Fluid Machines.

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Lecture-17.

Governing of Reaction Turbine.

Good morning and welcome you all to this session of the course on fluid machines. Last class we have discussed the evolution of axial flow turbines and purely axial from a radial flow turbine. And a purely axial flow turbine is named as Kaplan turbine following the name of the Austrian engineer Victor Kaplan who developed a lot, contributed a lot to the development of this machine. Now in this class we will discuss the governing, the basic principles of governing of reaction turbine, both radial flow or axial flow.

Now if we recall the genesis of governing, that the governing is required to maintain the speed of the rotor of the turbine, fixed, this is because the generator, electrical generator or alternator, it is coupled to the turbine to generate electrical power or mechanical power has to rotate with a fixed RPM, fixed value, rotational value, fixed value of the rotational speed to maintain the constancy in frequency of electrical power output. And the turbine rotor maintain the constancy in the rotational speed by a balance between the driving torque and the resisting torque.

And the resisting torque comes from the electrical load which may change because of the demand. So whenever there is a change in the electrical load, the resisting torque changes and accordingly the speed of the rotor changes for a given driving torque which is imparted by the flowing fluid by the rate of change of its angular momentum. This is the basic principle, Gross overall. Now to adjust with this we have to control the input energy of the fluid accordingly to balance, to make a balance with the resisting torque so that the driving torque is adjusted accordingly.

And this is accomplished by altering the fluid flow to the turbine and this is precisely what is governing. And in Pelton wheel we have seen that this has been made with the help of a sphere valve which is very important in this concept that while making the governing, 2 things have to be always kept in mind. One is that while governing, changing the flow rate, we have to be very careful that the condition for the operation of the turbine, that is the operating conditions in relation with the operating parameters should not change much that the turbine efficiency falls drastically.

For an example we have seen that for a Pelton wheel, it runs at the maximum wheel efficiency when the ratio of feel efficiency or the overall efficiency, when the ratio of the blade speed to that of the jet speed incoming water jet speed is having a fixed value. Theoretically it is 0.5 for the wheel efficiency but practically for overall efficiency, its value lies sometimes, somewhere between 0.45. So therefore one is to be very careful keep this value around this figure otherwise the efficiency of the Pelton turbine will drastically fall.

So therefore this is one aspect we have to be very careful from the operating parameters point of view that while changing the flow rate, while we change the flow rate, the velocity, the inlet velocity of the fluid will change. So therefore we have to see that whether this change the operating condition or not to reduce the efficiency. And number 2 is that sometimes there is a demand to drastically reduce the flow. For example load is suddenly reduced, so that the speed will go exceedingly high.

So therefore to maintain the constancy in speed, you have to reduce the flow, flow of fluid suddenly and as you know a sudden reduction of low in any hydraulic circuit causes a problem like water hammer. If you suddenly close the flow at a downstream section, this increases the pressure, immediately at the downstream section which is transmitted in the flow to the upstream section and the velocity of transmission is equal to the acoustic speed relative to the velocity of the fluid at that stage.

In an incompressible flow, this transmission is very fast, so very fast it reaches the upstream section and again it is getting reflected back from the upstream side to the downstream side and the deflection of pressure causes a problem known as water hammer which is detrimental for the hydraulic system. So therefore to reduce the problem of water hammer caused by sudden reduction of flow at the downstream section of say hydraulic circuit hydraulic system has to be avoided.

Therefore 2 things have to be kept in mind in governing the hydraulic machines that the governing should be made in such a way that it should not alter the operating parameters to reduce the efficiency drastically otherwise and at the same time the water hammer problem is not caused. Now in reaction machines, this is done by this mechanism, I will show you.

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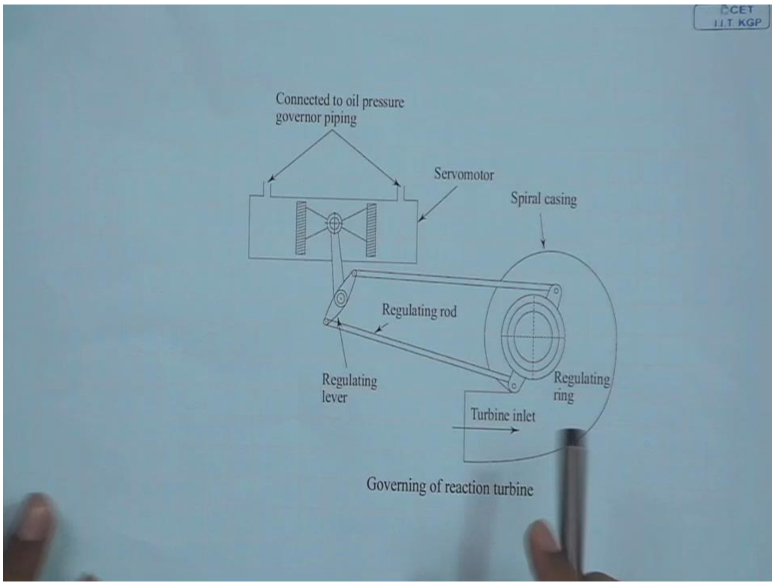

So in reaction machines, this is done like this. This is a reaction turbine, you see this is a scroll casing or volute where the water is entering, that is the inlet to the water, this is the turbine. Now the, as I have told earlier, here it is not shown, the turbine as it comes from the scroll casing, it made the stay vanes and the wicked gates and these wicked gates are the guideways which are pivoted at some point and it can be rotated or swivelled about this pivotal point to change its area of flow.

That means the passage area through which the fluid flows. And by changing this area, the fluid flow rate is adjusted. So this pivotal point is the main point of the wicked gate or the guide vanes, these points are now linked to levers connected to levers through a regulating ring. Connected through levers, through the links and levers through this, to this regulating ring. Here actually this connection of this pivotal point of this wicket gate or the pivots of the wicket gate through the links and levers to the regulating link is not shown in the figure.

So it is the regulating ring where this wicket gates, the pivots of the wicket gates are link, are connected through the links and the levers. Then you see here which is very clear, this regulating ring is connected by 2 regulating rods at this end, by the 2 regulating rods. And the other end of the regulating rods is connected by a regulating lever, you see the regulating lever to the servomotor piston of a oil pressure governor. This is a oil pressure governor, this is connected to oil pressure governor where the pressure pressurised oil enters.

So this is the oil pressure governor and this is the servo piston of the governor, so lever is connected like this. So what is done in case of changing load which is sensitive by this oil pressure Governor actuates this lever and finally through the regulating rod and the regulating ring to the pivots of the wicket gate and finally control the position of the wicket gate, alters the position of the wicket gate and adjust the flow rate and accordingly the mass flow rate entering into the turbine.

The mass flow rate entering into the turbine inlet here through scroll case remains same but when it is adjusted throughout the system reminds the altered mass flow rate. When the load is reduced, a reduced mass flow rate, when the load is increased and increased mass flow rate. So this way the, by the actuation of the oil pressure governor through this lever and the regulating rod and regulating ring, this is being controlled. And this way the control of all the reaction machines is done.

But apart from this there is another mechanism which is acting parallel to this which is not shown here that there is a relieve or pressure valves, relieve valves or we can tell the pressure regulator in the mainline, that means here in the mainline which diverts the water other way and not allows it to reach the turbine inlet. That means it diverts the water reaching from the turbine inlet. It is almost similar to a deflector vane which is not shown in this figure, that is why I am not showing this figure.

Deflector vanes or deflectors, they deflect the jet before going to this servomotor or the spear valve, just out on a different way so that it cannot reach the turbine. Here also the pressure regulator or relieve valves does the same thing. And in both the cases the 2 things work simultaneously together, this is known as double regulation. For example here one through the regulating ring and the oil pressure governor and parallely by this relieve valves.

Some flow is already diverted by the relief valve. For example in a Pelton wheel, double regulation works, some flow is already diverted, not allowed to reach the inlet of the turbine by diverging its way by the splitter, splitter blades deflector blades. And the rest part which is going to the turbine is being controlled by the movement of the spear, that is the spear valve mechanism. Here also the double regulation takes place by the help of this and the pressure regulator, both these things.

And in case of sudden reduction of flow, when the load is suddenly reduced, this pressure regulator is dominant one to reduce that so that the effect of water hammer is reduced. As I have already told that effect of water hammer is a severe concern and one of the important points to be considered. So to take care or prevent the water hammer problem, the pressure regulator or the relief valve in case of reaction turbine and the deflectors in case of Pelton wheel serves the purpose. They act as the sole regulating device.

Now in axial flow turbine, that is the Kaplan turbine, turbine, the type of Kaplan turbine, there, along with that while the mass flow rate is very huge, there is change in the mass flow with the load is little sensitive. So therefore it is made sometimes along with the stator or guide vanes, that is the wicked gates, the runner blades are adjustable to change its area, cross-sectional area of flow to adjust the flow rate or to alter the flow rate. So along with the wicket gates, there is a probability or provision of changing the flow area in the runner blades to change the or accommodate the change in mass flow.

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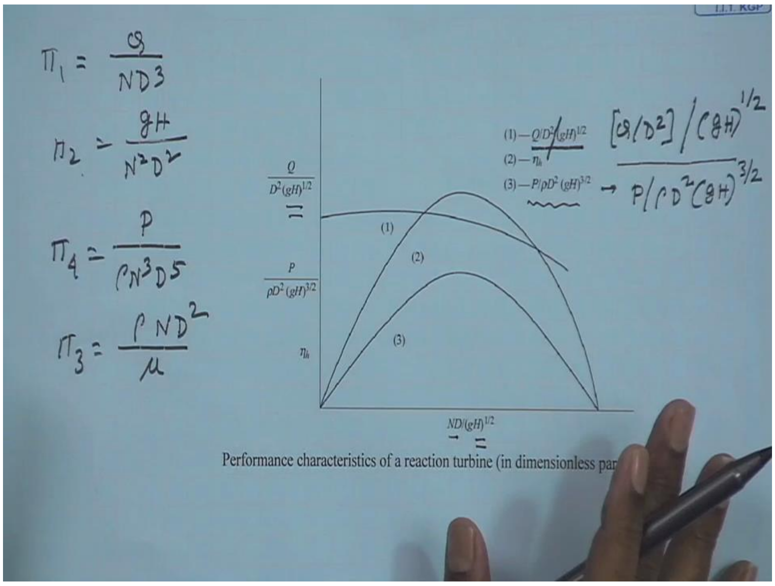

So this is in addition to that and it is usually made in practice in case of axial flow turbine, purely axial flow turbine, that is Kaplan turbine. Okay. Now after this governing mechanism, I will show you certain characteristic curve of reaction turbine in dimensionless parameters. Of course the quantity is not there, it is not quantitative but it is a qualitative. Curve 1 is this capacity and head, this is divided by this U by D square divided by GH to the power half, okay. So this is the 2nd curve.

2nd curve is the hydraulic efficiency and 3rd curve is P by, this is if you see, this is P by rho D square GH to the power 3 by 2. Okay. So this is it. So all these dimensionless parameters are derived from the basic pie terms which we derived at the beginning. For example if you remember we derived pie 1 is Q by the ND cube, pie 2 is GH by N Square D square, okay. So you can get this term, you can see very well that pie 1 by root over pie 2. If you make that, you get root over pie 2, if you make this, then you get Q by D square.

Similarly you get this term, if you remember pie 4 is P by rho N cube D5. Similarly one term pie 3 was there for rho ND square by mu, like that pie 1, pie 2, pie 3, pie 4, another pie term was there which was just this elastic, consideration of elastic force that is 4 compressible flow, okay. Now if you combine this pie 1, pie 2, pie 3, pie 4, you get these terms like that. That when I have given example like pie 1, pie 2 like that.

So this is a nondimensional flow rate or the capacity, this gives it trend like that, there is a decreasing trend for all reaction turbine with actually if you see this figure, GH is there a normalising this flow rate and GH is also there normalising this ND. So therefore this can be exclusively thought just by seeing the trend is the influence of Q with N. Now the hydraulic efficiency curve and this is, these are almost the same curve and this shows a maximum at a particular rotational speed, it increases and then again it falls down.

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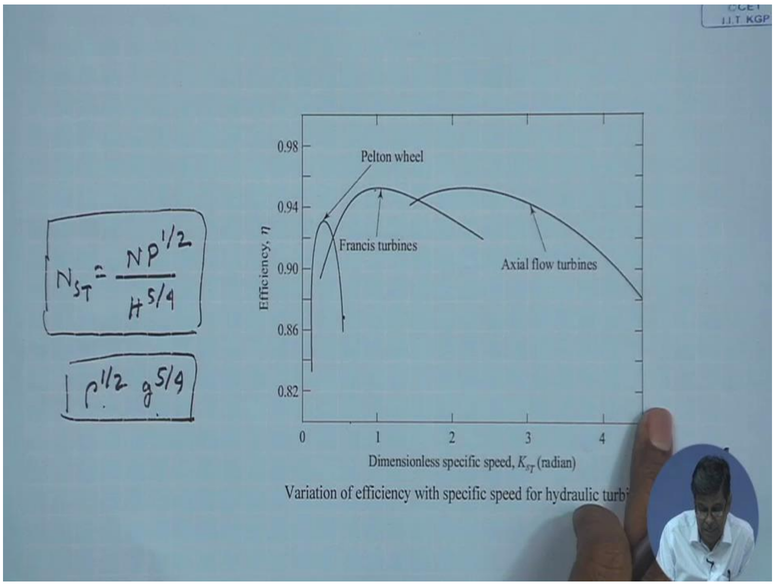

This is purely a qualitative trend you can have a look on it. Now after this, before closing the lecture on the reaction turbine, I will show you the most interesting part with which we started this class on hydraulic machines that the role of specific speed. Specific speed for the dimensionless parameter. From the basic dimensional analysis with the application of Buckingham's pie theorem we derived the nondimensional terms which maintain the principle of similarity of fluid machines belonging to a particular homologous series.

Now you can appreciate what is a homologous series. Pelton wheel is one homologous series, Francis turbine is one homologous series, Kaplan turbine is another homologous series. So therefore machines of a particular homologous series, if we sought similarities between the different machines of a particular homologous series, then those pie terms or the nondimensional terms which are similarity, known as similar terms have to be made same.

Now a combination of these have been made to derive parameter which is again the similarity parameter and it is also, it also physically signifies the principle of similarity between the different machines of the same homologous series. But this combination is done to get rid of the dimension of the machine that the diameter of the rotor. And in case of turbine this was done involving rotational speed, power of the turbine and the head available.

And in case of the pump or compressors, it is the rotational speed, the flow rate through the machine that of the compressors and the head developed by the fluid. And this is very useful in practice at that time we discussed. This is 1^{st} defined in terms of dimensionless quantity, then we got rid of certain constant values, for example for incompressible fluid, if you recall the density and the local gravity is always constant, we got rid of this. And we derived some dimensional specific speed.

Then we discussed that the specific speed represents a particular specification of a homologous series in a way that specific speed contains the operational parameter, most useful operational parameters by which a pump or a turbine is specified. For example for a pump, it is N, P and H. So if you know the NPH for designing a pump, particular pump it has to produce this power under this head and it has to rotate at this speed. Then what is our job, our job is to find out that specific speed.

And we have to search that which homologous series runs better high-efficiency at that specific speed. Now you understand that Pelton wheel runs at high-efficiency with a very high head, that means that low specific speed. So where the specific speed is low, that is obtained from the practical situation, then we will employ Pelton wheel. That means which type of turbine which homologous series will be employed there is the starting point of the design.

Okay. And that is done by reading the information from a figure or by evaluating this analytically that which homologous series give the maximum efficiency for that specific speed. And in fact when we tell colloquially this machine has the specific speed means that machine may have any specific speed because it may have any value, there is a combination of parameters. But a machine has this specific speed or this range of specific speed means this machine runs at maximum efficiency at very high efficiency and this value of specific speed or in this range of specific speed.

So here you see that this is the specific speed versus efficiency, this Pelton wheel you see has almost 94 percent efficient but at a very low speed. This is dimensional specific speed, this is dimensional, that means here we know that NST is N P to the power half divided by H to the power 5 by4. So what is missing, rho to the power half and G to the power 5 by4 in the denominator, that is missing. So therefore this is probably the missing thing.

So you see, you check it with the nondimensional specific speed, so this is the dimensional specific speed. Here the number is nondimensional specific speed. Probably the missing quantity in the denominator will be rho to the power half and G to the power 5 by4. So it is Francis turbine, so Francis turbine is efficient, more than 94 percent, okay, 96 percent like that but the specific speed increases.

Similarly the axial flow turbine, it is relatively flat, so axial flow turbine is therefore suited better because at this high-speed, when the specific speed is here, dimensional specific speed you see, how the efficiency of the 10 wheel falls. That means if we have a specific speed somewhere here, nondimensional, dimensionless specific speed, we can never recommend Pelton wheel. If the specific speed is very high, nondimensional, this means specific speed this has for example, we always refer the Kaplan or axial flow turbine.

So therefore this graph is very indicative for the starting point of the design, is the preliminary picture where you get the value of the, this efficiency is the overall efficiency with the dimensionless specific speed. So therefore for a particular operation if we know the specific speed, we have to find out that which homologous series, which type of the turbine is best suited for it by judging its efficiency at that particular specific speed. So therefore with this I will close the session on turbines.

Okay we have discussed Pelton wheels first, that is the impulse flow turbine, purely tangential direction where the turbine rotors are open to atmosphere, it does not need any casing for tactical purpose. Then next one is the reaction turbine which is purely radial type radiation turbine by the flow at the inlet is radial, outlet is radial, that is known as Francis turbine following the name of the engineer who contributed a lot to its development. Then we discuss the axial flow turbine, first we understood what, how the concept of axial flow turbine was evolved since the head is reduced.

And with the reduced head if we want substantial power at a higher efficiency, then we have to go for axial flow turbine. And we discussed the basic features of an axial flow turbine and at the same time we have discussed basic principles of governing the turbine, why the governing is required and how in general the governing is made for both impulse turbine and the reaction turbine. With this I will conclude the discussion on hydraulic turbine. Thank you.