[Principle of Hydraulic Machines and System Design
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Lecture – 10
Radial flow pump testing

So, we will continue our discussion on Principle of Hydraulic Machines and System Design. Today we will discuss about Radial flow pump testing.

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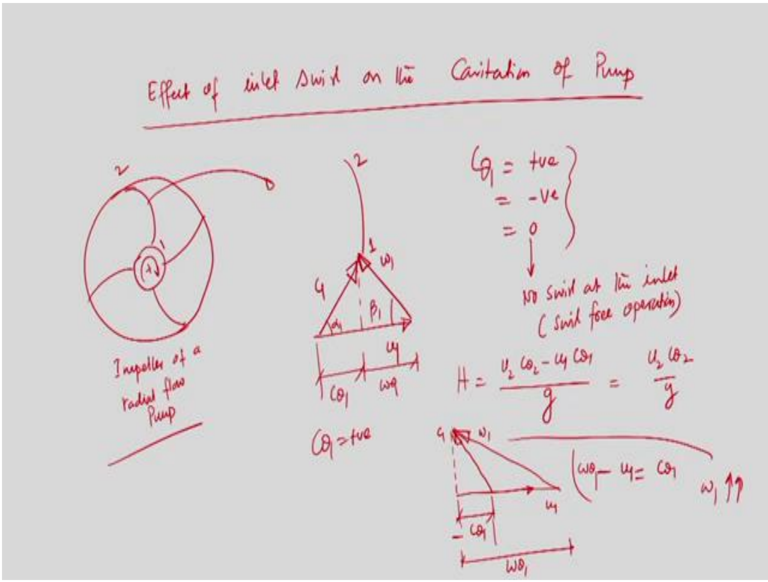

So, before I go to discuss about the pump testing procedure; I will briefly touch upon few important things that that is in continuation in my last lecture that is effect of inlet swirl on the cavitation of pump.

So, effect of inlet swirl on the cavitation of a pump. So, this is in, this is what we have discuss in my last lecture that cavitation is not a desirable phenomenon at all that is whenever we are installing a particular pump; we should prefer to install pump to run in a ferried suction mode. So, that apart from the atmospheric head you may have static height that is there above the impeller axis of pump datum.

Now, if we can recall that if we have discussed that the if the swirl component of velocity at the inlet have positive, negative or it may be a 0. So if I draw the inlet velocity triangles if I say if I consider a radial flow pump; so, this is the impeller of radial flow pump.

And this is blade 1 2 and if I take out this blade and if I draw the velocity triangle at the inlet; these are the components of velocity. And this is point 1, this is point 2; this is component of absolute velocity in a tangential direction and this is component of relative velocity in the tangential direction. And these angles is alpha 1 flow angle at the inlet and this is beta 1 that blade angle at the inlet.

Now, we have seen that the swirl component might have a positive value negative value or 0 that is $C_{\theta 1}$ may be a positive may be positive or it may be a negative value it may have a negative value or it may be 0. So, $C_{\theta 1}$ may have a positive value or negative value at 0.

So, if it 0 that is no swirl at the inlet no swirl at the inlet, that is swirl free operation right. And if you have a positive $C_{\theta 1}$, negative $C_{\theta 1}$ that is swirl component have positive value negative value here, this is $C_{\theta 1}$ is positive and we may have a negative component of $C_{\theta 1}$ that is negative component of $C_{\theta 1}$ that is negative swirl at the inlet.

So, what we normally go that as I said that we may have a positive component when the direction of, I mean the direction of rotation of the impeller and fluid are in the same direction or we may have a negative swirl component if the rotation of the fluid and the impeller are different.

Now, best possible case is there will be a no swirl at the inlet. So, if we now recall that head developed by the pump is $(u2\ C_{\theta 2} - u1\ C_{\theta 1})/g$; then if you have no swirl at the inlet then this head developed by the pump can be return u2 $C_{\theta 2}$/g.

But from this expression of Euler head; I we can see that a positive value from this expression we can see that a positive value of $C_{\theta 2}$; a positive value of c theta 1 will always try to reduce the head being developed. A 0 value is the best possible case because if neither we will reduce or neither; we will you know it on decrease rather it also will not increase the head develop, but a negative component will always increase the head developed by the pump.

So, we have seen that a positive value will always decrease the head being developed by the pump, 0 value is a best possible case because it will not increase, or it will not decrease. But a negative component; we will always increase the head rather we will impart a head that is being developed by the pump.

But we have seen that this negative component of $C_{\theta 1}$; that means, if we draw for a negative component of $C_{\theta 1}$; then since for a given inlet diameter of the you know impeller the tangential velocity at the inlet is remaining same.

So, now if we have a negative $C_{\theta 1}$ that is the component that are most the rotation of the fluid and the incoming fluid and impeller are in different direction. So, we may have this is c 1 c theta this is c 1 and to make you know that keep u 1 fixed we have a higher relative velocity at the inlet.

Since u 1 is fixed; this is c 1 and this is $C_{\theta 1}$; this is negative $C_{\theta 1}$ and this is $W_{\theta 1}$. Here; now $W_{\theta 1} - u1 = C_{\theta 1}$; that means, a negative component swirl velocity at the inlet can be produced whenever we are having rotation of the fluid and the rotation of the impeller at different.

But since the blade velocity at the inlet is fixed because diameter is fixed; so, to maintain the constant blade velocity are inlet and if you would like to have a negative swirl component at the inlet; the relative velocity w1 at the inlet should be high it should increase.

Now, if relative velocity at the inlet increases that is at the impeller inlet I of the impeller then pressure will fall and if pressure falls the vapor pressure at that temperature that what we have discussed that it may initiate cavitation in the you know pump and which is not a desirable phenomenon at all. So, from this discussion what we can tell that a negative c theta negative component of swirl velocity might import head that is being developed by the pump right may increase the head being developed by the pump.

But at the same time it is inviting another problem which is not a desirable phenomenon at all cavitation in the pump operation; so, we should not go for the negative swirl velocity. So, a best possible case is the no swirl at the inlet because it neither increases or decreases, not decreases the head being developed by the pump.

With this I will proceed to discuss our next that is the texting of a radial flow pump. So, very important that is should know whenever we at why we are testing a radial flow pump and why what are the steps need to follow while you are testing the radial flow pump.

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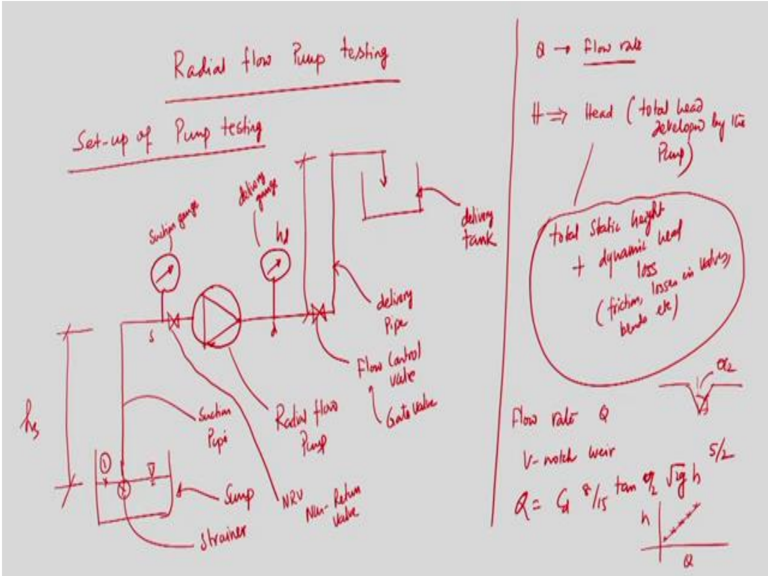

So, a radial flow pump testing radial flow pump testing; that means, why do; why do you need to study a radial flow pump testing? Because by testing we can generate H cube curve that is there; all the same times we should know what are the step and what are the procedure I mean why we do follow all though steps while testing is done.

So, again I have I will draw a schematic of the setup of pump testing; of course, a radial flow pump testing set up of pump testing. So, if I draw the schematic suppose this is the pump and pump is used to supply water in a delivery tank; where static height is where static height is z d.

So, here we have writing the static height is let us say hd and pump is withdrawing water; pump is withdrawing water you know pump is withdrawing water from the inlet from the sump. So, if the sump is located let us say hs distance below from the impeller axis or pump axis. So, this is the sump location which is located you know at a distance hs below the pump axis.

So, this is hs this is open to atmosphere and this is pump suction side. So, we are having one suction gauge, we are having one delivery gauge. So, this is suction pipe we are having strainer one half at the suction side we are not drawing all those. This is delivery pipe and it is supplying water in the delivery tank. This is delivery tank; this is sump and this one is the radial flow pump.

So, as I said that we go for pump testing to have to generate H cube curve; also we need to know the steps rather procedures of a pump testing so, that what could be the you know actual when you are designing a pumping system, what should be there in a pumping system I mean and how one operator can start pump; initially all this things can be you know understood from this pump testing process.

So, of course, we should have a flow control valve over here. So, here we will have one valve this is called flow control valve; we will have one strainer over here, strainer. The function of strainer is to arrest all the you know foreign particle if we do not provide strainer; the foreign particle might go through the through the flow velocity in the suction side and it may collide with the impeller; it may try to erode the impeller material. So, we should have a strainer to arrest all the foreign particle that is bearing the sump.

We should have a flow control valve at the delivery side and sometimes we are providing one also Non-Return Valve pump suction side. Sometimes we are providing one Non Return Valve this is called NRV that is Non Return Valve also we are providing another Non Return Valve at the pump delivery side; this is non this is called gate valve to control the actually we should have gate valve to control the flow, also it should have one Non Return Valve at the pump delivery side.

Because if pumps stop suddenly then if pump is discharging water to a certain height then whatever water is there in the delivery pipe line that may; if you do not provide any Non Return Valve that may eventually create a sust on the pump impeller and it may destroy the bearing there are sust bearing or you know bearing of the pump.

So, we should also provide a Non Return Valve in the pump delivery side only to prevent the water you know incoming water that is there in the delivery pipe when pump stop suddenly so this is Non Return Valve. Now if this is the point 1 suppose this is point 1 and this is a suction this is suction gauge; suction gauge and this is d delivery, and this is delivery gauge.

So, as I said that first objectives of pump testing is to generate H cube curves and second objective is to know what are the procedure of pump testing at least from these an operator should know what are the procedure when he or he touch the pump initially you know pumping system. So, how I can measure? Because whenever I am purchasing a pump on a from manufacturer; they will provide H cube curve, but we need to test we need to you know calibrate. So we need to test whether at the pump is really supplying that amount of discharge; I just the head H or I just you know particular head.

So, whenever pump is supplying water to a delivery pipe; so how do we measure fluid? So, in there are there are 2 important quantity I can measure flow rate Q. I can calculate H how I can calculate H? Because I know the head that will be developed by the pump that is what is the total static head pump needs to work come also the frictional losses in the delivery side and in the valves you know bends all those things. So, flow rate Q and head, this is head this is total head developed by the pump. It may be head loss in the suction side plus delivery side.

If the pump the schematic whatever I have drawn is in the negative suction mode that is pump is drawing water from the sump and discharging to a different place, but if it is in a flooded suction mode because in that case impeller axis of pump datum is always below the water level. Then on the top of the atmospheric head we are having another head which is equal to the static height that is the height you know above the pump axis.

So, I can calculate head that is the, this will be total static height that pump needs to lift plus dynamic head loss. Because of that is frictional because of friction losses in valves, bends etcetera. So, frictional head loss in the pipeline losses in a valve and also bends these total static height plus dynamic head loss the H. That I need I can calculate whenever a pumping is when whenever a pump is the installed in a pumping station to serve up certain purpose.

Now, I can measure flow rate suppose whenever pump is discharging; I can measure flow rate that I know that pump is delivering this amount of head that I can obtain from the delivery gauge reading and suction gauge reading. That is delivery gauge reading minus suction gauge reading is the total head being developed by the pump.

Now I can obtain that whenever the head is being developed by the pump is this then what is the flow rate? So, I can measure flow rate Q, whenever pump is discharging that I can use that amount of water that I can pass that you have that amount of water in a V notch; that flow measurement a flow measuring device that is V notch weir right.

$$Q = C_d \frac{8}{15} \tan\frac{\theta}{2} \sqrt{2g}\, H^{\frac{5}{2}}$$

So, in a V notch; this angle is $\frac{\theta}{2}$ and their height from height that is you know in sorted in this V notch we can obtain what is the height and I know the C d; I can calculate Q. So, by observing the height of the water in the notch and I know that $\frac{\theta}{2}$ that is notch angle. And I can calculate what is the amount of keep doing caring discharged by the pump; against the head that is calculated between the reading that is calculated based on the reading obtained in the delivery gauge and suction gauge.

So, from this I can you know obtain; so, I can obtain H versus Q for the particular pump and also I need not to a directly use this formula sometimes the calibration chart is provide in the V notch h versus Q. So, if I know the this is the h, this is the h and this is the h; so, I may obtain corresponding Q. So, I may not use directing this formula or sometimes we calibration chart is provided the V notch this only by measuring the height a what the notch I can directly obtain the flow rate from the chart.

So, this is all about the flow rate measurement and I know that what is the head being developed by the sump that is obtain from the suction gauge and delivery gauge reading. So, I can it easily or I can easily obtain H versus Q curve in the for the particular pump. And as I said from the discussion in the last problem in the; in my last lecture that H Q curve whatever I am plotting and that may not be the actual curve.

Because actual curve will look like it will not be a straight line; it may have some it may deviate from the straight line because of the recirculation losses and separation losses in the suction and delivery side respectively. Now this is all about the measurement of flow rate; now how can I measure suction gauge reading and delivery gauge reading that we need to know. So, I will now proceed, and I will now write the steps. So, what are the steps before I discuss about the calculation of head rather suction gauge and delivery gauge.

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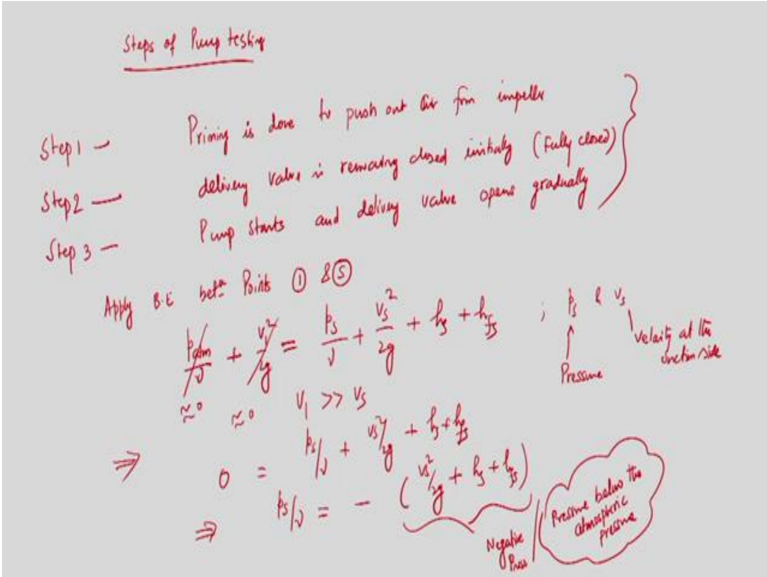

Now, I will write the step of pump testing because I cannot run, I cannot suddenly run the pump; so, I need to know what the basic steps are.

So, first step of the pump operation is that step 1 priming is done; this is very important operation and important operation priming is done to push out here from impeller. So, priming operation is done initially to push out air from impeller; that means, because as I said that the schematic that I have drawn is essentially for the negative suction mode; if it is a flooded suction mode.

So, always the impeller is filled up with the water because impeller axis itself is below the water level of the sump. So, always the impeller is filled up with water. So, there is no question of having here inside the impeller, but if the pump is running in a negative suction mode; we need to ensure that before I start pump all the air that is present in the impeller should push out I mean should go away.

So, we need to push out the air which is there in the impeller and that is known has priming operation. How it is done? Because there is a tank of water which is above the pump axis and tank is connected with a impeller by a pipe. So, before I start to run the pump; I mean before I start the pump initially tank is open and water is allow to come from tank to the impeller so that the impeller will be impeller will be filled up by water and the that air that is there in impeller will go away.

And we need to ensure that impeller is properly impeller and a suction pipe is properly filled up with the water; no air there in inside the impeller as well as in the pipe line. This is quite obvious because if air is there inside the impeller and we have seen if we go back; if I go back to my previous slide, if I go back to my previous slide then I can see that here atmospheric air is only the available head.

Because if air is there then again atmospheric air; then it is very difficult to have any driving force between the point 1 and s; so that water will go away. So, it is very difficult; so, you to ensure that we have to have priming operation I mean that is done before we start pump.

Step 2; so I cannot run pump suddenly step 2 delivery valve is remaining closed initially remaining closed initially and fully closed; remaining closed initially rather fully closed right step 3 this is very important. So, step 1 priming is done; we must ensure that there should not be any air inside the impeller or in the suction side and I had I told how to how priming operation is done.

That is water is being allow to come from tank which is located at the top of the pump and it will entered the impeller what impeller will be filled up by the water and water air will go away. Second step the delivery valve is fully closed before I stuck the pump delivery valve will remain fully closed.

Step 3 pump starts, and delivery valve opens gradually; opens gradually. So, these are the 3 basic steps that we need to ensure before I start operating the pump. We have to have priming operation; if it is again, I am telling if it is a negative suction mode. If the pump is located in a place where pump will run in a flooded suction mode, then we did not to worry about this problem because we need not to go for the priming operation; then delivery valve is we need to ensure the delivery valve will remain closed fully before I start the pump.

Step 3 pump starts whenever I am starting the pump and the same time I should you know open the valve delivery valve gradually; not fully. Now because usually of course, because if I open the delivery valve suddenly, then it will try to discharge huge amount. So, initially power will be high, and that power may not be equal to the you know power provided by the electric motor. So, pump may you know there will be a you know sort of condition; so, pump may trip.

So, because power depends upon ρQgH; so if I close if I open the delivery valve initially fully then pump will try to supply full amount of discharge against the full head. And then what will happen? The head you know power that will be drawn from the electric motor will be high so, that and if there might be a situation the electric motor on be a able to supply that amount of power.

So, pump may trip I mean pump may stop rather electric motor on be able to run the pump. Now, I will go to measure the suction and delivery gauge reading; so, if I apply Bernoulli equation, rather stead flow energy equation between points 1 and S how what can I write?

$$\frac{Patm}{\gamma} + \frac{{V_1}^2}{2g} = \frac{Ps}{\gamma} + \frac{{V_s}^2}{2g} + hs + hfs$$

So, h s is the static height, hfs which and you know text the loses I mean that is because of that is there fictional loses; loses be to bends, valves, strainer etcetera. Here Ps and Vs are the pressure and velocity at the suction side; pressure and velocity of suction side. From this expression what I can write again as I said the cross-sectional area of the sump is much much higher than the pipe cross section; so, V1 is much greater than vs.

So, this is the expression of creating by gamma form the suction side, that it is if I applied study flow energy equation between point 1 and s. So, I can write$\frac{Ps}{\gamma}$is equal to you know and this is also 0; $\frac{Patm}{\gamma}$ this is because this is open to atmosphere.

$$\frac{Ps}{\gamma} = -\left(\frac{{V_s}^2}{2g} + hs + hfs\right)$$

So, if I apply Bernoulli equation between point 1 and s; eventually I get that the pressure available suction is a negative pressure. So, this is negative pressure that is we have to have negative pressure of the suction side otherwise how that atmospheric pressure will try; will try to push water from sump to the pump.

So, this is negative pressure that is pressure below the atmospheric pressure. So in pressure below the atmospheric pressure or negative pressure; so, we have will have a negative pressure at the suction side and if you do not have a negative pressure on suction side they are wont be a pressure defines. So, pressure the suction it should be always less than the atmospheric pressure and it will and then we will have a driving force. And the driving force will allow water to go from sump to the you know pump.

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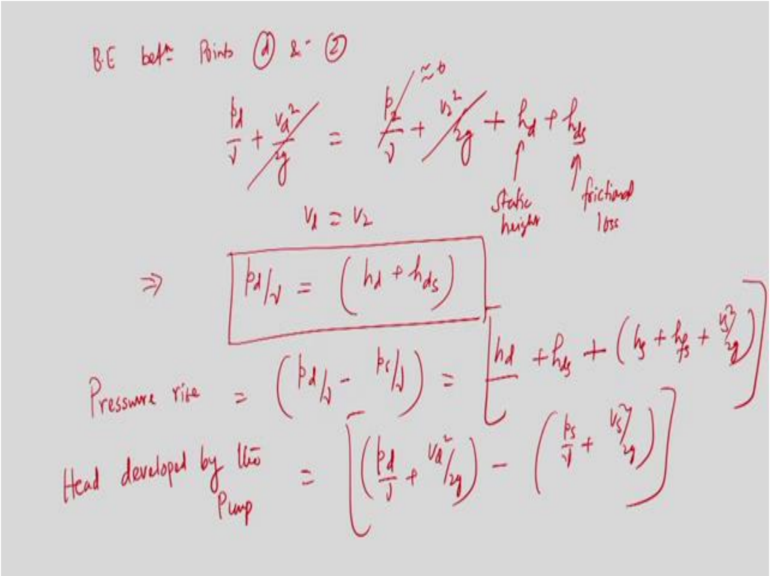

Now, again if I apply Bernoulli equation between point, again if I apply Bernoulli equation between points d and 2; mind it 2 is a point which is located at the atmosphere.

$$\frac{Pd}{\gamma} + \frac{{V_d}^2}{2g} = \frac{P2}{\gamma} + \frac{{V_2}^2}{2g} + hd + hfd$$

V1=V2

Pressure rise = $(\frac{Pd}{\gamma} - \frac{Ps}{\gamma})$ = $hd + hds + hs + hfs + \frac{{V_s}^2}{2g}$

Head developed by the pump H = $\left(\frac{Pd}{\gamma} + \frac{{V_d}^2}{2g}\right) - \left(\frac{Ps}{\gamma} + \frac{{V_s}^2}{2g}\right)$

So, if I go back to the you know my previous slide here say this is a point 2. So, it is discharging water open I am in the sump; so, this is open to atmosphere. So, now if I write Bernoulli equation between point d and 2 how what I what can I right? And I am taking impeller axis rather pump axis datum.

so, this is almost equal to 0. So, I can obtain $\frac{Pd}{\gamma} = hd + hds$, where this is the static height, and this is the frictional loss.

H = $\left(\frac{Pd}{\gamma} + \frac{{V_d}^2}{2g}\right) - \left(\frac{Ps}{\gamma} + \frac{{V_s}^2}{2g}\right)$

$$= hd + hds + hs + hfs + \frac{V_s^{\,2}}{2g} + \frac{V_d^{\,2}}{2g} - \frac{V_s^{\,2}}{2g}$$

$$= (hd + hds) + \left(hs + hfs + \frac{V_s^{\,2}}{2g}\right) + \frac{V_d^{\,2} - V_s^{\,2}}{2g}$$

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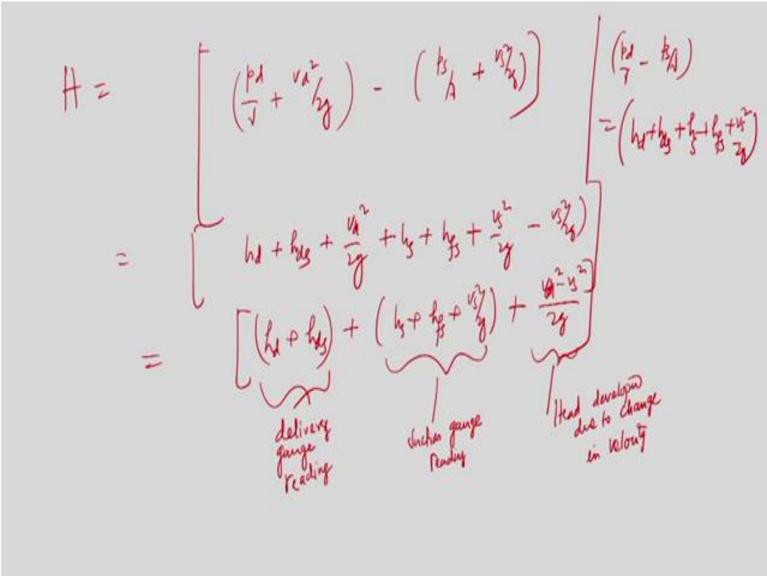

So, it is having 3 components this is delivery gauge reading. So, if we try to obtain the head developed by the pump is essentially the delivery gauge reading. This is suction gauge reading and this is the head developed due to change in velocity between the suction and delivery side delivery side. So, the total head develop the pump, from the pump testing operation I can obtain; by knowing the delivery gauge reading plus suction gauge reading plus head developed by the head develop due to change in velocity in the suction delivery side.

So, this is the total head developed by the pump; you know pump you know you know by the radial flow pump you know particular system. From here I can tell you that the velocity at the delivery pipes, you know of water and velocity at the velocity of water the suction side will be different.

Of course, because if the if we recall that the expression of you know suction gauge reading and delivery gauge reading. Rather if I go to my previous slide and if I look at the; So, velocity at the suction side should be always less; because if this quantity becomes high; then we will have a higher negative pressure.

So, if this quantity is high v s; so we have a higher frictional loses and hence from here we can obtain that the; this quantity is the positive quantities. So, velocity at the delivery pipe always should be have then the velocity at the suction side. So, if; so from here we need to know that the diameter of the suction pipe and delivery pipe should not be equal. So, we can obtain we can see that that we can obtain a clue about the diameter of the delivery and suction pipe from this expression.

Here that $\frac{V_d^2 - V_s^2}{2g}$ which provides which you know discuss the head because of change in velocity. So, velocity at the delivery pipe is always higher than the suction pipe because suction pipe delivery suction pipe velocity is not that much because if velocity increases frictional offers will be high. So, in order to keeps loses using the permissible limit we need to have relatively less velocity at the suction pipe.

So, if the velocity is at different in of course, pipe diameter will be different to maintain a same flow rate. So, we can get clue a form that what should be the diameter of the pipe at the delivery pipe delivery side and suction side from this quantity.

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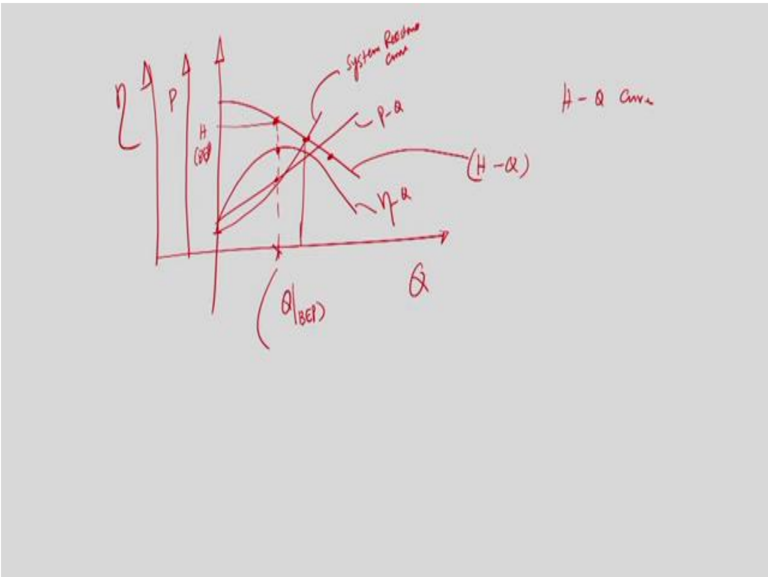

Now, we will discuss about the one you know pump characteristic curve that I have discussed that pump characteristics curve are H Q curve. We have seen that you know pump should have if I plot the experimental data; if I plot the experimental data; I will get I will get the pump H Q curve like this.

So, this is Q and this is H. So, this is H Q curve; if I super impose because we need to know the efficiency as well as the power. So, if it is power P and it is efficiency eta then this is H Q curve; I may obtain you know pump efficiency is like this. So, pump efficiency is like this and power will be like this.

So, this is the best of best efficiency point and; so, we should, and we should allow the pump to run at the best efficiency point. So, this is the discharge corresponds to best efficiency point and this is the head corresponds to best efficiency point.

So, efficiency we can obtain because we know that head being developed by the pump, what is the head being developed by the pump. So, the power developed by the pump will be ρQgH at the same time you know how much amount of you know electric motor electric power wire supplying. So, I can obtain the; you know power supply to the pump.

So, this is you know P versus Q this is eta versus Q. So, this is the best efficiency point where power will be less and you know the discharge and head corresponding to this point are known as head at best efficiency point and correspond a discharge at the best efficiency point. But now this H Q curve we obtain from the pump test pump testing process.

Now, we have system resistance curve. So, we always on the able to run the pump at the best efficiency point, but we should try, but if the system resistance curve is like this that this is a total static height and it crosses the pump here so; that means; so, if the curve like this. So, may be this is the this is system resistance curv; this is system resistance curve.

So, whenever a wire system resistance curve meets the H Q curve of the pump; then this is the operating point. Now see this operating point is not the operating point where you can obtain best efficiency, but this difference upon the system resistance. So, it is not powering able that we should always allow pump to run at the best efficiency point we should try, but it also depends upon the system resistance.

So, we know we need to know the system resistance and whenever we are supplying; whenever we are you know procuring particular pump, we should supply the system resistance. Maybe we should provide the system information about the total head loss in the system at including static height and dynamic head loss to the pump manufacture.

So, that they will try to I know have that all based on that system resistance pump can be operated at the best efficiency point. So, this is all about the pump testing procedure and how you can generate pump H Q curve from the pump testing data.

And as I said that it is not allow is possible to run pump at the best efficiency point because it depends upon a system resistance that is why we should always provide system information about the system resistance whenever I am purchase; whenever your procuring pump forming in pump manufacturer. So, with that I stop here today, and we will continue in the next class.

Thank you.