Introduction to Fluid Machines, and Compressible Flow
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Lecture - 14
Flow and Energy Transfer in a Centrifugal Pump

Good morning welcome you to the session of fluid machines today we will be discussing the flow, and energy transfer in a centrifugal pump flow, and energy transfer in a centrifugal pump the similar way we discussed in case of turbines well in the last class we discussed the head developed by a pump; that means, the head or the energy which has be gained by the liquid while flowing through a pump which is the difference between the total energy or total head at inlet to the pump, and the total head or the total energy at its outlet.

So, the energy at the outlet is more than that, and the difference between this two; that means, the energy at the outlet of the pump, and the energy at the inlet to the pump is the head developed by the pump; that means, this is the energy that the fluid gains from the rotor of the pump now today we will be discussing the shape of the rotor or the different components that a centrifugal pump has we have also discussed in last class that a radial flow pump, where the flow is radially outward, because of the obvious reasons that flow a fluid flowing through it gains in centrifugal head is known as centrifugal pump this radial flow pump is known as centrifugal pump.

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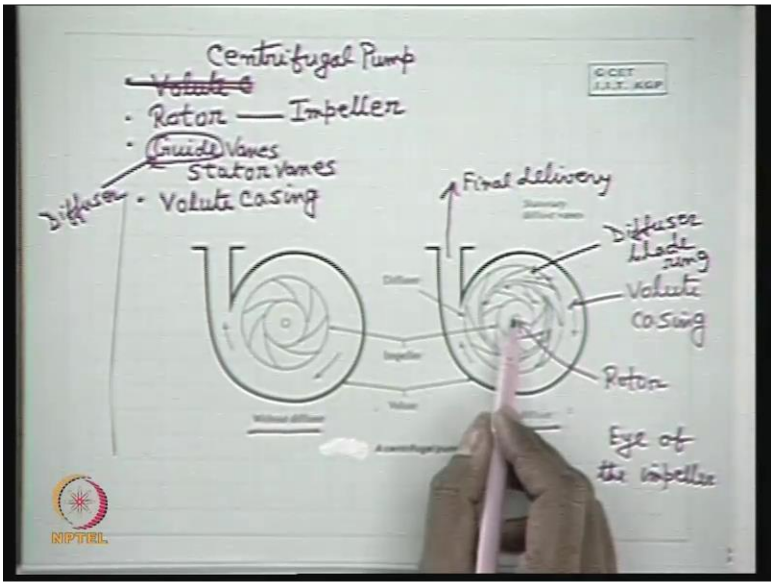

So, today we will see the different components of a centrifugal pump please come to this diagram here we see that a centrifugal pump has got three important components one is the rotor; one is the volute casing rather I will write in the sequence one is the rotor blades rotor rotor of the pump which is the moving part which is known as impeller this is the terminology impeller impeller in case of pump the rotor is known as impeller in case of turbine you know the rotor which is the rotating part of the machine is known as runner in case of a pump the rotor is known as impeller next is the guide vanes guide vanes or stator next is the volute casing volute casing this three components are the important components or these three components comprise as a centrifugal pump.

Let us look into this diagram this is of a centrifugal pump centrifugal pump three components rotor that is the moving part of the pump known as impeller, then guide vanes or stator guide vanes or stator vanes, then volute casing now see that two pick the pictures here that here if you see that this is the rotor this part is the rotor this part is the rotor rotor consists of a solid discs which is kit to a shaft, and the mechanical energy is imparted on it which rotates with an angular velocity constant angular velocity. So, this rotor consist a number of curved blades as you see here which is attached to the face of the disc solid disc, and stands like that these are the curved vanes, and these forms typical passages passages vane passages or blade passages through which the fluid flows.

So, after this rotor the fluid comes next to the guide vane or stator vane there is a ring of guide vanes, and stator vanes, you see these are the guide vanes or stator vanes after leaving from guide vanes or stator vanes it comes to a typical spiral casing or the volute chamber it is same as that of a francis turbine it is just in the reverse order to that of a francis turbine the fluid flows through this, and ultimately comes to the delivery end now these blades of the rotors are shore shaped that it while the fluid flows through it, it gives a diverging area; that means, the cross sectional area increases which means when the fluid flows through this rotor blade or vane passage the fluid gains in pressure also static pressure; that means, the relative velocity of the fluid while flowing through the blade passages decreases, because of the increase in cross section area.

Therefore the static pressure of the fluid increases due to that again since it is a radially outward flow; that means, fluid while flowing through the rotor blade passages increases its centrifugal head; that means, this is such that the radius from the axis of rotation is increasing in the direction of flow the fluid gains in centrifugally for which also the static pressure of the fluid changes. So, therefore, the fluid comes out at from this place with a high velocity, and high pressure now the blades of these rotors are sometimes attached to small plates at this tips to give shrouded blades these blades are known as shrouded blades which are attached to small plates at the tip sometimes it is made free; that means, the tips are not attached to plates; that means, the blades are not shrouded.

The advantage of having shrouded blades is that it prevents the flow from leaking from one passage to another blade passage. So, that the blades are shrouded now what is the function of this diffuser or guide blades this is sometimes known as diffuser best term is diffuser you can write here diffuser blades, it is a better term instead of guide vanes you can write diffuser vanes or diffuser blades. Now the purpose of diffuser blade is to convert just the reverse of a turbine to convert the kinetic energy or the velocity of the fluid in terms of the pressure energy; that means, to convert the velocity into pressure; that means, this fixed blades these are the guide blades or these are the diffuser blade these are fixed blades.

And when the fluid flows through this passage of fixed blades or diffuser blades, it is similar to the flow through diffuser; that means, it is flowing through a fixed draft of increasing cross sectional area. So, that the velocity of the fluid which was very high at the outlet from the impeller is gradually decreased, and the pressure of the fluid gradually increases well. So, after that it comes again in a spiral casing where we see that while the fluid flow takes place in the direction of the flow the cross sectional area of this casing is increasing. So, that when the fluid comes at this end that is the delivery end final delivery final delivery this is connected to delivery pipe this is connected to delivery pipe final delivery fluid is having a very high pressure instead of having a very high velocity.

You know already we have discussed earlier that in a pump or a compressor the stored energy in the fluid remains in terms of the pressure energy; that means, the fluid at the outlet of a pump or a compressor is at higher pressure, but at a lower velocity; that means, the pump or a compressor is a machine which delivers fluid at high pressure, but not at high velocity. So, just in contrast of a machine known as fan or a blower we have discussed earlier where the fluid comes out with higher velocity rather than a higher pressure; that means, at a lower pressure, but at a higher velocity.

So, therefore, what happens the fluid gains its energy from the rotor. So, at the end of the rotor the fluid is having its total energy which has taken from the or which has been impacted by the rotor, but this energy is in the form of pressure energy, and the kinetic energy. So, the kinetic energy at the outlet is being converted into pressure energy; that means, the kinetic energy is reduced, and pressure energy is increased this conversion takes place in the diffuser vanes which forms the converging passages in the direction of the flow this is made by placing different blades in a ring known as diffuser blade rings, and also by a chamber known as volute chamber this is a typical spiral casing which keeps an increasing flow area in the direction of the flow.

So, the function of the diffuser blades, and the volute casing is to convert the velocity of the fluid into pressure or to convert the kinetic energy of the fluid into pressure energy in some cases the pumps are available without the diffuser vanes they consist of a impeller this is the impeller, and a volute casing on this. So, therefore, they are the action of diffusion; that means, the conversion of kinetic energy to pressure energy or the deceleration deceleration of the flow with the increase in pressure is done only in the diffuser chamber or the volute casing.

So, this is volute casing you can this is volute casing I think this letters are small this is volute casing this is the rotor this is the this is the rotor this is the rotor well, and this is the diffuser or guide vane diffuser diffuser blades diffuser blade ring all right. So, this is a pump without diffuser, and this is a pump with diffuser usually the blades with ring this is known as diffuser here this is there is only a volute casing which is also acting as a diffuser, but the common terminology diffuser is used with this ring of fixed diffuser blades. So, these are the main components of a centrifugal pump.

Now, the center of this rotor is known as eye or the impeller is known as eye of the impeller eye of the impeller eye of the impeller this center of this impeller is known as eye of the impeller well. So, the liquid is drawn at the center or eye of the impeller the inlet pipe is axial; that means, it is parallel to the direction of the axis of the rotation. So, therefore, the inlet to the pump is almost axial with a very little tangential or wheeling component of velocity.

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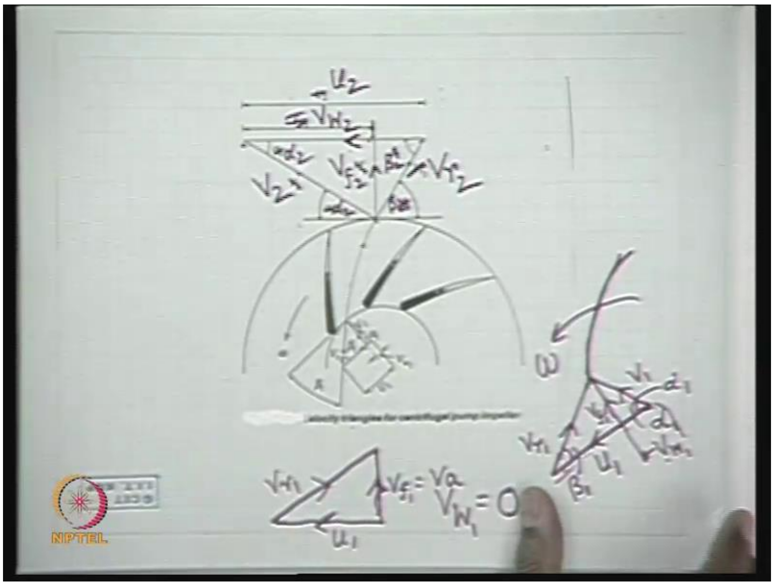

Now, if we come to a to the velocity triangles or to the pump impeller blade diagrams, then we see that this is now the exaggerated view of the impeller this is the impeller root this is the impeller tip, and this is these are the typical carved blades this is the impeller disc now the blades are designed in such a way that the fluid which comes. So, this is the blade passage. So, we have seen by the broken line as the representating line of the motion of a fluid element fluid flows through this passage between these blade passages. So, therefore, you see that at any point the fluid is drawn in such a way it has got a very less tangential component wheeling component.

I will explain why it is done. So, this figure you cannot see this, this figure I am drawing it here well drawing it here well (( )) well this is your v one this figure I am drawing it again this is your v r one well let this is the blade. So, this is the inlet well this is your flow velocity v f one well this is beta one this is alpha one now there is no guide vanes at the inlet before the rotor like a turbine fluid is directly drawn through an axial pipe at the impeller eye. So, this you can see clearly. So, this is the velocity triangle here you see this is the absolute velocity v one the direction of the absolute velocity is such that the wheeling component this is very small v w one. So, this is the angle alpha one that is the angle which the absolute velocity makes in the direction of the to the direction of the tangent. So, this is the relative velocity, and this is the angle beta one that the relative velocity makes with the direction of the tangent.

So, for a smooth shockless entry this beta one is the angle of the blade at this point; that means, angle of the blade at the inlet with the direction of the tangent this is the this is this is moving like this. So, this is the u one well this is the moving with an angular speed omega. So, you understand this now the blade angle at the inlet is designed in such a way that when the liquid is drawn by the axial pipe at the impeller eye it gives a very negligible in theoretically it is designed in such a way that this tangential component at the inlet or wheeling component becomes zero; that means, fluid enters purely in axial direction. So, the flow velocity here in axial direction.

So, therefore, the inlet to this pump impeller is in a axial tangential plane; that means, it has got axial component, and the tangential component axial component, and the tangential component, but the tangential component is made very low, and theoretically it should be made zero the blade angle at the inlet is designed in such a way. So, that the fluid is drawn axially purely axial at the inlet ok.

Now, what happens at the outlet can you see this outlet diagram no such a big diagram you cannot see let us I will be writing do not worry let us I will be writing, but you see the triangle can you see. So, this is v r two this is. So, this is v two this is u two. So, this is v w two, then it is all right this is v f two this is v f two. So, this is beta two. So, this is alpha two now the outlet this is the relative velocity with respect to the blade, and this angle is the angle that the blade make at the outlet with the direction of the tangent this is beta two this is a tangent here you can understand this is beta two, and this is alpha two which is the angle made by the absolute velocity in the direction of the tangent this is the absolute velocity all right, and this is the u. So, this is the u. So, therefore, this is the tangential component of the absolute velocity at the outlet v w two clear, well.

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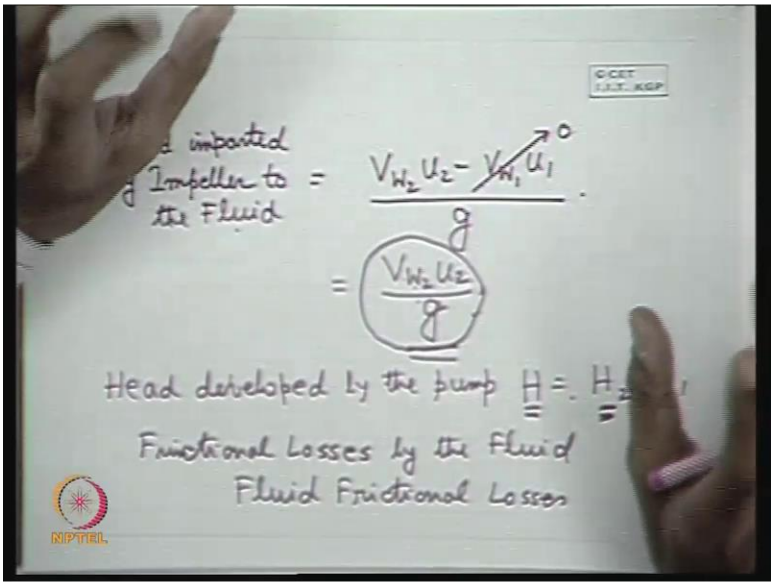

Now, if I write all right, now if I write the work head or the head imparted to the fluid by the rotor that head imparted by the rotor to the fluids sorry head imparted by impeller here the rotor is impeller to the fluid that is equal to you know that v w two from your generalized equation v w one u one by g all right v w two u two minus v w one u one by g this is the work per unit weight or the energy per unit weight or head whatever you call imparted by the impeller that is the rotor of the machine to the fluid all right.

Now, if we make v w one zero, if we make the design in such a way that the fluid enters purely axial, then this becomes the maximum, if you had to ask anything please ask me please any question please ask me any question, if you have got any query you ask me.

Sir, will you please explain the diagram (( )).

This diagram last diagram.

Yeah.

Yes where you cannot understand this is the inlet velocity triangle this is the inlet velocity absolute velocity v one its very simple this is the typical velocity triangle we have discussed. So, many times. So, this is the velocity tangential velocity of the rotor at the inlet this is the relative velocity with respect to the blade. So, this angle coincides with the angle of the blade at the inlet. So, this is u one, and this is the tangential component of the velocity in practice a little amount of tangential component is present. So, fluid cannot enter or a liquid cannot enter purely axial, but a theoretical diagram will be like this just the reverse of a Francis turbine that I will tell you now that it is u one that is v r one, and that is v f one which is nothing, but the axial velocity; that means, fluid is drawn purely axially without any tangential component of velocity is very clear why you cannot understand I do not know listen to thing.

So, this is the outlet velocity triangle where this is the velocity relative to the blade at the angle beta two with the tangent is the angle of the blade at the outlet with the tangent this is the absolute velocity, and this is the what is this, this is the rotor velocity or the blade velocity at the tip now you see therefore, the head imparted by impeller to the fluid is v w two u two by g well. So, when v w one is zero this head imparted by impeller to the fluid is maximum. So, maximum head is imparted if it has got zero tangential component of velocity.

So, try to recall what happened in case of a francis turbine in case of a francis turbine the inlet angular momentum was maximum; that means, it has got a value v w one, but v w two was made zero in that case to extract the maximum energy from the fluid. So, here it is just the reverse another thing is very interesting in a francis turbine what we had we had a radial, and tangential inlet at radial, and tangential flow at the inlet, and the exit is purely axial exit is made purely axial. So, that it has got zero tangential component well while at the inlet is radial, and tangential it is just the reverse in case of a centrifugal pump where the inlet is made purely axial theoretically at the design conditions. So, that it has got zero tangential velocities, and ultimately when it flows through the impeller vane it changes its direction in the radial direction through the blade passages, and then it comes out with a velocity in the radial direction, and tangential direction; that means, in a radial, and tangential plane it is just the reverse of that francis turbine ok.

Now, therefore, this is the head that is imparted by impeller to the fluid. Now try to understand one thing this head is not equal to the head developed by the pump head developed by the pump, if I write head developed by the pump h is equal to h two minus h one what is h two h two is the net heat at the pump outlet which comprises the pressure head the velocity head, and the potential head also though the pressure head is more than the velocity head, but velocity head is there, because the fluid has to flow through the delivery pipe the h one is also the total head at the inlet to the pump which also comprises the pressure head the velocity head, and the potential head. So, this difference of these heads at outlet, and islet is the head developed by the pump. So, why this two are not equal.

This is the head imparted by the rotor due to its motion to the fluid flowing through it, and this head is the head developed by the fluid; that means, this is the difference between the head at the final delivery point; that means, you can consider this at this point we have seen earlier that we have calculated the head at this point that is the inlet to the delivery pipe, and h one is the head before entry to this point that is entry to the pump. So, why this head developed, and this head head imparted by the impeller to the fluid is not equal.

Losses.

This is, because of losses yeah this is, because of frictional losses fluid frictional loss frictional losses by the fluid; that means, it is the fluid frictional loss that is fluid frictional loss; that means, for an ideal fluid this could have been same for an ideal fluid where there was no frictional losses the head imparted by the fluid could have been the head contained in the fluid in this connection I like to tell you one thing; that means, this discrepancy between this two head developed, and head imparted arises, because of fluid friction where as in turbine the head given up by the fluid, and the head on the work developed by the runner is not the same or the head at the inlet to the fluid, and the head on the work developed by the runner is not the same this is not, because of fluid viscosity only this is, because of some energy is rejected or wasted just I tell I will explain you let me first tell you the definition of manometric efficiency.

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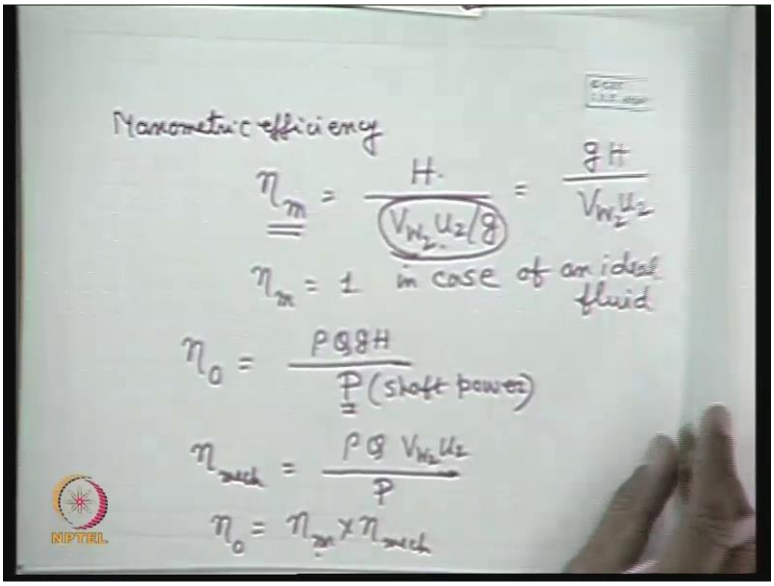

A definition of now the ratio of these two is defined as manometric efficiency in case of a pump manometric efficiency eta m as this head h head developed is known as the manometric efficiency divided by v w two u two by g; that means, g h this is this discrepancy is taken care of by a manometric efficiency which is defined as the ratio of head developed by the pump divided by the head given up by the rotor to the fluid head given up by the rotor to the fluid. So, this is the definition of manometric efficiency. So, the manometric efficiency will be one in case of an ideal fluid well.

So, manometric efficiency I can write is equal to one in case of an ideal fluid in case of an ideal fluid in case of an ideal fluid well whereas, if you recall that in case of a turbine we defined the hydraulic efficiency as the work developed by the runner divided by the head at the inlet head at the inlet; that means, head available at the inlet. So, head available at the inlet is numerator where the work developed by the runner do not consider the mechanical losses that is the work which the runner receives from the head available at the inlet that discrepancy comes, because of the fact some head is always rejected at the outlet even with all with the incorporation of the draft tube we have to reject some head in the form of kinetic energy or if there is no draft tube the pressure at the outlet of the runner for a reaction turbine may be higher than the atmospheric pressure. So, pressure air also the energy comprises pressure air also. So, some amount of energy is rejected.

So, even if the fluid is ideal if you define a hydraulic efficiency by these term that the ratio of the work developed by the runner divided by the head available at the inlet to the runner will be always less than one, because of the energy rejection at the outlet of the runner even if the fluid is ideal, but in case of a pump if you see this manometric efficiency becomes less than one this is, because of the fluid viscosity now overall efficiency is defined as the numerator remains the same; that means, this is the energy developed by the pump. So, you better write in terms of the total energy, then what you will have to do you will have to multiply with rho q g h well, then what is the total this is the power that is the shaft power shaft power shaft power. So, g will not be there o yes g will be there rho q g h.

So, this is the total power developed by the pump that is the head developed g into rho into q divided by the shaft power; that means, shaft power is the primary input to the pump, and this difference between the shaft power, and the power or work imparted this is per unit weight basis by the impeller is taken care of the mechanical losses that is the bearing frictions, and other frictions in the shaft coupling.

So, therefore, we can define a mechanical efficiency the mechanical efficiency which will be rho q into v w two u two; that means, this is the power that the impeller of the pump receives from the shaft power, because of the mechanical losses losses due to mechanical friction in bearings, and other mechanical attachments in this shaft couplings from where we can write that eta overall is equal to eta manometric into eta mechanical. So, overall efficiency is the manometric efficiency into mechanical efficiency well all right.

So, the same way as we defined earlier also the difference between overall efficiency, and the hydraulic efficiency, and the mechanical efficiency the manometric efficiency is same as the hydraulic efficiency as we defined in case of turbines, well.

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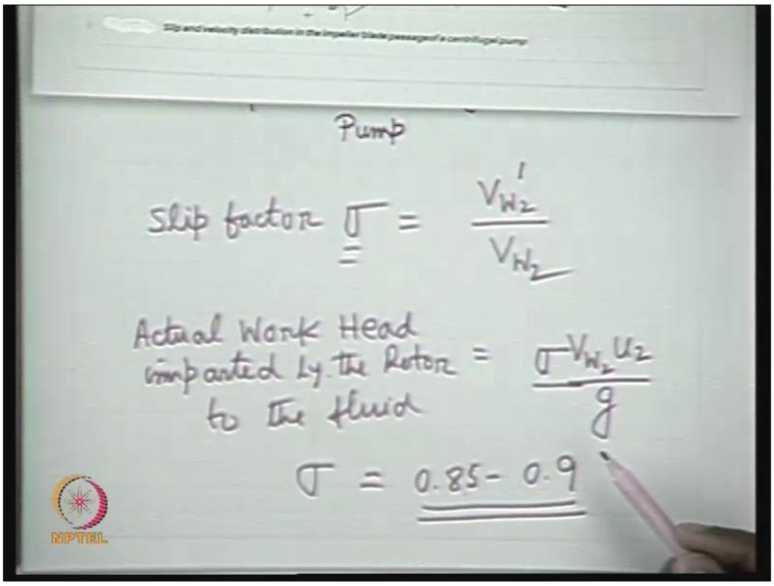

Now, we will come to another phenomena known as slip is very important phenomena slip in a centrifugal pump slip in a centrifugal pump slip in a centrifugal pump what is this phenomena slip.

So, what happens it has been found that in most of the cases or almost all cases under operation the velocity of flow coming out of the pump changes its direction for which the pump has be designed. So, pump blades has been designed within a range of operations that for a certain direction of the flow velocity at the outlet, and accordingly the head developed, and the work imparted by the pump impeller to the fluid that calculated, but it is found that the direction of the flow velocity changes at the outlet from that on the basis of which the pump was designed why it happens?

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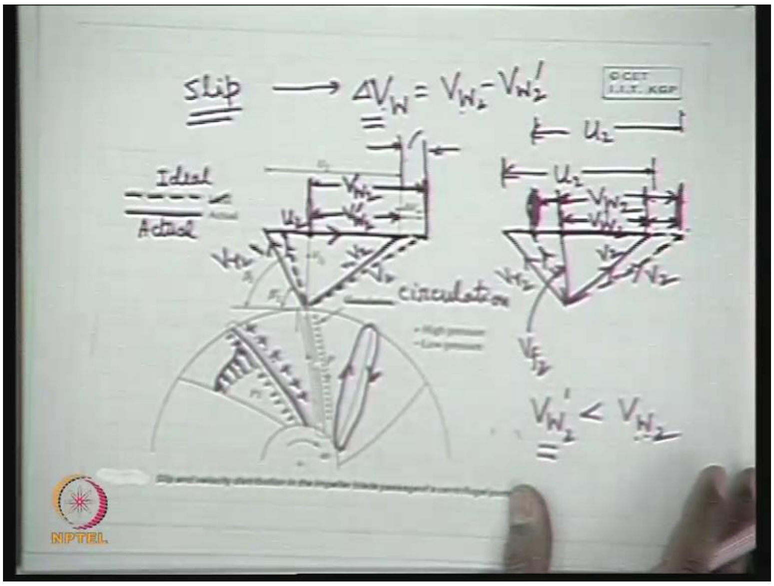

Let us see here a diagram, I think this better you can this is this dotted one is ideal diagram, let me first this one is actual form one you please draw the diagram this is v two this is dotted you can see the dotted one.

No sir.

No sir.

[FL] this I am showing you all right it is ok.

No sir.

No, then I am sorry you can still cannot see that this is ok.

Yes sir.

This is ok.

So, this is the front one this is the bold one this is the continuum all right this is the... So, now, what happens that the fluid this bold one this one is the actual velocity this is v r two this is v r two this is u two this one actual bold one is actual bold one is actual ideal all right bold one is actual now I write this again show that I draw this again here this is the bold one show this is v two this is v r two all right. So, this is this is v f two, and this is the the ideal one; that means, this is the ideal this is ideal v two this is ideal v r two.

So, u is this u is in both the cases u remains the same u two well u two remains the same in both the cases u two.

But what is the difference you see this changes the direction in such a way that the absolute velocity v two this is the ideal one, but actual one it shifts in this way such that it makes a reduction in the actual makes the reduction in the tangential component of velocity let v two w two is the ideal in ideal case this is the tangential component of velocity now the actual tangential component is v w two dash this one v w two dash this one this is smaller than this one.

Suppose the ideal case.

For the ideal case how it is that going to be (( )).

Which one perpendicular is one line this is the v two this is the v two this is v w two. So, this is the v w o sorry I am sorry I am sorry I am sorry this is all right all right sorry all right very good. So, this is the v. So, it is all right that the in actual case the v w two dash is less than v w two all right, I am sorry here it is clearly shown this is the here all right v w very good I am sorry it is a silly mistake I am sorry. So, this is the, you can make it by yourself this is the tangential component of velocity, and this is the tangential component of velocity in the actual.

So, therefore, we see the tangential component of velocity in actual case becoming less than that in theoretical case. So, therefore, slip is a phenomena by which now this is a gross observation that the velocity of the fluid at the outlet from the impeller blade is shifted in such a way that it gives rise to a lesser value in the tangential or wheeling component of velocity this is v w two dash than in its ideal value I think it is all right why it is. So, now, if it does… So, where do we loss please tell me where do you loss if it does so.

Less (( )).

The less work is being transferred to the fluid by the rotor. So, less work is being transferred to the fluid by the rotor than for which it is designed. So, why it is... So, which is very important it is. So, this is, because that when the fluid flows through these blade passages, then what happens? There are two faces; one is the leading face, another is that trailing face of the blade you understand this is a blade. So, when the fluid flows pass this leading face what happens the flow is decelerated, and pressure is high relatively high. So, this is shown by the plus sign while the fluid flows through this trailing faces the fluid is accelerated, because of the typical curvature of the blade, and the pressure is relatively low the same reasons for which the lateral forces are generated or lift is generated, because of this curvature in the blade the leading side pressure becomes high the fluid is decelerated while in the trailing side the pressure becomes low the fluid is accelerated.

So, because of these difference in pressure what happens a circulation loop around the blade this is the circulation can you read this circulation a circulation; that means, a circulatory flow takes place around each blade a circulatory flow takes place a circulatory flow takes place around each blade a circulatory flow takes place around each blade. So, therefore, what happens this circulatory flow disperse the radial flow he radial flow through the blade passages. So, as a result what happens a terrific non uniformity in the radial flow velocity takes place, because at the beginning we told that on an average we assumed the flow is uniform as far as this variation in the blade passage; that means, the radial flow velocity that is the main direction of flow velocity, but it becomes a non uniform of this type you can see this, this is a non uniform this is the distribution a non uniform distribution well.

So,, because of this the velocity vector changes. So, it changes in a way that it reduces the wheeling component of velocity at the outlet; that means, v w two dash which is the actual wheeling component of velocity becomes less than this. So, this difference here it is clear. So, this difference; that means, this difference; that means, this one this one this one this difference; that means, this is can be written as delta v w, that is equal to v w two that from ideal, and this is actual this is known as slip. So, slip is quantified by this difference in the wheeling component of velocity at the outlet; that means, the ideal minus the actual this difference.

So, this is the from here to here this is the ideal this is the actual. So, this difference here also you see this is the ideal, and this is the actual. So, this difference is the slip, and a parameter defined as which is very important slip factor which has to be known, and is symbolized by a common nomenclature as sigma it is the ratio of the actual wheeling component of velocity by the ideal one. So, in terms of this slip factor. Now we can write actual work head imparted by the rotor by the rotor to the fluid fluid becomes equal to we know that v w two this is from the design conditions, we know that this is the value where v w two is the wheeling component of velocity at the outlet from the ideal velocity triangle for which he blades have been designed.

So, if you know this slip factor, then we can multiply it to find out the actual work here it is ratio of this. So, in practice what happens that slip factor values are provided usually it a lie between point eight five to point nine. So, therefore, variation is very less for different type of pump impellers, and usual range of operation. So, therefore, if these values are there in our hand or you can take some approximate value in this range, and multiply it. So, therefore, actual work head imparted by the rotor to the fluid is multiplied by sigma v w two u two by g.

Now, here in this connection I like to ask you one question hello what you cannot understand.

Sir this sigma is...

V w two dash by v w two.

Sir, ideal one ideal one is v w two.

Ideal one is v w two. So, very simple thing ideal one is v w two, and the actual one is v w two dash which is less than this sigma is always less than one. So, that is way it is written like that all right all right. So, this is the work head imparted now here another very important conceptual thing I like to tell you just I like I told you in case of hydraulic efficiency or that manometric efficiency that in case of an ideal fluid also the hydraulic efficiency is less than one while as the manometric efficiency will be one here also another very important thing sometimes it may be asked that even if the fluid is ideal the slip phenomena occur the slip phenomena is not, because of fluid viscosity. So, therefore, this discrepancy of actual work head imparted by the pump to the fluid, and that of the theoretical work head is, because of the slip phenomena which is something related to the flow field that the pressure at the trailing edge becomes lower than that of the leading edge of the curved blade.

And this is typical fluid flow phenomena which happens for both the cases of real fluid, and ideal fluid, because of which a circulation or the circulatory flow takes place within the blade passages, and these circulatory flow takes place for both the cases of viscous fluid, and the in visit fluid ideal fluid, but the magnitude of the circulatory flow or the magnitude of the pressure difference which causes the recirculatory flow, and circulatory flow may be different.

So, therefore, the slip amount of slip that is the difference between the wheeling component of velocities for actual, and ideal cases or their ratio the slip factor may change nevertheless the phenomena slip will occur for which the work head imparted actual work head imparted will differ from that of an ideal that of the ideal work head imparted that of the ideal one even in case of an ideal fluids it is not a consequence of fluid viscosity while these work head imparted is not manifested by an equivalent amount as the head developed by the fluid head developed by the fluid, because of the fluid viscosity.

So, if the fluid is ideal this work head imparted given by this slip factor times the v w two u two by g should come as an equal amount as the head developed. So, this thing may should be made very clear all right well thank you today upto this any question well.

Thank you.