Introduction to Fluid Machines, and Compressible Flow
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Lecture - 11
Axial Flow Machine, and Draft Tube

Good morning a welcome to you to this session of fluid machines a last class we discussed the fancies runner, and a force exacted by the fluid on the fancies runner, and the power developed also we developed, and expression for specific speed of fancies runner mainly in terms of the angles of the guidance at the exit, and the angle inlet angle of the runner the usual values or the typical values that cover the actual case for a fancies turbine.

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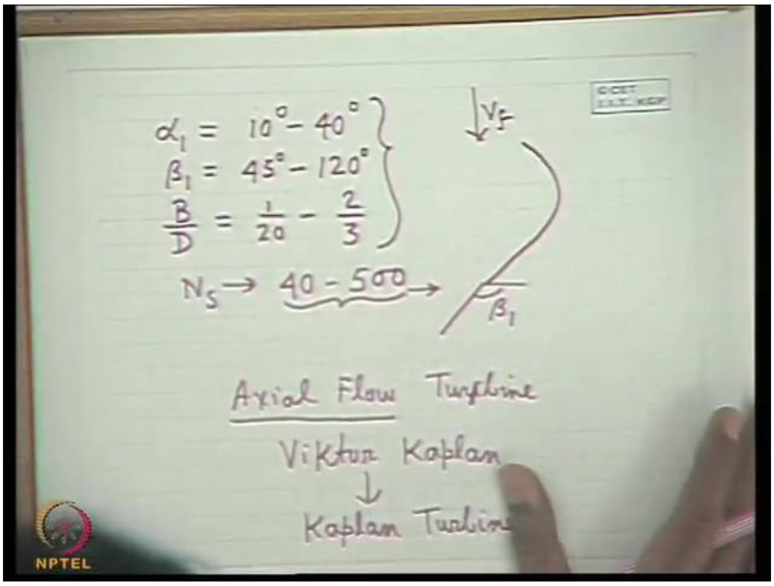

I like that the alpha 1 which we already noted that, it is the outlet angle of the guide blades usually varies from 10 degree to 40 degree you must know, this values in practice the beta one that is the inlet blade angle which varies from 45 degree to 120 degree with respect to an typical blade the fancies runner. So, this beta 1. So, this angle is beta 1well the ratio of width to diameter at the inlet b by the which is very important in determining the flow velocity v f determining the flow velocity v, which remains constant throughout the flow to the runner blade, which varies from a value of 120 to 230 these are the typical ranges between, which the pertinent geometrical dimensions are kept, and the combinations of these covers a white range of specific speed for the turbines from 40 to 500 very wide range of specific speeds cover by a fancies turbine a real turbine, Now, as this specific speed increases mainly beyond 500 what happens is that the under which there analysis is working is getting radius.

So, therefore, essential feature of a turbo machine at a higher specific speed; that means, at a lower rate is that we should a relatively large amount of flow to get some definite work out. So, therefore, the runner should be capable of handling or allowing a more amount of flow to get a definite work out when it is operating at a lower rate or a higher specific, and this for two meet this requirement the shape of the runner blades have to be change. And the type of the runner also change for a maximum flow through the runner the flow velocity has to be axial that mean if the flow rate through, the runner blade has to be made very high the flow velocity x to axial; that means, the direction of the flow velocity should be parallel to the direction of the a parallel to the axis of rotation, and to do this, and to accommodate the flow, and to extract the work from the fluid flowing through the runner the shape of the runner blades have to be change.

So, these is accomplish in a machine know, as axial flow turbine axial flow turbine, and a machine of this type axial flow turbine was first turbine, sorry axial flow turbine was first developed by an austrian engineer victor kaplan, and that is why the name of this turbine is kaplan turbine according to the name of this scientist kaplan turbine. So, kaplan turbine is specifically an axial flow reaction turbine which is used for a very high specific speed range beyond this five hundred at max higher efficiency.

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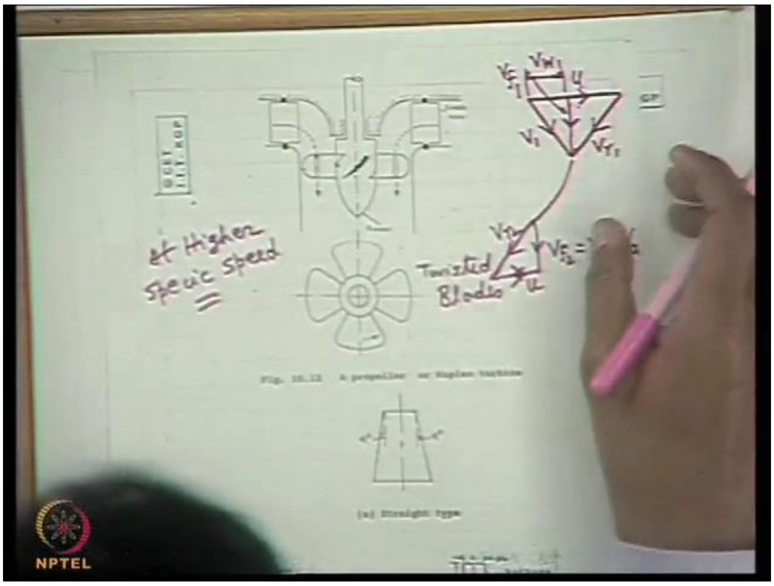

So, let us look, what looks like atypical axial flow turbine or the kaplan turbine, which is sometimes known as a popular or kaplan turbine you see these at the guidance. So, fluid while after passing through, the guidance the pipe bends are such the, it is bend right angles in the axial direction see it first enters to the giuden almost in the redial direction as it happens also in case of a fancies turbine, then it is turn to right angle to the axial direction. So, these are the rotan blades or the runner of the turbine. So, this is the usually those machines have particles are.

So, if we look a plane view. So, the runner blade looks like this the number. So, of runner blades are usually small. So, here what happens the fluid flows parallel to the axis of rotation throughout the runner, which means the entries axial the exit is also axial, now, I have mentioned earlier also. So, the purpose of the guidance is to direct the fluid accordingly to the runner blades, and also to input a little amount of; that means, a tangential component of velocity to the fluid. Now, the tangential velocity in the fluid approaching the runner is such that each can be approximated by a motion why if we neglect the friction in this ducted, then we can say that in absence of friction on a no work is done or extracted from the fluid, then the tangential velocity if there is any follows a pre type of motion, which means the tangential velocity decreases with the increase in radius, but what happens to the blade velocity the blade velocity increases with the increase indent radius because it is a solid body rotation. So, to take care of this different relationship between the fluid velocity, and the blade velocity typically the tangential velocity velocities the tangential velocity of the fluid approaching, and the blade velocity linier blade velocity blades are twisted twisted means the blade angles from inlet; that means, the route not inlet I will tell the route to the t is vary this is known as twisted blade these blade are made twisted twisted blades twisted blades twisted blades the blade are made twisted. So, this floated place axially almost axial through the blade typical peripheral section of the blade is like this.

Now, if you draw the velocity triangle here, you see that the velocity triangle is like this usually the most important feature is that flow velocity v f which is axially; that means, in reaction turbine radial flow. We have seen the inlet; that means, either with respect to blade or the absolute velocity was in radial an tangential plane, then it has both radial component, and tangential component in case or action flow turbine it is other way it has got tangential component this is the tangential component v w 1, and an axial component which is the flow velocity v f one the outlet velocity triangle if you draw will be the same.

As that of radial flow reaction turbine this, v f 2 is equal to v f 1 which is equal to v a; that means, the axail velocity of, and this is typical sorry this is this direction this is the u, and this is the v r 1 important thing is that the blade velocity is same, and both inlet, and outlet in my diagram also. It does not look like that the am not send,because they are same,because there in the same axial, there in the same radial location; that means, the flow is in axial direction. So, radial location at the inlet, and radial location on outlet is this end. So, this is the principle feature of a axial flow turbine the blades are twisted, and the flow is throughout the axial the main feature is that in this case the flow velocity is much higher as compare to that in the radial flow reaction turbine, and the flow velocity is here in the axial direction, because the main flow is in the action direction.

So, this way is turbine is capable of handling a very high floorage, and therefore, it is suitable for a lower head or a higher specific at higher specifics higher specifics the runner runs to completely filled with the liquid. So, that the reaction is important on the liquid, and more over the degree of reaction in this type of machine is higher than that in case of a radial flow fancies turbine well after these, Now, I will go to the discussion on draft you application of draft tube. Now, I have already told earlier that a draft tube is attached always to the outlet of the runner of a reaction turbine to minimize the energy loss at the outside.

Now, at the out let, end of the runner of a reaction turbine the kinetic energy which is coming out is lose. So, if the fluid comes with a very high velocity; that means, the laws in energy in terms of the kinetic energy of fluid is very high. So, therefore, what happens is that a attached to the outlet end of the runner of the reaction turbine. So, that the velocity of the fluid is reduced; that means, a flow is caused in the divergentive as you know in the fluid flows through a as the area of procession in this is the velocity decrease it. So, therefore, at the outlet end. The velocity of the fluid kits reduce, and therefore, the rejection of energy at the extreme outlet of the machine is very less in another look we can see we can see from another a point that, we have already discussed earlier seen that if you write the energy equation or the equation between the inlet to the draft to you; that means, the exit of the runner, and the final exit of the draft tube.

Which see that since the discharge from the draft, you is at atmosphere is pressure, and more over the flow through the draft tube is dislerating flow; that means, velocity is decrease. So, therefore, the pressure, and the off stream thought; that means, for example, that the inlet of the draft tube is be lower than the atmosphere equation, because pressure has to increase for dislerating. If you which means in other way the outlet end of the runner is running at a lower is a running, which a lower or a pressure in to that of a runner without a daft tube.

So, therefore, the a fifteen across the runner is increase by attaching the draft tube, this can be look from this angle also the draft tube deduces the pressure at the runner outlet. So, this is the precise principle of a drama draft tube how we the increase the head across the runner. Now, therefore, you see that the purpose of the draft tube is to reduce the energy at the outlet, and thus to increase the head across the runner, now, two things have to we kept in mind designing the draft tube.

Is a first thing is that when, we extract more energy in the draft tube; that means, how do you extract energy; that means, you reduce the loss at the outlet or we reduce the pressure at the outlet end of the runner to do that, we will have to keep in mind that the loss of energy while flowing through the loss of energy of the liquid while flowing through the draft tube should as small as possible. So, what are the source of is error one source of error that is the usual friction laws that is the friction between the fluid, and the solid wall or between the two fluid another source of error comes while a fluid flow, thorough a divergent ducted is the loss due to boundary do you know what is that a lose due to boundary do you know it well.

Now, what happens when the fluid flows through a ducked of uniform cross sectional area or fluid flows through a ducked of conversing cross sectional area; that means, either fluid flows in uniform velocity or fluid flows with increasing velocity in accelerating flow. Laws which is incurred is only due to friction; that means, between fluid to fluid that is fluid, and fluid to solid friction, but when the fluid flows to a divergent duct, then another additional laws comes laws in head the laws in total energy is known as boundary what happens is that when the fluid flows to a divergent duct you see the fluid is dislerating type; that means, according to continuity when the cross sectional area increases the fluid velocity decreases in complies with the equation the pressure de increases when the velocity decreases the pressure increases; that means, fluid flow is against at adverse pressure; that means, fluid flow from a lower pressure to higher pressure.

So, why the fluid flows yes the fluid does not flow from a higher pressure to lower pressure that is not the an nature's law nature's law is that fluid flows from higher energy to lower energy. So, fluid is capable of flowing from a lower pressure to higher pressure, because if energy at the lower pressure condition; that means, at the off stream condition is more than the downstream condition. Then only the fluid is capable to overcome this adverse pressure, but what happens, but the fluid which very near to the solid as you know the influence of solid to the fluid gives rise to the formation of a boundary layer or what happens these that due to the frictional interaction between the solid, and the fluid this the consequence of the fluid that the fluid partials near the while looses this velocity, and impact as the solid wall fluid velocity is 0. If the solid surface is at rest; that means, no slip condition you know from your basic knowledge in fluid make is that the relative velocity between the fluid particle length the solid surface at the wall the solid surface is 0.

So, therefore, for a static solid surface static duct. So, fluid velocity at the wall is zero. So, therefore, very near to the wall to the wall fluid velocity is are very small. So, this small velocity fluid particles do have sufficient kinetic energy to make their total energy compatible for flowing from upstream to downstream section. So, therefore, they become unable to surmount. The pressure what that do they follow the favorable pressure; that means, they follow the path from a higher pressure to lower pressure; that means, in a direction opposite to the direction of the bulk flow which is array from the solid.

So, therefore, you will see that the fluid particle near the wall goes on flowing in opposite direction in flow reversal takes place. So, this localize flow reversal makes a recirculated flow, and forms in terms of fluid, and this fluid at the circulated the loop along with the main bulk flow causes a loss of energy this lose of energy mechanism like that a pressure in energy a part of mechanical energy is converted into inter molecular energy which, we call as a loss of energy from the view point of mechanic energy as you know when we deal with the mechanical energy. We have already heard this term of lose of energy in equation energy never be lose from the conservation of energy principle which means a part of mechanical energy which is convert it to other form of energy which is not the mechanical energy call it as.

Lose of energy; that means, this is aloes of mechanical energy due to friction, because formation of due to circulated the reverse flow at the solid wall why the fluid particles cannot surmount at first pressure in, because of their low velocity this is a very important phenomena of separation wherever you come across flow thorough divergent duct or dislerating flow this type of phenomena comes known as non separation to avoid the or to keep this to a minimum value. The most important factor is that the angle of divergence or rather the rate of the diffusion, that is change in pressure or the change in velocity, it has to be made very low usual recommendation is that the angle should be within eight degrees eight to ten degrees to avoid the boundary as much as possible.

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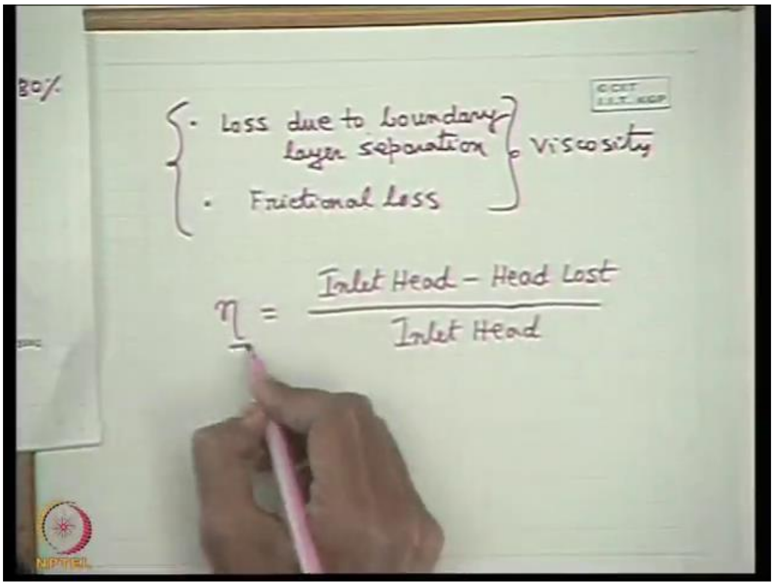

So, therefore, we see that in designing a any division duct in any application, it is not always for a fluid machines that there are two criteria comes into picture one is the a lose due to boundary layer, separation lose due to boundary layer, separation lose due to boundary layer, separation lose due to boundary layer, separation lose due to boundary layer separation another the another is friction laws frictional laws frictional laws, and one thing you must know at this level that this two loses at the consequence of the fluid is ideal neither of these loses we will take place you must cleared your basic concept in fluid mechanics along with the additional information in fluid machine that lose due to boundary layer separation, and friction lose takes place, because of the fluid viscosity wide, because the phenomena may occurred, but the boundary layer separation will not take place even if there is an adverse pressure in, because the fluid particle having a low of velocity at wall depends upon the interaction between the fluid, and the solid surface through the viscosity of the fluid.

So, these are contributed by the viscosity of the fluid, now, the basic intension of designing any draft you each to keep these lose to lose to a minimum. So, that the energy is not lost were want to retain the energy in the form mechanical energy similar will be the consideration for using or providing draft tube in a reaction turbine well let us see what are the different types of reaction turbines usually in corporated in practice number one is straight type you can read it this is straight type this the simple conical the of a cone a simple divergent duct straight divergent duct the angle included angle is limited to eight degrees the semi angle is four degree this type of conical draft to you these is a particle one it is directly attach to the outlet end of the runner it is very efficient, and its efficiency lies between almost equal to eighty percent in these connection I must tell what is efficiency.

The efficiency you can define of a draft tube or any divergent duct in transforming the pressure energy to velocity energy rather velocity energy to pressure energy like this the inlet head inlet head; that means, total energy of inlet head per united minus head lost in the flow divided by the inlet for an ideal fluid this efficiency id hundred percent; that means, it is an index of the head lost efficiency is lose of head by this two mechanism will be low. So, therefore, this type of machine gives almost eighty percent eighty or I feel eighty to ninety percent efficiency, and these are used for small specific speed low relatively low in s t specific with turbine with particles, now, another type of draft you.

These two types are elbow types, now, this elbow types draft tubes are used were sometimes in certain place sometime we see that to reduce the cost of particularly in drops we use this elbow type draft were if we go for a vertical draft you from a from the place where the runner is install at a height from tale race level which see that we have to go for in raw. So, to keep the cost of excavation minimum the draft you the this in the horizontal deduction to keep its length it is very rare in can seen very clearly in this figure. So, it is this is known as elbow type that is from particle to horizontal, because of the sharp change in the deduction flow the efficiency of this type of, and duct you is in the sixty percent sometimes the cross sectional area is change from a circular.

The inlet to a rectangular rectangular at the outlet to minimize the frictional loses. So, that the. So, that the efficiency is little higher so. In fact, this several type of draft tubes are used. So, you see the angle of the draft tube is limited that is diverges angle by the flow separation laws, and the length of the draft tube is being compromise within the frictional between the frictional laws in the draft tube, and providing the length suitably either in the particle direction or horizontal direction depending upon the places of application whether to reduce the cost of excavation in we have to place a horizontal part we have to a horizontal part were the particle part of the inlet portion has to be with horizontal part in sacrifice certain amount of lose by the changing direction, now, after these I will come to another very important phenomena cavitation in a fluid machines, now, cavitation.

This what as applied to the fluid flow is not necessarily restricted to fluid machines or reaction base this is the applied to any fluid flow problem or to any hydraulic probably we have heard the name cavitation while reading this in your basic fluid mechanic class while you have rate this we have seen that the pressure becomes low at some points in the were the problem of cavitation comes what is cavitation, now, let us define the cavitation in this way if there is an hydraulic circuit; that means, this circuit which contents the flow of a liquid, and if there is any chance of having special lower than the a pressure at some part or during in some region of the flow of that hydraulic circuit. So, one in that case in that case one has to be very careful that these pressure that the minimum pressure which is below the atmospheric pressure should not fall to the pressure.

Below the pressure or equals to the pressure of the liquid, and the working temperature why the minimum pressure in the hydraulic circuit fall to the pressure of the liquid at the working temperature liquid starts boiling at that pressure. So, in a liquid start boiling. So, pockets of liquid will be found simply lock the flow or stop the floor this is precise the what is known as cavitation, what happens? Thereafter is that when are found were the pressure is sufficiently low they are carried away with the liquid to a higher pressure is enquired the paper or bursts forming into cavities, and the liquid from surrounding zone rush to fill up the cavities, and if this phenomena bursting of the takes place very near to the wall an liquid from the surrounding region rushes to fill up the cavities they causes an a effect to the wall of the tube or wall of the duct causing damage the damage is found in the form of force in the wall of the duct or wall of the tube.

So, therefore, it is danger as two allow such phenomena to occurred not only the flow will be stop within few minutes the wall of the duct or the duct itself or the tube itself of the hydraulic circuits that part of the tube will be damage in to own. So, this phenomena is known as cavitation. So, therefore, we will have two minimum at the minimum pressure section or the point of the hydrologic circuit. So, that the pressure at that point should not should be at least more than the pressure of the liquid corresponding to the existing temperature similar is the case for a draft tube, now if you write the equation as I discussed earlier at the inlet to the draft tube, and the outlet from the draft tube.

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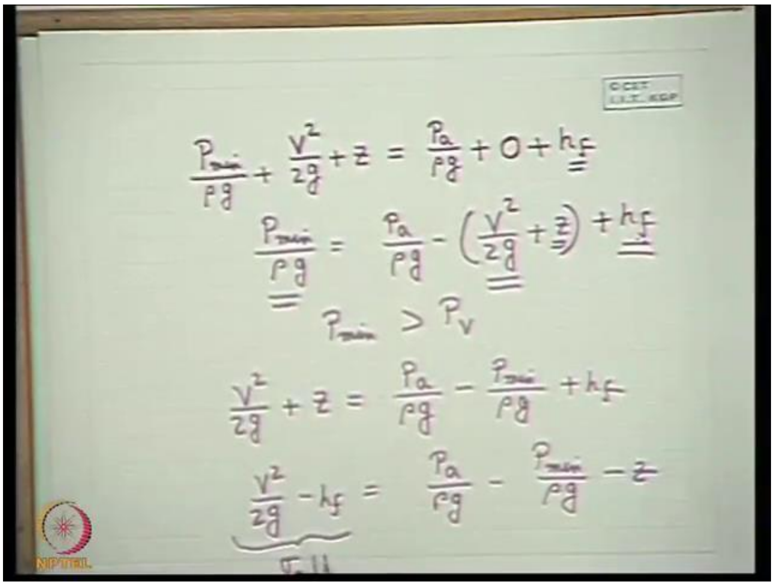

Let us considered the inlet were the pressure is p minimum, because we know that in draft tube there in a minimum pressure will occur at the inlet to the draft tube; that means, at the outlet of the runner then I can write the equation like that p minimum by rho g let we is the velocity they are; that means, this v is the velocity coming out from the runner outlet of this v is the velocity at the inlet of the draft tube let is the particle height from a reference that on which is usually taken as the; that means, this is the height from the to the inlet of the draft a; that means, this is the height at which the runner is place these I can write is equal to p a by rho g, because the outlet pressure of the draft tube is there atmosphere equation draft tube discharge is liquid into atmosphere.

Now, if we neglect the velocity at the outlet end of the draft tube, we can neglect the if we consider draft tube area is such that is velocity at the outlet is negligible is non to its inlet the is zero, because we have taken the reference data might level itself, then another term is the head loss h f that is the rho seen energy due to friction and boundary separation or due to the change in direction. So, it consist of all the losses in course of flow through the duct tube. So, here we see that t minimum by rho g is equal to t a by rho g minus is square by two g plus j plus h f. So, we see that if the velocity at discharge from the runner or at inlet to the draft tube is very high or the height at which the runner is placed from the level is very high there is every chance that the minimum pressure at the section any fall below the w pressure, because the minimum pressure will depend upon this quantity more is the velocity at the inlet to the draft tube more is the height of the runner from the level is the pressure at the inlet to the draft tube off course the friction mix an advantages case in advantages case this situation for the p minimum, but the frictional lose is very lessed as compared to the total energy three square by two g plus j the friction would short of resistance you can understand physically these way sir why you may ask that friction increases the pressure, because friction puts a short of resistance to the flow frictional law. So, that the off stream pressure that is somewhat increase.

So, the influence of friction here is favorable as per as the reduction in the p minimum is require, now the basic consideration for cavitation not to occur is p minimum should be greater than p v; that means, paper pressure of the liquid use, now what happens in practice is like that if write this equation that equation little here itself different manner we can write with a little other form an another form re arrangement p square by two g is p a by rho g minus p mean by rho g well plus or rather v square by two g minus h f is pa little re arrangement is minus p mean by rho g well minus z, now this part is express in practice as a function of the head across the runner that function is sigma c.

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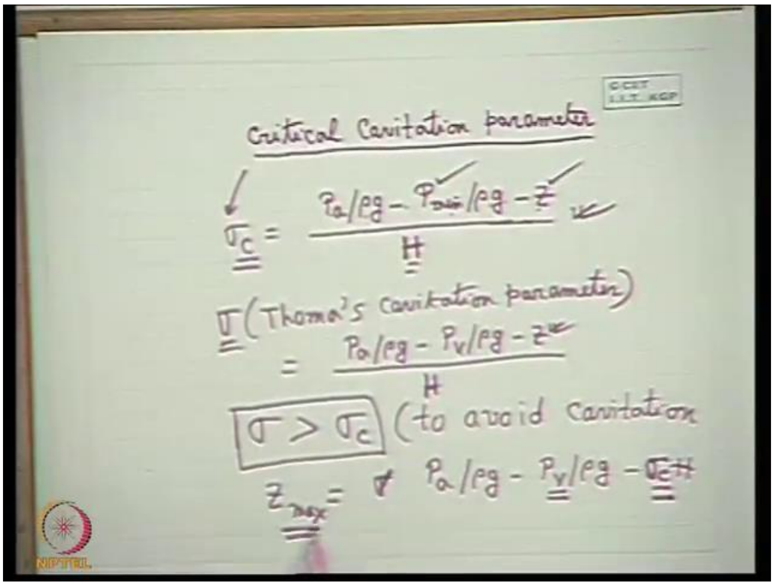

So, let us express this way you can see this, then we can write that sigma c becomes equal to becomes equal to pa by rho g by rho g minus t minimum by rho g minus j by h this sigma c I s know as critical cavitation parameter critical cavitation parameter critical cavitation parameter critical cavitation parameter, and it is an operating condition of the turbine which depends upon the minimum pressure t the runner outlet the height at which the runner has to installed, and the head across the machine another parameter sigma is define according to a german scientist thoma is known as thoma's cavitation parameter which is use as a design criteria or a design parameter to determine whether the cavitation will occur in a particular situation or not what is this? This is simply the same thing almost, but instead of p minimum we substitute the criteria, that is the pressure which is the limiting value by h.

That means, in under all situation cavitation to avoid this p minimum has to be more than p v which means sigma has to be greater than sigma c through avoid cavitation well to avoid cavitation what is done in practice that this sigma is calculated thoma's cavitation parameter with the pressure of the liquid, and under the operating conditions sigma c is calculated, and it check that whether sigma is greater than sigma or not, now, you see if the head of the runner is increase or the height of the runner from the label is increase sigma is reduced, and there is a chance of cavitation occur usually what is done in practice that from this equation the maximum value of z is calculated; that means, let us write the max that is the maximum height of the runner; that means, the maximum height at which the turbine runner can be placed will be sigma rather I can write these way p a by rho g when the p minimum will reach p v p v by rho g minus sigma c in to a; that means, these equation gives j it is equal to p a by rho g minus p minimum by rho g minus sigma c eight. So, in p minimum will reach the v that is the pressure which will give the maximum j. So, the values of sigma c the operating parameter are known to us in case design while we design the turbine. So, knowing the value of sigma c we find out what is the maximum j that is required, now, some time it appears that is very high; that means, turbine operating under a very, very high head; that means, a low specific speed z max is reduced sometimes it appears the z max may be negative that is turbine has to be place below the the situation is not.

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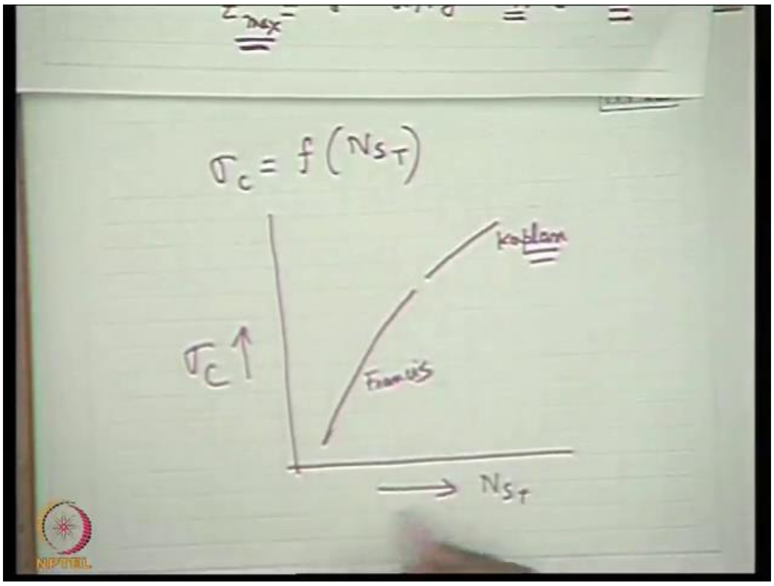

So, this is because the sigma c here is a function of is a function of specific speed of the turbine I give you an a example that if we the values of the sigma c which are available to the design engineer in practice with, and s t the values are like this for fancies turbine fancies for a kaplan turbine it is like this kaplan turbine, now it is found for a fancies turbine the values of sigma c is a direct function of the specific speed. So, when the head is high specific speed equation, and p to the power half by each to the power by four; that means, at a higher head the specific speed is low.

So, therefore, we do not go for a kaplan turbine rather we go for a fancies turbine were we find at a lower specific this all specific withy range for the reaction turbine only as lower specific speed the values of sigma c is also low. So, that if we employee the value of sigma c even at a higher a, we get a value of z max. So, it may not be negative. So, the difficulties can be avoided that turbine may not be set at a level below the water, but the high above the water level must be very small not very high to avoid the cavities well this is about all this is all about cavitation in a reaction turbine. So, if you have any questions you can ask me for today after this well please any question cavitation principle of draft tube, and the cavitation which is very important parameter cavitation is very important parameter in designing in any hydraulic circular, where there is a chance of pressure within the circuit two fall below the atmosphere equation you must know this thing any question.

Thank you.