Fluid Machines.

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Lecture-6.

Basic Principles, Analysis of Force and Power Generation Part I.

Good morning and welcome you all to this session on the course on fluid machine. In last class we discussed the concept of specific speed which originated from the principle of similarity and we recognised the different similarity parameters, nondimensional parameters which are the similarity parameters of fluid machines from where we derived an expression for specific speed which are also the similarity parameters and their physical implications. Now in this class we will describe, we will start describing from this class onwards different hydraulic machine.

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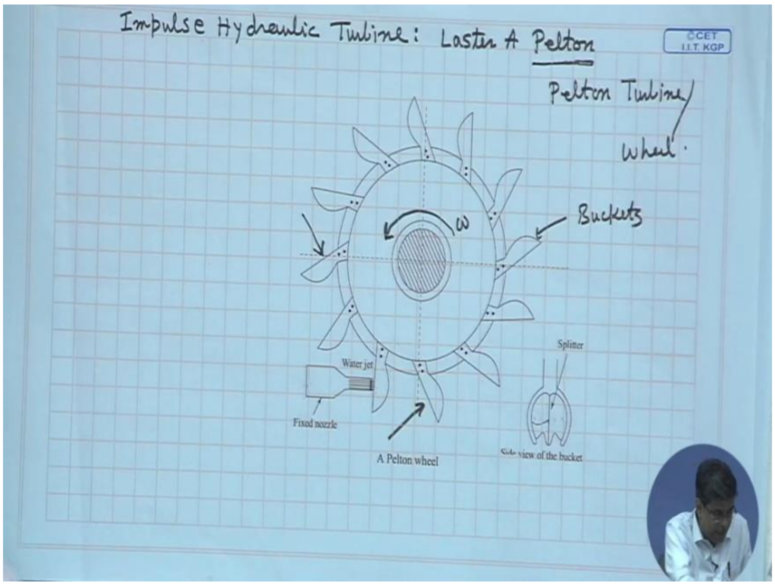

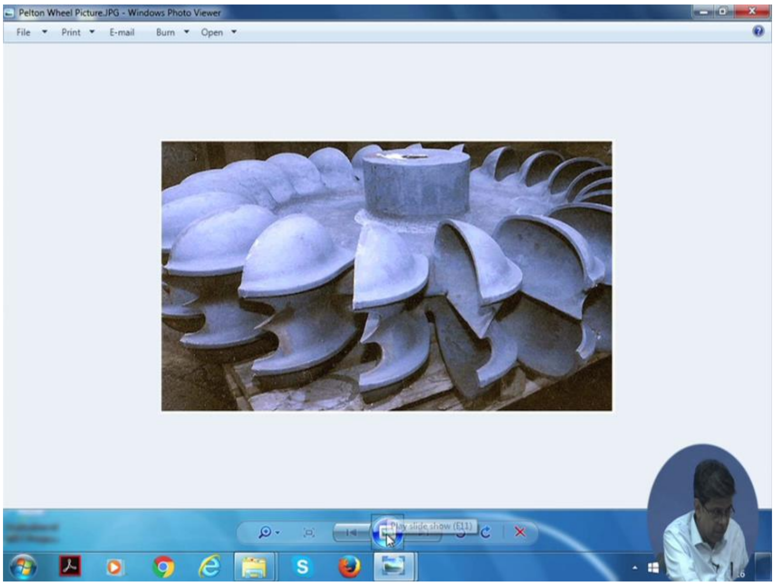

Now 1st we will start with an impulse hydraulic turbine. We start with an impulse hydraulic turbine, which the very simple type of impulse hydraulic turbine was developed near the end of 19th century and the person who contributed a lot to its development is named as Lester A Pelton, he was not American engineer, he was an American engineer and following his name, this impulse hydraulic turbine which we will describe today we will discuss today, I will describe today is known as Pelton turbine or Pelton wheel, Pelton turbine, Pelton turbine.

Or sometimes it is known as Pelton wheel. Now the Pelton turbine in its simple forms as you see is represented by a principally by rotor, this is the shaft on which a large disk or wheel is mounted, which executives a rotating motion, this direction, rotating motion, angular velocity omega and this large disk or wheel mounted on the shaft, there are number of spoon shaped buckets which are uniformly spaced over the periphery of this disc. These are the spoon shaped bucket or spoon shaped blades, these are usually known as buckets, they are usually known as buckets.

These are actually the blades, buckets, they are mounted on this disc, on the periphery of the disk uniformly throughout the periphery of the disk, the spoon shaped bucket. The shape of the bucket is like this, if you see a view from this end, a view from here is a view like this review like this if you will see, you will, if you see a view like this, you will see a shape like this, this is a spoon shaped is symmetrical 2 halves, there is one splitter which divides the flow into 2 halves, this is the 2 half, this is a typical spoon shape.

And there is one or more nozzles which are fixed, which directs a waterjet with high velocity to hit this bucket which hits this splitter reach, which hits this splitter reach and the splitter actually divides the flow into 2 equal halves, into 2 sections of this spoon shaped bucket and this nozzle is fixed one and at the inlet of the nozzle, liquid enters at a very high pressure because of its existence at a very great altitude. From a great altitude the liquid comes via pipeline and comes to the base of this nozzle at high pressure and this pressure is converted into high velocity by the nozzle and this directs a waterjet, high velocity waterjet to this bucket or this own shaped blade and this executes rotary motion.

Thus the power is developed. So this fixed nozzle is the stator part of this turbine and this is the rotor. Now this is an impulse turbine because of the fact you see that the entire pressure at the inlet of the nozzle, the stator part of the machine is converted into velocity, this is because the jet is injected into open atmosphere and therefore there is no casing needed as such for the operation of this turbine, casing may be needed so that water should not go out, okay, to actually splitting of water outside, to prevent that, casing may be needed but for operation, casing is not needed, which means the buckets are exposed to atmosphere, the jet is exposed to atmosphere.

That means the stator part of the machine, that means a nozzle issues a waterjet with high velocity but at atmospheric pressure. So when the flow takes place in both the halves of this wound shaped bucket, the pressure is throughout atmosphere. So there is a no change in pressure, pressure remains the atmospheric pressure, so therefore by definition it is an impulse turbine. And at the same time the turbine is a tangential flow type because the direction of flow in both the halves of this spoon shaped bucket is in the tangential direction of the rotation.

You can see a better view of this if you say picture like this, I will show you how does it look in a diagram, please you see this diagram, you can see this thing better, this is a practical, this has been taken from real Pelton turbine or Pelton wheel that operates in a hydraulic power station. You see this is the, this is the shaft here it is mounted, this is the huge, the large disk and this is the spoon shaped, this is your spoon shaped bucket.

This is the splitter, so water strikes here and it enters here and goes out like that. So it is divided equally into halves, so water jets strike here and it is flowing along the blade in or along the buckets in both the directions. So therefore you see, these are the spoon shaped buckets as I have shown you in the other picture and here it is very clear. So if you see the water inlet and the outlet, the fluid inlet and outlet in both the halves, they take place both the inlet and outlet at the same radial locations.

And the flow direction is mainly tangential, this direction, this direction is the tangential, the rotation is in this direction. So therefore this direction and the coming out direction is almost tangential, that is tangential flow. And inlet and outlet is that the same radial location, inlet vary with the radial location depending upon the height of this or the width of this bucket. Similarly the outlet at different points vary but for any point at any section if you consider of this bucket, inlet and outlet is at a given radius.

Usually the speed of the bucket is specified at the Central plane, that means this Central line, that means this line, that means this centreline of the bucket. That means the bucket has a width in this direction and the centreline, that means we calculate the linear speed by multiplying the multiplying the angular velocity with this radius at the Central plane. Now one thing should be clear that inlet and outlet does not vary in their velocity, that is the rotational velocity of the blade and they are at the same radial locations.

And this way the Pelton wheel walks, the jet strikes here and they glide along the spoon shaped bucket equally in both halves and come out like this, this is a typical thing and this thing rotates, this is the shaft. This is the vertical shaft, this entire rotor or it is known as Pelton wheel with the disk and with the spoon shaped buckets mounted on it rotates in the horizontal plane. Okay.

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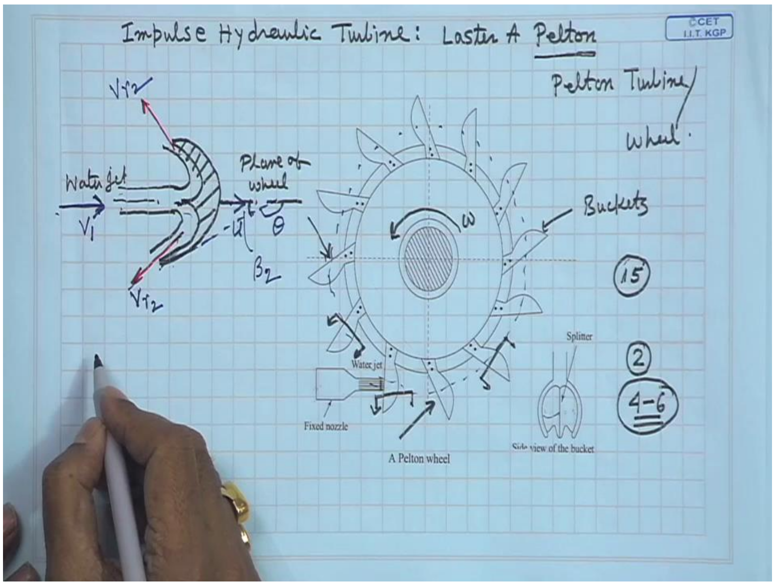

Now if you come here, you see that this is the same thing that is described by principles like this. So therefore it is impulse action, it works on impulse action. Now let us draw a diagram, that means as you have already seen the Pelton wheel in a better picture, now you can understand that if we see a sectional view like this, if we cut it like this and see a sectional view like that. That means if I cut this, the perpendicular direction if I see, it will look like this as you have already seen, now you can appreciate this, it is like this.

The bucket is like this, this is the splitter reach, this is the bucket. And the waterjet is directed like this and this is the plane of the wheel, plane of wheel, this is plain of wheel, this is the waterjet, this is the waterjet coming from the nozzle. And it comes here and it is divided into 2 parts. Before that let me tell you that the number of buckets are usually little more than 15 at it depends upon the specific speed that I will describe afterwards. It is usually little more than 15 and it is inversely proposal to the specific speed of the turbine and the number of waterjets and accordingly the number of nozzles are usually fixed, this is little more than 15, the buckets, it is usually 2 for horizontal shaft and 4 to 6 for vertical shaft.

These are for number of jets or the number of nozzles and this is more than 15 for number of spoon shaped buckets which depend on specific speed. Now, we concentrate here, the waterjet strikes here and smoothly glides smoothly glides over the blade and comes like this. This is the waterjet which comes like this. Now let us consider that the waterjet is coming with a velocity V1 in this direction which is tangent to the at this point. V1, this is the direction V1, it comes like this.

And as it strikes here, this bucket is moving, the bucket, linear velocity of the bucket is U, in the same direction. That means the water jet velocity is in the direction of the speed of the bucket, that means the tangential direction, this is the tangential direction. So this tangential direction is the speed of the bucket and that is specified at the Central plane as I have told, that means this line, the Central, the Central line of the bucket, we specify the speed U.

Which is given by the product of the rotational speed and the radius. Okay. So this is the U the the radial, this is the linear speed of the bucket. Now the jet comes out, the waterjet comes out from the bucket gliding over this surface, that means if we denote the velocity, now the direction of the velocity is coming out from the bucket with respect to bucket, if I write the velocity relative to the bucket is VR2 at the outlet, this is divided into 2 halves, VR2, we will see VR2 must glide along the bucket, that means the duration of VR2 must coincide with the angle of the direction of the bucket at the outlet.

That means if I draw a tangent like that to show this angle is Theta, known as camber angle of the bucket at the outlet and this angle, this site the acute angle is beta 2 as we already used that, the angle of the relative velocity with the tangential direction, this angle is beta 2. Then the relative velocity will be with this angle, that means the angle which will make with the tangential direction is beta 2, beta 2. That means this must glide along the surface. Similar is the case for entrance, that the fluid should enter in such a way that the direction of the velocity relative to the bucket should coincide with the angle or the curvature or the angle of the bucket at the inlet.

And this is a very important requirement for fluid machines that the direction of the velocity relative to the blade at inlet and outlet should coincide with the blade angles at inlet and outlet, otherwise what will happen, the fluid will neither glide at the inlet along the blade nor it will come gliding along the surface of the blade at the outlet for which there will be unnecessary losses. But it is difficult to have a design of a fluid machine which under varying operating conditions will maintain that. But usually at its rated condition it is designed in such a way that the angle of the relative velocity must match with the blade angles and outlet, at the inlet and outlet respectively for the relative velocity.

So therefore whenever in any problem we will specify the blade angles that inlet and blade angles at outlet means that this is the angle the relative velocity makes. If the blade angle at inlet giving with respect to the direction of motion in the, with respect to the direction of the blade motion is beta 1, that means this is the angle of the relative velocity with the direction of motion of the blade like this. So they should match each other VR.

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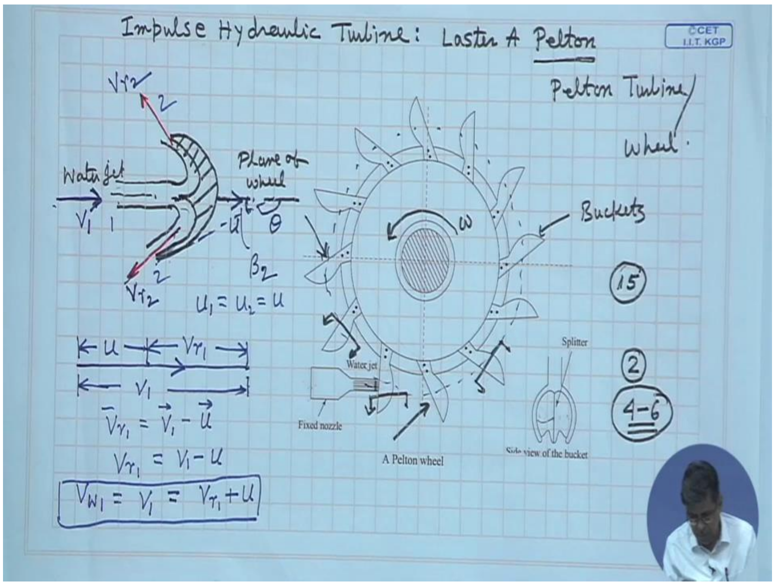

Now with this concept and taking a single cross-sectional view of a single bucket, the way the waterjet comes, hits it and glides along the surface of the bucket, we can draw now the velocity vector or the velocity to angle. At inlet, the velocity triangle will be like this. This is the V1, let us consider this is V1, V1 is in this direction. Now U the blade velocity is also in the same direction and he has one thing is that inlet and outlet, this is at 1 and this is 2, U1 is equal to U2 is equal to U because the blade velocity is same at inlet and outlet.

It hits here and comes out and you have seen in the earlier picture in much clear fashion, was clearly that inlet and outlet, they do not vary in their radial locations. So U1, U2 is equal to U. And they are in the same direction, so the vector diagram we just show you as this. So this part will be the relative velocity at inlet VR1. Well, now we know the definition, relative velocity is vector subtraction V1 - U and here they are in the same direction, so VR1 is V1 - U.

Now the tangential component of the fluid velocity at inlet VW 1 is nothing but V1 because V1 itself is in the tangential direction, so that will be equal to VR1 + U, VR1 + U, well VR1 + U.

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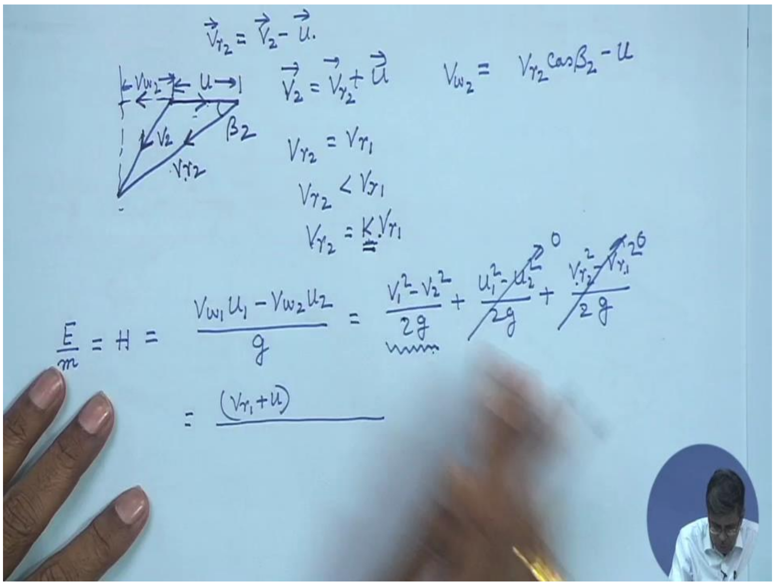

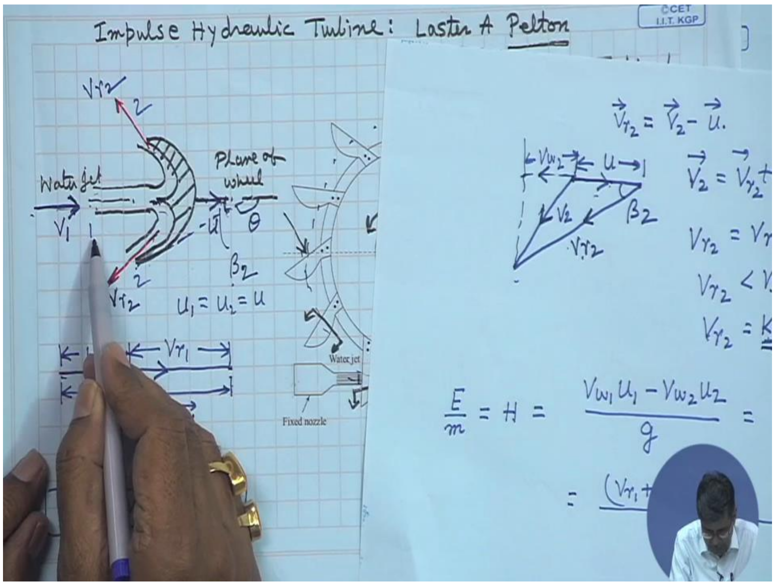

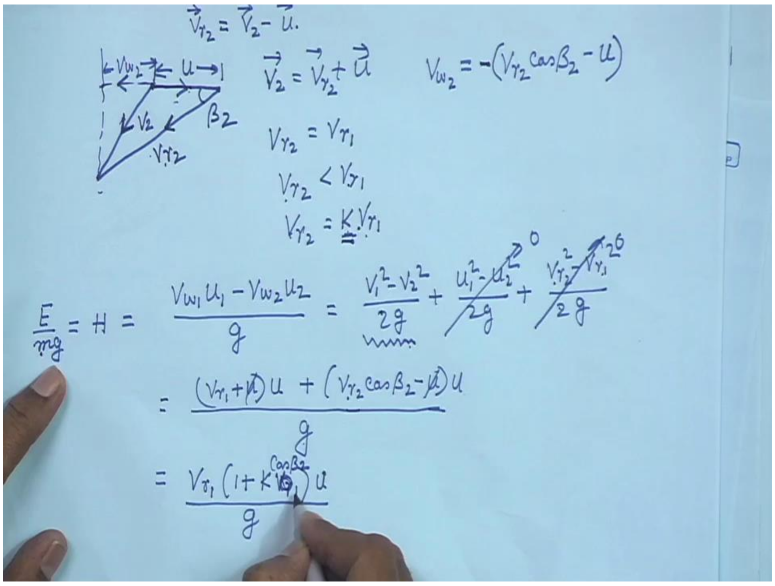

Now we draw the velocity vector or the velocity triangle for the outlet. For the outlet we will draw the velocity vector or the velocity triangle at the outlet. Okay. Now the velocity vector at the outlet if we draw, we see this picture, it will be enough. Now here, this is the VR2, so therefore here 1st we draw, now we write one thing that VR2, how to draw the velocity vector or the velocity triangle, VR2 is V 2 - U2. VR2 is V2 - U2, U2 is U, that is U only.

Now we draw this U, U is same for that inlet and outlet, okay. Now we draw the velocity vector like this, this is direction U because this was our direction U, this is the direction of U, okay. So this is the direction of, now this is the direction of V R2 and this is beta 2, this is given by this angle, this angle is beta 2, that is the blade angle at the outlet. And this is therefore V and you see this satisfies this equation, how because you can write V2 is equal to VR2 + U.

You check it like that, U + VR2 in a sense makes this resultant velocity which is in opposite direction in the triangle, velocity triangle, that vector triangle. So this is the outlet velocity. Now here there are certain things to understand. So this is the outlet velocity triangle. Now VR2 and VR1, the inlet relative velocity and outlet relative velocity should not change because this will change and I have told when there is a change in the flow passage, cross-sectional area of the flow passage, there is a change in the cross-sectional area of the flow passage.

But this is an open flow, the flow is open to atmosphere, so with respect to this bucket, the velocity of the fluid will change because only of the friction. So in absence of friction or liquid viscosity, VR2 is equal to VR1 but because of the friction, if we consider the friction of the blade or the bucket surface, then VR2 is less than VR1 and we use VR2 as some K times VR1, K is a multiplying factor which is little less than 1. The value is very high, it is in the order of 0.9 or more because the surface is very smooth and polished. So therefore VR2 is almost equal to VR1.

But there is a deduction in V2 and this is the component VW2. So therefore we see that VR2 remains almost same, U remains same, it is only the change between the V1 and V2 that gives the power, that gives the mechanical energy or head to the rotor. Now let us write that equation that head or energy given to the rotor per unit mass E by M, that is the head given to the rotor which we already VW 1 U1 - VW2 U2 by G. Well and this can be written also for understanding like this V1 square - V2 square by 2G, okay, I write 2G again and again.

U1 square U2 square by 2G in general, this is in general + VR2 square - VR1 square by 2G. Now in this case this is 0, U1, U2 and VR2 is also equal to V1, VR1 almost equal to VR1, this K value is very high so that there is a loss due to friction only and if you neglect the friction it is 0, so this is responsible only for this, this equals to this. So therefore there will be reduction in absolute velocity. Now if we write this VW 1 U1, now V W1 is V1 VR1 + U, so therefore let us write V W1 is VR1 + U. VR1 + U.

Now what is VW2 here? We write VW2 from this triangle, trigonometric relation, VW2 is VR2 cos beta 2 - U, VR2 cos beta 2 - U. Here beta 1 is 0, that is why I am not using beta-1 the angle because U is, V is or the VR1 is same direction, here in the tangential direction coinciding with the inlet angle of the bucket, so that is why it is 0. Now this component of V2 is in this direction, which is in the opposite direction to that of the VW 1, V W1 is this one, V1, it is in this direction and this goes in the opposite direction, this component is in opposite direction, that is the direction opposite to the jet velocity.

So therefore taking the direction of the jet velocity or blade velocity which are in the same direction as positive, this will be -. So therefore we take this as -, so this into U and - - + + VR2 cos beta 2 - U into U divided by G. Okay. So we can write this. So therefore we can finally get an expression that this becomes equal to V R1 into 1 + and VR2 if we just write K VR1, K is a multiplying factor which takes care of the friction. K VR1, 1+ K VR1, VR2 is equal to this U U cancels, one + U, okay, divided by G.

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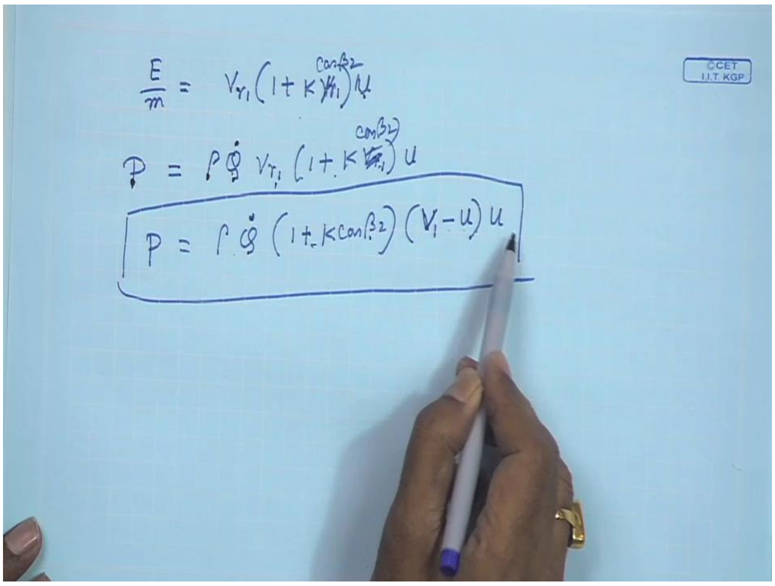

G is per unit mass, MG, sorry, but unit weight, okay. So therefore energy added or the head added per unit mass will be, therefore head added per unit mass will be E by M will be simply V R1 + K VR1, VR1 one + K VR1 into U, U is the blade velocity. Okay. Now if we want to find out the total power that is being delivered to the rotor by the fluid then we have to multiply this head given by the fluid to the rotor into the mass flow rate. And what is mass flow rate?

It is rho times, it can be written, the mass flow rate of density into the flow rate Q, that is the mass flow rate. Usually in hydraulic machines we use the nomenclature volume flow rate when the fluid is incompressible. When dealing with water, we always use the volume flow rate, that is why we are writing rho Q dot instead of M dot. Rho Q dot VR1 1+ K VR1 into U, okay. Now this VR1 we write 1 by Q, 1+, sorry K VR1, VR1 I have taken common, it is wrong, I have done something wrong here, sorry, K cos beta 2, I am sorry.

When we have taken VR1 is common, VR2 is VR1 cos K cos beta 2, sorry one + K cos beta 2, I am extremely sorry. So it is 1+ K cos beta 2, 1+ K cost beta 2. So 1 + K cost beta 2, now VR1 again I replace by V1 - U into U. This is the expression for power delivered to the rotor by the fluid. I am sorry this will be one + K cos beta 2, here I did a mistake hurriedly that U U cancels, VR2 is equal to K VR1, when I take VR1 as common it will be one + K cos beta 2 by G.

So per unit mass it will be VR1 1+ K cos beta 2 into U. So total power developed by the rotor or given to the rotor or the wheel by the waterjet is rho Q dot into one + K cos beta 2. VR1 again I am writing as V1 - U into U, this is the power delivered. So this class up to this, thank you.