Principle of Hydraulic Machines and System Design

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Lecture – 31
Cavitation in Hydraulic Turbine: NPSH

So, we will continue our discussion on Principle of Hydraulic Machines and System Design.

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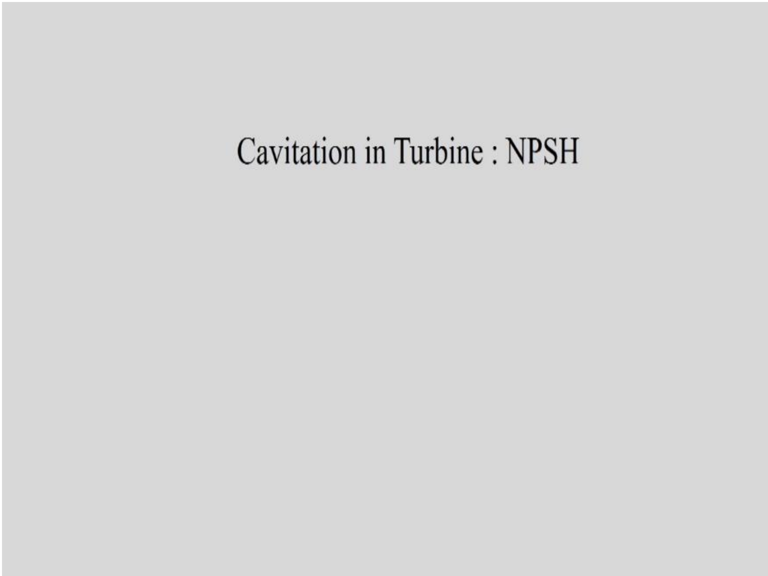

Today we will discuss about Cavitation in Turbine in particular cavitation in reaction turbine and what is the net positive suction head? Probably we have discussed this phenomenon in the context of the operation of pumps that we have discussed that, while fluid is flowing through the passage of an impeller there might be of I mean there might be a case. When; pressure at the you know flow passage might fall the vapour pressure at the corresponding temperature at that temperature then local boiling may start and it will lead to a undesirable phenomenon of cavitation.

So, it is not desirable phenomenon at all because, as I said you that cavitation if starts then it will try to erode some material from the impeller, and it will create an audible noise. So, and we have also discussed that you know to avoid cavitation, it is always advisable to run a particular pump I mean which we talk about radial flow pump that in a flooded suction mode; that means, the pump impeller access should be always below the water level in the you know reservoir.

So, similar to that, similar to that line even there might be a chance that cavitation might occur in reaction turbine, when it occurs because, whenever liquid or working fluid is flowing through the passage of a the passage of the runner rather reaction turbine. So, we should be careful that while the fluid is passing the pressure at any point should not fall the vapour pressure at that temperature otherwise, local boiling may take place and it may lead to a phenomenon of cavitation.

So, now we need to know where the probability is rather where this; pressure might fall I mean the vapour pressure at that temperature. So, we discussed that in the in a pump the cavitation may occur at the eye of the impeller that is at the inlet of the impeller. So, eye of the impeller has very common, I mean very not very common in most of the textbook it is written that at the inlet or entrance of the impeller.

So, that is known as eye of the impeller, where pressure might fall below the vapour pressure and we have discussed that even in the context of effect of inlets valve on the net head being developed by pump, that if say theta 1 become negative since u 1 that is blade velocity at the inlet of the impeller will remain same. In that case a relative velocity will increase, if velocity increases then pressure will fall and pressure falls if pressure falls below the vapour pressure, then it will create this undesirable phenomenon.

But, you know that in the context of pump is happening at the eye of the impeller rather at the inlet of the impeller, but in case of a reaction turbine the chances of having cavitation is at the outlet of the runner. Where pressure might fall below the vapour pressure because, we have seen that in a turbine in particular hydraulic turbine we are utilizing the net head available.

And then, the net head available net head is converted to the kinetic energy of the rotation that is you know and all the head may not be converted into the amount of kinetic energy of rotation. So, we may have little bit we may have some unspent rather unutilized head and to recover that we have a draft tube is the special arrangement in a reaction turbine. So, at the outlet of the runner rather the inlet of the draft tube there might be a chance that pressure might fall below the vapour pressure and cavitation may occur.

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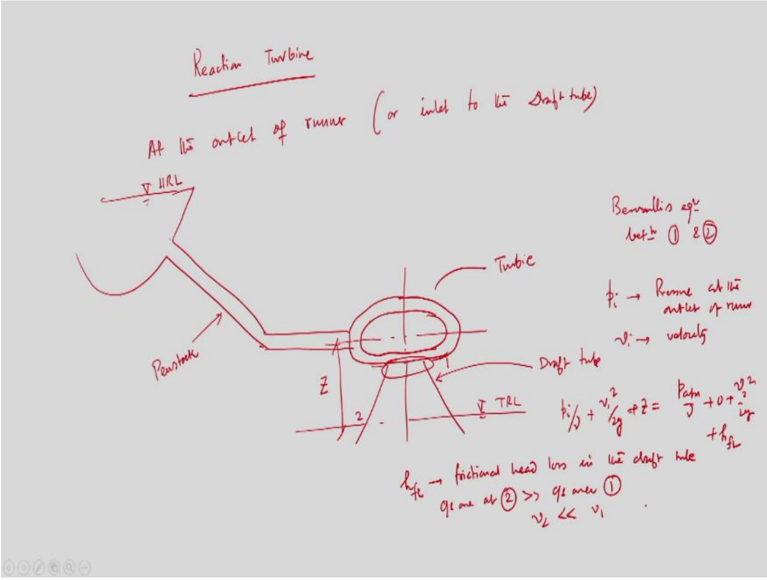

So, we will discuss today that in the context of reaction turbines. So, if I talk about reaction turbine then, an reaction turbine so, as I said you that at the outlet, at the outlet of runner at the outlet of runner or inlet to the draft tube, inlet to the draft tube pressure might fall the vapour pressure and in that case; chances chance is there that you know cavitation may occur.

So, we should be careful that there we should be careful to you know handle this I mean we should take preventive measure by how; like we have discuss that in case of a pump, we have discussed that pumps should be you know always pump should be always below; water level I mean of the sump or reservoir in that case we may avoid cavitation.

Similarly, if I draw the schematic now so, suppose this is the reservoir and this is the penstock, then water is going to the so, this is a turbine. So, and we have a draft tube like this, and this is TRL this is TRL Tail Race Level and this is HRL Head Race Level, this is penstock, this is turbine runner complete hydroelectric power plant, and this is draft tube. Now, if the runner which located let us say z distance away z distance above the tail race level, then highly chance are there you know these areas that is at the inlet to the draft tube and outlet of the runner where cavitation may occur. So, that means, there pressure might fall the vapour pressure at that temperature, and it may have it may lead to a cavitation.

So, now if I apply Bernoulli equation so, if I apply rather steady flow energy equation or Bernoulli equation between these two points, between these two points means this inlet of the runner and final discharge to tail race. So, this is the final discharge somehow draft tube is submerging at the tail race level so; if I apply Bernoulli equation between these two-point let us say this point 1 and this point 2.

So, if I apply Bernoulli equation or I can say steady flow energy equation, if I apply you know Bernoulli's equation between 1 and 2, this is two points then what can I write. This is very important that if I write Bernoulli equation taking this TRL level as a datum then what can I write this very important what I can write? That suppose pressure at the outlet of the runner is pi. So, if I have pi is the pressure at the outlet of the runner, outlet of the runner and vi is the velocity.

So, if I apply Bernoulli equation between these two points what I can write? Taking this datum is the TRL water level at the tail race level then I can write

$$\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g} + Z = \frac{Patm}{\gamma} + \frac{{V_2}^2}{2g} + hfl$$

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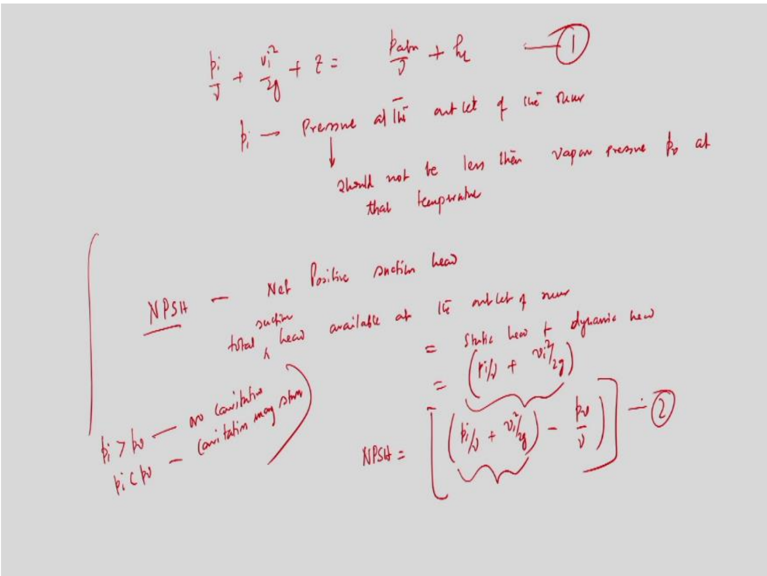

$$\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g} + Z = \frac{Patm}{\gamma} + hl$$

Therefore, we can ignore this term and if I write this equation so, if I write this equation again so, what I get I can obtain pi by gamma plus vi square by 2 g plus z equal to patm by gamma plus h L because, v 2 is negatively small as compared to vi. So, now this pi the pressure at this pi, pi is the pressure at the outlet of the runner and this pressure should not be less than vapour pressure Pv at that temperature.

So, if that pressure pi becomes less than the vapour pressure at that temperature then of course, cavitation will occur, cavitation is cavitation is I mean start cavitation will start rather cavitation is bound to occur. Now question is there is a parameter one is so; pi should not fall below the vapour pressure. Now we have defined one another one you know you know term that is known as NPSH; NPSH so, this is known as Net Positive Suction Head.

So, this is an indicator of whether cavitation is going to start or not. So, this is an indicator to and about the cavitation whether it is going to start or not in a pump or reaction turbine. So, we need to now define so, pi is the pressure so net positive so net suction head so, it is not only the static pressure static head. So, net positive suction head that is total head total head or total static pressure that is equal to total you know; static pressure total head that is very important because, that it is not only the static head.

So, total head suction head total suction head available at the outlet of the runner is equal to static head plus dynamic head, dynamic head static head is let us say $\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g}$. So, this is the total suction head available at the outlet of the runner, static head plus dynamic head. this head should not fall the vapour pressure; that means, there is an indicator so, what I told you that if pi greater than pv no cavitation.

And pi less than pv cavitation may start cavitation may start, now an indicator which talks about the occurrence or of cavitation which is not a desirable phenomenon at all that is net positive suction head. The total suction head available at the outlet of the runner is static head plus dynamic head $\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g}$.

So, this NPSH talks about that these term $\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g} - \frac{Pv}{\gamma}$ of course, because this is the NPSH so, this is the head available and this is the vapour head corresponding to vapour pressure. So, if this become positive that is net positive so, this net positive suction head and then if this is the case and it is if this you know I mean because, we can we can assume that frictional head loss is equal to 0.

Then so, this is the net positive suction head and if this is the case then we should not have cavitation; that means $\frac{Pi}{\gamma} + \frac{{V_i}^2}{2g}$ that is a total suction head this should be you know higher than the vapour pressure, head corresponding to vapour pressure. Now, if I give this equation number 1, then if I write equation if I use equation 1 in equation 2 that is NPSH what I can write? I can write that NPSH.

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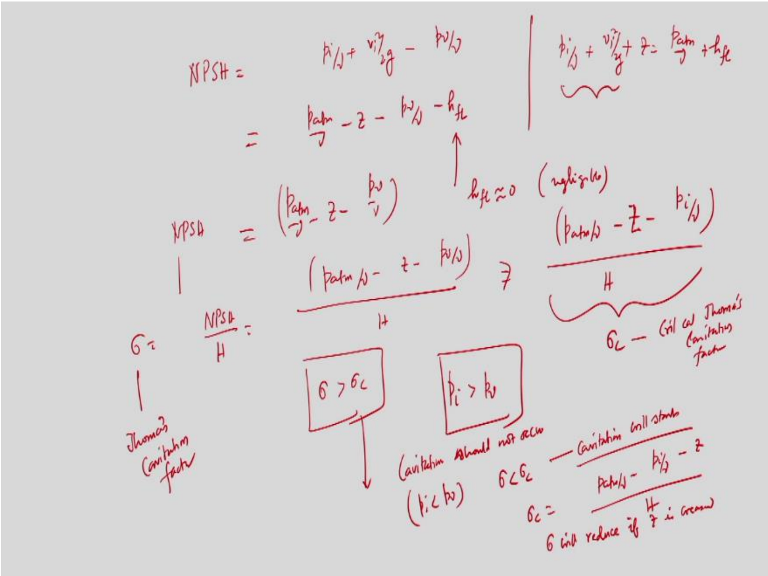

$$\text{NPSH} = \frac{Pi}{\gamma} + \frac{{V_i}^2}{2g} - \frac{Pv}{\gamma}$$

$$= \frac{Patm}{\gamma} - Z - hfl - \frac{Pv}{\gamma}$$

$$= \frac{Patm}{\gamma} - Z - \frac{Pv}{\gamma}$$

$$thomas\ cavitation\ factor\ \sigma = \frac{NPSH}{H} = \frac{\frac{Patm}{\gamma} - Z - \frac{Pv}{\gamma}}{H}$$

$$\sigma_c = \frac{\frac{Patm}{\gamma} - Z - \frac{Pi}{\gamma}}{H}$$

If $\sigma > \sigma_c$, Pi>Pv cavitation should not occur

If $\sigma < \sigma_c$, Pi<Pv cavitation will start

So, if z is increased then sigma c will be less so, I mean if z or h is increased sigma is reduced. So, sigma will be reduced will reduce if z is increased. So, if z is increased sigma will reduce in that case probabilities will be that sigma will be less than sigma c then cavitation might occur.

So, that means, sigma is reduced and; sigma if reduced and if it falls below the sigma critical value then cavitation might occur. So, that is why it is you know cavitation is occur or not occur sigma will be calculated and when sigma is greater than sigma c cavitation is not expected to occur. And z is increased; that means, if turbine is runner is located away from the tail race level then highly chances are there that the cavitation might occur.

So, it is recommended that runner should not be located far away from the tail race level rather runner should be very close to a tail race level. So, z should be minimum, so, if I reduce z then probably the chances are there that sigma will be high and in that case, sigma will be greater than sigma c so, we may a cavitation.

So this is the you know a mathematical formulation about NPSH in the context of reaction turbine operation. and we have seen that cavitation is likely to occur at the outlet of the runner where pressure might fall the vapour pressure we have derive the net positive suction head and we have identified critical value of Thomas cavitation factors and we have seen that here only the only one factor is that by H if H is increased this capital H then also the sigma will reduce.

So, the capital H should not be increased should not be high and also z should not be H; that means, turbine should install very close to the tail race level. So, that the sigma I mean Thomas cavitation factors will be high and it will be greater than sigma c and cavitation may be avoided. So, now, we will proceed to discuss about; you know a few problems that is what we could not solve you know we could not discuss in the last lecture.

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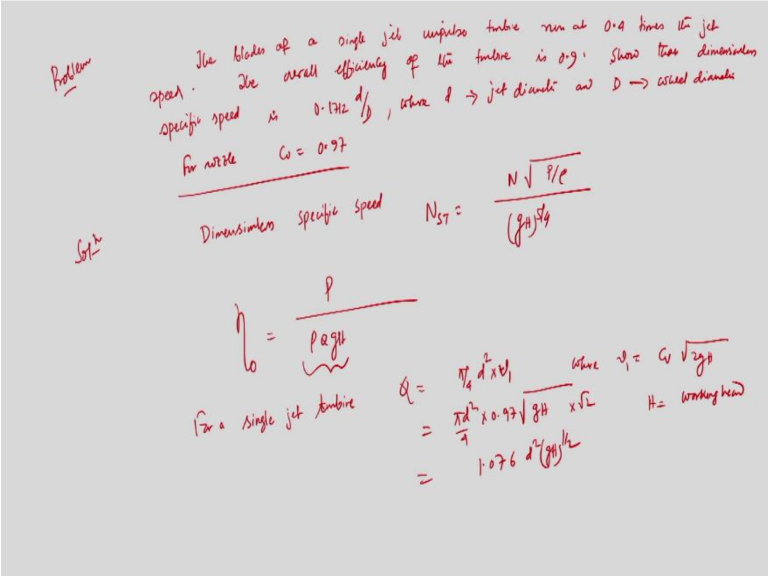

So, today we will solve another two problems based on the you know turbine. So, one problem is that at the blade of a simple jet impulse turbine I am writing another problem that the blades of a single jet impulse turbine run at 0.4 times the jet speed. Jet speed the overall efficiency of the turbine is 0.9 the overall efficiency of the turbine is 0.9 show that dimensionless specific speed is show that dimensionless specific speed is 0.1712 small d by capital D where d and d represents the jet diameter and wheel diameter respectively where, small d is the jet diameter and capital D is the wheel diameter right.

For the nozzle we have to consider for nozzle coefficient of velocity, we have to consider 0.97. So, we have to solve this problem because, we have derived the expression of a specific speed in last lecture. In the last lecture when I derived the dimension dimensional as well as dimensionless specific speed and we have also defined unit speed, unit discharge, you know and unit power.

$$N_{st} = \frac{N\sqrt{\frac{P}{\rho}}}{(gH)^{\frac{5}{4}}}$$

$$\eta_o = \frac{P}{\rho Q g H}$$

For a single jet turbine

$$Q = \frac{\pi}{4} d_1^{\,2} V1 = \frac{\pi}{4} d_1^{\,2}\, C_v \sqrt{2gH} = 1.076\, d_1^{\,2}\sqrt{gH}$$

$P = \eta_o \, \rho Q g H \; = 0.969 \, \rho \, d^2 (gH)^{\frac{3}{2}}$

$U \; = 0.4 \; V1 = 0.548 \; \sqrt{gH}$

$N = \frac{60 \, u}{\pi D} = 0.179 \, \sqrt{gH}/D$

$$N_{st} \; = \; \frac{N\sqrt{\frac{P}{\rho}}}{(gH)^{\frac{5}{4}}} = 0.1712 \; d/D$$

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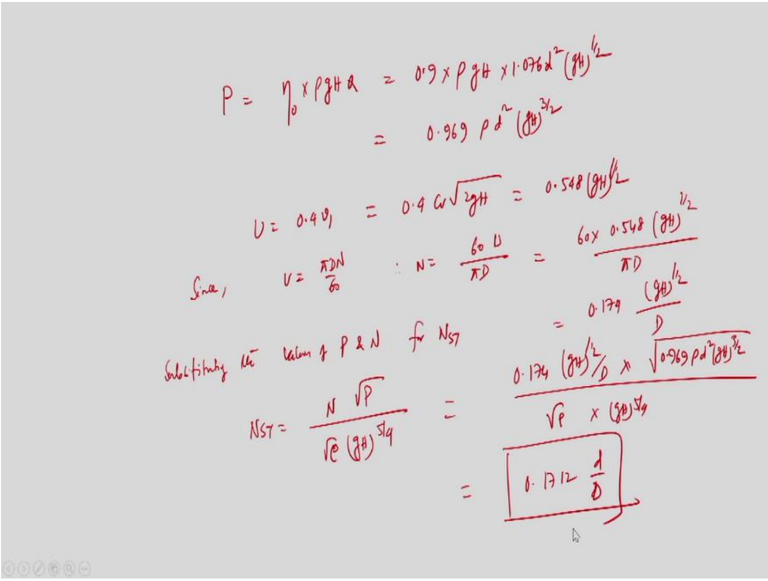

And we will solve another problem so, that is very simple that we everything is given we have to calculate based on the you know mathematical exercise, we have worked out in the context of our in the discussion of impulse turbine and from there we can easily calculate that the dimensionless specific heat can be given by this relationship.

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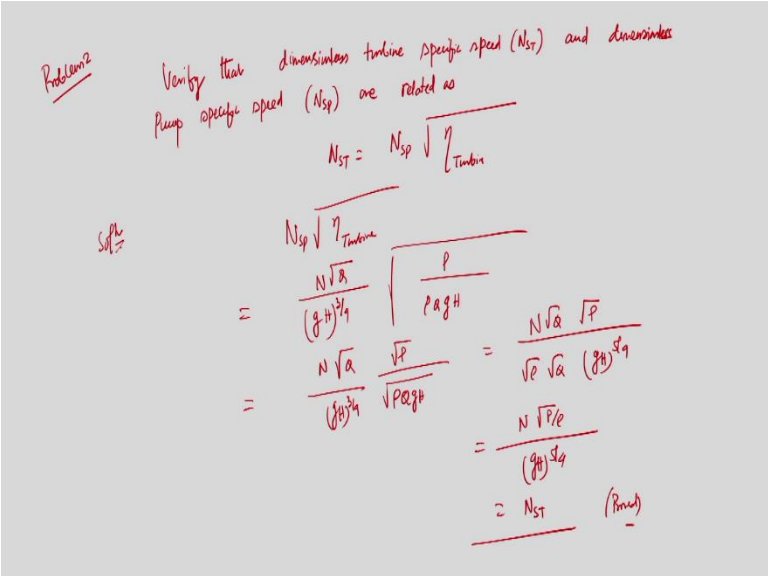

Now the next problem I will discuss is verify that problem 2, verify that dimensionless turbine specific speed and dimensional pump specific speed are related that dimensionless turbine specific speed NST and dimensionless pump specific speed NSP are related as NST is equal to NSP root of eta turbine.

$$N_{st} = N_{sp}\sqrt{\eta_{turbine}}$$

$$= \frac{N\sqrt{Q}}{(gH)^{\frac{3}{4}}} \sqrt{\frac{P}{\rho QgH}}$$

$$= \frac{N\sqrt{\frac{P}{\rho}}}{(gH)^{\frac{5}{4}}}$$

So, we have started from right hand side of the expression which we need to proof and we are ultimately proved that right hand side can be proved to the you know that is equal to lhs right hand side equal to lhs that is what we proved.

So, with we stop our discussion today and we have discussed today these about the cavitation and we have define one indicator is a net positive suction head, then we have defined Thomas critical factor, we have identified where cavitation is likely to occur. And we have also discussed that how the cavitation can be avoided by altering the z that is if the turbine can be placed very close to the tail race level probably cavitation can be avoided because, in that case sigma should be higher than the critical value.

And then, we have worked out two examples based on the you know mathematical exercise that we have carried out in a in my last lectures that is turbine and pump specific speed. And related to impulse turbine and one is a just you know how we can relate turbine specific speed dimensionless to the pump specific speed of course, it is also dimensionless ok.

So, with this I stop here today and whatever we have discussed in this lecture, I mean that is essentially the exercise of the previous theoretical derivation that we have done.

Thank you very much.