**Introduction to Fluid Machines and Compressible Flow**
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**Lecture - 8**
**Specific Speed, Governing and Limitation of a Pelton Turbine**

Good morning, I welcome you to this session, where we will discuss the specific speed and governing and limitations of pelton wheel. First we come to the specific speed of a pelton wheel.

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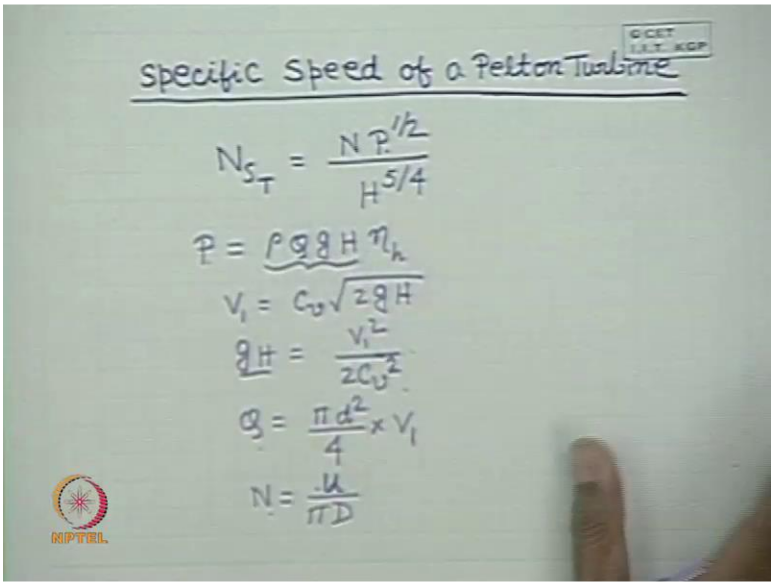


Let us come here the specific speed pelton turbine as you know this specific speed for any turbine in the dimensional form is defined as N s t is equal to the rotational speed N, the power developed P to the power half divided by the available head H to the power five by four. Now, to have an expression for this specific speed, what we do the power developed by a pelton wheel can be expressed in terms of the hydraulic efficiency like this rho Q g H into eta h, where eta h is the hydraulic efficiency, and rho Q g H is the available power. H is the available head, q is the volume flow rate through the pelton turbine. So, rho Q g H represents the total available energy to the turbine times the hydraulic efficiency gives you the power develop.

Now if we substitute the h in terms of the incoming jet velocity then we can write that incoming jet velocity is equal to coefficient of velocity into root over 2 g h. Now, this expression comes from the application of Bernoulli's equation between the inlet and outlet of the fixed nozzle, where C v is known as the velocity coefficient, which takes care of the frictional loss in the nozzle and h is the available head. So, therefore, we see from this equation g h becomes v 1 square by 2 c v.

Student: Sir, c v square.

Professor: C v square correct two c v square, this is the g h. Again Q can be written in terms of the diameter of the jet and the inlet velocity of the water jet as pi d square by four into v one pi d square by four is the cross sectional area of the incoming jet where d is the diameter of the jet. And v is the velocity of jet incoming velocity of jet v one, v one. And this rotational speed n can be written as pi n is equal to u by pi d, where d is the rotor diameter and u is the rotor velocity that is the tangential velocity of the rotor at the mean bucket high as we have explained earlier. So, therefore, the rotational speed satisfies the relationship with n, as n is equal to u by pi D. Now if you express this expression of g h in terms of v one, Q in terms of v one and the diameter of the jet in this expression of power.

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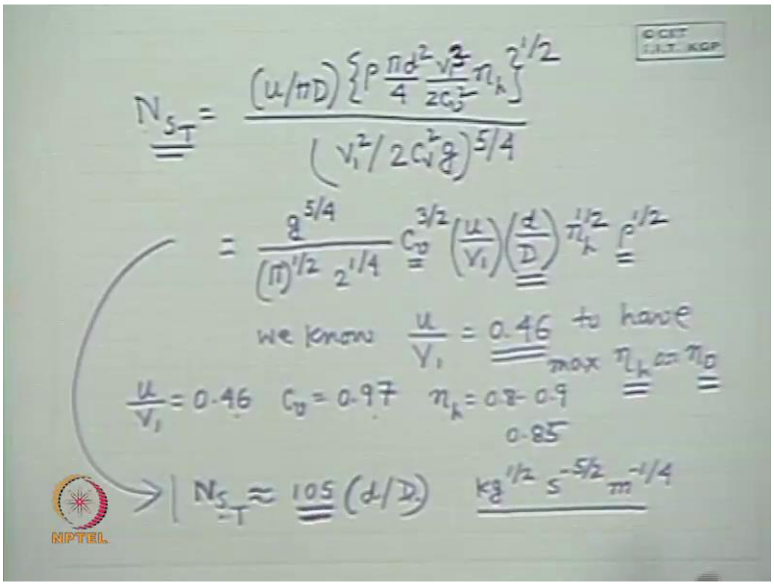


And this you substitute here and the value of n as u by pi D here what we get, let us see that we get N s t is equal to n, n is u by pi d then P to the power half. What is P, P is rho pi d square by four q, and g h is v one square by two c v square, rho q g h into eta h to the power half and h to the power pi by four. Again h can be written from this expression, h is v one square by two c v square g; that means, v 1 square by 2 c v square into g, this comes from again the same expression, h is equal to v 1 square by 2 c v square g whole to the power 5 by 4.

Student: Sir, v 1 q.

Professor: Here it will be v 1 q, because we have this v 1 square into v 1 because q is equal to pi D square by 4 into v 1, so that will be v one q very good. So, if you make a simplification of this, you get N s t is equal to g to the power pi by 4. You do not have to remember this expression, but you should know how it can be derived, what are the substitutions that have you have to make; that means, we have to express everything all the terms in terms of the inlet velocity of the jet and diameter of the jet. So, this becomes two to the power one fourth c v to the power 3 by 2 into u by v one D by d eta h to the power half rho to the power half.

Now, we see that a turbine handling a particular fluid in our case if we consider the water turbine the pelton wheel the working fluid is water, rho is constant coefficient of velocity usually varies within a very small range g is substantially constant. So, therefore, these two operating parameters decides the value of the specific speed of the turbine. We also know that for the maximum efficiency to have the maximum efficiency of the turbine wheel efficiency u by v one is fixed we know that we know u by v one is equal to point four six to have maximum eta h or eta o.

So, therefore, to have you have a maximum hydraulic efficiency or overall efficiency or even the blade efficiency the value of u by v one is fixed it is almost equal to point four six as obtained in practice. So, therefore, we see for the maximum for the optimum operation with a maximum efficiency of a pelton turbine handling water of a fixed liquid the most important parameter which decides the value of specific speed is the ratio d by d. So, the ratio of D by d is very important in designing the turbine usually.

If we consider the value, the typical values like this u by v 1.46, this equation can be reduced to a form, if we take a value of C v 0.97. A typical values of these parameters and hydraulic efficiency which lies between 0.8 to 0.9. For a calculation, if I take a value of zero point eight five then this expression can be written as n s t, the specific speed of turbine. That means, if we substitute those values we get hundred five is approximately hundred five into D by d here hundred five the constant is the dimensionless constant, because D by d is non dimensional n s t is also a dimensionless, the speed a rotational speed sorry it is the rotational speed something D by d the dimensionless value. Cv is the dimensionless value eta is the dimensionless value which are subtitled in this expression along with the value of g we get one zero five d by d. And here the specific speed comes the dimension is k g to the power half s to the power minus this is dimensionless constant because the specific speed is the dimensional term.

So, here D by d is non dimensional. So, hundred five is the dimensional constant because it includes the value of g it includes the value of rho which i have not written the value of g will be usual nine point eight one meter per second square in the value of rho you can take thousands k g per meter cube. So, considering those values for a water turbine and with the typical values of these operating parameters u by v one c v eta h we can express n s t is equal to hundred five which is definitely a dimensional coefficient into D by d where n s t is expressed by usual dimension like this.

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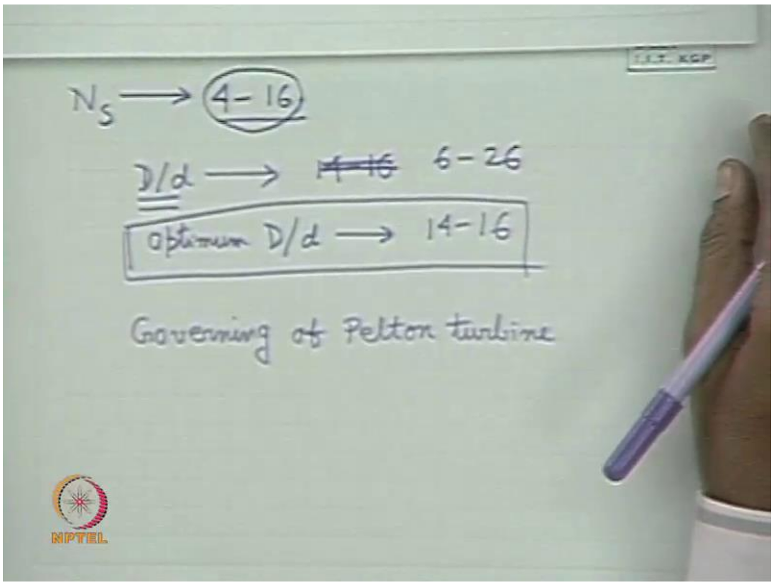


So, this is the values for specific speed and usually the specific speed of a pelton turbine varies from four to sixteen n s t varies from four t sixteen the specific speed of a pelton turbine usually varies from four to sixteen depending upon its operational efficiency. Now if we use this value from this equation, this equation N s t hundred five d y d, we get the value of D by d between fourteen to sixteen. That means, if we use the value of N s t as four to six, we get the value of D by d as fourteen, I am sorry the value of D by d is six to twenty six, the value of D by d lies between six to twenty six.

Now, you'll be fix the value of D by d now friction is like that if you make the D by d very large D by d very large; that means, a very large rotor diameter compare to the jet of the jet diameter of the nozzle. So, a large rotor diameter will make unnecessarily the friction loss of the rotor diameter is large the friction loss will be more, moreover for a given rotor speed, the r p m of the rotor will be low. Similarly, if we make D by d small or D by d low. Then what will happen the for a fix jet diameter the diameter of the rotor will be less which will give a very close spacing of the buckets for a given number of buckets the bucket spacing will be close which will again increase the frictional losses and will reduce the mechanical efficiency.

So, therefore, we see, if we increase the value of D by d, there also the mechanical efficiency will be reduced by increasing the frictional losses, moreover the rotational speed of the turbine will be reduce. And again if we use a lower value of D by d then also the frictional losses will be increased and the mechanical efficiency will increase because of the close spacing of the bucket. So, these two phenomena makes a (( )) for D by d which is optimum optimum D by d varies between fourteen to sixteen this is the optimum D by d this varies between fourteen to sixteen well.

Now, I will come to governing of pelton turbine. Well before coming to the governing of pelton turbine, I like to tell you what is meant by governing of turbines in general what is meant by governing of turbine. Now when a turbine drives an electrical generator or alternator the primary requirement is that the rotational speed of the shaft in which both the turbine rotor and the generator or alternator are coupled should maintain a constant speed the rotational speed of the shaft will be fixed well. So, therefore, the speed of the rotor rotational speed of the rotor will also be fixed why it is.

This is because the frequency of the electrical output has to maintain same to maintain the constancy in the frequency of the electrical output the rotational speed of the shaft coupled with the electric generator or alternator has to fixed. So, what happens, when the electrical load changes according to the demand then the speed of the turbine also changes, why, this is because the shaft in which the turbine and generator or alternator fixed rotates at a constant speed. Because of a balance between the resistance torque giving by the electrical load and the driving torque depending upon the change of the angular momentum of the fluid flowing through the turbine clear.

Now, when the electrical load changes the resistance torque changes while the driving torque remains the same. So, therefore, the balance is distorted and the revolutionaries speed or rotational speed changes for an example if the load load is increase then the resisting torque on the shaft increases while the driving torque remains the same which comes from the change in the angular momentum of the fluid. So, therefore, what happens this speed falls similarly if the reverse happens when the electrical load is reduced then the resisting torque is reduced while the driving torque remains the same to speed is increased.

So, therefore, to maintain a constancy in this speed we have to change the driving torque accordingly with the change in the resisting torque because of a change in load which means that if the load is increased. So, driving torque has to be increased or load is decreased driving torque has to be decreased now driving torque comes from the change in the angular momentum now you see the friction of the fluid velocity is fixed as far as the rotor is fixed because the design of the blades and everything is fixed. So, therefore, the change in angular momentum can be accomplished only by a change in the flow rate of the fluid.

So, therefore, it is the flow of the fluid coming to the turbine is changed to change the driving torque which means if the load is increased the flow of water to the turbine is increased. So, that the driving torque is increased accordingly to maintain the constancy in the speed of the shaft similarly load is decreased. So, the flow rate going to the turbine or flow water to the turbine is decreased. So, this change in the flow to the turbine with the load is done automatically and that is known as the governing of the turbine these response in the flow to the turbine with the change in the load is known in general as governing of turbine.

So, hence therefore, whenever you will refer to governing of turbine, this is not one hydraulic turbine, for any turbine to run at a constant speed rotational speed to maintain the constancy in cycle frequency. If it is coupled in electric generator or alternator the main criteria is that the when the electrical load changes according to the demand, the driving torque has to be change by the change in the flow of the working fluid to the turbine. It may be a liquid, it may be a gas that is known as the governing of turbines in general or governing of any turbo machines in general.

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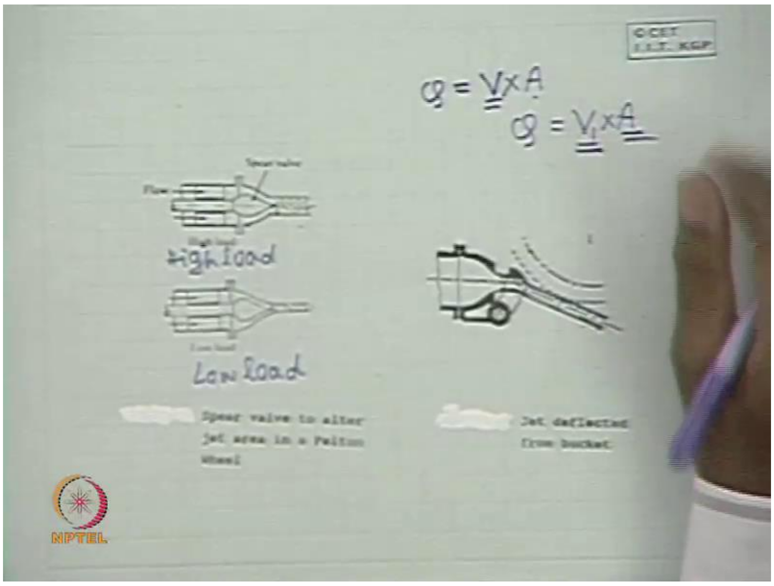


Now, therefore, if we come to the governing of pelton wheel one important requirement now you see that flow rate can be changed in two ways if you write the flow rate in any hydraulic or fluid circuit is the product of the flow velocity times the cross sectional area area normal to the flow velocity. So, therefore, from this simple equation, you see the flow rate can be changed either by a change in the flow velocity or by a change in the flow area now in case a pelton wheel the inlet velocity of flow is fixed for a given rotor speed. Why, because the value of u by v one is fixed because of the requirement of the maximum efficiency of the turbine.

So, therefore, this is fixed; that means, the inlet velocity of the water in jet; that means, in case of pelton wheel if I write that q is the inlet velocity of the water jet times is the cross sectional area of the jet we cannot touch this. So, long the rotor speed is fixed and we want its optimum performances; that means, for maximum efficiency the ration u by v one is fixed. So, therefore, we cannot touch the value of v 1; that means, incoming water velocity has to be fixed for a pelton turbine. Therefore, this change in q is brought by a change in the flow area how it is done this is done by a by the moment of a sphere wall in a nozzle this is the peculiar or the typical diagram this is a sphere wall which is moved axially in a nozzle.

So, that the effect if flow area changes according to the change in the load. So, you see this is a condition at high load where the sphere gives a relatively higher flow area this is the effective area of the nozzle when the sphere moves further to give a less effective flow area when the load load is low; that means, this is for high load condition and this is for low load condition. Now this sphere is designed in such away, this sphere wall, the shape that the flow water after passing through the collies into the form of a jet again. So, therefore, we can say that in the effect of the movement of this sphere wall in this converging nozzle, this to make a change in the diameter of the jet and hence in the cross sectional flow cross sectional area.

Now, sometimes it happens that the change in the load is showed drastic that it may not be possible to change the water flow rate by changing the flow area of only in that those cases a jet deflectors are used some plates that the deflectors. So, this is the reflected from bucket, what happens is that a portion of the jet is deflected from going to the bucket here that portion of the jet is shown. This is a deflector plate which is being defected by the deflector plate; that means, this jet this portion of the jet is not allow to go through the go to the bucket; that means, this a short off by passing then we can change the flow area to control further on the flow rate.

So, these are the arrangements which are made in controlling the flow rate or to govern the pelton turbine accordingly as the load changes well. So, now, we will discuss the certain geometrical constants on the or geometrical specifications of the pelton wheel.

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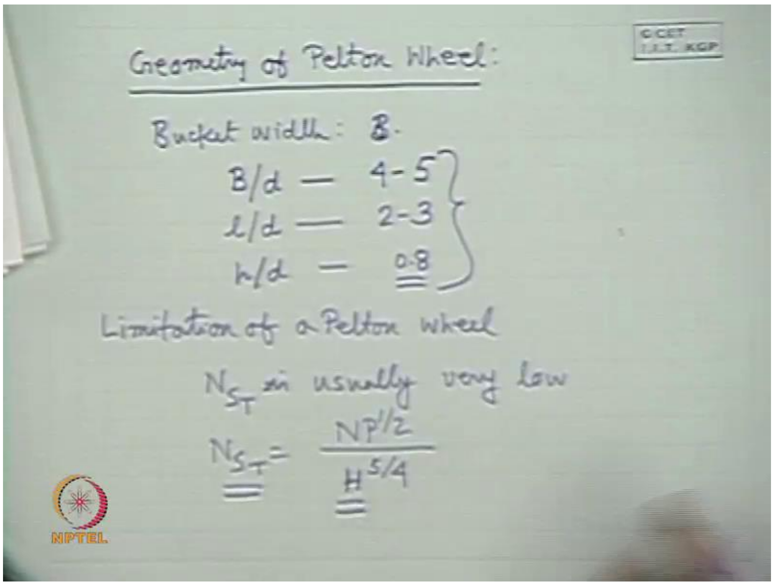


Now, geometry of pelton wheel .Well geometry of pelton wheel, usually the bucket width bucket. These are very simple that is not much physical thing. This depends up on the practical criteria bucket width. If you tell it as b the bucket width is usually optimized in a fashion that is the one bucket width is too small jets are not smoothly deflected if the bucket width what is the bucket width let us have a look this.

Now, let me tell you that this is the width of the bucket this is the bucket width this is the bucket width, I am sorry this is the length of the bucket. This is the bucket width, yes this is the bucket width. This is the length of the bucket, this one bucket width is, this one this is the plane view. And this is the bucket depth and this is the bucket depth let us tell it as h let us call it as b and this is the bucket length. So, with this terminology now we come with the bucket width is very small as compared to the jet diameter then liquid jets are nor deflected properly similarly if the bucket width is unnecessarily large with respect to the jet diameter then the frictional losses are more.

So, therefore, we make a (( )) to make this bucket width let is b b by d ratio of bucket width to jet diameter which is within four to five. Similarly the length of the bucket to jet diameter these are the typical values maintained in practice lies between two to three and the depth to jet diameter is around point eight point eight around point eight these are the typical values maintained in practice. Now we will come to limitations of pelton wheel what is the limitations limitation of a pelton wheel what is the limitation of a pelton wheel you must.

Now, this specific speed of the pelton wheel is determined as a function of the u by v one the ratio of the rotor speed to incoming jet speed and D by d small d by capital d. That means, the ratio of the water jet incoming water jet to the diameter of the rotor. Now specific speed of the pelton wheel is usually very low what does it means. That means, the if we consider the ranges of running of the pelton wheel under efficient conditions under high efficiency. We will see that the specific speed n s t is usually very low is usually very low.

Now you see the expression of n s t is n p to the power half h to the power five by four which means that the pelton wheel is more efficient at high head, because it gives a lower specific speed in the range of high efficiency. So, therefore, the pelton wheel walks at a very low head if i want that a pelton wheel a low on a sorry high head, if by one that pelton speed pelton wheel should operate at a high head. What will be the problem if head is very high then to develop a given power this flow rate through the pelton wheel has to be very high, but the requirement of the flow rate and jet velocity is already fixed by its maximum efficiency condition. So, what will have to make the diameter of the pelton has to be made very high.

So, the diameter of the pelton wheel if you make high it will be unnecessarily bulky and slow running or slow moving machine that is the reason for which it is not used at a lower head. So, pelton wheel is therefore, always referred to the operating conditions with very high head where pelton wheel runs that is maximum efficiency clear. So, this is about the limitation of the pelton wheel. Now next of course, we have finish this pelton wheel about the pelton wheel finish the everything about pelton wheel.

Now this limitation that I have told pelton wheel cannot be operated at a low rate to generate a finite amount of power or high power. And also running at maximum efficiency different types of machines have been taught off or have been developed known as reaction machines which will operate at a lower rate and yielding to a relatively higher specific speed. So, that at a higher rate this turbine develops finite power and runs at higher efficiency these at the reaction turbines, but before coming to the reaction turbines in this class I like to show you certain examples. So, you please see how you can solve certain example.

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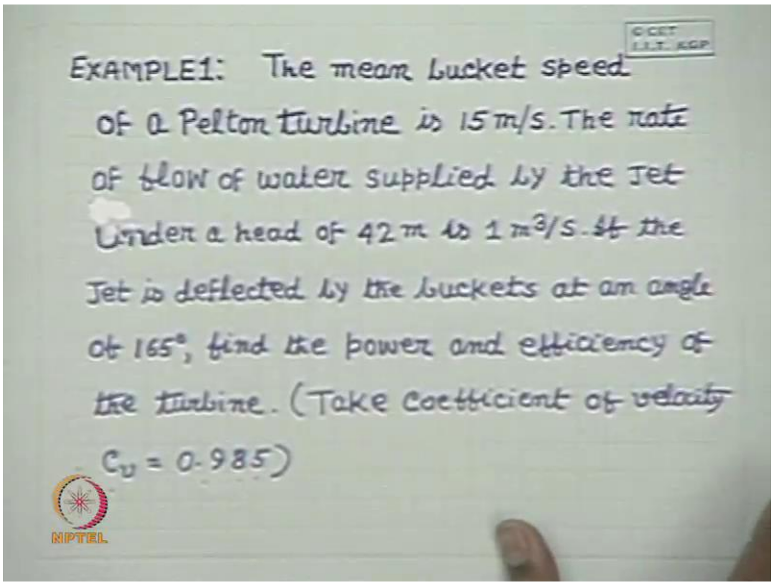


Let us consider the example one. Well, if you consider the example one here the mean bucket speed of a pelton turbine is fifteen meter per second. The rate of flow of water supplied by the jet under a head of forty two meter is one meter cube per second. If the jet is deflected by the buckets at an angle of one sixty five degree, find the power and efficiency of the turbine take coefficient of velocity c v is equal to zero point nine eight five this is a very straightforward application of the theory of pelton turbine. Again you will see that mean bucket speed is given as fifteen meter per second, I tell you the partition data and the flow of water is one meter cube per second and the head available is forty two meter.

And the jet is deflected at an angle of one sixty five that is the angle at the outlet of the bucket and coefficient of velocity in the nozzle is point nine eight five. So, now, if we want to find out the power and efficiency of the turbine the usual way of by taking a problem is that you should write the expression for the output quantities that you will have to find out can you write this thing from there. I can wait well you please write please write please then only, I will start please write please write please write it will fast.

The mean bucket speed is fifteen meter per second the head available is forty two meter the flow rate is one meter cube per second and the deflection of the jet by the bucket is one sixty five degree coefficient of velocity c v is point nine eight five, all of you have taken the data

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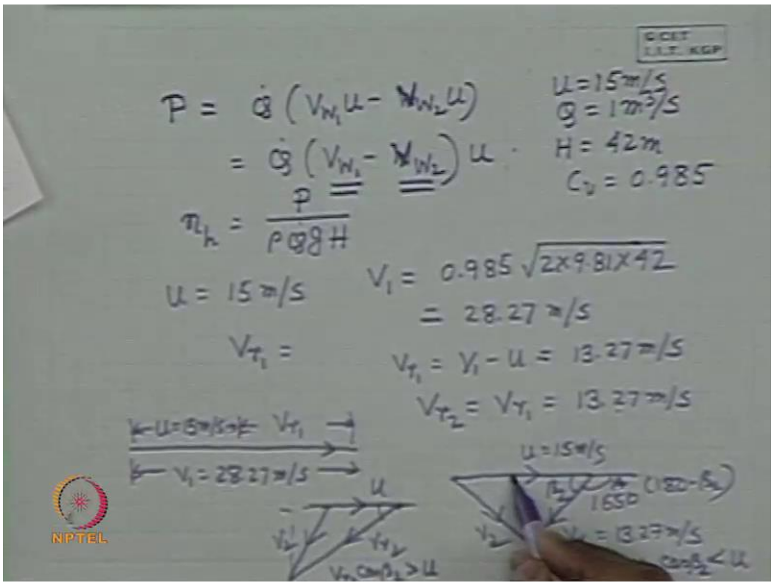


Now, you see the usual low is that if you write the power what is the power expression you know that it is the flow rate q dot into v w one u minus v sorry minus v w two u; that means, q dot into v w two into u. And what is efficiency, hydraulic efficiency is power develop divided by the total energy at the inlet; that means, rho q dot into q into h. Now, our first job will be to find out the value of v w one and v w two. The bucket speed is given u is fifteen meters per second, so how to find out v w one or v w two.

Let us find out what is the value of v one the incoming jets speed, how to know you know that h is equal to forty two meter given let me write what are the given quantities q is one meter cube per second. What are the given quantities u is fifteen meter per second, and c v is zero point. Now you know the formula by the application of Bernoulli’s equation at the inlet and outlet of the nozzle, we can write the v one 0.985 into root over 2 into 9.81 into 42. So, this comes out to be, if you calculate this, I can tell you this, values comes out to be well, what is the value please tell me just a minute will 28.

So, I will check this with my calculations twenty eight point two six very good the value of v one comes out to be i’ve calculated it has twenty eight point two seven. Let us say that meter per second well depends upon the approximation the last third place of decimal now what is v r one now you write the inlet diagram inlet velocity diagram. So, this is v one twenty eight point two seven meter per second what is u one u one is fifteen; that means, this is u or u one they are same fifteen meter per second. So, what is v one v r one v r one which equals to v one minus u and that becomes equal to thirteen point two seven meter per second twenty eight point two seven minus fifteen. Now if nothing is told about the friction loss within the bucket then we will consider; that means, friction in the bucket to be zero and v r two is equal to v r one is thirteen point two seven meter per second all right all right can you see.

Now, if we draw the outlet velocity triangles the outlet velocity triangles will look like this this is one sixty five degree this us u this equal to fifteen meter per second. This is your v r two, which is equal to thirteen point two seven meter per second. And this will be v two now here, I will tell you one eight bit which sometimes comes as a confusion to the students at level, we know that the velocity triangle my may either like this u v r two and v two which type of triangle will be there either like this or like this. That means, the velocity triangle will be an obtuse angle or a acute angle triangle how to judge it here it will not be of this type.

Because what is the difference between these two you see the v r two cos five cos beta rather if you tell this is as this is as beta beta two rather this is one eighty degree minus beta two in this case beta two is fifteen degree. So, v r two if this case is valid when v r two cos beta two is greater than u, and this is valid when v r two cos beta two is less than u. Therefore, you first calculate this thing before drawing the velocity triangle otherwise what will happen you draw velocity triangle and then calculate again you cut it and draw this velocity triangle. So, better to check because v r two is you know cos beta two, so therefore, you decide which you will be your velocity triangle in this case the velocity triangle will be like this. So, this is your v w two.

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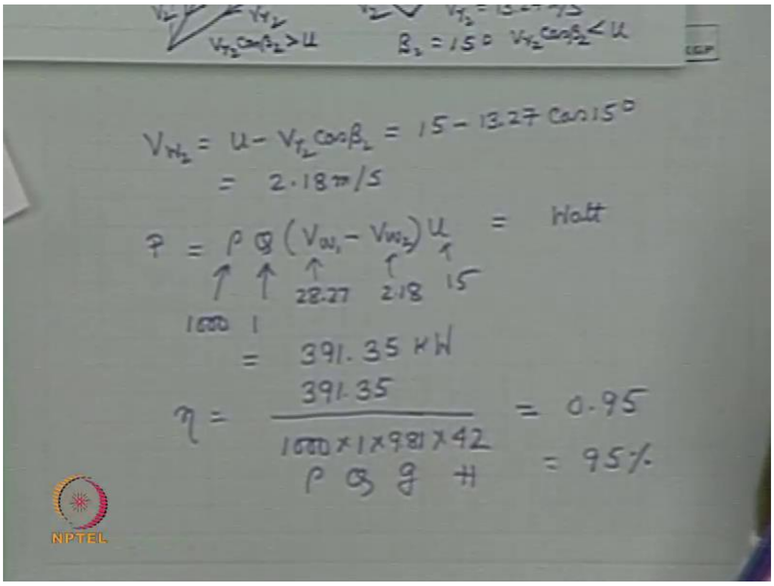


So, what is the value of v w two then v w two is equal to. So, in this case v w two is equal to v r two that is v r two cos u minus v r two cos beta two; that means, is equal to fifteen minus thirteen point two seven into cos of fifteen degree this gives a value of v w two as two point one eight meter per second. Now the problem is solve now, it becomes a simple arithmetic calculations that p is equal to rho into q into v w one minus v w two into u. So, v w one you put what is the value of v w one we got please twenty eight point two seven this is two point one eight this is fifteen q is straightforward given as one meter per cube second all are in consistent unit and rho in k g per meter cube is thousand.

So, that the p comes in terms of what and if you calculate this with these values it will be coming a very huge value three ninety one point three five kilo watt. Calculate it and efficiency eta will be this power develop total power, that means, denominator will be the total energy available; that means, it will be also rho; that means, thousand q; that means, what is the value of q one and nine point eight one into forty two. That means, the total energy rho q g h and if you calculate this value this value will be coming as point nine five; that means, ninety five percent. So, this is a straightforward application of a problem in pelton turbine, I give you another problem you can try to your house that example two that I will not solve.

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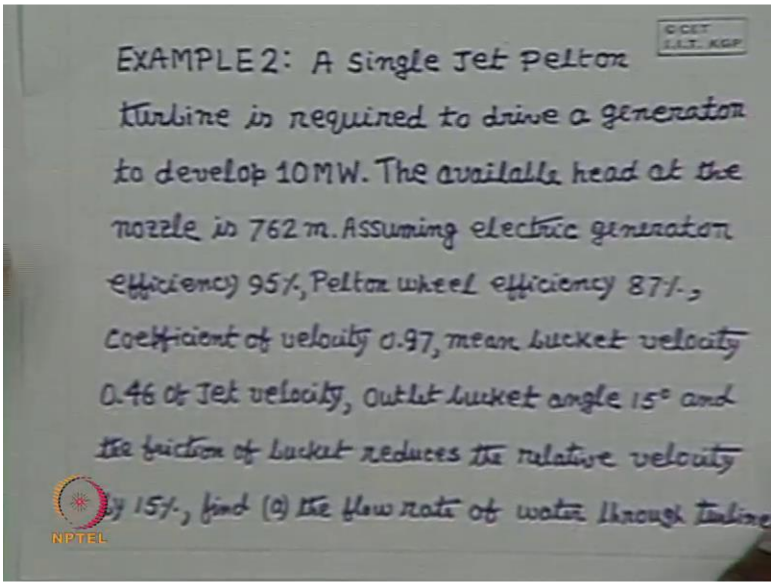


But you see that you write this problem example two a single jet well a single jet pelton turbine this is an example two which you try to solve I hope that you will be able to solve it. Next class, I will ask you a single jet pelton turbine is required to derive a generator to develop tem mega watt; that means, the generator is developing in ten mega watt this is the power at the generator end try to understand is required to drive a generator to develop ten mega watt the available head at the nozzle is seven sixty two meter; that means, this is total energy per unit head at the nozzle; that means, at the enters of the nozzle the available head at the nozzle is seven sixty two meter.

Then assuming electric generator efficiency ninety five percent electric generator efficiency ninety five percent; that means, this is the efficiency by which the mechanical power as the input to the generator is converted into electrical power pelton wheel efficiency eighty seven percent these are the input value coefficient of velocity is zero point nine seven well mean bucket velocity zero point four six of jet velocity usually this value is almost fixed the mean bucket velocity means u the rotor speed at the mean height of the bucket; that means, bucket velocity is point four six of jet velocity.

So, whenever the what jet velocity means it is the inlet velocity of the water because water strikes pelton wheel in the form of jet at least inlet point four six of jet velocity outlet bucket angle fifteen degree now whether is a fifteen or one sixty five you will have to decide from the triangles. So, either it is give in the obtuse angle or the acute angle the obtuse angle may be given or may be the acute angle will be given. So, fifteen degree and depending upon the relative magnitude of the rotor speed of the mean bucket speed, and the triangle component of the relative speed at the outlet. You should draw the velocity triangle these are very important points. These are very important point in solving the problem and drawing the velocity triangle at the outlet and the friction of the bucket reduces the relative velocity by fifteen percent is a very important data of the bucket reduces the relative velocity by fifteen percent; that means, relative velocity at the outlet is point eight five times than that its inlet.

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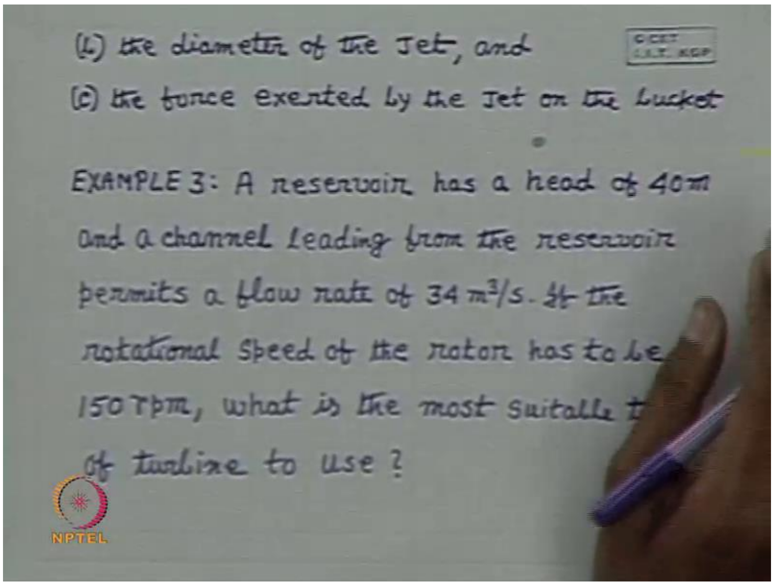


So, this important data. Find the flow rate of water through turbine, flow rate of water through turbine, the diameter of the jet and the force exerted by the jet on the bucket, and the force exerted by the jet on the bucket, and I think today up to this.

Well, thank you all.