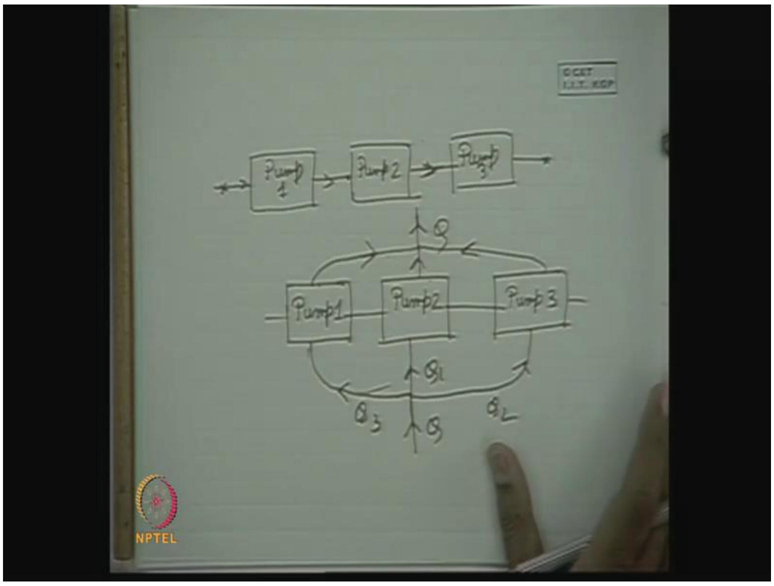
Introduction to Fluid Machines, and Compressible Flow

Prof. S. K. Som
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 18
Axial Flow Pump

Good morning welcome you all to this session of the course. So, today our topic of discussion as it is shown is axial flow pumps, but before coming to this topic we like to discuss about the characteristics multiple pumps used together or connected together in a system. So, first we have to know why multiple pumps; that means, more than one pump is used or are used in a particular application when the head developed or the flow rate delivered by a single pump is not sufficient or a particular application a number pumps that is more than one pumps are used pumps are used either in series or in parallel when it is used in series, then the heads are added; that means, when you require more head, then that developed by a single pump we use the pumps in series, and where we require more flow, then that developed by or delivered by a pump we use pumps in parallel.

(Refer Slide Time: 01:36)

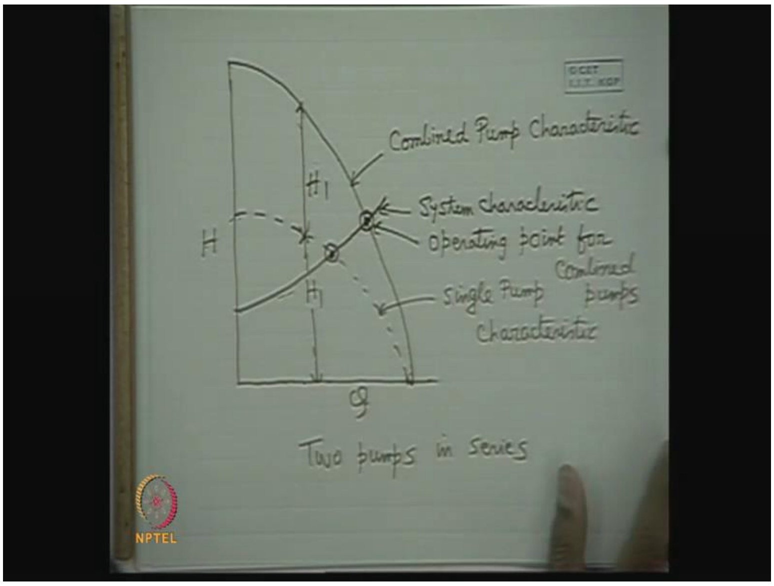


That means, in case of pumps connected in parallel the heads the flow rates are added just like this you can see here the pumps in series that if you have number of pumps that is pump one is simply geometrical series in series geometrically connected in series like this pump three pump, three like this; that means, the discharge from one pump is connected to the inlet to the other pump and so on.

So, therefore, you see if you consider the total head developed across this system of multiple pumps. So, it is some of the head developed by individual pump similarly when the pumps are connected in parallels for example, pump one the system is like this pump two, then pump three if they are used in parallel the arrangement is like this the inflow to the pump; that means, inlet to the pump inlet flow of water is divided into three parts for example, three pumps are connected is at the common shaft. So, they are not connected this. So, this is the common shaft. So, therefore, the flow is divided an ultimately the flow meets like this.

So, that the final discharge is the some of the discharges from all the pumps this the final discharge. So, here you see the q is divided like this in three parts q one q two q three. So, it automatically meets an. So, the total flow which is taken by the system some of the flow rates through individual terms, now we come to the characteristic of such a system of multiple pumps.

(Refer Slide Time: 03:36)



Let us consider characteristic of such a system of pumps in series, and let us consider two pumps of identical design; that means, two identical pumps if you recollect the head q characteristic with centrifugal pump you see the head q characteristics like this, this is the we give it by a dotted curve this is the head q characteristic of a single pump.

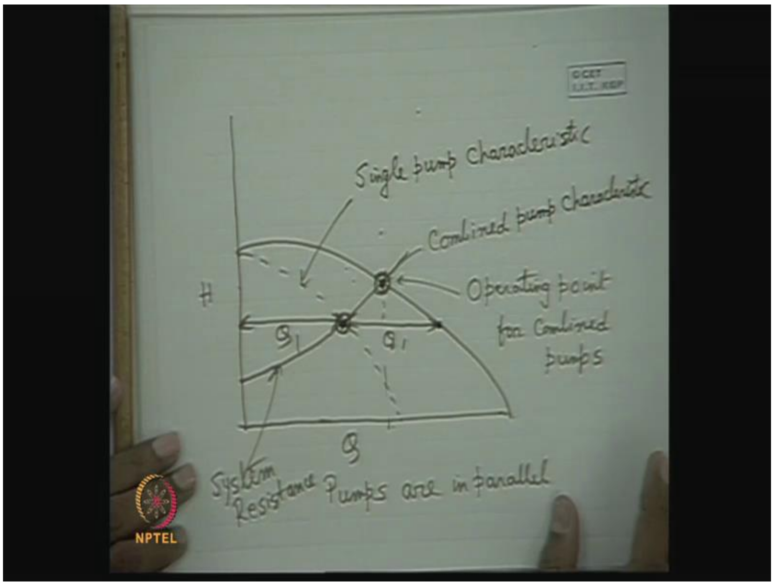
So, now you see if we use another same similar pump in series what will happen the head will become double at any given flow rate; that means, for a given the head will be double. So, therefore, we can draw the h q characteristic that relationship between head, and discharge q for the two pumps connected in series to identical pumps like this. So, like this. So, this meets here; that means, at any flow the heads are added up doubled; that means, this is h one. So, this is h one; that means, the two pumps in series are added. So, at any point the heads are being added doubled the same pump. So, the this is h one this is h one.

So, therefore, we can write this is the single pump characteristics single pump characteristics single pump characteristic well, and this is the double pump or combined characteristics combined the two pumps connected in series combined pump characteristics charter ristic. So, this is they are just two pumps in series two pumps identical pumps here in series in series now as we know the operating point dependence up on the system resistance; that means, it is decided or determined by the point of inter section between the pump characteristics, and the system characteristic.

For example as we have seen earlier that for a single pump the let it be the single pump characteristic we if we know the system characteristics for example, if this be the system characteristics what is system characteristics it is nothing, but the head discharged system characteristics head discharged relationship for the system that is the pipe line, and wall to which the pump is connected; that means, this is the head loss to the system for a given flow rate. So, if this characteristic or we draw no if this is the point of intersection the single pump; that means, the single pump.

And with this system characteristic this is the operating point in case of multiple combined pumps here two pumps the operating point will here this is the operating point this is the operating point or combined pumps system for combined pump operating point for combined pump whereas, this is the operating point for the single pump. So, one interesting thing is that though the characteristic curve for the combined pump when this two single pump of identical shape size, and design are used, then the heads are sometimes heads are at flow rate is doubled, but the operating point gives a head which is the higher than the operating head when the single pump was in used, but it is not exactly doubled. So, the head will be increased, but will not be doubled that depends up on the system characteristics well.

(Refer Slide Time: 07:22)

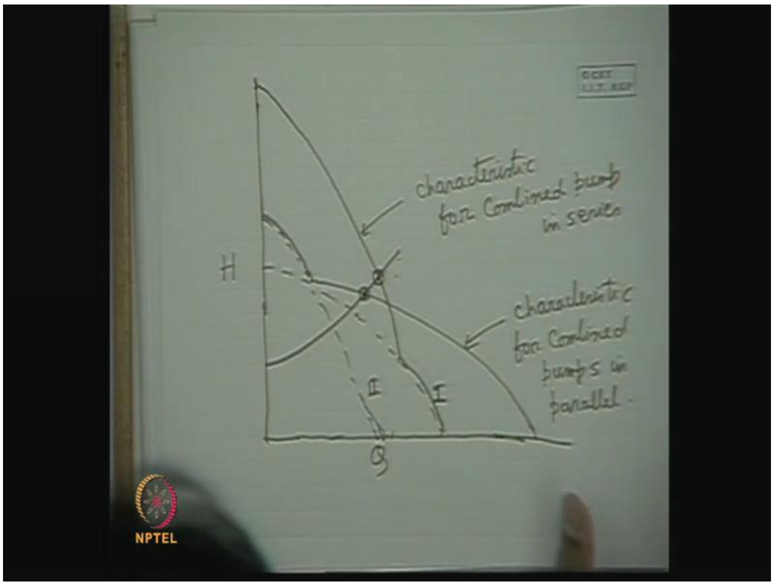


Similarly, we can show we can draw another the characteristics for combined pumps in parallel let us see the combined pump the same way we can draw the combined pumps let us consider this as the single pump h q characteristics when the pumps are used in the parallel as i have told you earlier. So, flow rates are added at a particular head. So, therefore, the combined pumps characteristics can be drawn like this; that means, at a given head the flow rates are simply doubled; that means, if this be the single pump flow rate q one for example,. So, this part will be q one; that means, for a given head we can find out the point in the combined pump by adding the flow arte; that means, the same flow rate, because the identical pumps are used in parallel, so this q one this q one. So, it will be same for all heads.

So, therefore, this is the single pump characteristics as it was shown earlier in case of pumps used in series single pump characteristics, and this is the combined pump characteristics well combined pump characteristic characteristic well when the pumps are in parallel. So, this is the case that pumps are in parallel similarly here also the operating point is decided by the intersection of the characteristics curves with the system resistance; that means, let be the system resistance let be the system resistance that is system characteristics or system resistance as you tell. So, system resistance curve.

So, this is the operating point for the combined pump where you see the operating point does not give double the head as shown by the operating point the incase of the single pump. So, the head is increased, but is not doubled. So, this is finally, the sorry not head the flow rate operating point. So, flow rate is increased, but not doubled operating point for combined pump i repeat it again that as we have seen earlier in case of pumps in series that pumps in parallel. So, the operating point is here. So, the head that is ultimately delivered depends up on the operating point. So, this si increased from that delivered by single pump, because single pump operating point is there. But it is not doubled, but characteristic curve itself that shows that at give any head the this discharge is doubled, but here the discharge is not doubled.

(Refer Slide Time: 10:27)



So, this is the combined pumps in parallel when they are identical in a similar way most general cases we can show we can show the pumps in series, and parallel when they are not identical; that means, pumps are not necessarily to be identical when they are used in series, and parallel system it is also very simple same thing we may have two pumps let this is one pump pump one characteristics pumps one, and let this be the characteristics of another pump where this characteristics is strip stripper, then the number one.

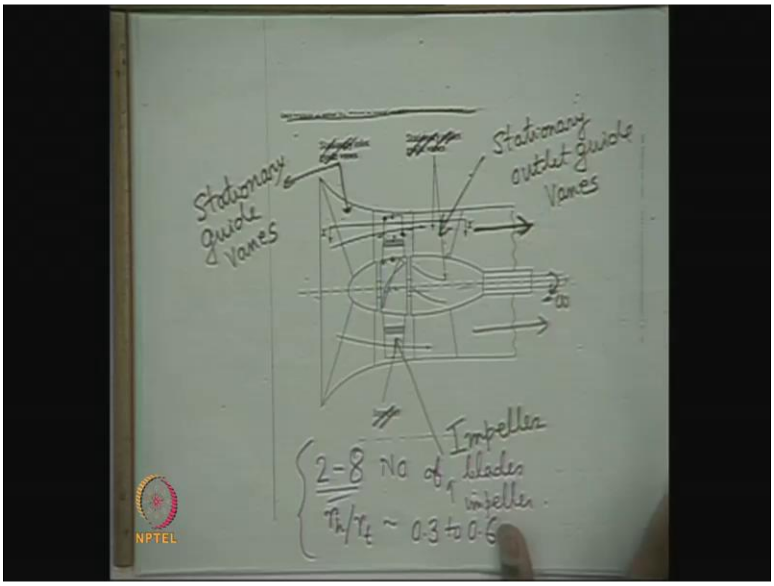
So, number this is one pump this is two pumps are the similar pump. So, if we use the two in series it is nothing at one flow rate we have add the heads; that means, you will have to start from here now it will come like this, and then it will follow the same, because here the head is zero. So, the where the head of the second pump is zero. So, it will follow the first one. So, this is the characteristic for combined pumps for combined pumps in series. Similarly we can draw for the pumps in parallel. So, up to this part there is now flow delivered by the pump one. So, therefore, this will closely follow or total follow the pump two, then it will be like this, because after that at any head the follow of the flow rate delivered by the two pumps will be added. So, it is very simple. So, therefore, it is for characteristic for characteristic for combined pumps in parallel for combined pumps in parallel. So, therefore, we see that the characteristics of multiple pumps whether parallel whether they are used in series or parallel can be drawn in this way by adding the heads at a given flow rate for pumps in series or by adding the flow rates for all the individual pumps are given at when the pumps are connected in parallel.

And the operating point will determine entirely by the for example, this will be the operating point if the system resistance is the for the combined pump in parallel, and this is for the combined pump in series under this system operating characteristic it will determine by the intersection of the system characteristics are system resistance with the characteristics of the combined pump systems well. So, now, we have completed this section of centrifugal pump now we will come to axial flow pump.

Now, an axial flow pump is a pump where the flow of liquid that is a water is in the axial direction; that means, the flow is in the direction of the axis of rotation well you have seen that the centrifugal pump flow is in the radial direction it is a radial flow pump, and the flow is radially outward as you known for a pump the for a radial flow pump the flow has to be radially toward this is, because to gain pressure to gain pressure energy of the fluid from the centrifugal energy. So, that the fluid has to go outward. So, that at the outlet this centrifugal head is more than at the inlet. So, therefore, we will see that centrifugal pump is a radial flow pump.

So, axial flow pump is a pump where the flow is almost in the axial direction; that means, the inlet, and outlet of the fluid do not vary in the radial location from the axis of rotation we have discussed this in axial flow turbine also this is the definition holds good as well for any axial flow machine. So, therefore, an axial flow pump can be thought of as an converse to an axial flow turbine or propeller turbine, and we can just have a look what how an axial flow pump looks like.

(Refer Slide Time: 14:41)

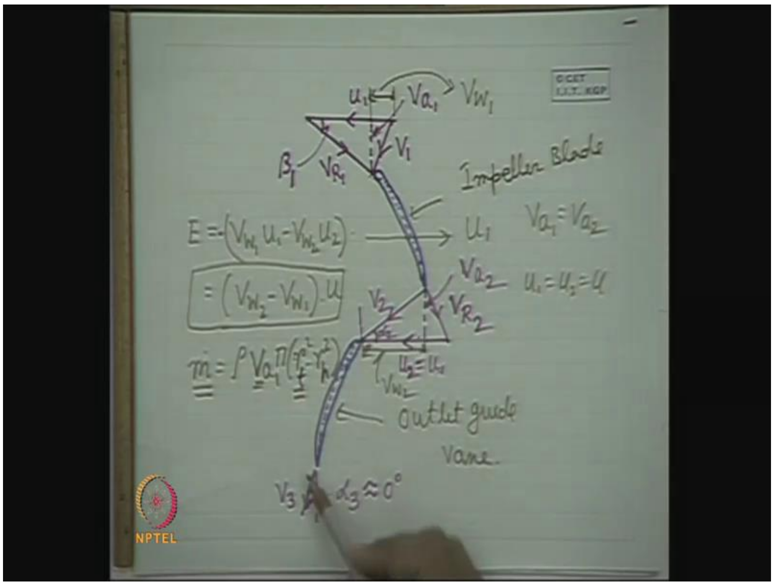


So, you see basically the axial flow pump consist of a central boss on which a number of blades or vanes mounted this is basically the impeller, and this impeller rotates within a cylindrical casing this is the cylindrical casing with fine clearance this is these are the clearance.

So, therefore, these boss with the number of blades mounted on it consist the impeller this is rotating the cylindrical casing. So, these are the inlet. So, therefore, you see this is the impeller this is the impeller this is this you cannot show see clearly impeller. So, this is this one i write it here stationary stationary guide vanes the purpose of the stationary guide vanes is to direct the fluid in the correct way to the impeller blades. So, that they can enter the impeller plate without any shock the most important part of an axial flow machine is this stationary blades stationary outlet guide vanes this is stationary outlet, which is not there outlet guide vanes in a radial flow machine the purpose of this stationary outlet guide vanes is not to convert any energy from kinetic energy to pressure energy its simply changes the directions of motion; that means, it reduces the welding component of the velocity which the fluid posses the water posses from the outlet or at the outlet of the impeller. So, this welding component is reduced. So, that it is directed in such a way the fluid directed in such a while it passes through this stationary outlet guide vanes. So, that the final discharge from the machine becomes almost axial; that means, in the direction parallel to the axis of rotation this is the axis of rotation this is the rotation omega this is rotating like this.

So, this is in general a schematic view of an axial flow pump let us see the velocity diagram of an axial flow pump.

(Refer Slide Time: 17:19)



Now if we take a section of the blade like this if we see a section of the blades, then it looks like this that this is the well this is the blade impeller blade one impeller blade, and this is the outlet guide vanes. So, this is the impeller blade impeller blade one impeller blade that section is made like this if we take a section like this we will see this is the inlet guide vanes this is the impeller impeller blade, and this is the outlet guide vanes. So, we are seeing the impeller blade, and the outlet guide vane.

So, this is the outlet guide vanes now usually what happens is that the inlet guide vanes directs the water in such a way as you earlier case is also that is guides; that means, its strikes smoothly with this; that means, this is tangential direction. So, that the angle make by the relative velocity that is the in this direction the blade is moving that is the u one. So, this makes the same angle with that the blade with that the inlet. So, therefore, this is the velocity triangle at the inlet this is the absolute velocity at the inlet, and this the hurling component or the blade velocity this is the blade velocity whether I will tell this is the blade velocity now another thing is very important the inlet, and outlet of the fluid rather you see here takes place in such a way that that the inlet, and outlet do not vary in the radial location from the axis of rotation.

So, therefore, the velocity triangle is shown at a mean height. So, that inlet and outlet which is varying with their axial location not in the radial location. So, this is this diagram is made at the means height of the pump; that means, at a means radius at a mean radius; that means, this is the axis of rotation. So, the radius varies from this place this is the hub radius there is the root of the impeller bade, and which is the tip radius. So, this is made at the means radius, and all the velocities are therefore, considered to be mean if there is any variation along the radial direction.

So, therefore, we consider this as the mean velocity it is an average velocity in the average velocity where the there is any variation in the radial direction. So, therefore, we see the outlet diagram here not when it comes out this is the absolute velocity coming out from the impeller blade this is the relative velocity. So, which is running out of the blade, and we see this is the blade velocity at the outlet, and since the inlet, and outlet at the slim radial location. So, u two is equal to u one u one is equal to u two. So, therefore, we see this is the v w two v sorry v w one the hurling component of velocity at the inlet.

And similarly this part is the hurling component of the velocity at the outlet, and this is the axial velocity, because this is the axial direction v a one, and v two at the outlet, and the design is made in such a way that v a one is v a two now we can write that the energy imparted the fluid in the impeller blade per unit mass can be written as from out earlier discussion as written as v w one u one minus v w two u two rather this is with a negative sign with a negative sign with a negative sign, because this is more than this or we can write this is equal to this is the energy imparted to the fluid v w one times the u one or u two simply we write u one is equal to u two is equal to u.

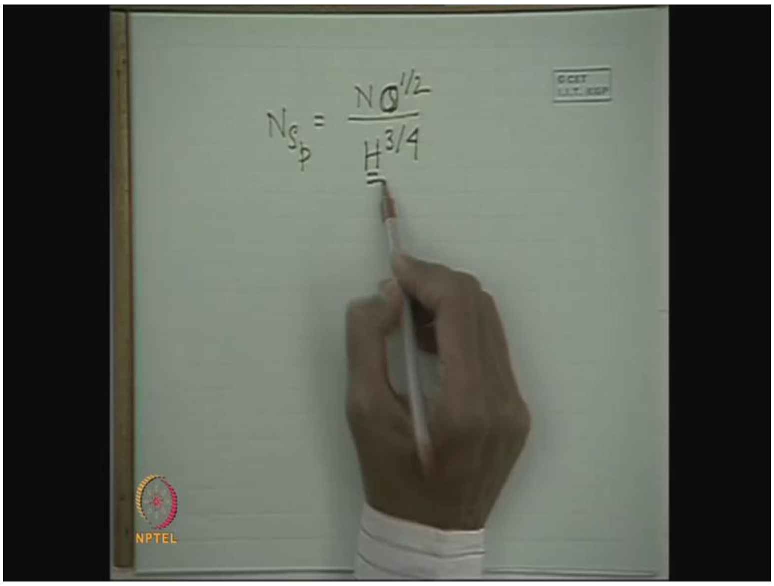
So, this is the amount of energy imparted to the fluid per unit mass. So, mass flow rate m dot can be expressed as the density times the average axial velocity which is known as the flow velocity is either v a one or either v a two, that is same in the design times the area that is pi r t square minus r h square where r t is the root diameter, and root radius rather r h is the hub radius; that means, if you see that this is the root root radius, and this is the tip radius. So, this is the hub radius this is the tip radius root or hub that is the hub radius that is the tip radius. So, impeller tip… So, this is the tip radius, and this is the root or hub radius. So, this is the average axial velocity or flow velocity.

So, this way we can find out the mass flow rate, which when multiplied with that will give the power that is being transfer to the fluid when it pass through the impeller blade now this is the outlet guide vane as I have told you earlier the purpose of these outlet guide vane is to reduce the hurling component of velocity or you see at the inlet to these blade is the velocity v two which is the absolute velocity from the moving impeller blade, and it has got a hurling component of velocity of this much. So, this is being reduced that depends up on the shape of the blade. So, that at the outlet the fluid which is coming out with the velocity v three which is the discharge velocity where the hurling component is almost reduced.

So, this velocity is almost axial this component is reduced. So, you understand very well this component is reduced. So, velocity is almost axial. So, this alpha three represents the angle with the axis which is almost zero. So, it is almost an axial discharge here alpha two represents the angle of the absolute velocity; that means, makes with the tangential direction the direction of blade motion similarly this is alpha one in the inlet velocity triangles this is beta one that is the velocity of relative velocity angle of the relative velocity with the tangential direction similarly this is beta two. So, beta one, and beta two are the blade inlet, and outlet angles for a smooth shock less flow well. So, this is the blade diagram, and we can find out the energy or power imparted to the fluid in a in the impeller blade of an axial form.

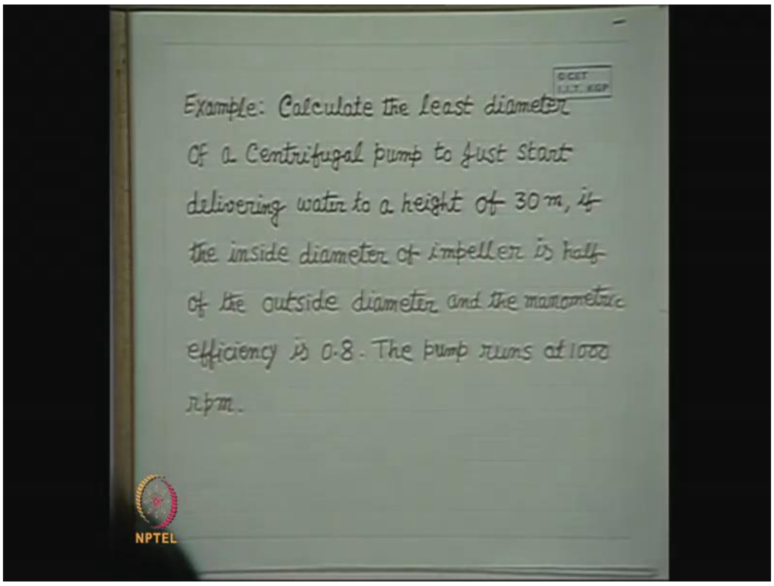
Now obviously, as you know in case of an axial flow machine for axial flow turbine the specific speed in case of an axial flow turbine once more; that means, axial flow machines the head developed will be less, and the flow is more similar the case in similar the case is with axial flow pump. So, axial in axial flow pump the head develops are relatively lower smaller rather the flow rate or flow delivered is higher as compared to its centrifugal pump centrifugal pump develops more head or a low flow where as an axial flow pump develop low head, but more flow in other words the specific speed as you know the specific speed the definition specific speed of pump.

(Refer Slide Time: 24:35)



If you recall the specific speed of pump dimensional specific speed n q to the power half h to the power three by four. So, specific speed for an axial flow pump is high; that means, it compare to that of a centrifugal pump; that means, it handles more flow, but at a lower head relative to centrifugal pump well. Now after this I will solve an interesting example before closing this lecture please

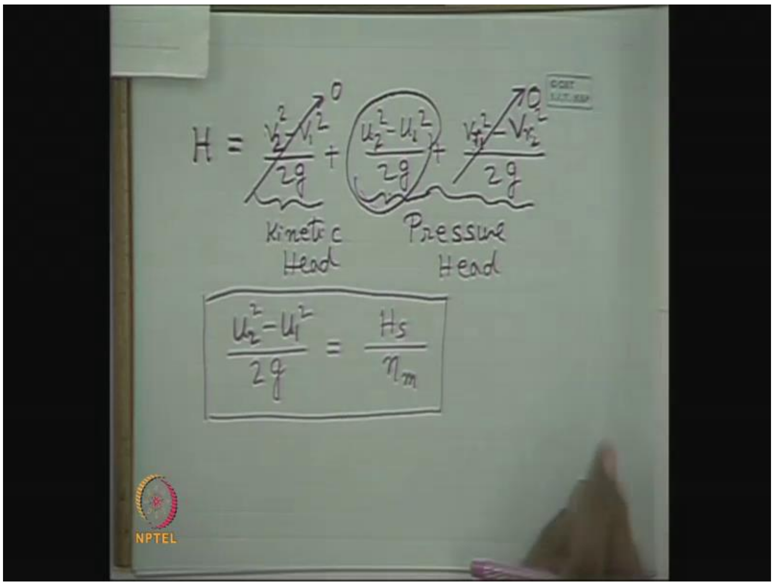
(Refer Slide Time: 25:09)



See that example, we will solve this problems very interesting problem calculate the list diameter of a centrifugal pump to just start delivering water to a height of thirty meter, if the inside diameter of impeller is half of the outside diameter. And the manometric efficiency is point eight the pump runs at thousand r p m again I am reading calculate the list diameter of a centrifugal pump. We have to find out the list diameter of a centrifugal pump to just start delivering water to a height of thirty meter this is the static head of the pump, and other condition is that the inside diameter of impeller is half of the outside diameter, and the manometric efficiency is point eight the pump runs at thousand r p m [FL] just before this problem I like to inform you another data which I forgotten to tell you that I have remember here, if we please excuse that you must know this number of impeller blades in an axial flow turbine usually lies between two to eight the number of vanes number of blades number of blades impeller blades number of here impeller blades.

And the ratio of the hub to tip radius; that means, r h r t varies between point three to point six these two are very important design information well. So, now, again coming back to the example of this problem the example problem the pump runs at thousand r p m; that means, if a pump has to start lift a water to a head of thirty meter the pump cannot start without a minimum diameter calculate the minimum diameter; that means, the impeller diameter will have to calculate if the pump runs if the r p m is fixed. So, pump diameter has to be there is has to be a minimum diameter below which the pump cannot start working; that means, this list of thirty meter is not possible.

(Refer Slide Time: 27:29)



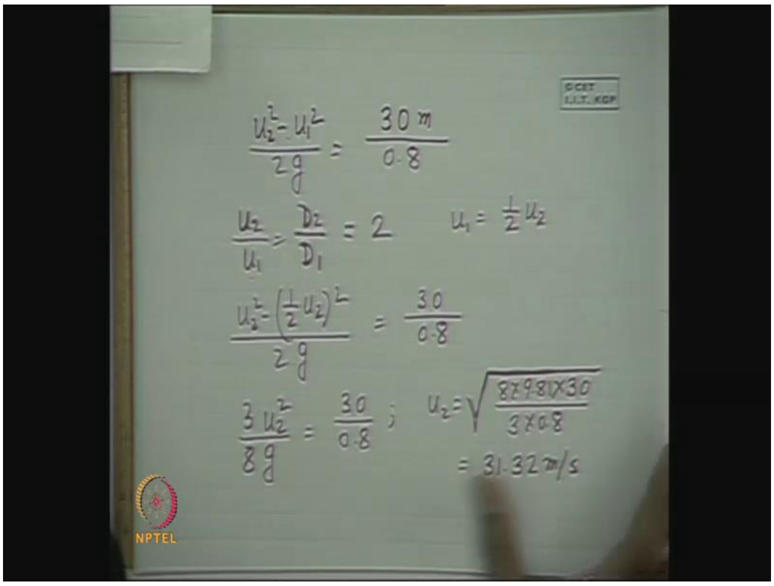
So, how to solve this problem now as you now if you recall it that the head developed by the pump to the fluid in case of a pump that head developed by the pump to the fluid is given by v one that is head means energy develop per unit where the energy per unit weight to be given to the fluid can be written as v two square minus v one square by two g if recall it plus u two square minus u one square by two g plus v r one square minus. So, for any turbo machine this is the total energy transferred between the machine, and the fluid for a pump this is the energy per unit weight that is the head energy per unit weight that has to be developed by the pump or that has been impacted by the pump to the fluid.

Now, as you know if you can recall this is the kinetic head or kinetic energy this is the kinetic head developed or imparted to the fluid, and this part is the pressure head pressure head. So, this part of the pressure head is due to the change in the centrifugal head, because the fluid is displaced in its position in a centrifugal fluid speed from one radial location to other radial location there is u two is the final one that is outlet u two square minus u one square by two g u two is always more than u one, because the flow is radially the outward, and this one is the change in the relative velocity usually in a pump the relative velocity v r at one at the inlet is more than that at the.

So, therefore, the relative velocity of the liquid while flowing through the pump impeller is reduced. So,, because of this reduction when the relative velocity there is an increase in the pressure. So, this part is the gain in the pressure energy, because of a reduction in the relative velocity according to Bernoulli's theorem there is a gain in the pressure energy. So, this part combine gives the pressure now when a pump just starts working, then at that moment we can neglect these two parts, because the velocity has not yet been established. So, at this start at the on shift of the start the pump has to develop only this centrifugal head.

So, therefore, in this problem we will equate that the pump dimension should be such, and its rotational speed should such that at the stud the centrifugal head is the only head that is being developed while these two terms are zero that must be sufficient one to overcome the friction, and this static head; that means, this much be equal to the statically h is divided by manometric efficiency this very important thing. So, in our problem.

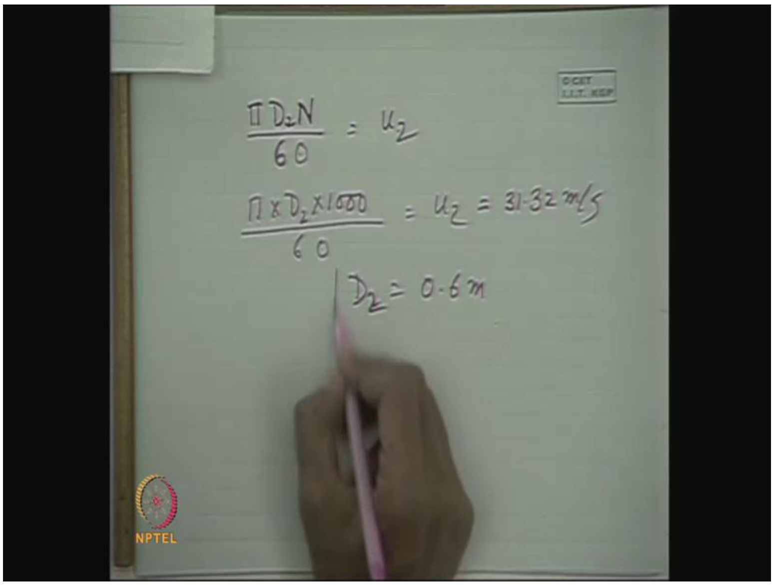
(Refer Slide Time: 30:19)



So, if we do. So, we see that u two square minus u one square by two g according to the problem it is given that thirty meter is the statically divided by 0.8. Now, according to the problem the impeller diameter inner diameter is half of the outer diameter; that means, you can write that u two by u one is d two by d one diameter where d two is the impeller diameter or the outside diameter of the impeller blade, and d one is the inside diameter of the impeller blade. So, d two by d one is two. So, u two by u one is two u two is the velocity blade velocity impeller blade velocity at the outlet impeller blade velocity at the inlet. So, therefore, we can write u one is half u two.

So, if you substitute, then we get u two square minus half u two whole square divided by two g very simple thirty zero point eight which from which you get three by eight one fourth one minus g u two square is thirty by zero point eight which gives u two is equal to root over eight into g is nine point eight one into thirty divided by three into zero point eight under root which will be if you calculate thirty one point three two meter per second.

(Refer Slide Time: 32:03)



Now, if we use this, then we can find out the diameter we know that relationship between rotational speed with the linear speed is like that where n is expressed in revolution per minute. So, by sixty per second pi d two. So, this becomes u two here if you use this pi into d two into revolution n r in r p m it is given thousand in the problem now on the next part is simple u two which is equal to thirty one point three two meter rest part is simple hw gives d two is point six meter.

So, this a very interesting problem that a pump therefore, this is the most interesting information is this. So, therefore, for a pump of given dimensions there should be a minimum rotational speed for pump to start against a static leaved with a manometric efficiency or for a given rotational speed the pump must have a minimum diameter impeller diameter for it to start well. So, today I think this is all, we have completed the axial flow pump, and we have solved one interesting problem today next class we will start the reciprocating pump.

Thank you.