Fluid Machines.
Professor Sankar Kumar Som.
Department Of Mechanical Engineering.
Indian Institute Of Technology Kharagpur.
Lecture-22.
Matching of Pump and System Characteristics.

Good morning and welcome you all on this session of fluid machines. Last class we discussed the head discharge characteristics of a centrifugal pump. This class and also we discussed the influence of blade angles on the head discharge characteristics. So here in this class we will discuss the matching of pump characteristics and the system characteristics. That means if you have to incorporate a centrifugal pump in practice, the pipeline connected to the centrifugal pump comprises the system.

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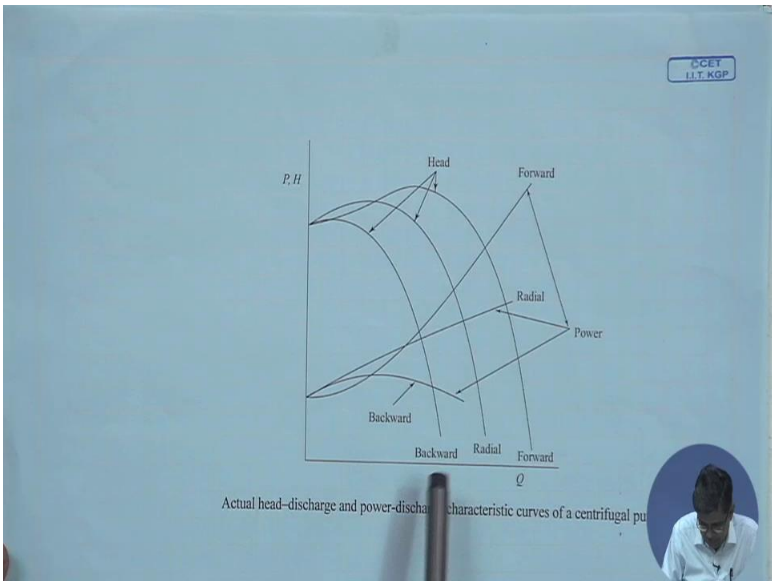

So therefore you have to know the system characteristics and you have to match the pump characteristics accordingly with the system characteristics so that the operating design point has to be found out. But before that I would like to discuss one thing that as I have told that these are the 3 characteristic curves for HQ relationship for 3 types of blade. One is the backward facing, another is the radial and another is the forward facing. And these are the typical power variations with the discharge characteristics.

Now here what happened, would like to mention, is a very practical issue that in case of backward facing vane, you see there is a maximum point in the power which occurs at the design condition. Now power reduces in both the direction. So what happens that if the pump operates beyond this design point and if we purchase a motor or if we employ a motor rated at the design condition, then this will be working as part load conditions and this will be used safely under that condition off design condition, because power is less.

But while in case of other 2 types of blades, since the power is monotonically increasing with Q, if we employ a motor at, rated at design condition, then at off design condition what will happen, this power, this will be work at the part load. That means it will be always underrated for a time or if we purchase, then that will be a loss of money actually. If you make it, most of the cases the off design conditions run at an underrated condition. But if you purchase or employ a motor rated at that condition, the off design condition, then if the design condition is met, then this will be overrated and there is a chance that pump motor may fail.

So this does not happen in a backward impeller blade, backward facing impeller blade or backward curved impeller blade and this is known as self-limiting characteristics. So HQ and power characteristic is such that in a backward facing blade, it is a self-limiting characteristics, that means you can have a pump, there is no chance that pump may fail and there is a little chance that pump will be always working underrated. So that is why this is being preferred.

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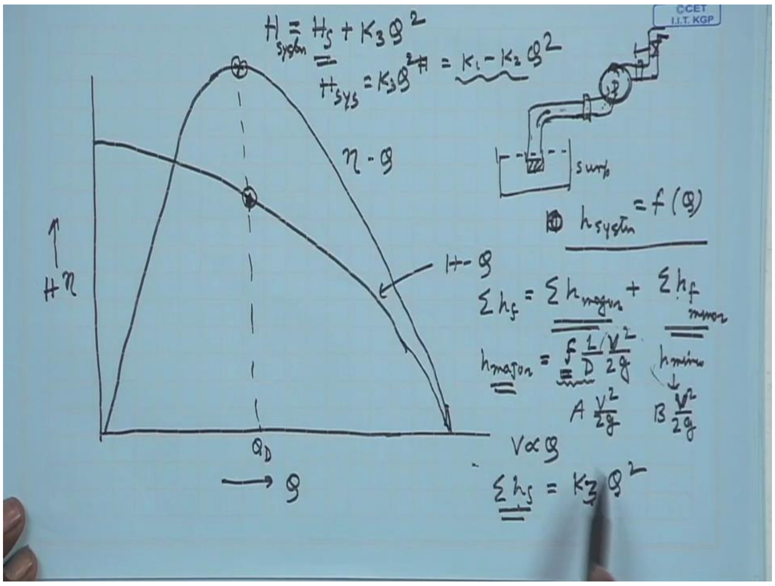

Now after that I will tell you about the pump and the system characteristics. Now let us consider the HQ characteristics which for a backward facing curve like this. Let us put H and it is Q and we have this HQ characteristics. Let us have the efficiency characteristic, the efficiency characteristic is like this. Now this H becomes 0 at some Q, that is also theoretically is seen that at some point, for example H is K1 - K2Q square. So at some point

H will be 0. Physically that means that at higher flow rate, all the mechanical energy is dissipated into intermolecular energy without developing any useful power or useful head.

So H means 0 at a high flow and similar is the efficiency, this is efficiency curve, this is HQ curve, this is Eta Q curve. Now this is the maximum efficiency point, so therefore this is the design point and this is the design flow rate and this is the design point theoretically, on the HQ characteristics. But actual operating point it is difficult to be at here because actual operating point is not in our hands. If we have these 2 curves as the characteristics curves of a pump, we will usually feel that pump should run at this point. That means at this flow rate and at corresponding this head but it is not in our hands.

Exact operating point will be determined by the matching characteristics of the pipeline. Now if you see the pump and the system like this, pipeline system, this is the inlet strainer, this is the sump, now if you consider this, that this is the pump and finally this is the delivery line, this is the delivery line, then you see pump has its own characteristics, that is H. But these lines, strainer, these lines, these bends, there are also valves, here there is a valve, here there is a valve, here there are flanges, there are flanges, so therefore valves, flanges, vanes, lines, these also incur some losses and that depends upon the flow rate in the pipeline.

The relationship of this energy loss with the flow rate in this pipeline which is known as system to the pump, pump and the system to which the pump is attached, the pump alone cannot work to lift water or to transmit water. So therefore this system relationship between H, the head loss, sorry small h, head loss in this system as a function of Q, flow rate is known as the system resistance. And this system resistance, total frictional resistance is contributed by 2 types of resistance, one major loss, one is the major loss, another is the minor loss, HF minor.

So what are the differences between these 2, these 2 are due to liquid friction, viscous. But this major loss is the loss due to the skin friction of the pipe surface. That means if there is a long pipe, the loss of mechanical energy which is manifested in terms of the loss of the static pressure or static pressure head is taking place because of the shear stress at the wall, which is known as the skin friction and that is a consequence of fluid viscosity. And these depend upon the diameter of the pipe as you know from your knowledge in basic fluid mechanics more is the diameter, more is the loss and depends directly upon the length of the pipe.

So over a given length, this loss due to the wall friction is known as major loss, this is a terminology used. Now another type of losses are there, this is also because of the fluid friction which takes place because of its change in direction, in the fluid, when there is a sharp bend, fluid flow through a bend, when there is a valve which provides an aperture or small area and the fluid flows through that, the streamline converges and again diverges, similar thing happens when the fluid flows through an abrupt contraction or abrupt expansion.

These losses, for example when the fluid flows through a mechanical strainer, these are also losses due to fluid friction or viscosity but these losses are usually termed as minor losses because of their magnitude a relatively low as compared to the major losses, that of course depends upon the length of the pipe. So all are frictional losses but they can be clubbed into major and minor losses. Now the major loss as you know in any pipeline, if you recall your basic fluid mechanics concepts, is given by L by D V square by 2G. Okay.

Where F is the Darcy's friction factor, L is the length, D the diameter and this is the velocity of flow in the pipeline. This is actually the equation that defines the friction factor. Because this part, the energy losses that are determined from the shear stress at the wall. This is the equation which defines the friction factor F but in practical purpose, we use this equation as if F is given and we can find out these energy losses due to fluid friction at the surface from the flow velocity V.

Now in turbulent flow region, F is substantially constant, remains substantially constant, so therefore this is a constant, this can be given A, A V square by 2G. So therefore major loss is proportional to V square and minor loss is also proportional to V square, this is usually expressed in all hydraulic circuit as a proportionality constant into the velocity head. So therefore the fictional losses comprising both major and minor can be expressed like this where V is the velocity of the flow in the pipe.

And this velocity of flow in the inlet pipe is the velocity, the inlet pipe and that in the discharge pipe is the flow velocity in the discharge pipe. But in both the cases, V is proportional to Q and the scale factor is the cross-sectional area. So therefore as a whole one can say that the friction losses entire comprising both major and minor losses in inlet and the discharge pipe can be expressed as a constant K4, let K1, K2, let it is K3, some K3 into Q square.

Okay, all the frictional losses can be expressed as K3 into Q square. So therefore this is the basic equation for relating the energy losses in terms of the flow velocity. Do you see these energy losses has to be overcome by the pump. So the pump has to develop a head as per the demand of the system that includes the static lift + this K3 Q square. You understand that if there is a static lift, if there is no static lift, that means the pump distributes water in a horizontal plane, so it does not lift water vertically above, so in that case H is 0, in that case, this you can write H system.

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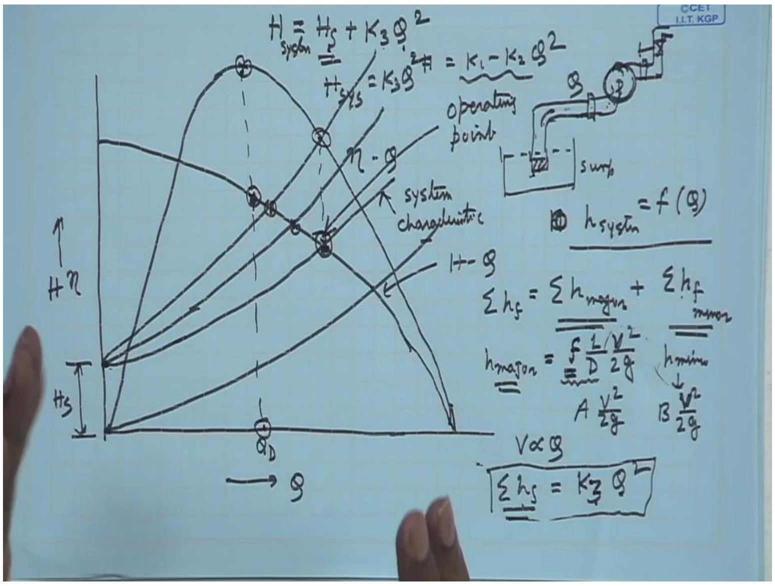

H system is equal to K 3 Q square. That means system will demand this type of head so that this pump can be in operation to maintain the flow, it contains all the losses and these minor losses also include the exit losses. That means the loss that is being incurred by the exit velocity. Okay. So therefore if we consider this thing as the system resistance with static lift HS, this can be expressed or this can be shown like this, here this is HS, let this HS.

So therefore this is system characteristic, okay, system characteristics which is HS + constant into Q square. That means the system demands that relationship and there should be matching. When the pump is in operation and there is a steady flow Q, so therefore this equation has to be satisfied again for the pump HQ relationship has to be satisfied according to this curve. So therefore the operational point or the operating point will be the intersection between these 2.

That means this is the operating point. So therefore one thing is clear that operating point is the intersection between the pump characteristic and the system characteristic and this point is not close to the not exactly at the same efficiency point because there the efficiency is lower than the maximum, not the maximum efficiency point. So this is, this operating point is not at the maximum efficiency point. So if you want to run the pump at the maximum efficiency point, we can generate different system characteristics curve by changing the system resistance by changing the valve, changing the pipe length, bend and anything so that the system resistance curve, these are the series of system resistance curves.

So if you change the system resistance curve with different resistance from one, this point P moves like this. And this way we can make things closer. But the system resistance is also not always within my hand, that depends upon the resources, the requirement of the pipe length, the valve and all these things and therefore we cannot come very close to that. So depending upon the system resistance required for the purpose or available for the purpose we can find out the operating point by the intersection of the pump HQ characteristics, as pump as an isolated equipment and the system characteristics, this intersection is the operating point.

So therefore operating point does not always give a maximum efficiency which is there as the rated design conditions. So this way one can think of matching the system characteristics and the pump characteristics to get the operating point. If there is no static lift, the system characteristic is like this. So each and every curve is valid for a particular system, particular length of the pipe, diameter of the pipe, number of bends, the type of bends, valve, the strainer at the inlet, everything. So this is specified by this particular curve.

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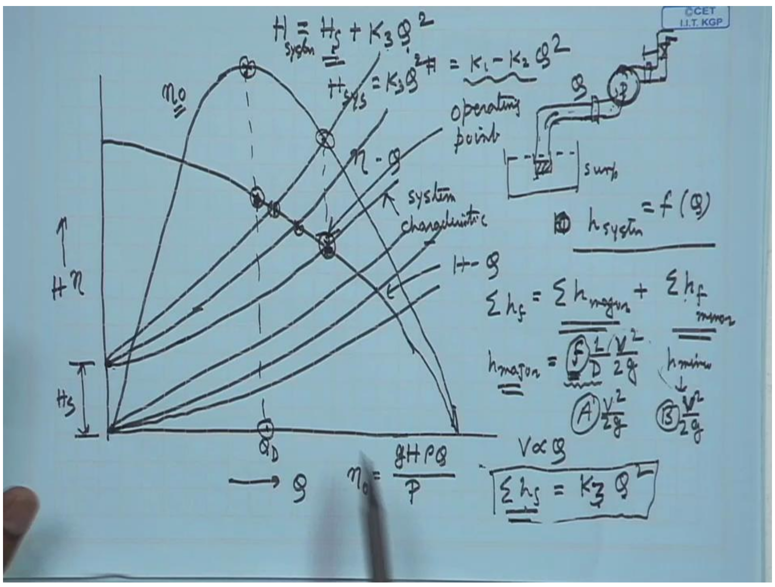

So this curve looks like that because this is bearing a function, H is proportional to Q square. Therefore it is clear now that the operating point depends upon the matching of the system and the pump characteristics and here this efficiency curve is actually the overall efficiency, the overall efficiency. So that we are concerned with the output, input, the main input with the head developed. That means this is, this overall efficiency is the head developed to the main input, that means the head developed at the pump H into rho Q.

Okay, G, GH into rho Q is the head developed by the pump divided by the power input at the, to the shaft at the coupling. So this is the overall efficiency and this is the maximum efficiency, efficiency all seems both the direction. So therefore we can generate a series of system resistance curve with static lift or a series of system resistance curve without static lift. And the slope of the curve depends upon the resistance in the flow path which is determined in terms of S, these values of the constants.

So therefore this depends upon the flow configuration actually in fluid flow system configuration, the type of the bend, the type of the valve, the pipe of the area contraction and all these things and the length of the pipe and the diameter of the pipe, 2 things are major dimensions. And different system characteristics curve we can generate. And this way we see that the operating points are being generated and our main motto will be such that the system characteristics and this pump characteristics matching determining the operating point should be as close as the maximum efficiency point.

And at the same time you must bear in mind with this that head, this characteristic curve which is very important for a centrifugal pump should be a self-limiting one and that is obtained for a backward facing impeller blade and we go for that. And that is why I have discussed this and this type of pump set of matching of system characteristics and the HQ characteristics can be also shown for HQ relationship in case of radial blade or forward facing impeller blade, so similar way.

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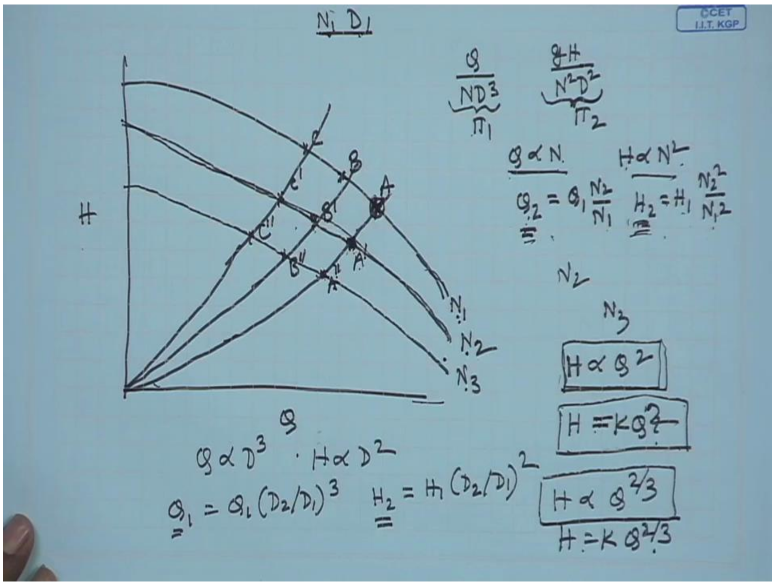

But I have shown it because this is in practical use. So therefore we, we are able to recognise the operating point of the pump in practical application. Now we will see the effect of rotational speed and the rotor diameter on the head discharge characteristics of a centrifugal pump. Now what is this? This is like this, that if we have a head discharge characteristics like this as already we have discussed, let us consider a head discharge characteristics like this.

Now this head discharge characteristics when we draw, this is specified for a given rotational speed, N1 and for a given diameter, N1 and D1. So therefore for a given rotational speed and a given rotor diameter, this is the HQ. That means for a particular pump, this is the HQ characteristics. Now if I want to draw the HQ characteristics of the similar pump, that means the centrifugal pump at different speed and different diameter, then how can we draw? Which means that the influence of N1 and D1 on the HQ characteristics.

Now let us 1st find the influence of N1. Okay, how to do it? Let arbitrarily we take a point A on this HQ characteristics at N1. Then we recall the similarity terms, 2 similarity terms, Q by ND cube if remember and GH by, Q by ND cube and GH by N Square D square. Well, so these 2 we require, we just take. Now this is pie 1 as we symbolised and this is pie 2. This term is defined as flow coefficient and this term is defined as head coefficient. So these pie 1, pie 2 terms you know, you are already acquainted with this.

Now we take this head and if the diameter is fixed, now when only the speed is changing, then Q by N is constant, Q is proportional to N and H is proportional to N square. So therefore if Q1 is the flow rate and H1 is the corresponding head for this pump 1 or pump which is rotating at speed N1, then we can find out this flow rate or the discharge Q 2 as Q1 into N 2 by N 1 and similarly we can find out that H2 is H1 into N2 square by… That means we take the help of the similarity parameters, nondimensional parameters pie 1 and pie 2 and

That means if we know the value of Q1 and H1 at particular point at A, we can find out Q2 and H2 at the corresponding point on the different speed N2. What is meant by corresponding point? Corresponding point means the pump will rotate at a different speed N 2, the speed of the pump will be changing from N1 to N2 in such a way that the head and the discharge will change but making the similarity of the operation. That means this is, if this is one of the operating point, then this operating point at N 2 will be physically similar to that one.

The 2 will be physically similar to each other and let us denote this as A1, A dash. Similarly if we arbitrarily choose another point B, we can also generate this, another point B dash, corresponding point, that is point corresponding to B dash. And this way we can generate the point if we take a point C, we can generate the corresponding point C dash. And if we join these points A dash, B dash, C dash, we get the head Q characteristics. That is HQ characteristics of the pump at different speeds N2, rotational speed N2.

So these are the corresponding points of these A dash is A, B dash is B, that means therefore A dash, B dash, C dash are some characteristic points on the HQ curve of the pump at N1, at the speed N 2, we take the help of the pie terms. Okay, this way we can draw this. But similarly we can take, we can take another speed N3 and draw the curve, draw the corresponding points like this B double dash and C double dash and we can generate this. So therefore we can generate the curve, the HQ curves or HQ characteristic curves at different speed N1, N 2 and N 3.

Now the most interesting part is that if you see that is Q varies as N square and H varies as N square, which means that Q, H is proportional to Q square because H varies as N square and Q varies as N. Therefore H is proportional to Q square. Now if H is proportional to Q square, then locus of all these similar points will follow this H is proportional to Q square, means H is KQ square, so they will lie on a parabola passing through the origin. They will lie on parabola passing through the origin.

The most interesting part is that, this type of relationship is also there for the system resistance. System resistance equation is also H is equal to some constant into Q square. That means this locus of the corresponding points that if, for example A, A dash, A double dash lie on the system resistance, some system resistance curve. This is, this represents one system resistance curve for a given system resistance. Similarly this resistance, this curve also represents another system resistance curve for another given system resistance like that.

That means the locus of the corresponding points automatically lies on the system resistance curve which gives a very important information that if we have a system resistance like that and if A is the operating point of the pump at speed N1, if we apply straight the similarity principals and find out Q1 and Q2 and N2 with this, Q2, I am sorry, H2 by these 2 formula, Q2 is Q1 N 2 by N1, H2 is equal to H1 N 2 square by N 1 square. Then this point will be automatically the operating point, will be the intersection between the characteristic point and the same system resistance curve and will determine its operating point.

Similar is the case for speed N3, which means that if we have a fixed system having a given system resistance curve or relation, then we can find out the operating point by changing the head and the discharge by applying the similarity parameters, flow coefficient and head coefficient pie 1 and pie 2 terms and the QH given will be the point on the head discharge characteristics of the pump at N2 and also on the system resistance curve. That means that will give the intersection between the system resistance and the new HQ characteristics of the pump at the altered speed N2.

This will give automatically the operating point because the locus, here you see the locus gives this equation which is also the system resistance curve. Now this is for the, how, therefore how we can draw, this gives the or you can get the head Q or HQ, head discharge curve or characteristic curve for different rotational speed. Now for different diameter, what we do, for different diameter we use this equation Q is proportional to D cube and H is proportional to D square.

So therefore we find Q 2 as Q1 into D 2 by D1 cube and H2 is equal to H1, the same as before because it is proportional to both N square and D square, D2 by D1 square. And this way we can find out the corresponding Q and H and draw the curve. But here one thing is that if you think this way that Q is proportional to D cube and H is proportional to D square, therefore H is proportional to Q to the power two third represents the locus of the similar points on the HQ plane, just like the locus of the similar points on the HQ plane for different speeds.

And this gives, this equation, that means each is equal to some constant into Q to the power two third gives the locus of the similar points on the different HQ curves of the pump with different values of diameter of the pump. And that is not same as that of the system resistance curve. So therefore we can find out the similar points, we have to draw and this we get or you can draw the head discharge characteristics for the machine or the pump at different diameters.

But the operating point will be again the intersection of the system resistance curve which may be a different point than that one, the corresponding point of A. Okay, this is the way by which we can generate the head discharge characteristics of from one speed to other speed and from one diameter to other diameter. Okay, thank you.