Fluid Machines.

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Lecture-18.

Introduction to Rotodynamic Pumps.

Good morning and welcome you all to this session of the course on fluid machines. Now today in this session we will start the discussion on centrifugal pump. At the, at the beginning of this course we have recognised that pumps, compressors, fans, blowers are the machines of that category where mechanical energy is being converted to the stored energy of the fluid. So the output of these machines is in the form of the stored mechanical energy.

And in pumps and compressors, this stored mechanical energy comes in the form of static pressure, that means in the static head, while in fans and blowers, there in the form of kinetic head of the velocity of fluid. Pumps are those machines which use liquid and mainly water as the working fluid, while the compressor use air, this is already recognised. Now pump again can be of 2 types, one is radial flow, another is axial flow. Now radial flow pumps are known as centrifugal pumps.

The word centrifugal comes from the fact that in any radial flow machine, there is the changes centrifugal head because of the change in the radial position of the fluid while it flows through the rotor of the machine. And for this change in centrifugal head, the fluid either gains or release static pressure or static head depending upon whether it is a pump compressor or a turbine. But the word centrifugal is not used in case of turbine but in case of form that is used.

And at the same time this was also recognised that in case of pumps or compressors when it is a radial flow type, that means centrifugal one, the flow should be radially outward. This is because when it goes radially outward, at the outlet, the centrifugal head is more because of the higher radial location as compared to that at the inlet. So therefore while the fluid flows through the runner, it gains in the centrifugal head and accordingly in the Static head. So therefore it is always radially outward, while in case of a turbine, it is radially inward.

So therefore it is apparent that a centrifugal compressor is in general the reverse or converse of a Francis turbine. Okay. Now before going to describe this pump, force on the rotor vanes, rotor blades and all these things, we first discuss the pumping system in general. Now the word pumping a hydraulic system refers to the lift of water, static lift of water vertically. But in broad sense, it is to develop static pressure, develop the or to build the energy in the fluid in the form of the static pressure by virtue of which the fluid can be distributed over a distance through pipe network systems or it can be lifted up.

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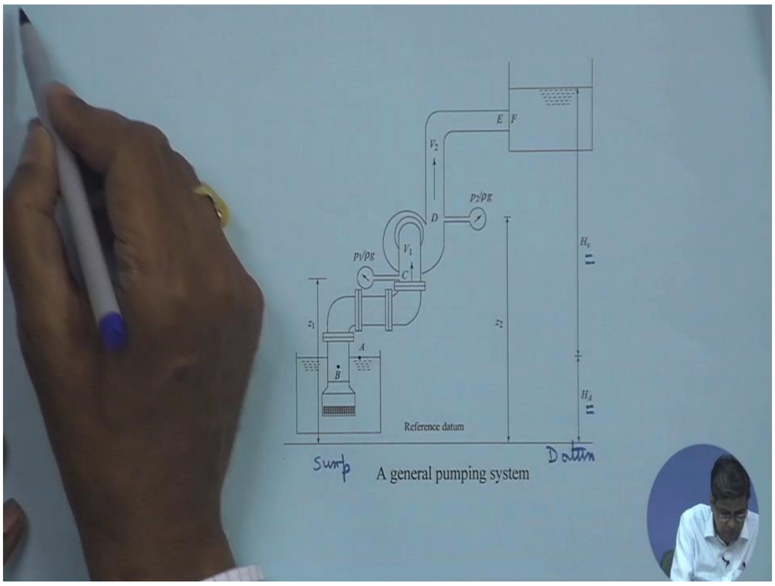

And first of all we just try to understand this pumping system and the net head developed by a pump okay. So for that let us just this picture. Here, this is a system, this is a centrifugal pump. Now this is a 2, there are 2 reservoirs. Here it is explained in terms of the water lifting from a lower reservoir to a higher reservoir. This is a lower reservoir, this is a higher reservoir. The lower reservoir is usually known as sump, while this is the higher reservoir.

Now the liquid, for example here we take water, water pump now is there in the sump and it enters through this pipe, that is the inlet pipe and it goes to the pump, this is the wpump. Then from imparts energy to the fluid, it acquires energy and at the outlet, the energy is mostly in the form of static pressure by virtue of which it goes up and is discharged in the higher reservoir. Now if we see the different points, representative points, if we designate and see the total energy per unit weight in terms of head, we give some representative points A, B, C, D, E and F and take this line as the datum. Okay.

And from the datum, the free surface in the lower reservoir is at a height HA. Okay. And this, the difference in the free surface or the height, the elevation of the free surface of the upper reservoir or higher reservoir and the sump, the lower reservoir is HS, these are the nomenclatures. Z2 is a vertical distance, elevation from the datum of the discharge plane, that means the discharge plane of the pump is that a vertical distance Z2 above the datum.

And similarly the inlet to the pump here, just after the flange is Z1 from the datum. And in this picture we show 2 pressure gauges, one is that the inlet to the pump, just at the inlet to the pump which is recording the present and its corresponding pressure, it is P1 by rho G, the 1, subscript 1 is given at the inlet to the pump and this is P to by rho G, that is the pressure head at the outlet from the pump, the subscript 2 is given at the outlet from the pump.

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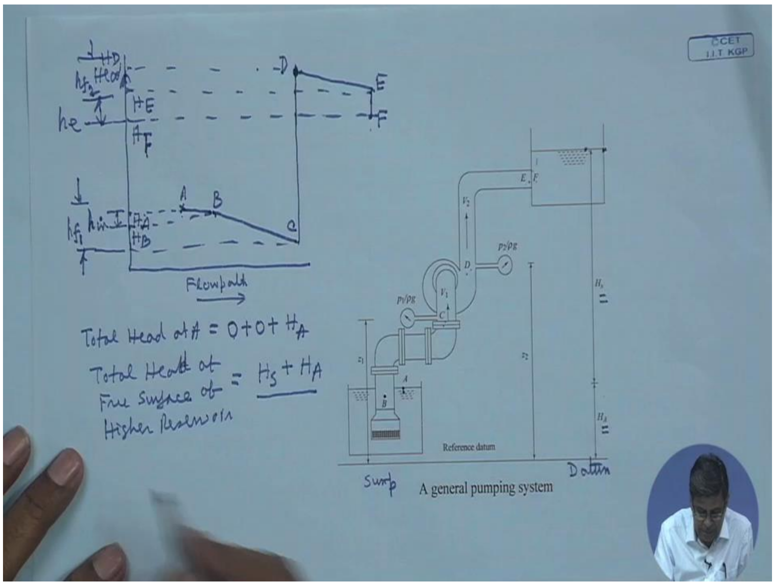

Now if we draw a diagram like this, head versus the flow path, head versus the flow path, this is the head and this is the flow path, this is head and this is the flow path. So we will see like this, if we start from the point A here, a point A here which has a head. Now at A, the head is only, we now 1st designate as H, HA, HA is the head at A which is only the potential head because at A there is no velocity, no pressure, that we will come afterwards.

Then when the fluid flows through this intake, this is the mechanical strainer, there is some loss at the inlet. When the fluid goes to B, therefore there is a slight loss, small loss at the point B. That means this loss if you put like this, this is HB, this point and this loss is given by H in. That is the head loss, frictional head loss, loss in the energy per unit weight in the intake H. Now as the fluid flows from B to the point C, there is no other energy interactions with the outside but there is again the head loss, that means the energy is lost due to friction and the mechanical energy is being converted to inter molecular energy which we call as loss of energy per unit weight or head loss, frictional head loss from B to C.

So that the total head at C again drops from that at B. That means this is the point C where if we draw this, this part is our, this part is our loss of head in friction in the inlet pipe. This we show as HF1. HF1 is the loss of head in the pipe, inlet pipe up to the inlet of the pump. Then at point C, the energy is added to the fluid, the fluid gains head and that is the objective of the pump. So when fluid comes at D, the energy, total energy per-unit went or total head at D, that is HD, there is a sharp increase.

So from C we draw a curve like this which goes here at the, this is the point D. This is point D which is our, if we just see HD, HD. Okay, then at D, the fluid comes at a very high head, high energy per unit weight, high head because of the high head given to the fluid by the pump. Then as it flows from D to E, this point E is just at the outlet of the delivery pipe. All the points you must observe, A is that the free surface of the sump, B is just after the inlet, C is just before the inlet to the pump.

D is just at the outlet, at the discharge end of the pump. E is at the outlet of the delivery pipe. So head at D and head at E will differ by the frictional loss in the delivery pipe. So therefore if we just show this, like this HE, then HD and HD, this difference is HF 2. That is the frictional head loss in the delivery pipe, okay. Then from E to F, there is a loss known as exit loss. What is that physically, it is E there is a velocity of discharge, that is a kinetic energy.

When it is discharged into atmosphere, into the reservoir, then the fluid comes to rest. That means the entire kinetic energy at this discharge end is being lost and this kinetic energy is lost, this is actually what happens is degraded, there are formation of eddies and finally the liquids comes at rest. That means this kinetic energy actually is dissipated into the inter molecular, is converted into inter molecular energy. And this from the mechanical energy point of view recall as the loss of kinetic energy or the loss of kinetic head.

And this is known as exit loss and that we denote as H, that means if this is the final point F, F is this point, just after the discharge, that means fluid at rest in the reservoir, so if we take this one, then this part, that means E and H, HE - HF is the HE. So these are therefore the nomenclature, HS 1 is the friction in the inlet pipe, HF 2 is the friction in the delivery by, H in is the A to B loss, that is inlet loss, this is also due to friction. And ultimately HE from E to F, that is the exit loss, that is the loss of kinetic energy which is designated as HE.

Okay, now if we write certain equations, now if we denote the head at A is H A, total head at A, total head at A is what, velocity pressure is 0 because all pressure is expressed in terms of gauge pressure, that is the pressure about atmospheric. That means the pressure head or the static head is the head above the atmospheric pressure head. The velocity is 0, so +, only this

HA, HA, that means total head at A is H. Now if we write the total head at a free surface, total head at the free surface of this, this is total head at A.

Now if I write the total head at free surface of the higher reservoir or F, we consider F and total, the free surface, this height is negligible at this, then we can write total head, total head at free surface, total head, sorry. Total head at free surface of larger reservoir, of higher reservoir, not larger, I am sorry, higher reservoir, higher reservoir is what. It is HS + H, HA + H. Because here also similar way 0+0 there is no pressure head, there is no velocity head, so HS, only the potential head.

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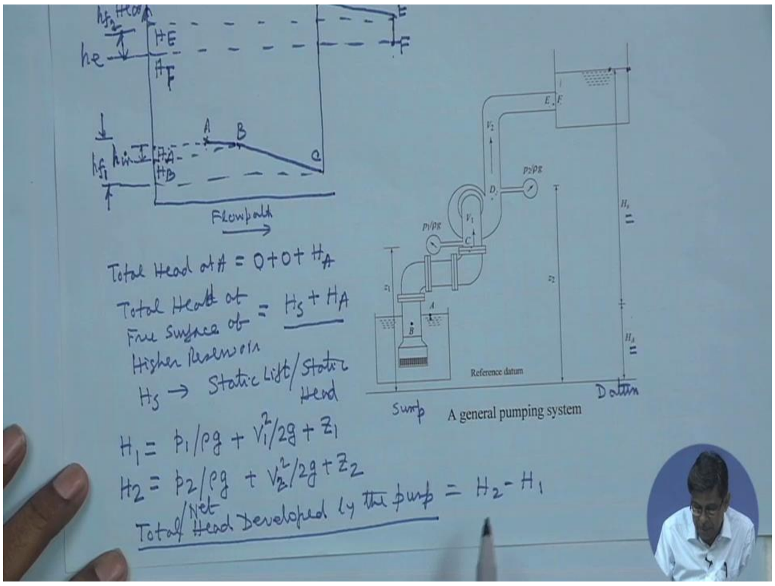

So therefore difference of these 2, that means the total head between this point A and this point at the free surface of the higher reservoir is HS. And this difference, this HS is known as static lift or static head or static head. Means that the pump has to make this static lift of the water. Now what is total head developed by the pump. The total head developed by the pump is different.

Now if we designate H1 as the head at inlet to the pump. I am not writing everything. This is what P1 by rho G, pressure head, where P1 is the pressure above the atmosphere at inlet + which can be read by a pressure gauge V1 square by 2G + Z1, that is the potential head. Similarly if we write H2, that is the head, total head at discharge end, that means just at discharge or outlet from the pump as P2 by rho G + V2 square by 2G + Z2, then the total head developed by the pump, total head developed by the pump, developed by the pump by the pump is H2 - H1.

Total head outlet, total head at inlet, and that is the total head developed by the pump. Or sometimes we call net head developed by the pump. Total or net, whatever head developed by the pump is H2 inlet head, outlet head - H. And this is not equal to the static lift, that can be found out like this.

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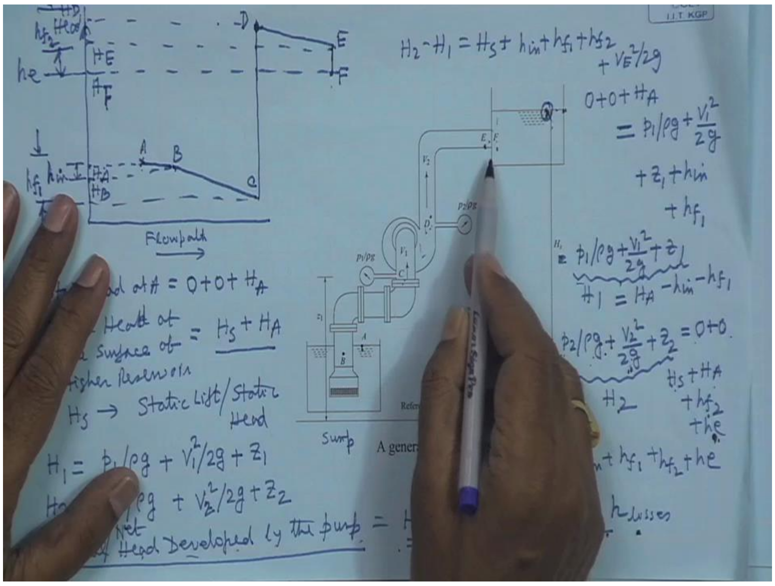

If we want to find out the difference, this, here itself I will do. The difference between the total headed developed by the pump and the static lift. Let us write the Bernoulli’s equation between point A and C. If we right Bernoulli’s equation between point A and C, rather I should do this we that if we write this here itself, I can write the Bernoulli’s equation between point A and C, we write 0+0+ HA.

Well equals to, this is at A and at C, that means at inlet to the pump, if we write the modified Bernoulli’s equation, that means consideration of the viscous loss through the friction head loss, that means this will be P1 by rho G + V1 square by 2G + Z1 + H in class HF 1. Well. And similarly if I write the Bernoulli’s equation between D and E, now here we can write one thing that P1 by rho G, this can be written like that + V1 square by 2G + Z1 equal to HA - H in - H F1.

Not similarly if we write the Bernoulli’s equation between the point D and F, final point. The fluid in the reservoir, liquid in the reservoir, water in the reservoir, then we can write P2 by rho G at the point D, the head are like this V2 square by 2G + Z2, okay equals to. Here at this point or at the free surface, same thing, equals to all 0, all 0. Free surface of that, so we can write what, so therefore it is Z2 and the free surface, it is HS + HF, only elevation.

That means one can write the P2 by rho G + VQ square by 2G + Z2, that is the head here at D2 is equal to 0, pressure head, velocity head 0, only potential head. Now this is the total head at the outlet of the machine and this is the total head at inlet of the machine which has been defined as H2 and H1. And the difference between the 2 is total or net head developed by the pump H2 - H1.

So if we subtract this one from this, we get H2 - H1, H2 - H1 from this equation if you subtract this H2 - H1 we get HS, now HA HA will cancel + here of course I have done a mistake, the head loss in the pipeline is a chef to has to be written, Bernoulli's equation 0+0, HS + HA, that means this is the total head + the head loss due to friction in this path. So HS + Hin + HF1 + HE also loss, HF2 + H. That means HS + some of all the losses.

Now here again I repeat, there was a mistake that the Bernoulli equation if I write here, the total head, total energy per unit weight P2 by rho G + V2 square by 2G + Z2 and here 0+0+ HS + H is the potential head + all the losses incurred or all the losses that has been, that has taken place in the course of flow up to this point or this, same thing. What is that, HF 2, the frictional loss in the delivery by and HE is the exit loss. That means exit loss. This is nothing but the kinetic energy loss, that is the kinetic energy at the discharge end.

So if you now subtract this H1 from H2, because this is H1, this is H2, you get this. So here it is clearly seen that H2 - H1, which is the net head developed by the pump, total or net head developed by the pump is H1 - H2, H2 - H1, sorry, that is the total head at the outlet - total head at inlet becomes equal to static lift. What is static lift, static lift is the vertical height of the free surface of the high higher reservoir from the free surface of the lower reservoir, sump.

+ all the losses, so therefore H due to losses. It is very clear from a commonsense that a pump has to draw the liquid to have a static lift HS, the liquid as to flow. And if liquid flows, it has to overcome all the resistance, flow resistance in the path. So some of the flow resistance in the path. So it has to overcome, it has to spend energy to overcome the resistance, flow resistance and that is, that energy is known as energy lost or head lost, sum of all head losses.

So the pump has to deliver or pump as to gain that head which is equal to the static lift + all losses, that means the energy or head spent to overcome the flow resistance in the path. And here if we just separate this HE, that means here this we, if we could have written this equation instead of this point or at E, then instead of HE, we could have written V square by

2G. In that case, this is for your understanding is HS + all the losses, H in + HF 1+ HF 2+ VE square by 2G.

That means if I keep it here, there is no reservoir, the water is discharged in the atmosphere, then it can be interpreted that total head developed or the net head developed by the pump equal to the static lift + all the frictional losses in the flow path, that means the energy spent to overcome the flow resistance in the flow path + the kinetic energy with this delivered at the outlet. This energy delivered at the outlet is also being developed by the pump.

So this is like this. But if we consider reservoir when the fluid is at rest and final point is at the free surface of the reservoir or any point in the reservoir, then it becomes the total losses because this becomes also a part of the losses that is known as exit loss has you have read in fluid mechanics. So therefore this is static lift + sum of the, sum of all the losses. So therefore in this diagram we have been able to appreciate what the different terminologies like the head developed by the pump, the static lift and how we can use the Bernoulli's equation to express this thing.

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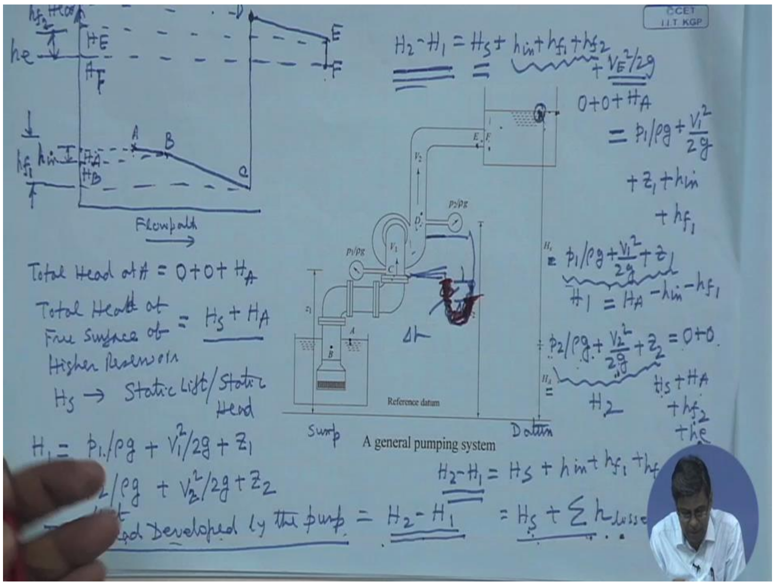

Now here, this P1 by, total head developed here is this - this, therefore we can write the total head or net head developed by the pump H is H1 - H2 is P1 by rho G - P2 by rho G + V1, sorry P2 by rho G, sorry, sorry this is mistake. H is equal to H2 - H1, so therefore it is P2 by rho G, if you, you can write this way - P1 by rho G + V2 square by 2G - V1 square by 2G, it is just rearranged form I am writing, Z 2 - Z1.

Now in most of the cases, the diameter of the suction pipe or the inlet pipe and the delivery pipe is same. And for the flow rate, volumetric flow rate, V2 and V1, these are cancelled, this is 0 because V1 equals to V2 equal to V1. But it is not always true, it may not be there if the diameters of the inlet and delivery pipe are different. So in that case this becomes P2 by rho G + Z2 - P1 by rho G + Z1. So this is nothing but the difference in piezometric pressure which is being registered if we apply manometer across this pump.

And as you know that manometer registers that means if we apply a manometer here, that means here and here if we apply a manometer, so the deflection, from the deflection of the manometer, let this is the deflection of the manometer delta H, this is the manometric fluid, so manometer reads the difference in piezometric head. Sorry, this will be other way. I will show you like this. This deflection, the fluid, this pressure is high, this will be other way so that, this is the interface, this is another interface of the manometric liquid, usually mercury is used when water is a working fluid.

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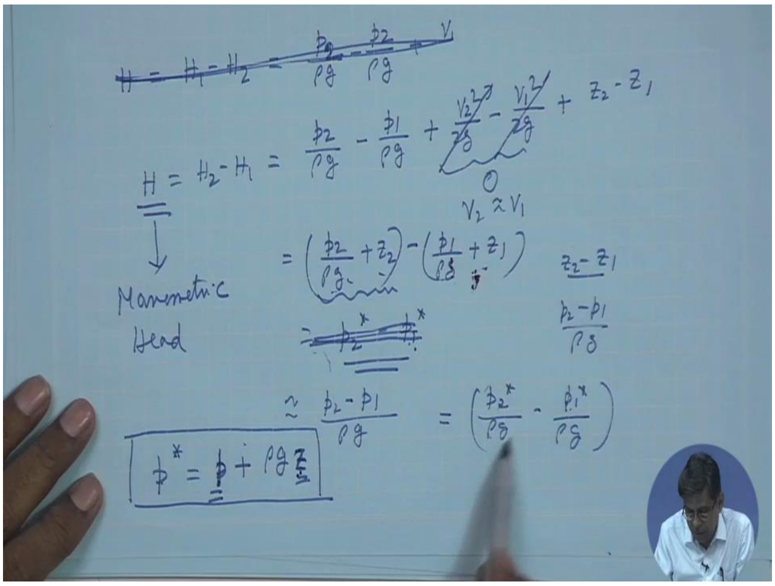

So therefore a manometer attached between inlet and outlet, this is you have already read any of fluid mechanics class that this read the piezometric pressure difference. And if we neglect Z2 - Z1, small compared to P2 - P1 by, compared to P2 - P1 by rho G, you can neglect and this becomes is equal to simply the piezometric pressure drop becomes equal to the simple static pressure drop of static head. So therefore we can find out this head developed approximately equal to that in the difference in the piezometric pressure head which can be registered by a manometer, manometer measures the piezometric pressure drop.

P2 star - P1 star. So P2 star is P2 by rho G P2 star actually is P2 + rho G Z2, it cannot be written as P2 star, it is the piezometric pressure head. So therefore it can be written as P2 star by rho G - P1 star by rho G, however sense is the same. That is why this head is known as manometeric head by because it can be found out by manometer, by the reading of the manometer.

This is the piezometric pressure head, you remember a piezometric pressure is defined as P + rho G Z where Z is the vertical elevation of the point where the static pressure is defined as P from reference datum, that represents the piezometric pressure. If 2 points are in the same horizontal line or horizontal plane, then Z will be same, so the difference between piezometric pressure will be difference in static pressure, this is piezometric pressure head, piezometric.

So this becomes the difference in piezometric pressure head provided the velocities are same. And usually in many of the cases, the inlet and outlet diameters of the pipes are same. That inlet diameter, diameters of inlet and delivery pipe are same. Okay, thank you.