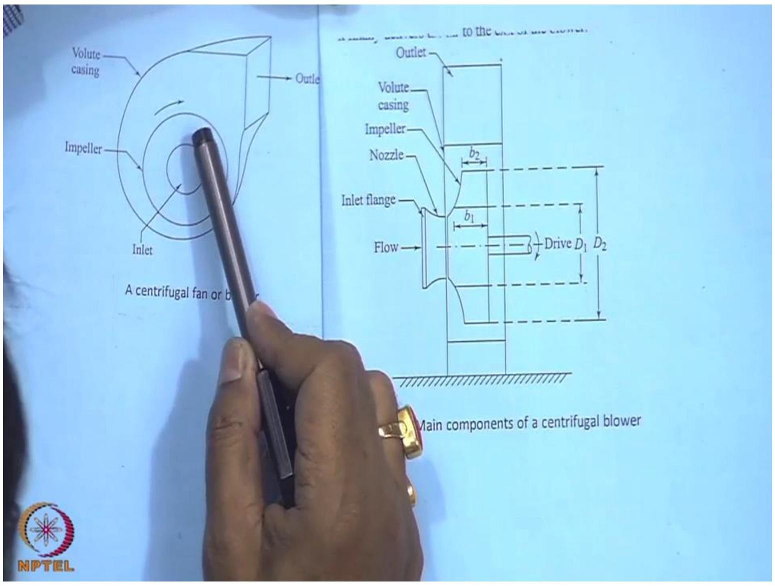

Good morning and welcome you all to this session of the course. So you see a typical centrifugal fan or blower here. I will show you simultaneously, I do not know it may be little difficult, okay, I will try, yes, this is the thing. So let me show you, this is the thing, let me, just a minute. Let me make this thing, let me show you this thing. This is a typical centrifugal fan or blower. Now centrifugal fan or blower consists 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 spiral casing known as volute chamber, spiral of scroll casing. This is the volute where this gains the energy in terms of both velocity and pressure rise at the end of the impeller, high velocity and high-pressure, some of the velocities are then converted into 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 a little acceleration of the flow before it enters into the impeller. Now impeller, it goes radially, in the same way that it happens in a centrifugal compressor, that means it is sucked or it is induced in the axial direction, then the flow change in the radial direction. So this is the radially outward flow. Then it comes out and this is the volute casing and this is the outlet. So this is the main component of a centrifugal fan and compressor, centrifugal fan or blower.

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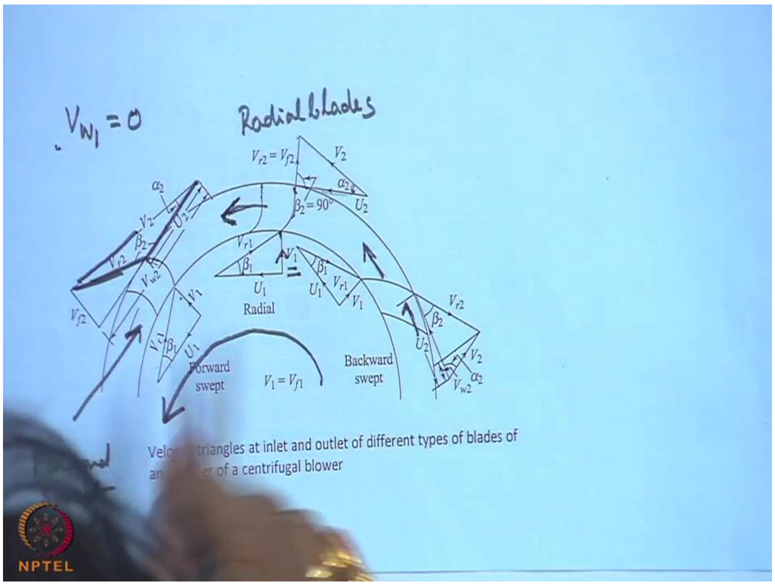

Velo triangles at inlet and outlet of different types of blades of an er of a centrifugal blower

So after this I will tell you about the, the typical type of blades in the, 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 flow rate required, the fan blade shaped different. Now 3 types of blade shapes from the fluid mechanical principles are used, I tell you. One is known as forward swept blades, you see this left one. 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 blades. Another type of blade is, this is known as radial blade, this is known as, this is known as, this is forward, forward step blade, forward swept blade, blade, forward swept blade, forward swept blade. So this type of blade is known as radial blade, radial blade. What is the radial blade? Radial blade.

Their outlet, that means that the outlet, the blade is radial. But at the inlet, that the curvature 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 outward, flat, but this is curved at the inlet which is forward swept. Another is the backward swept, that means this curvature, this is the direction of the motion, its curvature is in the opposite direction of the motion.

So velocity triangles will definitely change, that I will tell you, you can understand because the direction of velocity and the curvature of the blades are in the opposite direction or relative directions are changed. Now before that I tell you, the forward swept blades are used where large flow rates are required, relatively large flow rates and higher pressure rise is required as compared to backward swept blades. Whereas radial blades are preferred where the fluid is, that is air used contains more impurities and dust.

This is because of the fact that these are less prone to the blockage and they work more efficiently with the dust laden gas. So therefore these radial blades are preferred for that. Now if we see the velocity triangle, so velocity triangle at the inlet, for example in the radial you see, this is same for all the blades. 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 W1 component is 0, V W1 is 0.

Everything, that is the problem here. VW 1 is 0, we W1 is 0, okay, VW 1 is 0. See that can be seen, V W1 is 0 can be seen, V W1 is 0. So radial blades, so entry for all the blades are same. That is V W1 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 speed, this is the direction of the flow, direction of the rotation speed.

This velocity, that is the relative velocity matches the blade angle, that means it is radially 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, is the 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, is this one. This is the, it is visible, velocity diagram.

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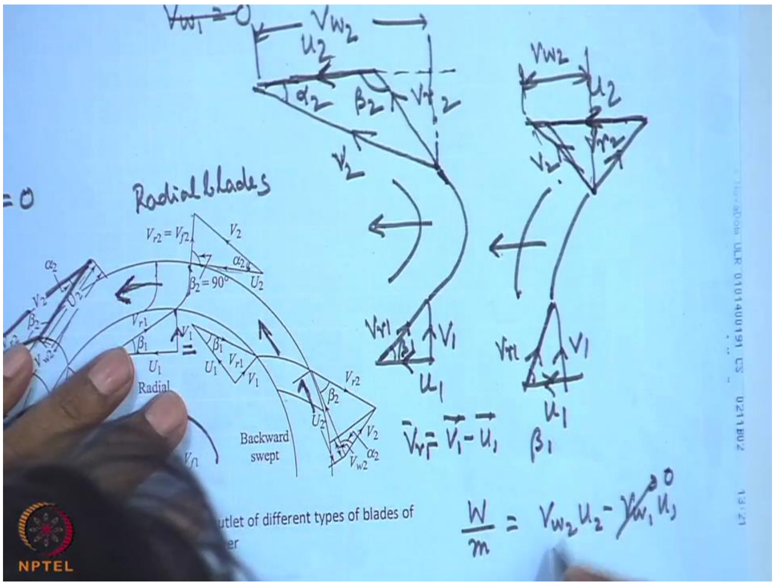

Let me draw the velocity diagram here. I think for you it will be forward swept blade, I write. This is the inlet diagram, it is already same as that, that means there is no tangential component, it is axial and this is the, now here forward swept, this is the U, the direction of U is this. So therefore the direction of U, this is VR1, okay and this is the U and this is the V R1, this is a beta 1. Okay, VR1 is equal to V1 - U1, very good. Because they differ, it is a radial flow machine, radial outward.

Now at this end, what will happen, this will be my radial flow, sorry relative velocity directions and this will be the, the diagram will look like this. So this will be, obviously from the VR2, this will be U2 which will be higher than U1 and this will be the V2. 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, this is defined as the beta-2, that makes in the positive sense, U2 is this direction, with this, this is an obtuse angle, this is this 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, the things are not properly shown, not legible. However for a backward swept, backward short, this can be visible, backward swept one, I again draw it here for the backward swept, what will be that, so this curvature is in 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, okay, this is the inlet velocity triangle, this is VR1, this is V1, let this is, this is U1, sorry, U1 and this angle is beta 1. So the outlet angle for example here or here I can draw the velocity, the relative velocity is this. Then what is this velocity, relative velocity is this direction, okay, that is VR2. Then this velocity is in this direction, this velocity is in this direction.

So therefore the absolute velocity will be, so this looks very odd. So absolute, little more, the relative, this is U2, this will be V2. So this will be, now if you draw it in scales, for a given value of U2 at the outlet and for a fixed value of VF, you will see that for forward swept blade, the component, that V2 is more and the component that VW2, that this one, VW2 is much more compared to this, this is V2, this VW2. So therefore you see VW 1 is 0, therefore work done per unit mass is again VW2 U2.

Since V W1 U1, VW 1 is 0. So therefore in this case, this is okay, understandable. In this case, VW 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. Okay. So more work will be imparted to the, can be imparted to the fluid flowing through it. So 3 types of possible blade configurations forward swept, radial blade and backward swept blades are possible.

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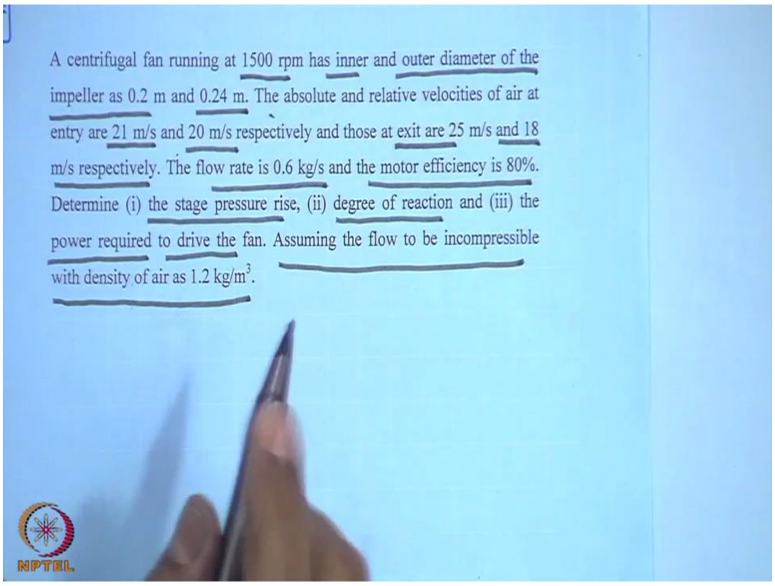

A centrifugal fan running at 1500 rpm has inner and outer diameter of the impeller as 0.2 m and 0.24 m. The absolute and relative velocities of air at entry are 21 m/s and 20 m/s respectively and those at exit are 25 m/s and 18 m/s respectively. The flow rate is 0.6 kg/s and the motor efficiency is 80%. Determine (i) the stage pressure rise, (ii) degree of reaction and (iii) the power required to drive the fan. Assuming the flow to be incompressible with density of air as 1.2 kg/m^3.

So with this, now other treatments I will tell you in the axial flow fans and compressors are almost identical to that of the centrifugal compressors which I have told in case of centrifugal blowers and centrifugal fans. Now with this I will go on solving a problem. Let us see this problem. A centrifugal fan, okay, a centrifugal fan running at 1500, that this at 1500 rpm has inner and outer diameter of the impeller as 0.2 meter and 0.24 metres. That is the inner diameter of the impeller, outer diameter of the impeller.

The absolute and relative velocities of air at entry are going to, So absolute and relative velocity of air at entry are this respectively and those, that means exit, entry and exit, absolute and relative velocity is 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 the flow to be incompressible with density of air is 1.2 KG per metre cube. Now this particular problem I tell you will make your total understanding of the fan or blower clear.

So let us 1st see that what this problem tells. Now this problem tells that velocity, absolute and relative is given. Now if you recall, this type of problem, what you will do? 1st you have to find out the stage pressure rise. So how to find out the states pressure rise, so you have to find out, so 1st of all you find out the stage pressure rise by which expression, you have to find out the stage pressure rise. Stage pressure rise means what? The total pressure rise in the stage. Okay. So total pressure rise in the stage depends upon the work done, total work done.

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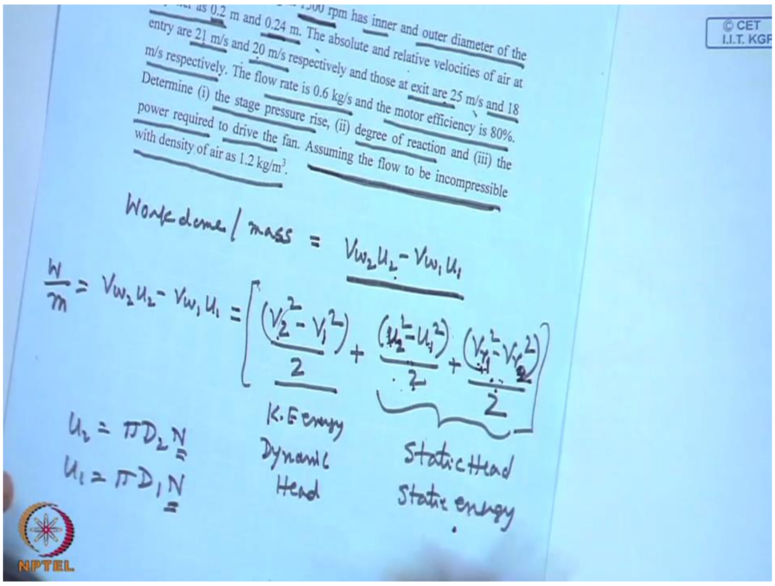

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Determine (i) the stage pressure rise, (ii) degree of reaction and (iii) the
power required to drive the fan. Assuming the flow to be incompressible
with density of air as 1.2 kg/m³.

Work done / mass = $\underline{V_{w_2}U_2 - V_{w_1}U_1}$

$$\frac{W}{m} = V_{w_2}U_2 - V_{w_1}U_1 = \left[\underbrace{\frac{(V_2^2 - V_1^2)}{2}}_{\substack{\text{K.E energy}\\ \text{Dynamic}\\ \text{Head}}} + \underbrace{\frac{(U_2^2 - U_1^2)}{2} + \frac{(V_{r_1}^2 - V_{r_2}^2)}{2}}_{\substack{\text{Static Head}\\ \text{Static energy}}}\right]$$

$U_2 = \pi D_2 N$

$U_1 = \pi D_1 N$

If you 1st find out the work done per unit mass, what is the work done per unit mass. Now if you remember the work done per unit mass is VW2 U2 - VW 1 U1. Without going for a change in temperature, stagnation temperature, so far we did. This is because this problem has told that assuming the flow to be incompressible. So for an incompressible flow, better we do this type of analysis that this is the, this is true for any fluid incompressible or compressible.

If you remember that this work done part, VW 1 U1, that is work done, that is W by M can be written as different components, that is V2 square, that is work done on the fluid - V1 square by 2+ U2 square - U1 square by 2, okay, + VR1 square - VR2 square by 2. This I explained in detail in one earlier class of our fluid machines that this can be splitted like this from the geometry of the velocity triangles. Why it is required, because this gives a very clear understanding.

This is the gain in kinetic energy where the absolute velocity, here in terms of compressor, in terms of pumps, in terms of fans, blowers, while the fluid gains energy, V2 is always greater than V1. So this is the gain in the kinetic energy, this is again in the kinetic energy or dynamic, we sometimes tell as dynamic head. It is per unit mass, usually energy per unit mass or unit weight, we call it as head and these 2 is the gain in the static head. Why? Why it is called static head or static energy which is not very much used?

That means this is manifested in terms of the increasing the pressure of the fluid. This is because of the change in, this is the change in the peripheral velocity at outer radius and inner radius and the fluid, therefore when it reaches at outer radius from inner radius gains in static pressure and that change in the pressure energy is given by U2 square - U1 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 we are one is more than VR2, that means VR2 is less than VR1. So passage is made in such a way that VR2 is less, it is a diverging passage for which the pressure is gained. So this pressure is gained out of the momentum change or the change in the kinetic energy relative to the blade passages. So these 2, this is due to the centrifugal action, the radial pressure gradient is imposed as I told many times and this is because of the diffusion from the change in the kinetic energy.

VR1 in higher and VR2 is lower, so therefore pressure is lower and pressure is higher at the outlet. So the combination of these 2 is the static head, static energy and this 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 passages uniform, there is no change in the relative velocity, still there is a change in the static pressure head because of the change in the U, the peripheral velocity.

In case of turbine, there is a loss in pressure, in case of pump or compressor 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 diffusing passage in case of compressor, there will be an additional pressure rise, so these 2 sum up, give this static head or static energy, this is very important, I want to repeat it again. I want to repeat it again. Here what happens, I know V2, I know V1, I know VR1, I know VR2 because all the relative velocity that inlet and outlet is given.

And again I know U2, U1 because the impeller diameter such given and the speeds are given. I am not solving this problem, I just write U2 is pie D2 N and U1 is pie D1 N. N is given, greater speed 1500, 1500 rpm. So that we can, 1500 rpm, so that we can do this thing, better I write here.

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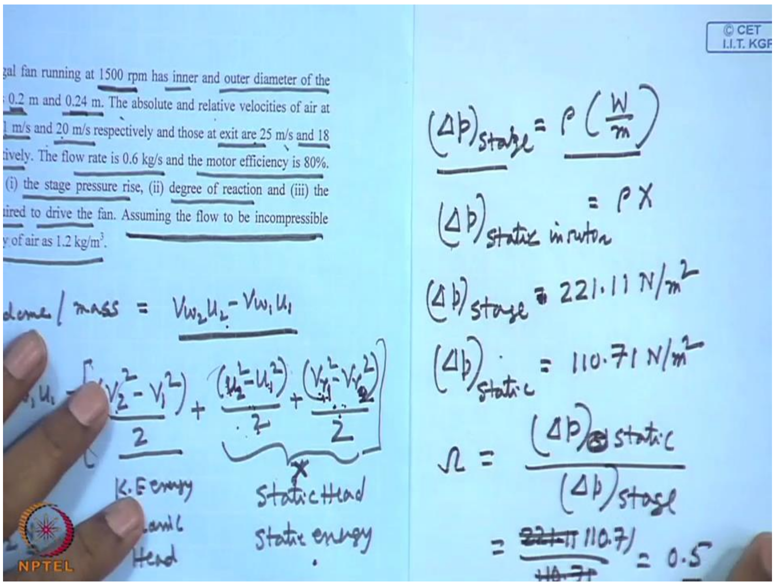

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done / mass $= V_{w_2}U_2 - V_{w_1}U_1$

$$U_1 = \left[\frac{(V_2^2 - V_1^2)}{2} + \underbrace{\frac{(U_2^2 - U_1^2)}{2} + \frac{(V_{r_1}^2 - V_{r_2}^2)}{2}}_{X}\right]$$

K.E energy and Head

Static Head

Static energy

$$(\Delta p)_{stage} = \rho\left(\frac{W}{m}\right)$$

$$(\Delta p)_{static\ in\ rotor} = \rho X$$

$$(\Delta p)_{stage} = 221.11\ N/m^2$$

$$(\Delta p)_{static} = 110.71\ N/m^2$$

$$\Omega = \frac{(\Delta p)_{static}}{(\Delta p)_{stage}} = \frac{\cancel{221.11}\ 110.71}{\cancel{110.71}} = 0.5$$

So that U1, U2 I find out U1 this way, U2 this way, we can find out and then what we do, we can find out the work done. 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, 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. Okay, 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 denote as X, rho into X, this part I am denoting as X, rho into X. So if you find out this by putting this value, you get Delta P, total stage, that means impeller and the diffuser, total P stage. Because the work is done only in the impeller, Delta P Total is 221.11, okay, Newton per metre square and Delta P in rotor or static pressure rise, static, okay.

So that is static pressure across the stage is 110.71 Newton per metre square. Now here is 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. Okay. 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 110.7, sorry, it is just reversed, 110.71 by 221.11, this will be 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 discussions 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 diverted by the, 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 machine.

And this definition holds true for every machines in case of centrifugal compressors and axial flow compressors, this was manifested in terms of the enthalpy change, where you considered along with the temperature change. Okay, but here, what happens, when you consider the flow to be incompressible with a 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 we discussed in terms of hydraulic machines that Delta P static divided by Delta P stage.

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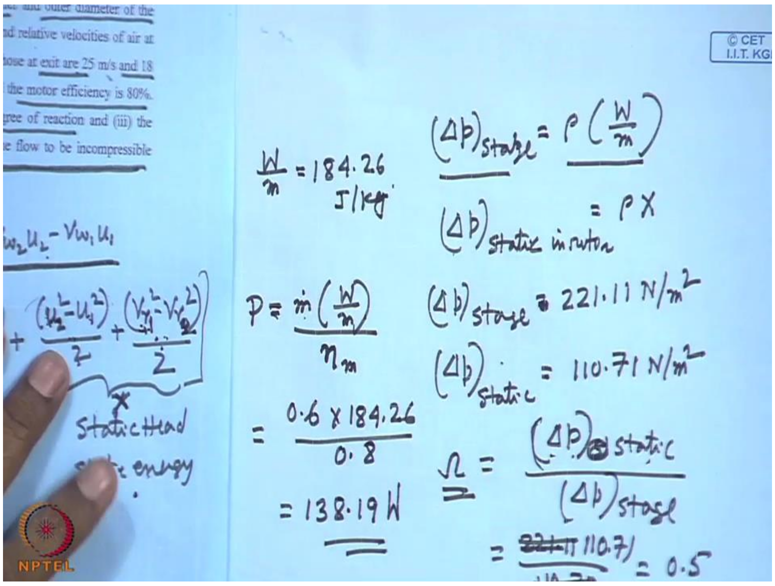

Okay. So this is the same. So therefore we find this, now next is the power required, what is the next one? And the stage pressure rise, degree of reaction and the power required to drive the fan. How to find out the power required? Power required is very simple. Power required we can write here. Power required is a 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 efficiency. That means you write the motor efficiency in the denominator. That means, 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.

Actually W by M here, W by M calculated will be 184.26 joules per KG. So therefore this will be 0.6 into 184.26 divided by 0.8 which is ultimately in 138.19 watts. Okay. 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 a Euler’s equation, this can be splitted in this term. For an incompressible flow with a constant density, it is better to look upon this way that this is the static head rise and this is the kinetic energy.

Sum of all the 3 is the energy input to the machine and that is the total head that is raised in the fluid. So this is the denominator there per stage and this is the numerator. Okay. So therefore the degree of reaction is this divided by this, it was discussed earlier, when I discussed hydraulic machines in general, this is from degree of reaction. So this is called out to be the numerically, Delta P stage, which is found out rho times the work done per unit mass. That is the total pressure change in the machine and the static pressure change in the machine is rho times this part, this is X.

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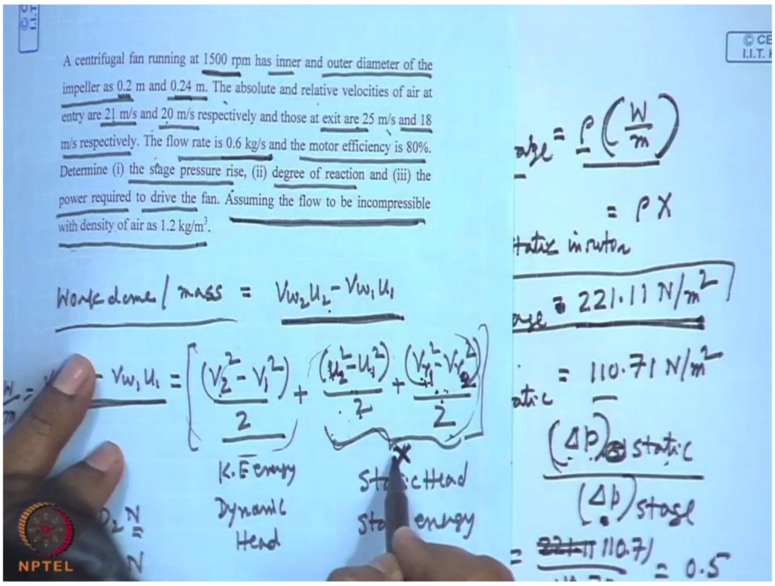
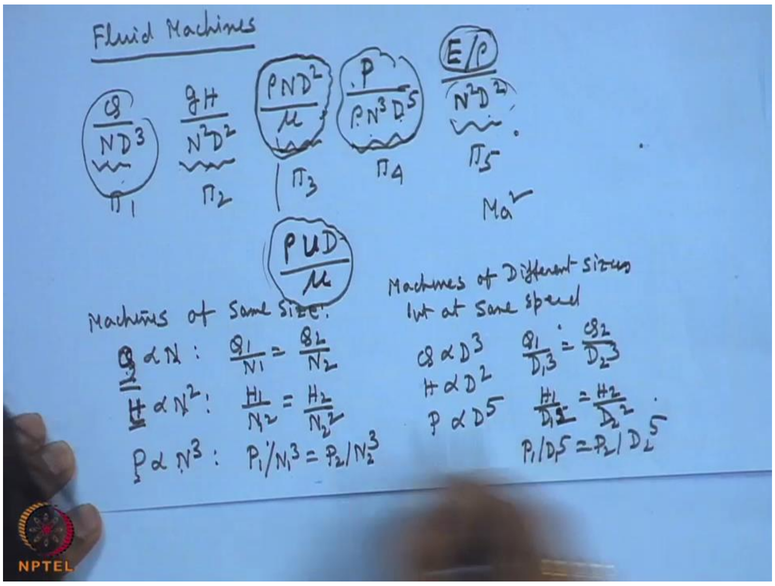


A centrifugal fan running at 1500 rpm has inner and outer diameter of the impeller as 0.2 m and 0.24 m. The absolute and relative velocities of air at entry are 21 m/s and 20 m/s respectively and those at exit are 25 m/s and 18 m/s respectively. The flow rate is 0.6 kg/s and the motor efficiency is 80%. Determine (i) the stage pressure rise, (ii) degree of reaction and (iii) the power required to drive the fan. Assuming the flow to be incompressible with density of air as 1.2 kg/m³.



Again I repeat this part, the static head, that means this is the energy per unit mass, this into a rho is the Delta P static, so 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? Because sometimes, you will see that people tell about fan laws, what is fan laws? This is a terminology actually. Now in general for any fluid machines.

When I discussed 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 Buckingham's pie theorem, the different pie terms as the criteria of similarity parameters. If you recall that, see my earlier lecture notes, then you will find these terms are like this, Q by, one term is like this ND cube, another term is GH by, there are 5 terms, N square D square, another term is rho ND square by mu, another term is P by rho N cube D5, another term is E by rho divided by N Square D square.

Now these are all pie terms. This is let pie one, this is pie 2, this was told at length in one of the earlier class there are 5, 4 and 5. Now when we derived the pie terms for centrifugal compressors, we had 4 pie terms, this is because this term be neglected, the effect of viscosity we did not take. In fact the viscosity has less effect in fluid machines, why I will tell you now. Earlier also I told but these 4 terms we got but not in this fashion, in a different fashion.

I told you earlier in last classes, this is an essence or corollary of pie theorem that that depends upon the choice of repeating variables. You arrive, number of terms are same, you arrive some pie terms which may not match exactly the pie terms you want or the way you express the results. Then a combination of pie terms is also a pie term. So different combinations can be made by making the numbers same so that you arrive at different pie terms. So therefore the pie terms of centrifugal compressors which we derived can be recoupled or rearranged to get the similar type of things.

So these things were earlier explained, I am not going into detail of it, but this term I tell you, as you know this term represents a sort of Reynolds number. Because rho ND is the velocity U D by mu. That means this U is peripheral speed, that means it is a Reynolds number based on peripheral speed. So it can be changed to Reynolds number based on another flow velocity also. Physically it represents a sort 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 pressure loss or any other parameter, the Reynolds number does not have much influence. So therefore in centrifugal compressors also, we have not included the property new to find out this dimensionless term. So therefore, in the fluid machines, earlier I also told, this term is not of that relevance, so only these terms are relevant.

Now if you take this term, now you see, this is not only for fan, for any fluid machines, that if you, now this term is a nondimensional power rho N cube D5. Disturb you know that E by rho is the square of the acoustic speed or the speed of sound in the fluid medium relative 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 thing.

So therefore you see that, now if you see all these pie terms, now you see that for any fluid machines, if we make the fluid machines, machines of same size, machines of same size, machines of same size, machines of same size, then we can tell that Q is proportional to N because D is same from this pie term, 1st pie term, which gives Q1 by N1 is Q2 by N 2, this is school level thing. From the 2nd pie term, we see that the head, because flow and the head is very important. What is head, this is GH, that means energy per unit mass. That means energy per unit weight, that means this is the energy either gained by the fluid or available by the fluid or given away by the fluid depending upon whether it is the compressor, pump or turbine, H is proportional to N square.

That means H1 by N1 square is H2 by N2 square. Similarly, if we take this term, then we can write power is proportional to N cube, which means that P by, P1 by N, that means this is the scaling law, P2 by, that means we are interested in 3 quantities, Q, H and P. And multiplication of these 2 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 the same size.

And machines of different sizes but at same speed, different sizes, sizes but at same speed, one can derive from this formula that Q is proportional to D cube, H is proposal to D square, obviously if you know these 2, you do not have to see the pie term. Otherwise pie term is wrong, means it has to be D5. That means Q1 by D1 cube is Q 2 by D 2 cube. Q H1 by D1 5 is H2 D1 square is H2 by D 2 square. And similarly P1 by D1 5 is P2, this is so simple, D2 5.

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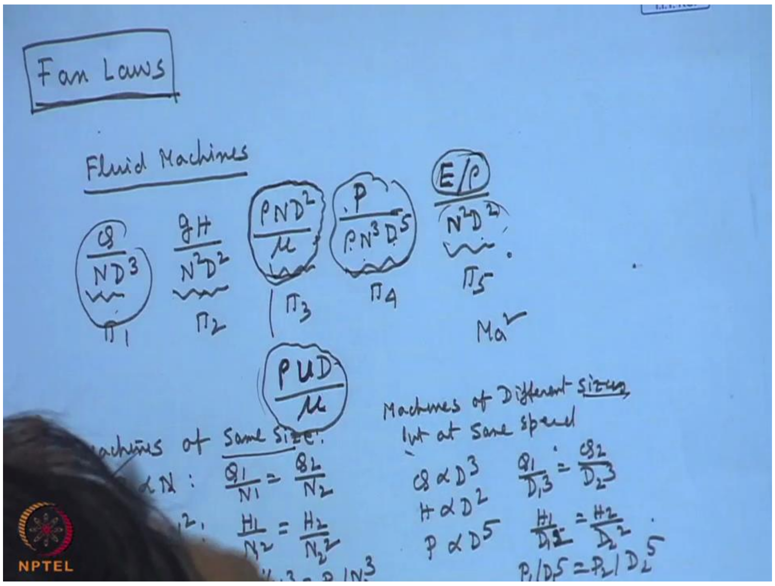

That means the scaling laws with speed for the same size and with size which is represented by the impeller diameter is a representative characteristic size for the same speed is known as, this is the scaling based on the similarity parameters of fluid machines and valid for all fluid machines but usually because this grew like this that initially the fans and blowers, they were designed to make the prototype, they use this type of scale. So till date, these scaling laws are known as fan laws in designing the fans.

So therefore while studying the fans, we must know what is the fan law, fan law is nothing but the scaling law for the volumetric flow rate, the head, that means the energy per unit weight or energy per unit mass, you can take GH, does not matter, G is constant and the power with the speed for the same size and with the size for the same speed are known as fan laws.

So I think today we will stop here and, we are, we, I would like to close the lecture on these fans, blowers and last class we discussed the axial flow compressors, before that we discussed the centrifugal compressors. And including all today I will stop or I will close my lecture series on fluid machines, initially hydraulic machines, basic principles of fluid machines, hydraulic machines and then centrifugal compressors, axial flow compressors and the fans and blowers. Okay, thank you.