Fluid Machines.

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Lecture-13.

Draft Tube.

Good morning and welcome you all to this session of the course on fluid machines. Now in this class we will discuss a little bit about the draft tube. Already in one of the earlier classes I told that the draft tube is a very essential and integral part of reaction turbine. For example in a Francis turbine which is a tube of diverging cross-section and is attached to the exit of the runner, so the water coming out from the runner flows through this tube and it increases its pressure and decreases the velocity.

And the use of the draft tube allows the turbine to be set at a higher height from the tail water level and at the same time to develop more power. It reduces the waste kinetic energy from the machine by reducing the velocity of the fluid as it flows through a diverging duct. That is the principle of the draft tube. And at the same time it can be understood that while going through the, while in course of flow through the draft tube, the pressure at the inlet to the draft tube or the runner outlet becomes lower than the atmosphere.

So we can look from another angle that the head across the runner blade gets increased because its head, pressure head at outlet is below, close to the suction head, below that of the atmospheric pressure. So this way we can see that the output or the power developed by the turbine is more and it can be safely placed above the tailrest level. Now with this and the background, let us understand certain terminologies of the draft tube. Now, these are the draft tubes used in practice.

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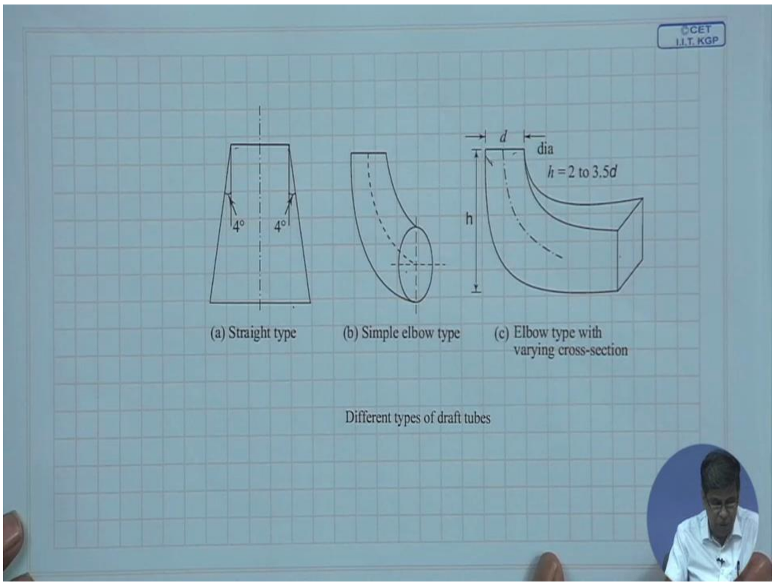

One is the straight type draft tube, this is straight once, a diverging section, inlet is this, that is the outlet of the runner and this is the outlet of the draft tube which is just below the tail rest level. The draft tube outlet has to be kept a little below the tail rest level to avoid any water because it discharges in the at the atmospheric pressure. So if we discharge this just at the tail rest level, then there is a chance of air comes into the draft you, to avoid that, little below the tail rest level.

Sometime the elbow type draft tube is used. This elbow type draft tube is used where the direction of the draft tube changes from vertical to horizontal, vertical direction is the direction of the shaft, that is the axial direction. For a horizontal turbine, this direction is the axial direction which is vertical. Here the tube is entirely vertical but here you see the tube is from vertical to horizontal and elbow type and the cross-section may be circular. This type of draft tube is used where the vertical height of the tube is required to be less to save the cost of excavation.

And especially in the rocky places, this type of draft tube is preferred. Sometimes the similar elbow type draft tube may change its cross-section from a circular one at the inlet to a rectangular one at the outlet. All these modifications of the draft tube, different types, different cross-sectional shapes and the change of the cross-section from inlet to outlet are all made in consideration of 2 things, the efficiency of the draft tube is high and at the same time the draft tube should not induce any cavitation that I already discussed earlier.

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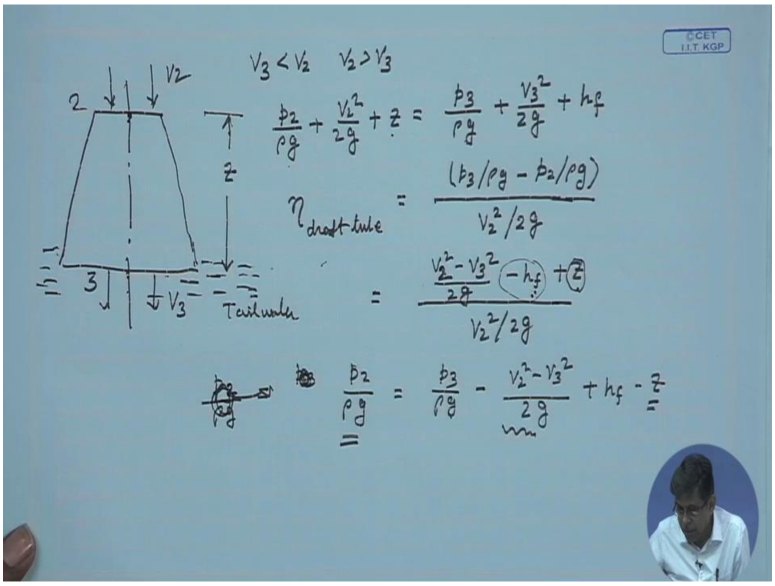

And the draft tube should smoothly discharge the water rat tail rest without incorporation of any air into the draft tube. So these are the different types of draft tube used in practice. So with this I will now just make you acquainted with certain terminologies. Let us first a very simple nomenclature that let us have this draft tube like this which, this is the outlet of the draft tube, this is the tail water, tail water, tail water. Okay, tail water. Now let this is the typical draft tube diverging section, simple straight draft tube, 2 and 3 are the letter outlet, the flow velocity is like this and it comes out like this, V2 and V3.

So area, cross-sectional area is higher, so V3 is less than V2. Or V2 is greater than V3. And let us have this, consider Z is the elevation or the vertical height from the discharge, cross-sectional area from the discharge plane Z. Now if we write the Bernoulli's equation between this point and the fluid element at this point along the streamline, we can write P2 by rho G in terms of the energy per unit weight head + V2 square by 2G + Z is equal to P3 by rho G here + V3 square by 2G, Z is 0 here, from here, this is considered as the datum from where we have defined this Z + the losses, that means we are considering the viscous effect through a head loss.

This is a modified Bernoulli's equation. So therefore we can write this and from here we have seen that P2 by rho G will be lower than this P3 by rho G which is usually the atmospheric pressure, that we have already recognised. Now here we will define a terminology which is known as Eta, that is efficiency of draft tube. Now efficiency of draft tube is defined as the rise in the pressure head, that is here P3 is more, that means P3 by rho G - P2 by rho G divided by the inlet kinetic energy.

In terms of G, so V2 square by 2G. If we follow this definition as the efficiency of a draft tube, that it is a ratio of the pressure rise or pressure recovery, sometimes this word is used, divided by the inlet kinetic energy, then we can write this P3 by rho G - P2 by rho G is equal to what. V2 square - V2 square - V3 square by 2G. V2 square - V3 square by 2G - HF + Z divided by V2 square by 2G.

And here we see that the efficiency depends upon many things. That mostly this HF and Z. Most, if we have more losses, the efficiency will be less, so the losses should be low and at the same time Z has to be low but Z has got another restriction in the cavitation. So this is the definition of draft tube efficiency. So the designing a draft tube, we have to be careful in calculating the efficiency should be high so that we can have a efficient operation of the draft tube in utilising the head, effective head of the turbine.

And again I tell you that P2 by rho G is equal to what, P3, P2, P3 by rho G Rather P3 by rho G, that is the, no sorry, P2 by rho G, P2 by rho G is equal to P3 by rho G - V2 square - V3 square. V2 is greater than V3 2G, okay, + HF - Z. This is what P2 by rho G. So therefore we see because this thing - + HF - Z is positive, this is positive, so P2 by rho G is always less than P3 by rho G. And P3 by rho G is usually the atmospheric pressure and therefore the pressure at the inlet is the suction pressure and that should not be reduced to the vapour pressure.

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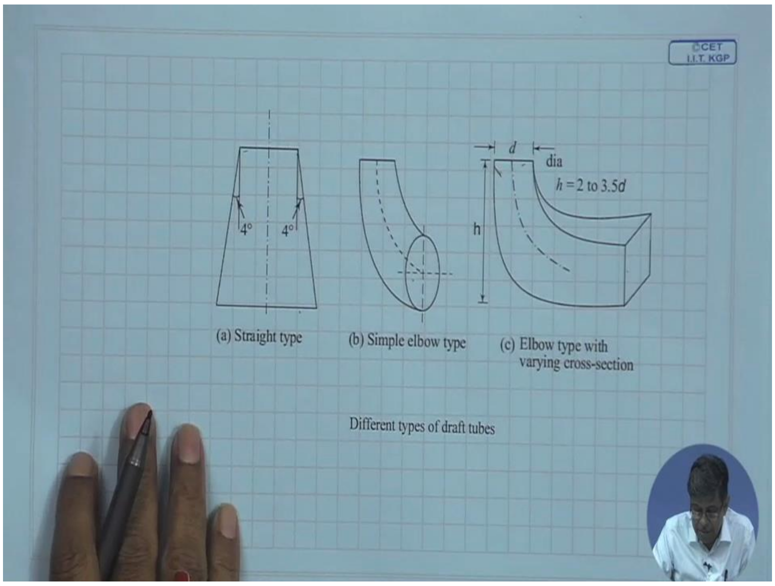

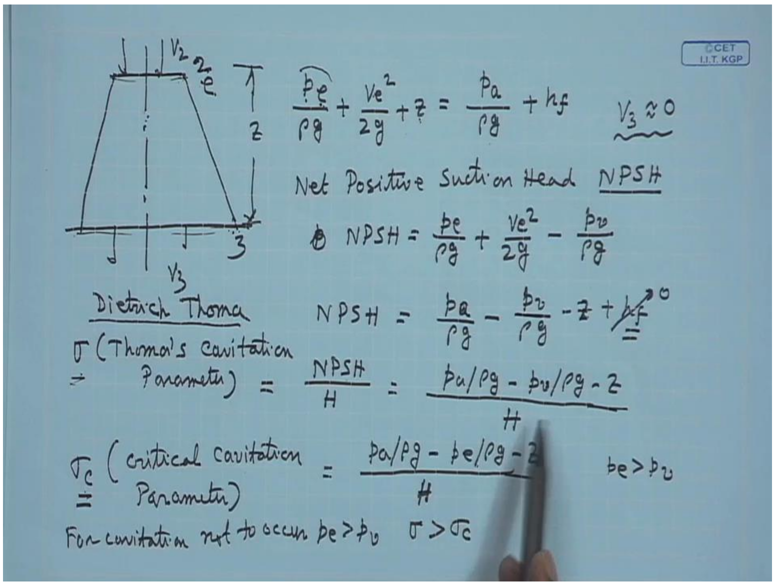

Now if we think that for cavitation to occur, that PE should not be more than the vapour pressure, then what we do. We again draw this, 2 and 3, V2, V3. Now for cavitation to avoid, for cavitation to avoid, this section pressure to be this, this section pressure should be higher than the vapour pressure. Now if we designate the exit as V, the pressure at the exit as in not the section 3 and if we write the Bernoulli's equation between these 2 points, that is the exit and the exit means this is the exit of the, if we define this exit of the runner.

That means inlet to the draft tube, this is for example E, section E. And if we write the Bernoulli's equation PE + rho G + we square by 2G and as usual this is the Z, this elevation, + Z and if we consider this outlet pressure, P3 is the atmospheric pressure, PA is the atmospheric pressure + rho, by rho G + HF. If we write this, that is the equation with in consideration of the fact that V3 is 0. That means we consider the velocity at the outlet of the draft tube with negligibly small. Draft tube area is very large.

Here of course one thing I have forgotten to tell you that this is very important for designing any diverging passage since the flow takes place with an adverse pressure gradient that the pressure is increasing in the direction of the flow, this angle should be very less. This should be kept below 8 degree to avoid the boundary layer separation. There is every likelihood of the boundary layer separation and add more losses, this is because the fluid is flowing in adverse pressure gradient.

The pressure in the downstream is more than the upstream and in this situation, we meet with the we incur the boundary layer separation, the particles within the boundary layer having very low kinetic energy because of flow velocity due to the interaction with the surface and there is a no-slip condition at the surface, the velocity is 0 relative to the surface, velocity along the surface, 0 relative to the surface, low kinetic energy particles close to the surface cannot surmount this adverse pressure gradient and they flow in the opposite direction.

That is precisely the boundary layer separation phenomena. So to avoid this in case of any flow with adverse pressure gradient, in this type of flow in a divergent duct in a diffuser, we have to always take a caution that the divergence angle should be kept below 8 degree to avoid separation. Okay, now the, without separation if we can have a area so large that V3 is almost 0 in consideration of the outlet velocity 0 we can write this equation with E as the exit of the runner.

That means the P is the pressure at the exit of the runner or at the inlet to the draft tube and V is the velocity + Z PA by rho G + HF. We can write this thing. So now here for cavitation not to occur, P has to be more than the vapour pressure, will be higher than the vapour pressure. Now here in this connection a terminology is defined known as net positive, this is known as net positive suction head NPSH, which is defined as the available suction head at the inlet to the draft tube over that of the inclusive of the dynamic head, total available suction head inclusive of the dynamic head, the pressure head and the dynamic head over the vapour pressure head.

That means this is defined as the P, that NPSH is equal to PE by rho G + this is the available head, suction head inclusive of the dynamic head. That means the pressure head + dynamic head over the static head corresponding to the vapour pressure. So this is defined as net positive suction head, okay. So now with the help of this equation P + rho G is equal + V is equal to PA by rho G + HF - Z. So NPSH can be written as PA by rho G - PV by rho G - Z + H.

Now if we discard the loss, frictional loss in the draft tube, then with comparison to this value of Z and this pressure head, atmospheric pressure head and the pressure head corresponding to the vapour pressure, if this is small, we neglect, then this is the expression for NPSH, net positive suction head PA by rho G -… That means this is defined as the available suction head over the vapour pressure head at the entry of the draft tube.

Now here 2 parameters are defined, one is Thomas cavitation parameter. It is Thomas cavitation parameter which is after the scientist Diettrich, German scientist, Diettrich Thomas, who made it, who defined it is a German scientist. Thomas cavitation factor is defined as NPSH divided by the total head available. That means this is equal to PA by rho G - PV by rho G - Z divided by H. And another parameter is defined which is known as critical, okay, cavitation parameter.

Critical cavitation parameter which is defined as, here PA by rho G, PV by rho G, just in line with this, following this but instead of PV, P by rho G - Z by H. This is known as critical cavitation parameter Thomas. Now up to this you are following mechanically the deductions, okay, all right, here we have neglected the HF which is very less but you can include HF, it does not matter much. So this is the Thomas cavitation parameter, this is the critical…

Now it is obvious that for cavitation not to occur, if cavitation not to occur, what will happen that P has to be greater than PV. That means P has to be the reason PV, PV will be less than P. That means for cavitation not to occur, for cavitation not to occur, not to occur, P has to be greater than PV, obviously, that is the vapour pressure at the working temperature and in that case Thomas cavitation factor will be greater than the critical cavitation parameter.

Thomas cavitation parameter will be greater than the, because PV is less than P. P is greater than PV, so therefore by comparing Sigma C and Sigma we can find out whether there is likelihood of the cavitation or not but what happens in practice but what is done in practice is that this critical cavitation parameter of a Francis turbine at its rated condition is known. This is the practice I tell you in the design, so we know the critical cavitation parameter which is given by this equation.

So what we do, we find out the Thomas cavitation parameter by putting the value of PV for the liquid used, for example water, at its working temperature and determine what should be the value of Z. That means at which level the turbine than should be set to avoid cavitation. That means critical cavitation parameter will be known, this is a design parameter for a particular Francis turbine and depends on specific speed.

So if we know Sigma C, in actual condition what we do, we find out the Thomas cavitation parameter and we now find out, we use the Thomas cavitation parameter formula to find out the value of Z, maximum height up to which the turbine can be set without causing the cavitation to occur in the draft tube, that is the purpose. So this is the purpose and here you must understand what is the net positive suction head which is very important, that is the available suction head at inlet to the draft tube.

So therefore draft tube is it tube which is added to the turbine to reduce the kinetic energy at the outlet of the machine, this is the tail water level and the draft tube should be designed in such a way that it can efficiently do the job in converting, introducing the kinetic energy without causing the cavitation in the turbine. And to, at the same time to play the turbine runner at an appreciable height from above, height above the tail water level. So this is all about the preliminary understanding or preliminary information about the draft tube and the reaction turbine and I think today we close your. Okay, thank you.