Introduction to Fluid Machines and Compressible Flow
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Lecture - 06
Concept of Specific Speed and Introduction to Impulse Hydraulic Turbine

Good morning, I welcome you to the session of fluid machines today we will first discussed the concept of specific speed in a fluid machine. Well in the last class, we have seen that by the application of principle of similarity is derived the different dimensionless terms representing the similarity criteria for a flow in a fluid machine.

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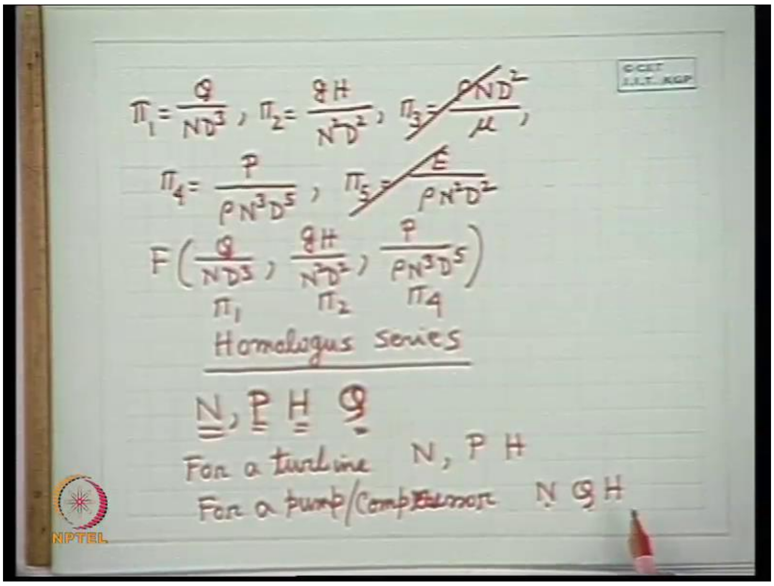

What are those terms, if you recall the terms are like this pi one, the different pi terms was q by n d cube. The second pi term pi two is g h by n square d square, the third pi term was pi three. If you recollect rho n d square by mu fourth pi term let us write here pi four is equal to p by rho n cube d five, and the fifth pi term is e by rho n square d square. Now this pi terms represented the similarity parameters that means, to maintain the similar flow situations in fluid machines will have to make this terms fixed.

Now we have also recognized that in case of fluid machines handling incompressible fluid whether compressibility affect is not important then the pi term does not come into picture. Again we recognized that in most cases the influence of viscosity is very negligible consider to the secondary in respect of flow through fluid machines, so that pi three times terms can also be this regarded. So, therefore, we are left with this three pi terms pi one, pi two, pi four and flow in a fluid machines can be described by this three dimensionless terms that q by in d q g h by n square d square and p by rho n cube d five. These are pi one terms pi two terms and pi four terms. Therefore, we see for a fluid machine handling incompressible fluid that is the liquid these three non-dimensional terms represents the similarity criteria of flow through fluid machines.

Now at this juncture, I like to tell you one very important thing that the similarity sort. All the similar conditions are short in problem of same physics problem describe by the same physics. For an example, similarity cannot be achieved between the problem of a fully developed flow through a pipe and flow through a channel and a flow passes flat surface. Why flow through a pipe fully developed flow through a pipe is govern by the pressure force and viscous forces. While the flow through a channel is dominated by the gravity forces; gravity forces is the dominating force again flow passed a flat surface it is the typical ground level flow where flow is dominated by inertia force and the viscous force. So, therefore, the distinct classes of problems govern by the different physics.

So, therefore, similarities cannot be maintained or similar situations cannot be obtain between these different classes of flow. So, we can have a similarity in a particular class of flow, for example, in the case of flow through a pipes in that case we can consider different situations and different operating conditions. Similarly flow through channels, we can consider the different conditions at different different flow situations, the different operating conditions which are similar in nature. Another important thing in this respect is that if for a particular class of flow, for example, you consider the flow with an open boundary flow passed bodies, again you see that the shape of the bodied or the geometry of the body, these are very important thing. That means, is an important things that means, flow fastest spear or flow fastest cylinder are different; that means, similar conditions cannot be maintain between flow fastest sphere.

And flow fastest cylinder we can maintain the similarity conditions for flows flow fastest spear different situations of flow fastest sphere or a different situations of flow fastest cylinder. So, therefore, it is also very important that the shape or size or the system flow geometry is very important in define a particular category of flow. So, therefore, the similarities are short in same physics of flow in the same category of flow at different situation. Now here also if you see the fluid machines well you see the different fluid machines are of different shape and size. Now we have seen earlier that the geometry similarity or geometrical similarity between different condition, the different conditions or the different system represents the similarity of shape and size.

So, they vary in the geometrical dimensions, a geometrical dimensions are proportion to each other; that means, one system is a enlargement, it is an enlargement or reduction of the other system, but shape is not changed. Now in similar, we can tell that fluid machines may be of different shapes, for example, the impulse machine is a having a different geometrical shape shape means shape of the a rotor and stator. Similarly reaction machines are also having different shapes even for a reaction machines the redial flow machines.

And axial flow machines vary in the different vary in the geometrical shapes. So, therefore, the similarity conditions between the impulse machine and reaction machine and different types of reaction machines having different geometrical shapes cannot be maintain. So, what we can do that similar conditions can be maintained of a particular kind of fluid machines for example, impulse machine of a particular type radial machine a sorry reactions machines of a particular type radial flow reaction machines.

So, in that case we can tell the different situations may be they are referring to a particular kind of a machines of a particular geometric shape which operate under different operating conditions and also the geometrical size or dimensions of the system may be vary one will be an enlargement or a reduction of the other. So, therefore, the machines in which the the physical similarities are shown belong to a particular category of the machine. And all such machines of a particular category form a series known as homologous series, these very important a terminology homologous series; that means, homologous series refers to a particular category of machine or a particular type or shape of machines where there may be different machines which are only varying in their geometrical dimensions working under different operating conditions.

And they form a particular series known as homologous series, now you come to another situation usually the performance of a fluid machine is expressed as or expressed by the rotational speed power head developed. And the flow rate, these are the three four quantities that rotational speed power transfer between the fluid and the rotator head across the machine and the flow rate through the machines this four quantities at the performance parameters of a machine that machines are usually specified by this four performance parameter. For a turbine usually a turbine, for a turbine usually which develops power n p and h is the three quantities are refer to as the performance parameters that means performance of a turbine is expressed by this three parameter rotational speed the power which is delivered by the turbine and head which is given away by the fluid.

Similarly for a compressor or a for a pump; that means, for a pump or for a compressor the performance parameters are the parameters by which the performance of as pump or compressor is expressed are rotational speed. The flow rate that is the capacity of the compressor or pump, and the head developed by the pump. So, therefore, we try to find out a parameter preferably a dimensionless parameter combining this performance parameters n p h and q depending upon whether the turbine or compressor and this parameter will be independent of the size of the machine rotator d. So, therefore, we search for such parameter how we can get a combination of n p h or n q h as a dimensionless parameters from the existing pi terms we see.

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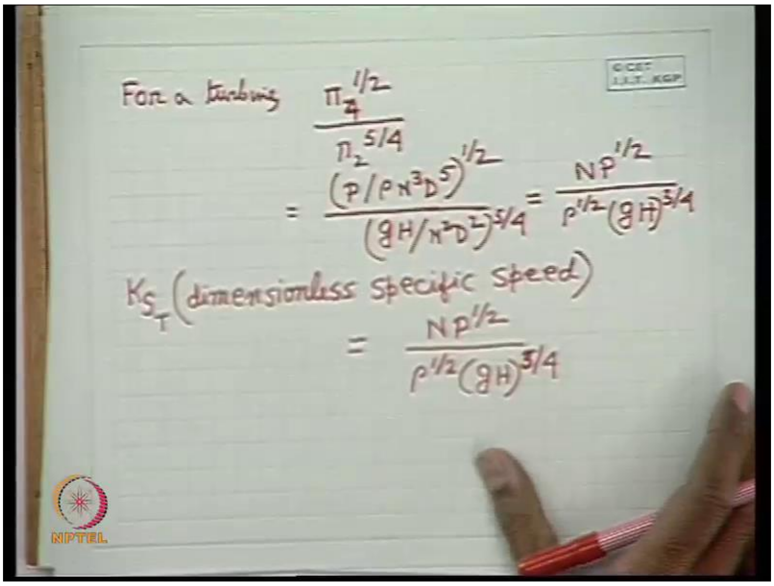

Now, here for a turbine you see for a turbine what we can make for a turbine. If we find out a term which is equal to pi two to the power pi four rather pi four to the power half divided by pi two to the power five by four. This can be done by this manipulation, in case of turbine then what becomes it becomes what is pi four pi four is p by rho n q cube d to the power five to the power half divided by pi two that is g h by n square d square to the power five by four. Then you get a term where d will be eliminated d to the power five by two will be cancelled we get a term like that n p to the power half by rho to the power half and g h to the power five by four.

If you calculate this, if I make pi four to the power half divided by pi to the power five by four we get a term like that. So, pi four and pi two are dimensionless. So, therefore, there combination in this fashion also a dimensionless parameters. So, therefore, we see that for a turbine we get a dimensionless parameter containing n p and h of course, rho and g are there and this dimensionless parameter we defined as k s this is the usual nomenclature t t suffix for a turbine which is known as dimensionless dimensionless dimensionless specific speed for turbine dimensionless specific speed.

So, name is given to this dimensionless term obtain from some typical combinations of the pi terms namely the pi four and pi two terms in this fashion. And we get a combination of the performance parameters that is n p and h in this fashion, n p to the power half rho to the power half and g h to the power three by four let us also obtain a similar dimensionless parameters for a pump.

Students: Five by four

Professor: Five by four sorry, good five by four.

Student: Sir

Professor: Yes please

Student: Why we are taking this combination.

Professor: Why we are taking this combination, because this combinations will give a parameter which is free from diameter. You can see a straightforward combination, you have to make which you will be a parameter independent of the diameter. I have just explain that we search for a dimensionless terms which will be free from the rotor size this is because the performance of a machine is expressed by rotational speed for example, turbine power developed and head where the size of the machine does not come into the picture. So, therefore, we see for a dimensionless parameter which include only the performance parameters n p and h. So, we take this typical combination to get the n p h in the similar fashion if we follow for a pump. And compressor with the with the idea that in or with the idea.

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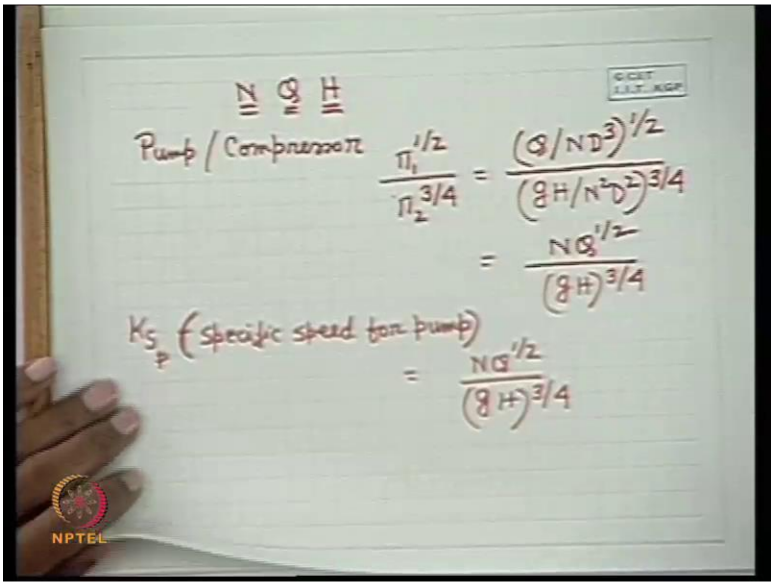

That in case of a pump or a compressor N, Q, H at the three parameters of three quantities which are usually refer to as the performance parameters of the compressors. Then we can do that in case of a pump or a compressor how we can make a combination of the pi terms to a eliminate the d and to get the term which combine only N Q and H. This is done in this way pi one to the power half by pi two to the power three by four and it gives you see that pi one is q by n d cube and make it half. That means, d to the power three by two and pi two to the power three by four; that means, g h by n square d square and make it three by four d to the power three by four which will be canceling.

So, therefore, we obtain a term like this n q to the power half divided by g h to the power three by four in the similar fashion we define this term is a dimensionless term because pi one and pi two are dimensionless which combine n q and h along with g. Of course, the name is the k s is the dimensionless specific speed for pump or compressor we give a nomenclature p for pump. So, we write the same thing specific speed specific speed for pump or compressor also is equal to n q to the power half g h to the power three by four.

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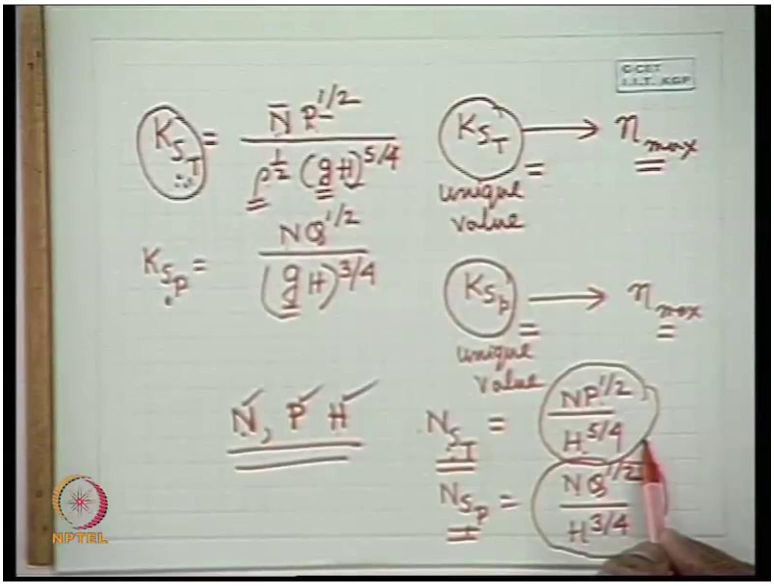

Now, therefore, we see that will have come or we are arrived at to dimensionless terms which are known as specific speed of turbine that is n p to the power half, I am writing it again rho two to the power half g h to the power five by four. And specific speed for pump k s p n q to the power half g h to the power three by four. Now this two terms are the dimensionless terms this is because they have been derived from the dimensionless pi terms. So, therefore, this two terms also represents the similarity conditions in fluid machine. That means, for example, in turbine, this term represents the similarity conditions in the flow to the fluid machines under altered conditions are n p and h which means the unique value of a k s t represents a similar conditions of flow through the fluid machines under altered values of n p and h. That means, this can give a number of combinations of n p and h to yield a unique value of k s t under which the flows are similar in turbines.

And same is the case for pump or compressor that this quantity represents a typical combination of n q and h. So, a fix value of k s p which refers to a similar conditions to the flow in pumps; that means, which can give a number of combinations of n q and h. So, that the conditions of flow become similar in the pumps now we see that usually we are interested to know that when we develop a machines what are the ranges of this performance parameters n p h in case of turbine or n q h are in case of a compressor a machine can cover. So, this is very interesting to know for which from which we can find out the particular machine a particular shape of the machine or a particular type the machine which is best fit for a particular operating conditions.

So, now when the machine is design, it is always specified by its operating parameters in a way that at this operating condition it run at the maximum efficiency; that means, I develop a turbine, and I tell, if this be is revolutionary speed or a rotational speed n. It develops this power p under a head of h this much it will be running at the maximum efficiency. So, which some tolerance limit from that rated conditions both the sides almost it will run at very high efficiency or if you run this machine at a condition much altered from this specified conditions. The machine will not be running at a higher efficiency or at maximum of a efficiency. So, it will be running at a very low efficiency that is not desirable to run the machine at those operating condition.

So, therefore, you see here again that which means that for a particular machine of a particular design, there is a unique set of values of n p and h which give a unique value of k s t for its running at a maximum efficiency and this and since this is a dimensionless parameter and criterion of similarity. We can till that for a same homologous series or a same shape or same size or same type of machines we can consider a different machines of different sizes of the same series; that means, of same shape working under altered conditions; that means, alter conditions of operating parameters, which means the rotational speed power developed n h.

But if you have to run the machine at the maximum efficiency you will left to make the operating conditions such that the same value of this dimensionless parameter k s t has to be obtain. So, therefore, these value of k s t we get an unique value of k s t a unique value of k s t which refers to maximum efficiency.

So, we get therefore, the conclusion is that we get an unique value of k s t for a particular shape and particular category of fluid machines which gives which unique value of that at the where the efficiency is maximum similarly for a particular category of pump; that means, for pumps of a particular or of a homologous series. We get a unique value of this k s p corresponding to the maximum efficiency eta max of the pump for a particular machine the set n p h or n q h either there is turbine or compressor fix, but it can vary. But the combination should yield to a fix value of k s t or k s p for all machines of a particular homologous series. So, that if we operate at those of the parameter operating parameters the machines of a that homologous series will be running at maximum efficiency now i give you the actual conceptual design now for an example just practical concept we know that n p and h now how the type of the turbine is first fix.

Let us consider, we know some operating conditions are that we have a limitations on the rotational speed. We know the this much power has to be developed by a turbine and the turbine will operating under this head; that means, we have got some available head h and we know the this much power will have to develop. And we know the rotational speed of the turbine will be like that then we find out this k s t. Now we see that this value of k s t as obtain from this n p and h which are specified as the performance parameters as the output parameters that I have to be made we will see that which class of turbines gives the maximum efficiency at that value of k s t.

Then we will see like that class of turbine, because that class of turbine will give the maximum efficiency for these operations; that means, from practical operating data; that means, we if we are told by our customer that we want this much power to be delivered. We have this much amount of head available with us and rotational speed is restricted for these r p m, what first of all will have to think that what kind of turbine will be suitable for this purpose. Then we find out the dimensionless parameters the specific speed then we see from a list from a figure that which type of turbine that which homologous series corresponds to the maximum efficiency for this specific speed. Usually the specific speed for different shapes of fluid machines for different turbines different category of compressors or pumps; that means, for a different homologous series are coated for maximum efficiency.

Tell me specific for axial flow turbine this much specific speed or radial flow turbine this much specific speed for an impulse tangential flow turbine this much; that means, that when the specific speed value are coated for a particular homologous series refers to a particular kind the category of machine means that it refers to is maximum efficiency. So, will match the specific speed calculated from the operating parameters giving to us for its design to this specific speed coated for a particular class; that means, which refers to this particular specific speed of a class when it runs that is maximum efficiency will chose that particular class.

And we will tell that this class of machines will be the best fit for these operations then we will go for is geometrical dimensions for it design to find out the geometrical dimensions. So, this is the a well the precise concept of this specific speed. Now one thing we can derive also from here that since the acceleration due to gravity does not vary in our practical operations. And if we consider the fluid handling an incompressible fluid for whose densities not varying much, for example, if we consider only the hydraulic turbines handling water then we can get rid of this rho and g terms. And we can define the specific speed for turbine n s t this is the dimensional specific speed which is the combination of only n p and h so.

So, what we do similarly for the pump this is n q to the power half and h to the power three by four. So, what we do we eliminate the unnecessary terms g n rho when we see the acceleration due to gravity does not vary from pump to pump, or turbines to turbines and also the turbines or pumps handling water, where the rho remains virtually constant then we can get rid of this g and rho. Because equality of k s t means the equality of n s t similarly equality k s p means the equality of n s p; that means, we come across through only the combination of n p h and n q h.

But the only difference is that this terms are not dimensionless these are dimensional terms because it is dimensionless when rho and g h where there in this fashion similarly here g was there. So, these are known as dimensional specific speed of turbine or dimensional specific speed or pump nevertheless they refer to similarity condition because the constancy of k s t, which refers to similarity condition or constancy in case which refers to similarity condition is not violated since rho and g are constant; that means, constancy in k s t.

And constancy in n s t constancy in k s p means the constancy in n s p, but they are the dimensional specific speed; that means, they have they are dimension depending upon the dimensions of n dimensions of p and dimensions of h and dimensions of n dimension of q and dimension of h. So, therefore, whenever this specific speed are referred in usual practice or in usual problems when it is told the specific speed then it is the dimensional specific speed for our practicaluse when the specific speeds are coated as dimensional specific speed then we will refer to these expressions ok.

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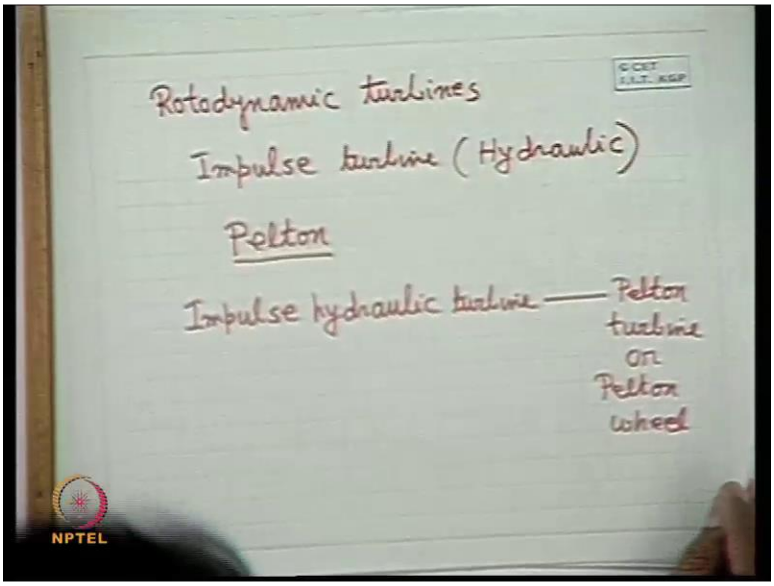

Now, we will come after this to the a typical or hydraulic turbines. Now we will start our discussion on rotodynamic machines rotodynamic turbines first rotodynamic turbines. Now we will start that discussions on rotodynamic after this general discussions after this general discussions on principle of similarity applied to fluid machines the efficiency of fluid machines what we have done so far. The basic principles of operation of a fluid machines how the force exerted by fluid to the rotor and rotor to the fluid while the fluid force to rotor vane, and then how the energies transfer what is the basic equation of energy transfer then the definitions of efficiencies in general for turbines and pumps.

And then the principle of similarity applied in general to fluid machines we will come to the description of different fluid machines separately. So, first we come to rotodynamic turbines impulse turbines impulse turbine hydraulic impulse hydraulic turbine rather hydraulic. So, the impulse hydraulic turbine that uses water was first develop by the person is an american engineer known as pelton. So, therefore, an impulse hydraulic turbine is referred as an impulse and impulse hydraulic turbine and impulse hydraulic turbine is refer to as pelton turbine pelton by the name of the scientist or engineer american engineer pelton turbine or pelton wheel turbine rotor is a typical wheel pelton wheel.

So, we will come to the description of an impulse hydraulic turbine you know that a definition of any impulse turbine. So, it is an impulse hydraulic turbine that uses water and it was named after the name of the inventor who was an American engineer as pelton turbine or pelton wheel.

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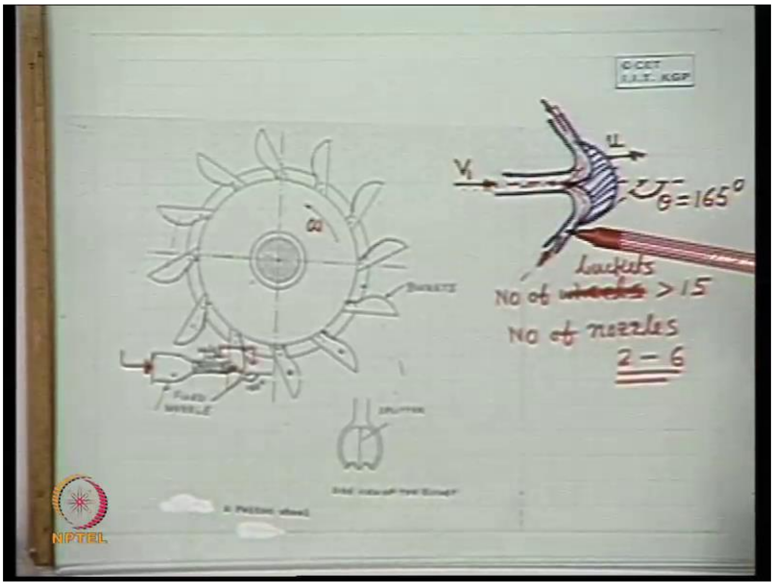

Now let us come to this, what is a pelton turbine. So, this is a typical pelton wheel. Here you see a pelton turbine, which consists of a rotor, which is a wheel or a disk on the periphery of which a number of spoon shaped buckets are attached. These are all spoon shape buckets, which are attach to the periphery of a disk or wheel which rotates let this is the angular speed omega rotate now there are number of nozzles. One such nozzles is shown which directs water at high velocity. So, what happens is that the water enters to the nozzles, the nozzles are fixed nozzles, water at high pressure enters to the nozzle and nozzle convert the pressure of the water into a high velocity water jet. And the water jet is directed by the fixed nozzle to the spoon shaped buckets, these are known as spoon shape buckets or you can consider this the vanes usually the terminology buckets are used.

So that the jet strikes the bucket at the centre tangentially, which means the water jet strikes in such a direction which becomes the tangent to a circle drawn at the through the centre of the bucket. That means, if you see a plane view of the bucket here that means, this cross section, if you see this cross sectional view here, come this bucket is a spoon shaped bucket, which is just section sectional view sectional plan looks like this which has got two symmetric equal parts like this the jet comes and strikes the bucket and it smoothly glides along the two parts of the bucket these are this this is the spoon shaped bucket now you see here therefore, the jets strikes yet at tangent to this bucket; that means, the direction of the jet velocity incoming jet velocity is in the direction of the tangent to the circle through the center of buckets the tangential direction.

Now, if we look a side view of the bucket you see this is the bucket. So, at the middle here this one this splitter reach there is a splitter reach which divides the flow equally into two half. Now you see if we consider the bucket a wheel and the buckets in a vertical plane the jets strikes bucket at each and every bucket tangentially; that means, this flow is in a horizontal plane which is in a tangential direction to this bucket. So, there for we see the inlet of the jet or inlet section of the jet and the outlet section of the jet is at the same radial location from the access of rotation they do not vary in the radial location.

So, they strikes the plane tangentially and comes out tangentially that mean this is the plan view, where your concept will more clear the strikes here and goes out like this. Now you see here the inlet velocity v one and the buckets speed u, which is the tangential velocity at the center of the bucket; that means, that depends upon the rotational speed and the radius from the access of rotation to the center of the buckets. So, this is the tangential velocity you shown for a typical bucket section the plan of a single bucket where this z velocity is v one.

And they are in line. So, the jet is being deflected by the bucket. Now you see for a maximum change in the momentum of the liquid and hence accordingly the maximum force to be exerted on the bucket, this change should be exactly one eighty degree; that means, this relative velocity or the jet velocity with relative to vane should come exactly opposite to the v one. That means, the jet should be deflected one eighty degree by the bucket, but usually this deflection theta in practice is made at 165 degree not exactly opposite to v one.

This is because that the jet coming from one vane or one bucket should not heat the back of the following bucket. So, that this can be made one sixty five is the optimization, so that we can get maximum change in the momentum. So, that maximum force can be exerted by the fluid while flowing through the bucket at the same time the fluid jet should not strikes the back of the buckets following in. So, this is the arrangement of a pelton wheel. Now the number of wheels depends upon the different designs the type of operations its start from number of wheels. You write number of wheels usually greater than fifteen number of buckets I am sorry number of buckets and number of nozzles which is fix number of nozzles this varies from two to six depending upon the design.

So, I will come again about this numbers and the diameter when the design aspects i will discuss, but usually the number of nozzles vary from two six. So, therefore, the fix nozzles are this stator of the machine they the fix where the pressure of the fluid is converted to velocity here. So, when the fluids comes and strikes the bucket it partly fills the bucket spoon shaped bucket. So, bucket is the rotor which is moving part and fluid vane comes in contact with the bucket this is a free jet and this is open to atmosphere. So, therefore, the pressure of the fluid all along through the rotor; that means, to the bucket is atmospheric pressure.

And is constant therefore, this is an impulse machine; that means, while the fluid flows through the machine the relative velocity at inlet and outlet remains virtually same there is a little reduction because of the friction through the bucket, but there is no change in pressure. So, conversion from pressure to velocity does not take place where as the entire pressure energy at inlet to the machine; that means, at the inlet to the stator of the machine that fix part nozzle is totally converted into kinetic energy. That means, total expansion from a higher pressure liquid at its inlet is made in the nozzle to a exploit the maximum velocity available in the form of the water jet. So, thank you, this is the basic introduction that means, type of the pelton wheel. Next class, I will discuss the force analysis then the power generation by a pelton wheel.

Thank you.