Fluid Machines.

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Lecture-8.

Specific Speed, Governing and Limitations of Impulse Turbine.

Good morning and welcome you all to this session on the course on fluid machine. Last class we discussed the power developed by Pelton wheel and how the hydraulic efficiency and the overall efficiencies are defined. And the condition for which we have the blade efficiency or the wheel efficiency maximum and also the practical condition for which the overall efficiency is maximum.

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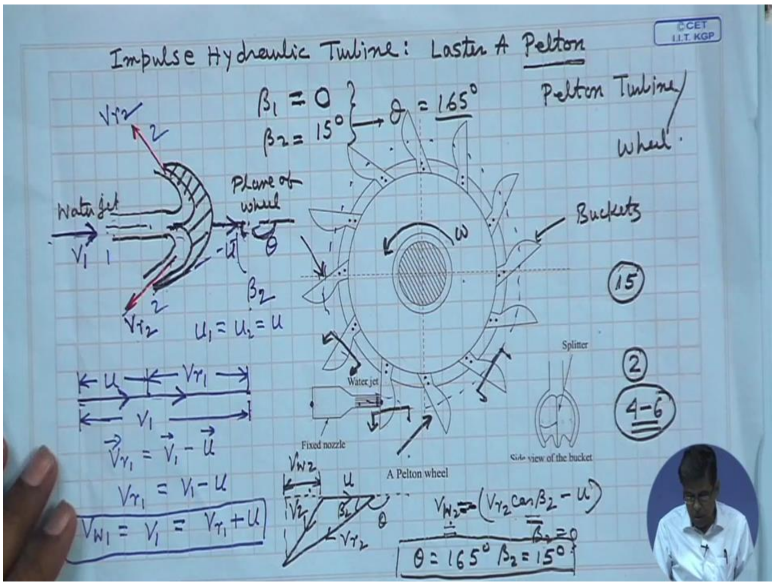

Now today we will start the discussion with one thing that this bucket if we go back to our earlier picture of a basic wheel of a, main wheel of a Pelton turbine or Pelton wheel. Now the shape is a spoon shaped bucket which already be discussed earlier. Now we did not discuss this in the last class, about this angle of this this blade or the bucket at the inlet and outlet. Now it was told that inlet, the angle is in the direction of the tangential motion. That means if we define the angle with respect to tangential direction as beta 1 and beta 2 that is the blade angle at inlet and outlet angle made with the direction of motion, the tangential direction.

Now at inlet the blade is made like this or the bucket is made like this, the cross-section of the bucket, that beta 1 is 0, this we already realised and used this, the velocity triangle becomes a or the velocity vector diagram becomes a straight line. Now this is the outlet velocity triangle or velocity vector diagram where we have denoted beta 2 as this angle, this is beta 2 or Theta, 180 degree minus beta-2 as the angle of the bucket at the outlet. Now from the momentum change point of view, for the maximum change in the angular momentum, this VW2 should be maximum when beta 2 is 0.

Should be maximum and in that case beta-2 will be 0, which means that the velocity of the fluid relative to the bucket has to be deflected by 180 degree, completely opposite to its inlet velocity or the velocity at the inlet with respect to the bucket. To do that, beta-2 has to be 0, from here also we see that beta-2 0, we get the maximum value of VW2 and hence in the maximum change in the angular momentum and hence in the maximum driving torque or the maximum energy transferred to the wheel.

But though it is true from the theoretical point of view, it cannot be realised in practice because if we make beta-2 zero and make this velocity relative to the bucket, that means this relative velocity VR2, just opposite to that of V1 or VR1, then what will happen, the jet coming out of one packet will hit the preceding bucket, will hit the back of the preceding bucket which may cause damage to the bucket. For these reasons, the 1 degree angle is not made for Theta and Theta is made equal to 165 degree and hence beta-2 is 15 degree. So this is the recommended blade angle at outlet by the recommended blade angle at the inlet is 0.

So therefore we can write here 15 degree. That means this corresponds to Theta if we define Theta this way, 165 degree. Now next, we are going to derive an expression of specific speed for a Pelton wheel. Specific speed for a Pelton wheel.

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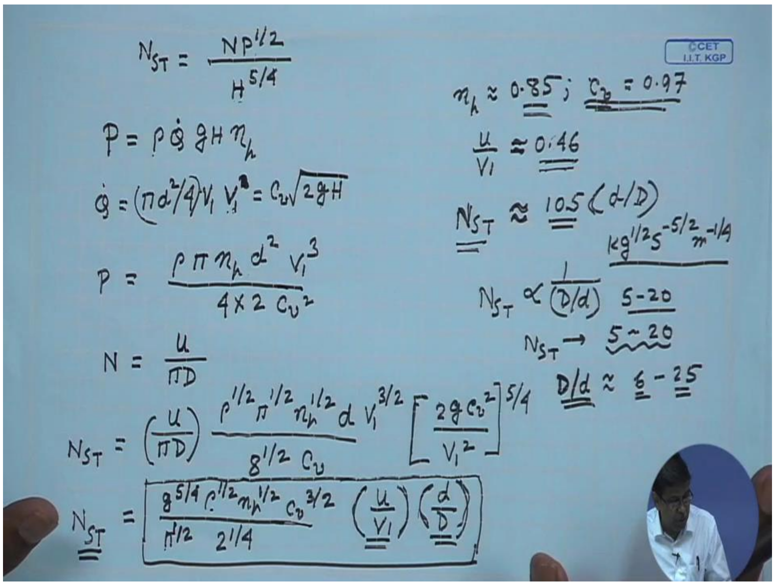

Now if you recall, the specific speed is defined as for a turbine, NST is defined as NP to the power half H to the power 5 by 4, NP to the power half H to the power 5 by 4. Now for a Pelton wheel we can write this P, what is this P, N is the rotational speed of the turbine, P is the power developed by the turbine, H is the head available to the machine, to the turbine. Now if we define this power developed in terms of an hydraulic efficiency this way, that rho Q dot is the rho is the density volume flow rate into GH where H is the head available at the inlet to the machine times the hydraulic head.

That means this is the definition of hydraulic efficiency, P divided by the energy, rate of energy available at the inlet to the machine rho Q dot GH where H is the gross head. If we define in this fashion Eta H and at the same time if we use this relationship Q is equal to pie D square by 4 and at the same time the inlet jet velocity to the wheel V1 square rather 1st I write V1 is CV root over 2 GH, that is from the use of Bernoulli's equation where we get V1 is root over 2 GH and multiplied by a factor CV known as coefficient of velocity which takes care of the friction in the nozzle.

So if we define this way, then we can write this thing as P is equal to rho pie, okay, rho pie, now we take Eta H here. Take these things together. Pie D square by 4, so D square by 4 into V1, okay. Pie D square by 4 into V1 and again GH is V1 square by 2 CV square. So combining these 2 we can write 4 into 2, that is it will be 8 CV square V1 Q, CV square V1 Q. That means we are substituting Q as pie D square by 4 rho, this is Eta H so D square into GH, Q is equal to pie D square 4 into V1, sorry pie D square by 4 into V1, I am sorry.

So V1 and GH we can write V1 square by 2 CV square. So V1 Q by 8 CV square, this is P, now if with this value of P and the rotational speed N equals to U by pie D. If N is the rotational speed in revolution per seconds, RPS and U is in metre per seconds, linear velocity and D is the diameter in metre, we can write N is equal to U by pie D. Now if we replace this in the equation, what we will get, we will get NST is equal to U by pie D, 1st we write N, U by pie D, that is N, then P to the power half, that means rho the power half pie to the power half Eta H to the power half D V1 to the power 3 by 2, then this will be 8 to the power happen this will be CV.

Then H to the power 5 by 4, this is the numerator, N to the power half, for the specific speed. The denominator H to the power 5 by 4, we replace ageing terms of V1 against, GH is V1 square by 2 CV, so H is V1 square by 2 CV, 2G CV. So just it is in the denominator, so therefore we can write just you watch or you see CV square, 2G CV square 1 by H divided by

V1 square. It is 1 by H whole to the power 5 by 4. Okay. So this can be written in this fashion, now if I take all this constant together, that means it is like this, if we take G to the power 5 by 4, then pie pie pie 2 the power half this pie pie pie to the power half, then rho to the power half Eta H to the power half, Eta H to the power half, okay.

Then CV, before coming to, let us see CV is 5 by 2 and here CV is 1, so 5 by 2 - 1, so CV to the power 3 by 2. Now 8 to the power half and 2 to the power 5 by 4, it is 2 to the power 3, 3 by 2 -5 by 4, it will be 2 to the power 1 by 4. 3 by 2 minus 5 by 4, 1 by 4. So G has come, here CV we have taken, Eta H rho, pie, then left, what is left, the left part is U by V1. How V1 comes? V1 is 5 by 4, V1 square tend to, we went to the power 5 by 2 and here we were to the power 3 by 2. That means there will be only V1 at the denominator, U by V1 and this D and this D will make it d by D.

So therefore the specific speed of the Pelton wheel can be expressed by this formula. G to the power 5 by 4, formula remains like this, rho to the power half, the hydraulic efficiency Eta H half, CV, the coefficient of velocity 3 by 2 pie to the power half, to do the power 1 by 4 into U by V1 d by D. Which clearly tells that the specific speed depends mainly on these 2 nondimensional parameters, the ratio of bucket speed to the inlet jet speed, bucket velocity to the inlet jet velocity and the ratio of the jet diameter to wheel diameter.

Now these values are almost constant, now G is local gravity, if we take the usual value of rho for water and Eta H Usually lies between 0.85 to 9, 0.85 if we take, the typical value. The typical value of CV, typical value of CV equals to 0.97, if we take the usual value happened in the practice, this Eta H and CV and at the same time we know that if we think that this wheel will run at its maximum efficiency, maximum overall efficiency, then U by V is roughly equal to 0.46. So these values are almost fixed, these values are fixed rigidly and this value is almost fixed.

It runs somewhere, this value 0.46, so if we use this value, then we can express the specific speed of the Pelton wheel by putting these values, you get this type of expression with 105, which is the dimensional constant because this has a unit, that unit is kg as I have already told second to the power minus pie by 2 metre to the power minus 1 by 4. So in this unit, so this is the dimensional unit. This shows that under usual conditions, Pelton wheel specific speed is a function of d by D, that is the ratio of jet diameter to the wheel diameter. It can be expressed in this fashion that this is inversely proportional to the ratio of wheel diameter jet diameter.

This is one very important information. Now Pelton wheel is usually very efficient at a small head so that, small available head, usually specific speed lies between 5 to 20, that means the specific speed of a Pelton wheel usually lies between 5 to 20. Of course this depends upon the number of jet. With smaller number of jets, this value is between 5 to 20. And if you take these values from 5 to 20, the value of d by D becomes equal to from this expression is 105 by 5 or by 20, that means this is something like 6 to 25, roughly. Roughly 5 or 6 to 25, this is the value of d by D.

So therefore you see the ratio of the wheel diameter to the jet diameter depends, the range of this value depends upon the range of the specific speed. Now there are certain things to be known at this stage. That if we have a large d by D, what will happen, if we have a large dia wheel to jet dammit, then the machine will be large and the speed will fall, it will have a lower speed but the machine will be large for which the mechanical efficiency will also be low, which is not desirable.

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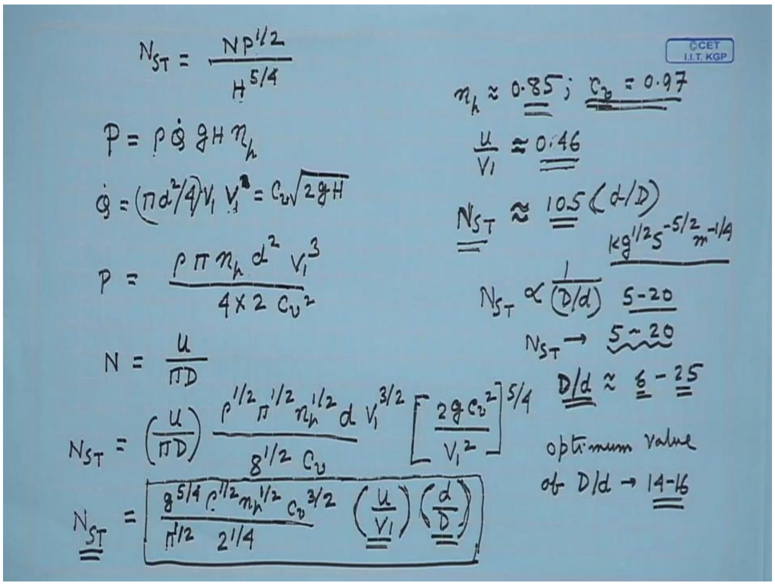

Similarly if we have a small d by D, then what will happen for a small d by D, small d by D means small wheel diameter. Then to get a given power, we have to give more number of buckets so that the bucket spacing is closer for which the hydraulic efficiency falls drastically. And that is also not desirable. So from these 2 points of views, that is 2 contradicting points of views, the optimum value of d by D, optimum value of d by D d by D is lies between 14 and 16 so that it should not be very large to machine making unnecessarily large and bulky, flow running and ultimately leads to a low mechanical efficiency and overall efficiency and again not to be very small to have more number of buckets with closed spacing, also to have a lower efficiency.

So a compromise between the 2 will be made and usually the Pelton wheel gives high efficiency with a lower head so that we tell that Pelton wheel, head his low means what, sorry, I higher head, I am extremely sorry, I take higher head, when head available is high, that means the specific speed is small. I have told usual specific speed is 5 to 20 in this unit, that means at these values of specific speed, low values of specific speed as compared to other machines, the Pelton wheel runs at high efficiency.

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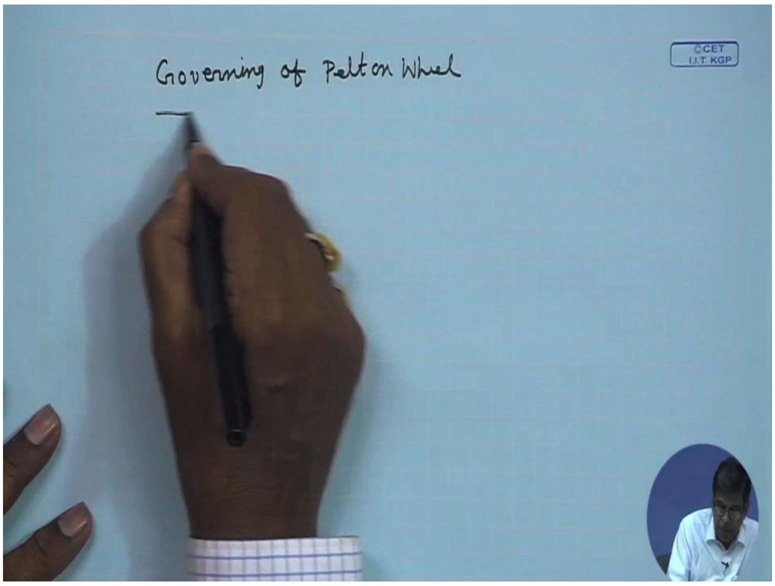

That means Pelton wheel is suitable for low specific speed means at a higher head, where the head available is high. Okay. After this we will come to a very important very important phenomena, what is known as governing of Pelton wheel. And in fact the governing of Pelton wheel, the principle is same as the governing of any turbine. The 1^{st} of all we have to know what is meant by governing of any turbine so that the governing of any turbine if you know the basic principle is same which is utilised in different ways in practice for different turbines, Pelton wheel or reaction turbine.

So what is meant by governing of turbines? Now as we know that turbines generate the mechanical power which is converted to useful electrical power by the use of an electrical generator or alternator which is coupled to the turbine. Now to maintain a constancy in the frequency of electrical power output, the rotor of the turbine has to rotate with a fixed speed. So therefore the constancy in the rotational speed of the rotor has to be maintained.

Again from another viewpoint or from another side, you can see that the speed of the rotor of a turbine depends upon the driving torque which is given by the fluid flowing through the blade passages by exchange of angular momentum and the resisting torque, a balance between driving torque and the resisting torque and this resisting torque comes from the electrical load. So a balance between these 2 torque help the rotor or enables the rotor to run at a constant angular speed. Now what happens when this electrical load changes because of the demand, either it falls down or it goes up.

Then what happens, the speed of the rotor of the turbine changes if we do not change the driving torque. If you do not add any mechanism to changed the driving torque, the speed of the rotor will change, the rotational speed will change. Which is not visible because the frequency of the electrical output will change. Now how to restore the initial speed, this can be restored by manipulating or changing the driving torque to the desired value of resisting torque because of this changing load.

Now for example if the load is decreased, then what happens for a given driving torque, the speed of rotor will increase, so therefore we have to reduce the driving torque. Similarly if the load is increased, then what happened for a given driving torque, that means the resisting torque is more, the speed of the rotor falls down. So therefore we have to increase the driving torque to boost up the speed of the rotor, the speed of the rotor to the earlier value.

And this change or control in the driving torque is done by changing the flow of fluid. Because the energy with that is given to the turbine rotor is directly proportional to the fluid flow rate, so therefore by changing the fluid flow rate it is done that when the load is reduced, we increase the fluid flow rate, to increase the driving torque when the load is increased, we reduce the fluid flow rate to reduce the driving torque to make a balance with the resisting torque that changes because of the change in the load to maintain the constancy in the speed of the rotor and hence in the frequency of the electrical power output.

This is in simple the basic idea, Genesis of governing of all turbines. Now this is done in a Pelton wheel how? Now Pelton wheel as a added constraint because we know the Pelton wheel runs at maximum efficiency for a desired value of U by V1, U is the rotor speed and V1 is the jet speed. So if you reduce the fluid flow rate, then V1 will be reduced, okay. Now when V1 will be reduced, then U by V will be change, U by V1 for example will increase. So we have to see that the change in V1 is not desirable because this will change the ratio U by V and the machine will not run at its maximum efficiency.

You understand that to keep U constant, if you change V1, then U by V1 ratio will change. Why the question of changing V1 comes because you have to manipulate with the fluid flow rate, fluid flow rate is increased or decreased if you make a decrease or increase, then V1 usually gets increased or decreased. So therefore for a Pelton wheel, the attention has to be made that the change in the fluid flow to the turbine should be done in a way that V1 remains substantially the same.

Since for given U1 or given U, there is a V1 for the machine to run at the maximum efficiency. For example for maximum overall efficiency, it is 0.46. So therefore U by V 1 is 0.46, so V1 has to be U divided by 0.46. U is kept same, so V1 has to be kept same. So the fluid flow rate has to be changed, not changing the flow velocity. How it is done, it is done by changing the area in such a way that the flow rate changes along and in same proportion with that of the area by keeping the fluid velocity same. And this is done in a Pelton wheel by the use of a spear valve.

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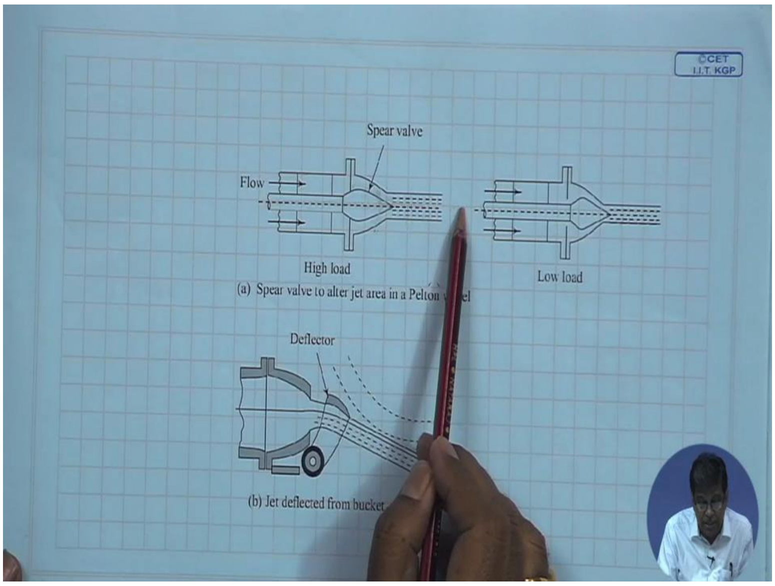

So you see this is a spear valve, this is a spear valve, now this is the nozzle. So by use of a spear valve in a nozzle, now what happens with the load, the spear valve, the entire spear, it moves in the nozzle in this direction. So what happens when it moves in this direction, it controls the annular flow area, there is a flow area, the annular flow area, it is increased or decreased depending upon the motion. If it moves in this direction, this area is decreased, if it moves in this direction, the area is increased.

And accordingly what happens the change in area changes the diameter of the jet. The flow takes place, the streamline is such that it again meets and changes the diameter, diameter is reduced or increased. Here it is increased, here it is reduced. That means the cross-sectional area of the jet is changed in such a way that the change in the mass flow rate of the fluid as demanded by the change in the load should be in proportion to the change in the area. Another way, the change in the area should be in proportion to that so that we can implement or we can execute this change by keeping the velocity same.

Because velocity V1 is equal to Q dot rho that is mass flow rate divided by the cross-sectional area of the jet, cross-sectional area. So what is happening, happening is that these 2 are changing by keeping the V1. And this is reduced, Q is reduced keeping the V1 same. This is increased, Q is increased by keeping the V1 same. This is done in this situation to maintain V1 same. Now this is a case where low load, the area is reduced and the jet area is reduced, the annular area is reduced, jet area is reduced so that it gives less flow rate.

And this is the situation where this is for high load, that means the chat area is relatively high. Now in certain situations, if there is a sudden decrease in flow rate, then what will happen, you have to suddenly choke the flow like this, that means you have to keep the spear like this, choke means to stop the flow, do not confused it with the choking off the compressible flow, that means you have to stop the flow like this. So spear has to move suddenly to this section, to this part, the downstream of the nozzle, that may create a problem of water hammer.

That means a pressure wave may be generated that may go to the upstream and cause the problem of water hammer. So to reduce that problem, what is done, deflector plates are used which deflect the water from the mainstream for the jet to reach the Pelton wheel so that the spear movement may be done slowly. That means the deflector plates help in reducing the flow rate along with that done by the spear movement so that the spear movement in the nozzle may be slow and the water hammer problem may be reduced.

So that the deflectors are used to deflect the jet from the bucket for reaching to the Pelton wheel in case of a certain decrease in the load. So this is all about the Pelton wheel but before I close this thing, I tell the limitation of Pelton wheel. So after reading that one can understand the Pelton wheel works well at a relatively higher head or a lower specific speed because it has to compromise with the ratio of the diameter of the wheel and the jet diameter to have a wide range of specific speed for its efficient operation or to operate at a relatively lower head or higher specific speed.

This we have discussed, otherwise what will happen, the efficiency, the mechanical efficiency will reduce, the hydraulic efficiency will reduce, so we cannot have efficient Pelton wheel at this lower head or higher specific speed. So for these reasons the Pelton wheel cannot be used for those purposes and a solution to that is given by another class of turbine, reaction turbines which we will discuss in the next class. Okay, thank you.