Introduction to Fluid Machines, and Compressible Flow
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Lecture - 09
Introduction to Reaction Type of Hydraulic Turbine – A Francis turbine

I welcome you all to this session of fluid machines. Today we will start the discussion on reaction type hydraulic machines, the first introductory concept about the reaction types is like that as you know earlier that a reaction machine is a type of machines where both the change in velocity, and pressure takes place while the fluid lows through the rotor; that means, the basic difference is that for an impulse machine the fluid the pressure of the fluid remains remains constant in the rotor of the machine the fluid the energy of the fluid at the entrance of a fluid machine can be thought of to be comprised the kinetic energy, and the pressured energy.

That means the fluid at the entrance to a machine comprises both kinetic energy, and pressured energy. So, what happens in an impulse machine that the fixed part of the machine known as rotor which in case of a peltoner is the nozzle that expands the fluid from these higher pressure to the ambient pressure; that means, the fluid coming out from this stator o the machine is in the form of a high velocity jet; that means, it is ully in the form of kinetic energy. So, pressure is totally expanded the pressure energy is totally exploited in the form of kinetic energy.

So, therefore, the rotor it is only the change in the absolute velocity of the fluid or change in the kinetic energy of the fluid which is responsible for the work done by the rotor, but while in case of a reaction machines the fixed part or the rotor of the machine does not exploit the entire pressured energy in converting it to kinetic energy; that means, a part of the pressured energy is being converted into kinetic energy. So, therefore, fluid approaching the rotor blades or the moving part of the turbine has both the pressured energy, and the kinetic energy. So, therefore, fluid flowing through the rotor blades suffer a change in both its kinetic energy, because of the change in its absolute velocity, and also in pressured energy.

So, how the pressured energy is changed, then when fluid flows through the rotor passage, then the flow area is changed, and accordingly the relative velocity o the fluid with respect to the rotor changes or the pressure of the fluid changes. So, therefore, simultaneously velocity, and pressure of the fluid changes in a reaction machine, then their rotor of a reaction machine changes. So, that is the basic difference between a an impulse machine, and the reaction machine of any kind now the most popular in the field of hydraulic machine is known as francis turbine which was first developed by an american engineer j francis this is the francis turbine francis turbine.

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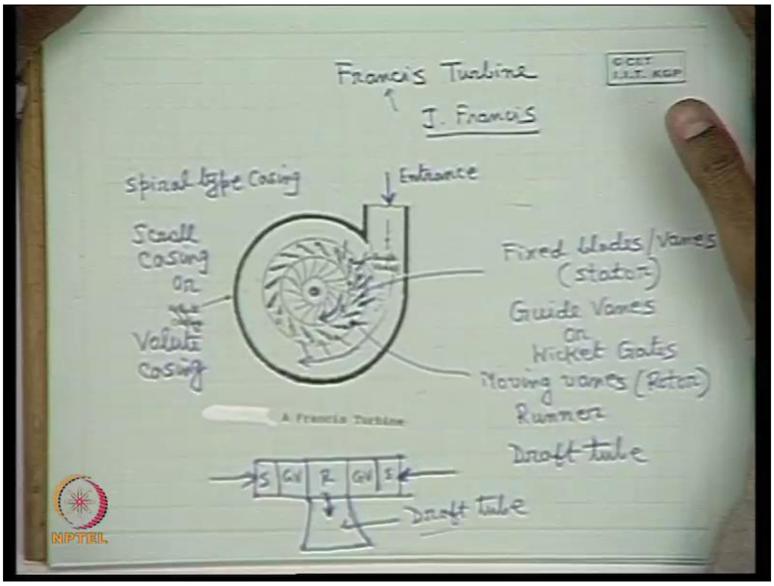

So, the first hydraulic turbine reaction type hydraulic turbine was developed by this is the name of j francis an american engineer who developed this known as francis turbine it is a typically a radial flow turbine as you know that in case of a radial flow machine when it is a turbine; that means, it develops work, then it has to be an in work radial flow; that means, inlet to the turbine should be at a higher radial location from the access of rotation as compared to its outlet this is, because that the dynamic say centrifugal head is released by the fluid.

That means the as the fluid passes through the rotor blade a decrease in its centrifugal head occurs which can be utilized in the form of work developed by the turbine. So, therefore, in case of turbine the radial flow machines will be inward flow type that mean the inlet to the rotor will be at a higher radial location from the axis of rotation. So, here also it is a radial inward flow hydraulic machines now the main component. Let us first see that this is the entrance this is the main entrance of the fluid which is having both the velocity, and pressure high velocity, and pressure; that means, the energy at here which the fluid possesses is in the form of both kinetic energy, and pressured energy.

This it flows through a typical space like that or typical cross section like that where flow machines will be inward flow type that mean the inlet to the rotor will be at a higher radial location from the axis of rotation. So, here also it is a radial inward flow hydraulic machines scroll casing or volute can you see this volute casing volute volute casing. So, a spiral type casing known as scroll casing or volute casing why it is spiral type, because it area changes n such a way looks like a spiral as the liquid flows through it, then there are certain vanes or blades which are fixed.

And as the liquid flows through the spiral casing scroll casing the liquid enters into the passages formed by these fixed blades. So, these blades are known. So, these blades are known as there are fixed blades fixed blades or vanes blades or vanes, and this is the stator of the machine, and this is the stator of the machine; that means, the fixed part these are known as guide vanes these are the terminology guide vanes or wicket gates this is the peculiar terminology or typical terminology wicket gates in hydraulic machines wicket gates I will come afterwards the function of each, and every component before that let me tell you that what are the components.

These are fixed blades these are pivoted at those points. So, that these are they are usually fixed for a particular operating conditions, but they can be moved they can be sewable above this pivotal point to regulate the flow through these guide vanes in case of governing of turbines, which we will we will come afterwards, then the last next component is a series of moving blades. So, this blade is moving this s moving this is the shaft where it is mounted the rotor. So, this is the rotor disc, and on the periphery of the disc you see the number of vanes are attached. So, these are known as moving or this is the moving vanes moving vanes which moves.

That means these vanes are mounted on the periphery of a disc which is coupled to the shaft which is rotating. So, therefore, this vanes rotate these have got an angular velocity. So, these are moving vanes or known as runner. So, the moving vanes that is the rotor the rotor part o the machine is known as runner. So, machine is composed of now we will come afterwards let us see moving vanes, and runners. Now if you see the low of liquid you see the liquid comes here at this point this is the entrance as the liquid flow through the guide a through the sorry scroll case of volute case while liquid comes here the liquid goes on entering through the passage of the guide vanes.

Now, you see this area is decreased, because to make an equal amount of fluid to flow through the passages of the guide vanes as you see as the fluid flows through the passage of the guide vanes. So, therefore, some fluid flows in this in this direction. So, when the fluid comes in the scroll case. So, the fluid mass is reduced. So, the area is accordingly reduced. So, that the entrance velocity of the fluid in the passage of these rotor vanes becomes almost same; that means, to maintain the uniformity in the entrance velocity to all the passages this area; that means, this scroll case area is reduced this is, because the amount of fluid as it flows in the scroll case in this direction is getting reduced.

The flow rate, because of the flow in the vane passages guide vane passages now the guide vanes are pivoted in a such a way that this area passage area; that means, if you consider one such passage through found by two guide vanes is such that it gives a convergent area to the flow of fluid. So, that what happens when the fluid lows through this pressure of the fluid is deduced, and the velocity is increased. So, therefore, when the fluid flows through the guide vanes what happens? The pressure of the fluid is reduced, and the velocity of the fluid is increased.

So, the inlet to the machine why is that the total head at the inlet to the machine, and this is the total head at the out let where pressure is reduced to zero; that means, the atmospheric pressure head a potential head is zero, because we have taken this tail race label as the data, and the velocity is v three square by two this is given by this. So, this much amount is the net head across the turbine which is equal to the work done provided the friction loss is neglected. So, actual work done will be less than that, because of the friction loss it is a very important tube known as draft tube draft tube.

Now, we should conceive all these components to conceive all these components let us consider the way that this turbines are set in a horizontal plane that they shaft is vertical; that means, the shaft is vertical usually all reaction turbines of this type except for turbines of very small capacities have vertical shaft; that means, the entire thing is this turbine is in a horizontal plane. So, therefore, you see the entrance is like this fluid comes in to the scroll case, then it enters to the guide vanes the passage is formed by the guide vanes, then it enters to the runner or the rotor of the machine; that means, the fluid here has got both radial velocity, and the tangential velocity well here also fluid has got both radial velocity, and tangential velocity.

So, the radial, and tangential velocity both makes a plane which is the horizontal plane. So, this much amount is the net head across the turbine which is equal to the work done provided the friction loss is neglected. So, actual work done will be less than that, because of the friction loss it is a very important question.

Sometime I ask that a hydraulic machines there is a for hydraulic turbine there is always an hydraulic efficiency even if you have an in visit fluid as he working fluid in visit liquid as the working liquid which is not the case in case of pump which is not. So, in case of pump I will come across afterward, because in a hydraulic turbine you will have to reject some energy at the end of the machine as the kinetic energy. So, even if you remove friction there is a difference simple example that or a impulse machine or the axial flow type as you are filtered with it is a tangential flow type draft tube . So, now, before coming to all the components again let me tell that why such a tube with diverging area is attached for the final discharge of the liquid the turbine.

So, liquid is not discharged from the rotor as such at the outlet of the rotor where it is allowed to flow through a diverging tube or diverging closed duct known as draft why it is done when you know that for any fluid machines at the discharge of the machine or example why we cannot reduce their discharge velocity from the draft tube to a very low value; that means, how much low pressure we can allow at the inlet to the draft tube it is a very simple that this pressure should not fall below the vapour pressure of the liquid heat developed by the machine is equal to what one by two g.

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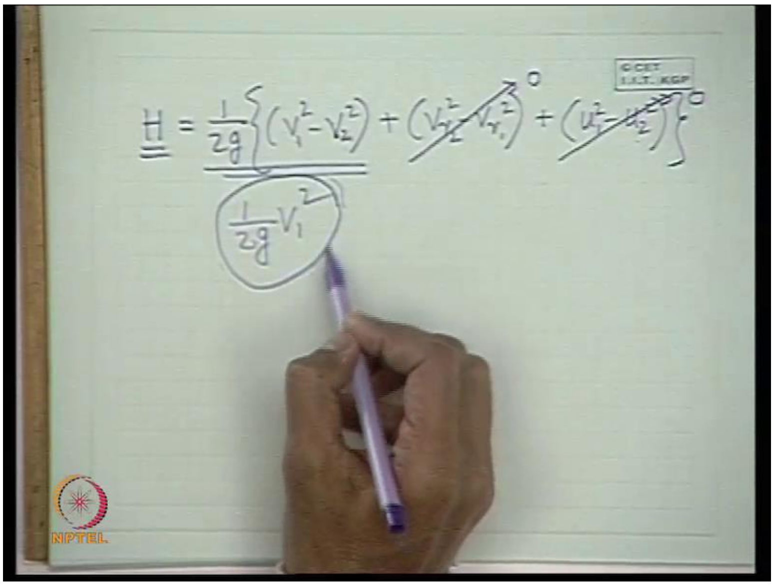

If you recall it v one square minus v two square plus v r two square minus v r one square plus u one square minus u two square. So, therefore, you see even for an impulse machine this is zero this is zero or the axial flow type as you are filtered with it is a tangential flow type. So, the work done even for an in visit liquid without friction is equal to one by two g v one square minus v two square; that means, the change in the kinetic energy; that means, initial head is one by two g square by two. So, final kinetic energy can never become zero you can we have to discharge the with some flow velocity whereas, the unit energy to the fluid turbine is v one square by two g or this more little more than that if you consider at the entrance of the nozzle. So, the entire energy the kinetic energy in case of an impulse machine could have been utilized.

So, which now I like to say liquid has to be discharged with some velocity discharged means it has to be discharged with some velocity which corresponds to some kinetic energy which is a loss. So, therefore, this is the loss. So, this has to be made as small as possible. So, what happens when the liquid coming out of the runner outlet it has got a high amount of velocity; that means, the velocity at the discharge of the runner. So, if we can reduce this velocity at the final discharge, then what we can do we can reduce the loss in the form of kinetic energy of the liquid. So, therefore, if it is allowed to pass through a divergent duct is reduced as the consequence of continuity for an incompressible subsonic flow.

So, therefore, if we allow divergent duct to be followed at delivery pipes. So, therefore, when the flow takes place through this pipe along with the pump the operating point of the pump will be decided by this system characteristics of the we we will depend on the system characteristics also well. So, what is the system characteristics let us find out system characteristic means that what is the relationship between these head loss through this system, and the low rate which gives the head to be developed by the pump we know that head to be developed by the pump is given by what volute casing.

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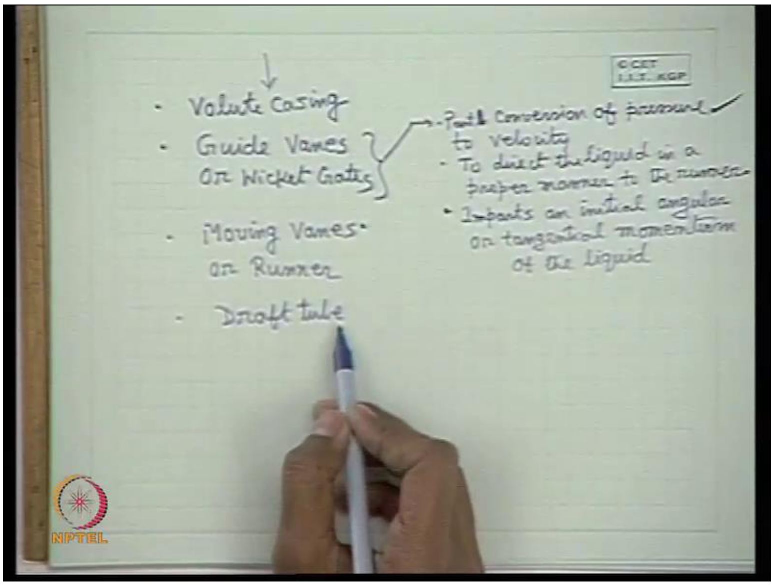

Next is guide vanes or wicket gates guide vanes or wicket these are the terminologies gates wicket gates wicket gates next is moving vanes moving vanes moving vanes moving vanes or runner, and next is the draft now we have to understand the function of each, and everything very simple this is the entrance point liquid entrance to volute case. So, volute casing initially guides the liquid to guide vanes the function of guide vanes is to increase the velocity partially partly partly part conversion of pressure to velocity, and another function is to direct to direct to direct the liquid to direct the liquid in a proper manner in a in a proper manner in a proper manner to the runner in a proper manner to the runner.

What does it mean; that means, it decides the correct angles when the liquid flows through it. So, which now I like to say liquid has to be discharged with some velocity discharged means it has to be discharged with some velocity which corresponds to some kinetic energy which is a loss afterwards that it imparts imparts, and initial and initial angular momentum an initial angular or tangential you can call the same thing tangential momentum of the liquid momentum of the liquid momentum of the liquid. So, therefore, you see that there are three distinct functions o the guide vanes it partly convert the pressured energy to kinetic energy by allowing the liquid to flow through a convergent passages formed by two successive guide vanes this is number one.

Number two it directs the liquid in a proper manner to the runner the entity runner becomes smooth end shock waves; that means, the liquid velocity relative to the runner allowing the liquid to flow through a convergent passages formed by two successive guide vanes this is number one tangential momentum of the liquid this we will come after wards, then moving vanes moving vanes is the vane where the head is extracted that mean the energy of the fluid is extracted in the form of useful work that we already we know there head or head producing valve or net heat across the turbine by attaching a draft tube; that means, a diverging duct to the turbine.

So, therefore, to create a negative pressure at the outlet of the turbine to increase the heat across the or net heat producing work by making it by making the turbine to be set at a height from the tail race. So, this is another very important point. So, you should not you do not have to place your turbine at the outlet increases from that at the inlet this is, because of the convergent duct from which we get a release or a pressure energy is released in the form of the work developed by the turbine try to understand this part that the impulse machine pressure in the turbine rotor remains constant.

That means we can have free jets as the liquid in the rotor of an impulse machine, and the liquid in the form of jet can engage one rotor at a time one rotor blade, sorry one rotor blade at a time, but in case of a reaction machines sine the pressure changes all the fluid flows what happen the pressure changes when the fluid flows through the turbine rotor of the turbines therefore, that fluid should feel the entire passage of the rotor formed by the rotor blades which should not engage any particular blade at a time it should totally expanded the pressure energy is totally exploited in the form of kinetic energy.

So, therefore, the rotor it is only the change in the absolute velocity of the fluid or change in the kinetic energy of the fluid which is responsible for the work done by the rotor, but while in case of a reaction machines the fixed part or the rotor of the machine does not exploit the entire pressured energy in converting it to kinetic energy; that means, a part of the pressured energy is being converted into kinetic energy. So, therefore, fluid approaching the rotor blades or the moving part of the turbine has both the pressured energy, and the kinetic energy. So, therefore, fluid flowing through the rotor blades suffer a change in both its kinetic energy, because of the change in its absolute value. So, that the final discharge from the turbine takes place with a very low velocity of the liquid.

Now, the velocity in corresponding flow is non dimensionalized by three reference velocity now here one very pertinent question comes that this at any section is itself a dimensionless parameter, but this cannot be used as a dimensionless velocity this is, because a change in mach number implies both in change in v.

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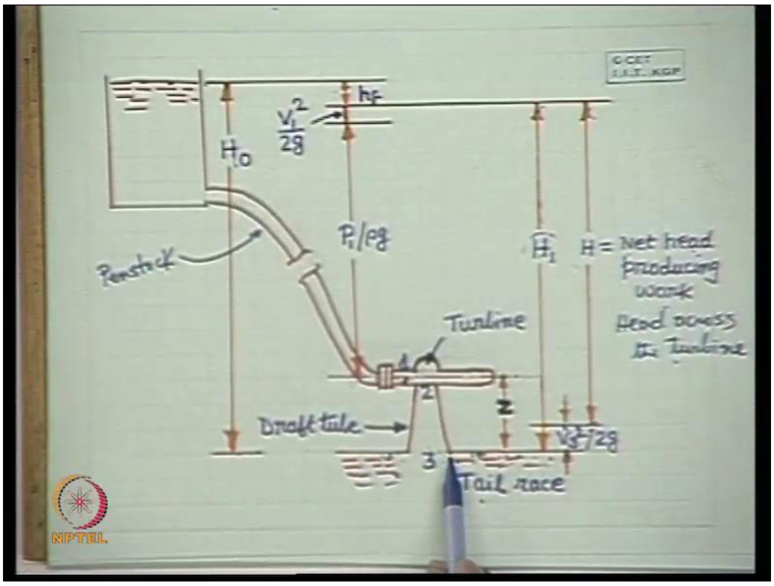

And a this is, because when the flow changes from section to section the flow velocity along with that the velocity of providing a draft tube a clear idea of the working principle of the draft tube. Now let us consider a very simplified diagram which will give you a clear concept of the change of head across the turbine.

Let us consider his is a reservoir at r height; that means, the liquid stored here which is at a great height from the ground level this, it is very simple, we can write from a differential in a differential form as d of we can write h rather we write d h plus d v square by two plus d of g j is equal to zero, because if we integrate it between section one, and two you get h two minus h one plus v two square by two minus v one square by two plus g j minus zero you can write this now if you recollect the thermodynamic property relation which I will discuss again in this class that t d s is equal to d u plus p d v, and we can write h is equal to u plus p v.

So, d h is equal to d u plus p d v plus p d v sorry. So, if you replace the d u in terms of d h we can write d h is t d s minus v d this is the very useful relationship, which we get I will explain this in the next class also d h is t d s plus v d p yes d h is t d s plus v d p all right. So, if you substitute this. So, for an isentropic flow. So, I have told you that in visit irrotational flow is synonymous to isentropic flow without work interaction. So, if I replace it we get v d p plus d v square by two plus d of g z is.

So, I we integrate this equation well if we integrate this equation we get integration of v d p plus integration of t v square by two plus integration of d g z is equal to zero. So, far we have put the constant of isentropicness of the flow isentropic that is the flow is isentropic that is in visit without any work interaction, but incompressibility has not put into consideration if we put the incompressibility into fact that this v comes out from the integration plus sorry it is constant after integration it is constant very good d v square by two plus integration of d d z is equal to constant ok.

So, therefore, we can write after integration p by rho v can be written as one upon rho plus v square by two plus g z is constant, and this is constant throughout the flow field, and this is simple the mechanical energy equation for an in visit for an in visit invisuid steady irrotational irrotational; these are the conditions in compressible flow in gravitational field in gravitation force field; that means, if a in visit steady irrotational in compressible flow in gravitational force field takes place the irrotational flow means there is from the energy point o view no energy interaction neither it nor work total mechanical energy that is the pressure energy kinetic energy, and this thing constant.

But if we we draw this the head developed by the pump this must be equal to this potential head difference between the sump, and the upper reservoir luid has to be put from the point a to the point a along with all the losses that it incurs along its flow; that means, the losses through this system system means the suction pipe, and the delivery pipe.

Not only on the pump also have to be taken account. So, that we can find out the total head developed by the pump; that means, this is the difference between the elevation of these two water surface that is h is known as that head plus the losses if we write the bernoulli's equation at this point between this point, and this point, and between this f, and d, and from these two equations we have shown that the total head developed is equal to this difference elevation hid between these two surfaces that is the static head known as static head plus all forms of hydraulic glosses in the suction, and deliver pipes let us find out the mathematical expression for that.

Now let us write the head loss in the suction pipe as h one suffix one is the head loss in the suction pipe which is the loss in total loss in the energy per unit weight due to flow through the suction pipe this comprises two distinct part one is the loss due to fluid friction that is the friction between the fluid, and the solid valve which can be expressed as a friction coefficient f one, typical fluid friction loss can be expressed in terms of a darcy's friction coefficient f one times the l one by d one that is the length to the diameter ratio, and the velocity; that means, this is the darcy's friction efficient which can be expressed in terms of the friction coefficient l one where l one is the length of the suction d one is the diameter of the suction pipe l one is the length of the suction pipe one is the suffix suffix one used for the suction side v one square by two g where v one is the velocity of flow through the suction pipe.

So, the plus another loss take place due to the veins, and valves see in this pipe when the fluid flows through the error bins, sorry sorry plus z plus z z is this height vertical height zero plus v three square by two g. So, you see that p two well p two by rho g p two by rho g is equal to minus z plus what is there v two square minus v three square by two g now in this situation for a divergent duct as the draft u you know v three is less than v two. So, therefore, this quantity is positive this quantity is definitely the high positive. So, therefore, we see always we have a suction pressure that is pressure is below the atmosphere it is also a common sense the intelligent student can very well grasp it.

But if there is a divergent duct, and the final discharge of the duct is at atmospheric pressure. So, stagnation pressures are not same later. So, this is the measure of the irreversibility measure of irreversibility irreversibility now before going for a routine evaluation of this you must know this thing that in a flow the stagnation temperature remains constant when the flow is adiabatic, because stagnation temperature is the index of this stagnation enthalpy all right, because in a perfect gas when there is no heat transfer in adiabatic flow this stagnation enthalpy remains constant total energy enthalpy plus the kinetic energy, and in case of an idea gas the enthalpy can be expressed as c p into t. So, therefore, c p into t plus v square by two is known as the stagnation enthalpy.

That means create a negative pressure at the outlet of the turbine to increase the heat across the turbine a net heat producing where by making it by making it turbine to be set at a height from the tail ways. So, this is another very important point. So, you should not you do not have to place you turbine at the tail ways. So, that you can place you turbine at a greater height at a height above the tail ways, and at the same time we do not drop you do not have any drop in the available head or head producing valve or net heat across the turbine by attaching a draft tube; that means, a diverging duct to the turbine.

So, therefore, to create a negative pressure at the very important point. So, you should not you do not have to place your turbine at the tail race. So, that you can place your turbine at a greater height at a height above the tail race, and at the same time we do not drop you should not you do not have to place you turbine at the tail race. So, that you can place you turbine at a greater height at a height above the tail ways or in other way it increase the net heat producing work or heat across the turbine.

And at the same time allows the turbine to be say at a greater height at a greater elevation or at an elevation from the tail race bottom. So, I think today that is all about the energy transfer or head transfer across the reaction turbine, and the basic introduction to reaction turbine if you have got any question please ask any question please you can ask the question in this session please.

Sir is that diagram.

Yes this diagram.

Yes good.

T one minus rho g.

Yes.

Do they add to the head across the turbine.

That the inlet to the turbine. So, at the inlet to the turbine the total head comprises both pressure head, and the velocity head. So, v one square by two we have seen shown the relative proportion usually a small kinetic head, but a large pressure head why, because this bane stock this line is of large cross sectional diameter large cross sectional area diameter of the pipe is very high. So, therefore, the velocity head is not very high, but due to the flow of the liquid it has got both velocity head that it has got velocity head, and the pressure head. So, sum of these two is equal to the h one; that means, h one is ok.

So, what is h one h one is from this point to this point oh sorry plus plus zero, because it is the reference data; that means, the energy at any point in a flowing fluid mechanical energy is the sum of kinetic energy plus pressure energy plus the bottom energy; that means, the potential energy; that means, velocity head kinetic heat pressure head, and the potential head. So, we have chosen this line; that means, this tail race label as the data. So, therefore, the total energy comprises a velocity energy which is v one square by two g plus the pressured energy p one by rho g plus this z.

So, therefore, this is the total head at the inlet to the machine why is that the total head at the inlet to the machine, and this is the total head at the out let where pressure is reduced to zero; that means, the atmospheric pressure head a potential head is zero, because we have taken this tail race label as the data, and the velocity is v three square by two this is given by this. So, this much amount is the net head across the turbine which is equal to the work done provided the friction loss is neglected. So, actual work done will be less than that, because of the friction loss it is a very important question.

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So, the work done even for an in visit liquid without friction is equal to one by two g v one square minus v two square; that means, the change in the kinetic energy; that means, initial kinetic energy minus the final kinetic energy. So, final kinetic energy can never become zero you can we have to discharge the with some flow velocity whereas, the unit energy to the fluid turbine is v one square by two g or this more little more than that if you consider at the entrance of the nozzle, because of the friction loss in the nozzle, but if you neglect the friction in the nozzle totally in the fluid. So, v one square by two g is the net heat coming to the turbine in the form of pressure energy which was converted in the velocity energy kinetic energy star the outlet of the nozzle, and that is being converted to work by an amount one by two g v one square minus v two square. So, therefore, even for an in visit fluid there is an hydraulic efficiency, because we have to reject some amount of energy, but this is again reduced, because of the friction between the liquid, and the solid parts of the machines.

And also, because of the friction between the liquid that is the liquid viscosity clear any other question.

Sir, what is it is the height of the draft tube.

Yes the height of the draft tube; that means, at which height runner should be placed what should be the cross sectional a area of the how much divergence you will have to give what should be the cross sectional area we will be discussing afterward these are very interesting problems, and the basic physical phenomena which determines these things are known as cavitation this is limited by or constant by the physical phenomena known as cavitation which we will discuss in the next class which will give the limitations for this height above which a turbine have to be placed or which should be the height of the drat tube, and what should be the cross sectional area of the drat tube.

Why we cannot reduce their discharge velocity from the draft tube to a very low value; that means, how much low pressure we can allow at the inlet to the draft tube it is a very simple that this pressure should not fall below the vapour pressure of the liquid at the working temperature or the liquid will be vaporized liquid will vaporize that is very simple I will discuss it in the next class that phenomena is known as cavitation.

Thank you please, because probably.