Fluid Machines.
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Lecture-23.
Diffuser and Cavitation.

Good morning and welcome you all to this session of the course on fluid machines. Now today we will 1st discuss the diffuser. Already we recognised that the centrifugal pump consists mainly of an impeller and a diffuser. Now the main function of the diffuser is to convert the kinetic energy into static or pressure head because the final output of the centrifugal compressor is in the form of the static pressure. When the water comes out of the impeller, then it has a substantial portion of kinetic energy along with the static or pressure energy.

So this kinetic energy is ultimately converted to pressure energy or the static head or a diffuser. Diffuser is a fixed part and that is the stator of the pump because you know in general, fluid machines as a rotor and the stator. So rotor is the rotating part where the energy transfer takes place, that is the impeller here and stator here is the diffuser. So basically diffuser provides a flow area where the, flow area which increases in the direction of flow. That means it provides a diverging passage to the flow so that the velocity is decreased and the pressure is increased.

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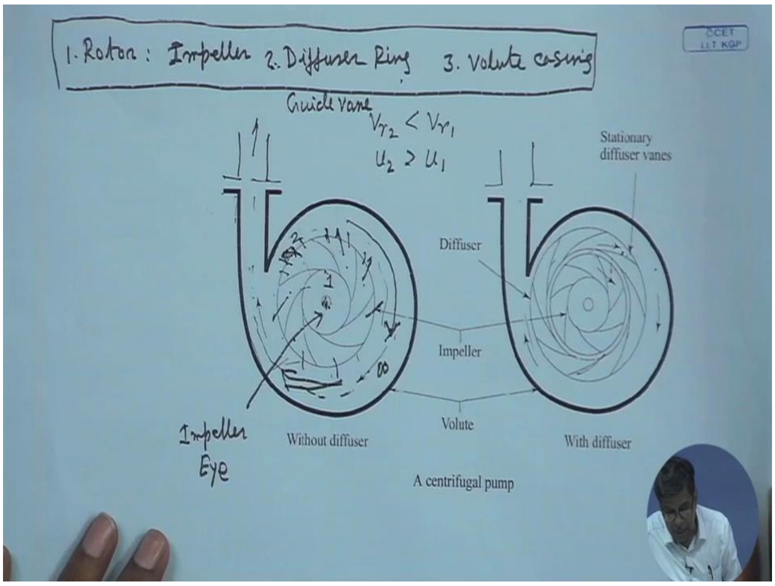
1. Rotor : Impeller 2. Diffuser Ring 3. Volute casing

Therefore we recover the static head from the kinetic head, static energy from the kinetic energy. Now the diffusers are of 2 types, one of the simple volute, as already we have seen in the centrifugal pump, that the impeller and the volute. So in volute, is the spiral casing for the scroll casing like this if you recall. So this we already recognised earlier that the impeller as a volute here you see, this volute, this is the volute casing, where the flow comes out of the impeller passage to this spiral casing and this spiral casing in the direction of flow provides an area which is increasing and ultimately the kinetic head is converted to static or pressure head.

Now when it comes out, you see in the diffuser, if you neglect a viscous effect of the fluid, its angular momentum is conserved. And the fluid actually executives emotion which is similar to free vortex motion with respect to its tangential velocity. And at the same time it is coming with the radial component of velocity from the impeller outlet which are under ideal case is uniform. But there is a nonuniformity for several factors I told because of the viscous effect of the fluid in the passage + the slip.

So radial flow is superimposed with a vortex which is close to that of a free vortex flow gives a spiral type of flow which is known as spiral vortex flow. So it is designed, the surface of the volute is designed in such a way that this matches with the spiral vortex, streamlined for the spiral vortex. So accordingly the surface of the volute is designed. Usually the 10 percent of the head generated by the impeller is lost in the volute casing because of the viscous action of the fluid.

So finally the fluid, that is the water comes out of the value chamber where the pressure energy or the pressure is, sorry the kinetic energy, that is the velocity is converted into pressure, that is the static head. So this is a typical volute which is a spiral casing. Now, we already discussed that to have better diffusion and an efficient, diffusion means this process is known as diffusion here. In terms of the fluid machines terminology that this decrease in velocity and increase in pressure in a flow is known as the process of diffusion and this passage is known as a diffuser passage or diffuser.

So to make this process more efficient we sometimes use that I told earlier a vane diffuser, that means there are rings, ring in which these vane diffusers are there. That means before going to the volute or scroll call casing, the fluid flows through the vane diffuser and these passages of the vane are diverging types, and this is also fixed, these vanes are fixed. This is known as such vane diffuser. And if you provide the vane diffuser, that means the pump becomes more compact with efficient conversion of kinetic energy into pressure energy.

That means the process of diffusion becomes more efficient and in a relatively smaller area, that the size of the pump is less. So therefore in depending upon the requirement, sometimes this is recommended that pump with diffuser vane and also volute casing as the diffuser. Okay.

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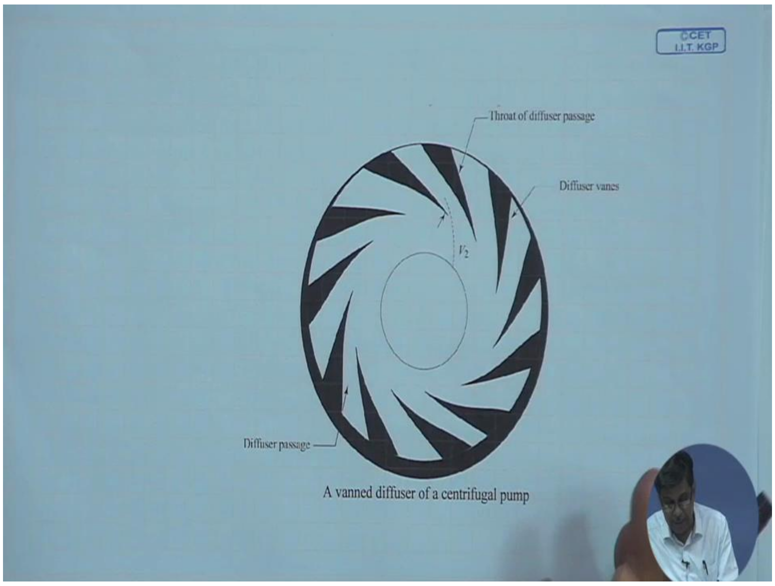

A vanned diffuser of a centrifugal pump

You see a typical such a diffuser with vane, so these are the vane, vane diffuser, a vane diffuser of a centrifugal pump. So only the vane part of it. So this is the diffuser vanes, so this gives a area diverging to that, this is the diffuser throat. Initially it is little convergent and then ultimately it becomes diverging. Now one interesting part is that there is always a vane less space, this is the impeller outer periphery. So from the impeller outlet to the entry to this ring of diffuser blades, there is a vane less space.

Now this vane less space is provided to accommodate this spiral vortex flow, the direction of the spiral vortex flow in a way that there is a shock less entry, proper entry to the diffuser vanes without much loss. That is why vane less space is given. Now while designing the diffuser vanes, few things are taken into consideration. Number-one is that the angle of divergence of the diffuser vane, that is the diffuser passage or the diffuser should not be more than 8 degree, maximum 10 degree, between 8 to 10 degree to avoid the boundary layer separation, number-one.

Number 2 is that the number of blade, sorry, the diffuser vane passages and at the same time the number of diffuser vanes is optimised in consideration of the 2 contradicting things. One is that if the number of passages, diffuser passages is more or the number of diffuser vanes, vane diffuser, diffuser vanes is more, then the process of diffusion or the process of decreasing the velocity and increasing the pressure becomes efficient, if we can divide in more and more channels of diffusing passage.

But at the same time if you give more vanes and more number of channels, the frictional losses increases. So a compromise is made between the frictional losses and the process of diffusion that recovery of pressure from the kinetic energy, a number of diffuser vane is optimised. And number 3 consideration is that the number of diffuser vanes and the number of impeller vanes should not have common factor so that resonant can happen anytime.

To avoid resonance, the common, there should not be a common factor, common multiple, one should not be a common multiple of other. That means number of diffuser vanes and number of impeller vane should not have common factor. So therefore these 3 things that taken into account while designing a diffuser vane. So finally in a centrifugal pump, we have an impeller which imparts the energy and coming out from the impeller, the fluid has both high pressure and high velocity.

So this high velocity is being reduced to a lower one and pressure is increased much more so that at the final outlet from the centrifugal pump, that is the discharge end of the diffuser, we have high-pressure but low velocity water. And this diffuser may have only spiral casing which is known as volute chamber with increasing area in the direction of flow or for an efficient diffusion and for a reduced size of the, in a reduced, with a reduced size of the pump, we have both vane diffuser and the spiral casing or the volute chamber, both, okay. And with this I just conclude the brief discussion on the diffuser of the centrifugal pump.

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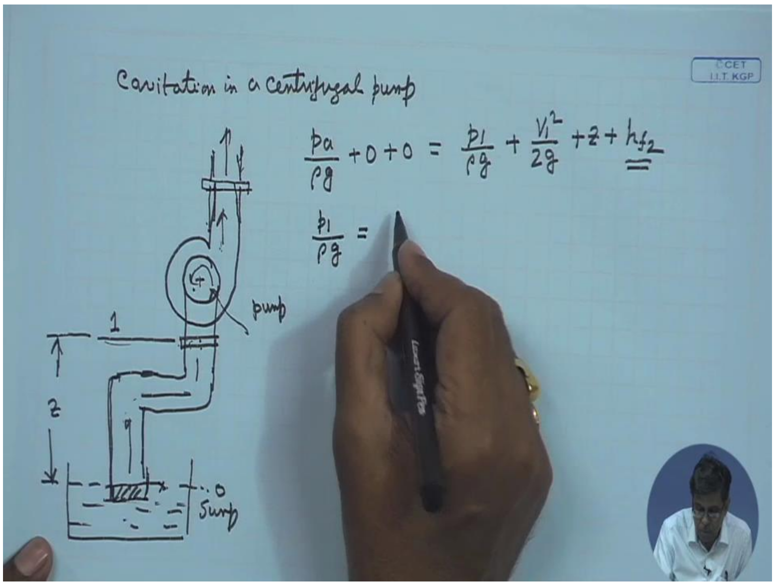

Now we will see one very important thing, that is cavitation in a centrifugal pump. You just recall the cavitation which we already discussed in relation to Francis turbine. So cavitation in a centrifugal pump, cavitation in a centrifugal pump, in a centrifugal pump. Now in general cavitation in any hydraulic circuit means, what is cavitation, cavitation in any hydraulic circuit means that the pressure anywhere in the circuit should not fall below the vapour pressure of the liquid at the working temperature so that vapour bubble gets generated.

This is in general the basic principles. So vapour bubble should not be generated. What happens, the generation of mobile takes place, they collide each other and ultimately they come and hit or bombard the surfaces of the blades, surfaces of the diffuser, diffuser and ultimately erode those surfaces. So this makes a detrimental effect and cause damage to the machine. So this phenomena, this cavitation is avoided if the pressure of the liquid is below in the circuit at any point in the circuit, any section in the circuit is always above the vapour pressure at the working temperature.

So that the vapour cannot be formed. In fact the cavitation forms, even when the pressure is, not the vapour pressure, a little above the vapour pressure where the dissolved gases for example air, dissolved air, they are liberated in the formation of bubbles which randomly move and bombard or strikes the different solid surfaces, the blades of a fluid, impeller, the machine impeller or the surface of the diffuser, stator part of the machine, guide vanes so that the machine gets damaged. The erosion takes place and the machine gets damaged.

So this is precisely the cavitation phenomena. In reaction turbine we have seen, there is a likelihood or chance for the pressure to fall below the vapour pressure at the inlet to the draft tube where the pressure is always below the atmospheric pressure. Similarly in a centrifugal pump we have to see that where whether there is a chance of pressure going below the atmospheric pressure or much below so that we have to take the caution that the cavitation is avoided.

So then let us just see this, draw this, a pump, like this. Let us say that this is a reservoir, lower reservoir or sump, let this is the pump, let this is a flange at the end of the inlet pipe and this is the discharge, this is another flange, this is the discharge, this is the discharge and this is the inlet. So therefore fluid is, as the impeller rotates, the fluid is shucked from the sump, lower reservoir, go to the pump and it gets the energy from the impeller, diffuser, all these things you know and comes out at high-pressure and with low velocity and it goes through the discharge line to either vertically up or for the transmission and distribution in the, even in the horizontal plane.

Now in this case you see, if we designate this inlet section, this inlet section as 1 and this free surface of the sump as 0 and let us define this elevation, vertical elevation, height of the pump, centre from this free surface of the sump as Z. And now if we write the Bernoulli's equation between any 2 points, one at the free surface here, another at any point here, at the section 1 along the streamline, we can write this.

Here the pressure is atmospheric pressure PA by rho G, velocity is 0 at the free surface and we consider this free surface as the datum, so this is 0. Okay, equals to, the pressure here is P1 at the inlet to the pump, at the end of the inlet pipe + if we consider V1 is the velocity of the flow in the inlet pipe, considered to be constant throughout if the diameter is same.

Otherwise V1 is the velocity at the end of the inlet pipe or the inlet to the pump + this elevation Z + the head losses due to friction and which include all the losses, major and minor losses, Valve friction in the pipe along its length, losses in the bends, losses here in the flange, losses here there is a strainer, there is a strainer, there are losses in the strainer, that means it includes all the frictional head losses.

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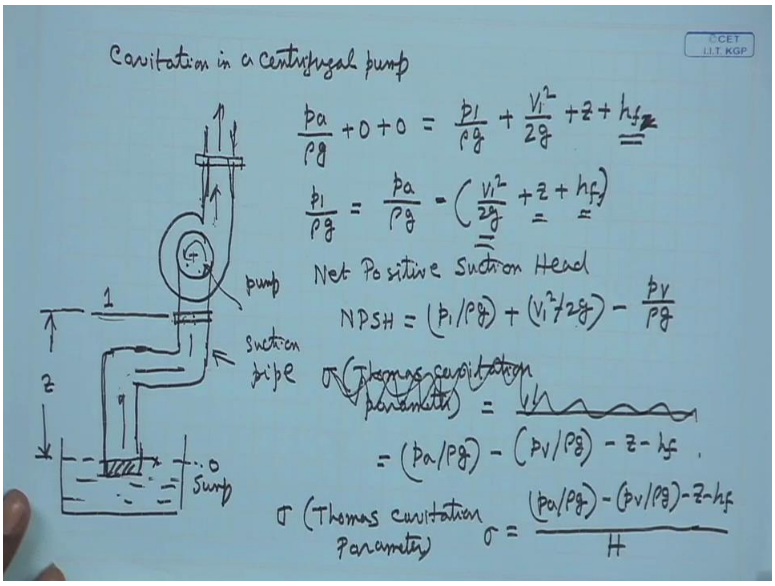

Cavitation in a centrifugal pump

$$\frac{p_a}{\rho g} + 0 + 0 = \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z + h_f$$

$$\frac{p_1}{\rho g} = \frac{p_a}{\rho g} - \left(\frac{V_1^2}{2g} + z + h_f\right)$$

Net Positive Suction Head

$$NPSH = (p_1/\rho g) + (V_1^2/2g) - \frac{p_v}{\rho g}$$

σ (~~Thomas cavitation parameter~~) =

$$= (p_a/\rho g) - (p_v/\rho g) - z - h_f$$

σ (Thomas cavitation Parameter) $\sigma = \frac{(p_a/\rho g) - (p_v/\rho g) - z - h_f}{H}$

Okay, now from here it is evident and apparent that P1 by rho G equals to P A by rho G - V1 square by 2G + Z + H F, HF, not 2, HF. So therefore this is positive, this is positive, head loss is a scalar quantity, positive. So therefore you see the pressure at the inlet to the pump, at the end of the inlet pipe or it is known as suction pipe, sometimes it is known as suction pipe, these are the terminologies you must know, suction pipe, always falls below the atmospheric pressure.

How much it will fall below the atmospheric pressure or what will be the suction pressure depending upon the values of this quantity. So there is a likelihood that the cavitation may occur here if we allow this pressure to fall below the vapour pressure of the water at the working temperature. Now in this case also we define that, the similar way we defined as in case turbine, net positive suction head, net positive suction head which is NPSH as the sum of the pressure head + velocity head at the outlet of the suction pipe or inlet pipe over the head corresponding to vapour pressure, vapour pressure head.

That means PV by rho G, when PV is the vapour pressure at the working temperature, similar way we define the net positive suction head. That means available suction head inclusive of dynamic head, pressure head and dynamic head over the vapour pressure head and similarly we define Thomas cavitation, you just recall in case of turbine, Thomas cavitation parameter, Thomas cavitation parameter, parameter following the name of Ditrich Thomas equals to this NPSH that is, no before that, sorry, before that we have to work out something.

I am sorry, before that they can write this NPSH as, if we now substitute P1 by rho G + V1 square by 2G, from here, PA by rho G - Z - HF, this can be written as PA by rho G, - same thing but written in a different way, the way it is expressed, - Z - HF. Now we define Sigma as Thomas cavitation parameter, Thomas cavitation parameter, Thomas cavitation parameter, Sigma which is equal to this NPSH PA by rho G, this is the definition of NPSH, here I replace this with the help of of this equation so that this becomes this - PV by rho G - Z - HF divided by the head developed by the pump.

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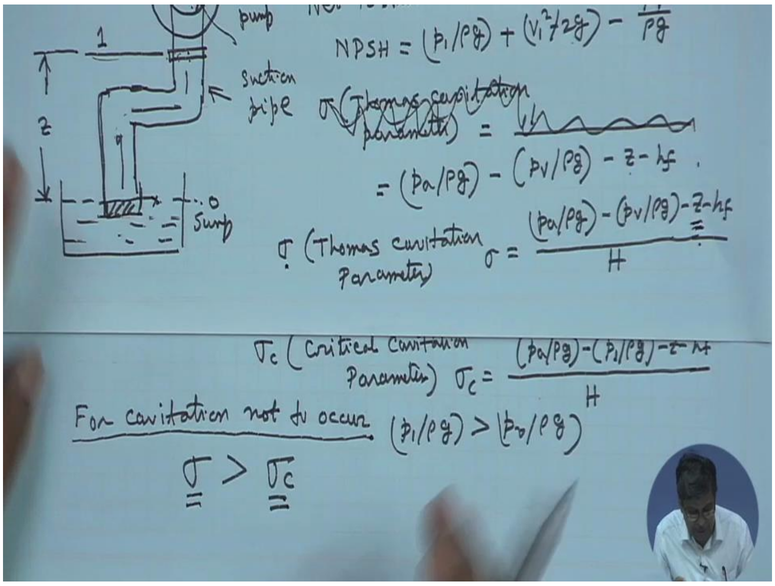

Similarly we define for case, in the case of turbine. And the same way we define the critical cavitation parameter, the critical cavitation parameter, sigma C equal to PA by rho G instead of the vapour pressure, it will be the inlet pressure to the pump, that means the pressure at the outlet of the suction. So it is not NPSH, instead PV by rho G I write P1 by rho G. The same way, now for cavitation not to occur, for cavitation not to occur, what will happen?

P1 by rho G has to be greater than PV by rho G and therefore the Thomas cavitation parameter has to be greater than C. Now the Thomas cavitation parameter has to be greater than that, in the similar way I will explain what is then in practice. The sigma C is the characteristic parameter of the pump itself. But the design, from the design of the pump we get this value at its design condition, sigma C. So we have to make this Sigma higher than sigma C.

So always we give some allowance that sigma should be as large as possible than Sigma C. This is done by reducing the value of H, Z, sorry Z. That means this Z has to be reduced to have a higher value of Thomas cavitation parameter for which Sigma must be greater than sigma C so that there is no likelihood of cavitation to occur. Okay, for cavitation not to occur, this is the condition. So therefore Z has to be made as close as possible. And this is also very clear from the very 1st instance by writing the equation.

You see this P1 by rho G will be lower provided Z is high, V1 square by 2G high and HF is high. So for this reason, things are done like that, sometimes if the sump level is at a very lower level, then Z is sometimes reduced even to a negative value. That means the pump is set sometimes below the free surface of the water. A reduction in Z you can think that if you want to pump water from a well, so if you place the pump on the surface of the well, the ground surface and if you make a suction pipe or inlet pipe a very long deep pipe to take water from that free surface of the well which is much much lower, then what will happen?

This Z, this value of Z is tremendously high which may create or may result a pressure, suction pressure at the inlet to the pump or at the end of the inlet pipe below the vapour pressure of the water. So therefore to avoid that we have seen that in almost all operations for this type, the pump is actually kept at a lower level. That means it is not kept at the top, it is kept very close to the free surface. So therefore Z has to be made lower. Another thing is that HA, friction factor should be made low as less as possible.

Therefore the suction pipe should be more smooth and it should avoid the bends, unnecessary valves, so that is why unnecessary valves are not given in the suction side so that it should have minimum number of valves, minimum number of bends and other things which cause frictional losses. And for this that is sometimes a very common question that if there are 2 pipes which are lying on the laboratory or in your shop floor, one with a higher diameter and another with a lower diameter and you have to use one at the suction side of a centrifugal pump for its installation and another one at the delivery side, you will always use the higher diameter pipe on the suction side and lower diameter pipe on the delivery side.

This is because if you use the higher diameter pipe, the flow velocity will be less, the friction factor will be less and if flow velocity is less and friction factor is less, then there is less likelihood of cavitation to occur. So reduce the cavitation, always we will use a higher diameter pipe in the suction side. The length of pipe, bends and other things, valves, should be made as small as possible, as less as, as small as possible, as low as possible so that the cavitation is not likely to occur.

That means the pressure at the end, that is the most critical point, the pressure at the end of the inlet pipe or at the inlet to the pump should be higher than the vapour pressure, should not fall below the vapour pressure, should be higher than the vapour pressure, little more higher than that so that air cavitation cannot take place, the dissolved air cannot come out in the form of bubble which happens even at a pressure higher than the vapour pressure, higher than the vapour pressure of the liquid at the working temperature.

Okay. Now after this, the discussion on cavitation is over. Now I will tell you another very important thing with respect to the operation of a centrifugal pump that there is a relieve valve here in the suction side. There is a relieve valve here in the suction side of the pump whose function is not to allow the water in the suction pipe going back to the sump before this operation of the centrifugal pump is there. Why it is done?

Before the start of the centrifugal pump, we always fill this suction pipe and the pump with the water. Why? If we do not do so, the pump inlet, pipe and the pump is full of air. Now if the pump rotates, starts rotating, it will rotate in the air, so what will happen, it will generate head which is equal to VW2 U2 by G, so the final power or the total energy that will be generated will be multiplied by the density of air at the flow rate of air.

So some flow of air will come and this and air will come from the atmosphere through this water, so this will generate a very less amount of head because of the low density of air which cannot lift the water from the sump. So what will happen, the picture will be like that this head will leave the water from the sump but it will not go up, so water will fluctuate after going to some height because the pump is rotating in the air and generating very less head because of the lower density of the air.

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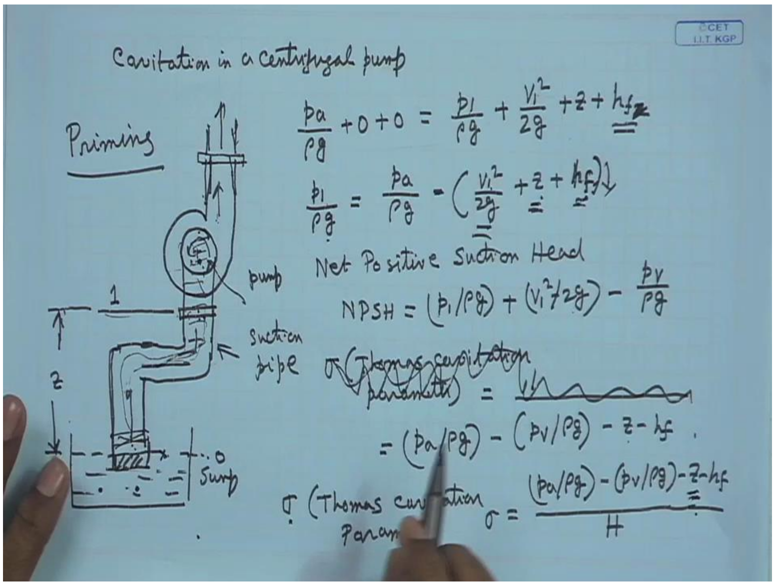

Cavitation in a centrifugal pump

Priming

$$\frac{p_a}{\rho g}+0+0=\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z+h_f$$

$$\frac{p_1}{\rho g}=\frac{p_a}{\rho g}-\left(\frac{V_1^2}{2g}+z+h_f\right)\downarrow$$

Net Positive Suction Head

$$NPSH=(p_1/\rho g)+(V_1^2/2g)-\frac{p_v}{\rho g}$$

σ ~~(Thomas cavitation parameter)~~ =

$$=(p_a/\rho g)-(p_v/\rho g)-z-h_f$$

σ (Thomas cav ation Param

$$\sigma=\frac{(p_a/\rho g)-(p_v/\rho g)-z-h_f}{H}$$

So pump will unnecessarily be heated if it works for a long time and it may fail and get damaged, maybe burned out, the motor may be burned out because of the more current flow through it. So for this reason the pump before operation should always be filled in with water which is known as priming of centrifugal pump. Okay, this all makes a brief discussion on centrifugal pump. Of course we will, we may discuss something else in the next class because time is not there for this class, little more.

So this is not the end of centrifugal pump, a few more, little more things I will just discuss in the next class. Thank you.