Principle of Hydraulic Machines and System Design
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Lecture – 25
Impulse Turbine: Pelton wheel – I

We will continue our discussion on Principle of Hydraulic Machines and System Design. So, today we will discuss about Impulse Turbine; Pelton wheel is an example of an impulse turbine and we have discussed about the classification of hydraulic turbine. If you can recall that the turbine and pumps all are turbine machines, but based on the direction of energy conversion; we call it pumps, when it absorb energy mechanical energy and the mechanical energy is stored is converted to the you know to increase the stored energy of the fluid in terms of either in terms of velocity or pressure. Or whenever we are utilising the potential energy of the fluid to the kinetic energy there by rotating, by moving a by rotating a rotor of a turbine machines then it is turbine. That is prime mover it is absorb energy.

So, whenever we are utilizing the potential energy of the fluid and we are converting the potential energy to the rotational; I mean rotational energy that are to be precise kinetic energy of the rotation. And then we can rotate a rotor of a turbine, and we get power because as I discussed that the rotor and the alternator both are mounted on a common shaft. So, when rotor is rotating at the turbine and then alternator also generated also rotating and we are getting electricity.

Now question is: that is very important that based on the direction of energy conversion, we call it pump where it absorb when it when mechanical energy is converted to increase the stored energy of the fluid either in terms of pressure and velocity. While, when we are utilizing the potential energy of the fluid which is remained which is stored in the reservoir to increase the kinetic energy of rotation then probably you can rotate the rotor of a turbine and we get electricity.

And we have defined based on the you know that that is very important that we have discussed that whenever you know we are utilising the potential energy stored energy in the reservoir. That means head I mean which is available. So, depending upon the head available which varies from 5 you know 500 metres to you know 1000 metres or even sometime 200, 2000 meter to handle such a wide range of the head class hydraulic turbines are classified into two broad categories. One is impulse turbine and another one is reaction turbine. That is what we have discussed in the last class; that impulse turbine example is a Pelton wheel. It was you know you know to one of the name of American engineer you know Lester Allen Pelton the name is Pelton wheel.

Basically it is kind of impulse turbine and which utilizes a higher head, because to get say if you would like to get some particular amount of electricity a particular amount of power from a hydraulic hydro turbine power plant then we need to have higher head for a Pelton or impulse turbine. But we can have the same amount of energy if we install a reaction turbine, but for a minimum amount of head. So, that is what is important so, as I said that depending upon based on rather to handle such a wide range of head which varies from 500 metre to 2000 metres turbines are classified into two broad categories impulse turbine and reaction turbine.

Then reaction turbine is further classified into two subcategories that is axial flow and radial flow. And that is what we have discussed that axial flow is sometimes again classified into two categories adjustable blade and fixed blade. Adjustable blade is essentially you know Kaplan turbine and fixed blade are propeller turbine. And also we can have radial flow that is that is Francis turbine. So, today we will discuss about impulse turbine and a common example is Pelton wheel, and what are the components of the Pelton wheel and how we are utilising the head and how we are getting energy.

Rather maybe we are supplying energy we are giving energy input to the rotor and from there we are getting some energy output. So, that is why we can define on efficiency and how the Pelton wheel works and we have probably discussed that in a impulse turbine there is you know no change in pressure. You know that is I mean I can tell that you know in a impulse turbine I mean in a reaction turbine pressure gradually changes as it as the fluid you know flows through a runner of it the turbine. But there is virtually no change in pressure I mean whenever fluid is flowing through the rotor I mean of a impulse turbine.

So, that is what we have discussed in the last class. So, today we will take an example of Pelton wheel and we will try to figure out the how it works and then we try to figure out the mathematical expression. So, first let us draw the schematic of a Pelton wheel which is very important and that is what I will discuss that how total energy stored energy of the fluid that which is stored in the reservoir is getting converted into the kinetic energy of rotation? And as I said that you know practically no change in pressure as fluid flows through the runner of the turbine. But in reaction turbine completely different because pressure what gradually changes as it as the fluid flows though the runner of the turbine.

So, if we now draw the schematic of a Pelton wheel and what are the component that is what we will discuss today. So, sometimes it is known as hydro turbine. So, in a hydral power plant or hydraulic power plant hydro turbines is very important component. So, if I try to draw the schematic and the main components of hydraulic power plant are normally what are those. So, before I go to discuss about Pelton wheel let us first revisit I mean what are though rather let us first you know discuss about the main components of a hydraulic power plant which are important to operate the inter system.

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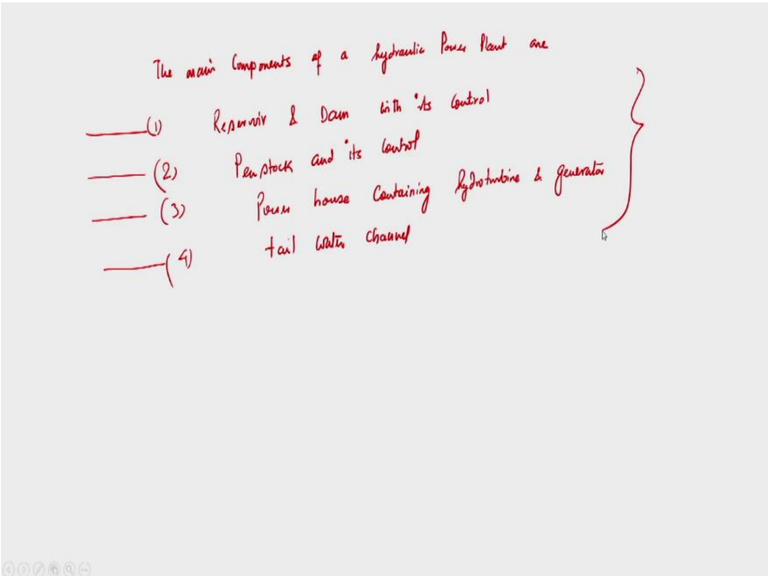

So, I am writing the main component, the main component of a hydraulic power plants are, what are those? Number one, we need to have a reservoir and dam with it is control because without reservoir we need to store energy in a reservoir. And then we are allowing the fluid to fall from the reservoir through certain arrangement and then it will strike the runner; by how it will strike and the strike striking arrangement differ from one turbine to other turbine. In one case we have nozzle other case we do not have nozzle. So, we will discuss that how it is you know the fluid energy stored energy getting converted to the kinetic energy of rotation. So now, one will have reservoir that is very important and dam with it is control, because we should have controls; with it is control.

Number two, is very important: as I said you that we are having stored fluid in the reservoir, then water is allowed to fall from the reservoir to the hydraulic at that is at the inlet of the turbine. And that is the water is conveyed through certain arrangement and one special arrangement is known as penstock. So, we should have penstock essentially a penstock and its control; very important we should have control. So, penstock is a basically arrangement through which we can conveyed water from reservoir to the inlet of the turbine. So, this penstock and it is control.

Then, three is powerhouse: powerhouse containing hydro turbine and generator. Number four: so this is the main component of course, we are allowing water to fall from reservoir through penstock and it will then go to that inlet of the runner through some arrangement again it should have nozzle to increase to convert the pressure head to the velocity head or that to convert the kinetic energy of rotation. So, there you and then we have powerhouse containing hydro turbine and generator, because generator and hydro turbines are connected in a common shaft and this is the powerhouse mainly.

Number four is tail water channel tail water channel or tail rest level tail water channel is very important. Because, when water is allowed to move through the passage of a rotor then of course we need to collect the water and we can recycle it, because it is not always possible that we should have sufficient amount or the abundant amount of water. So, we can recycle it and we are collecting water in a special arrangement which is known as tail water channel. So, these four are you know main components of a hydraulic power plant.

All of these, I mean all of these you know components may be reservoir dam it is having one function, penstock also for you know is having a special function, powerhouse is very essential. Because, we should have hydro turbine and generator so for that we are keeping hydro turbine and generator in a house which is known as powerhouse. And then, we will have a tail water channel because we need to collect the water or the fluid which is being utilised rather which is being used to rotate the rotor of a turbine. And after it flows through the runner of the turbine then it is collected in a tail water channel. And then either we can recycle back to the reservoir or sometimes we may need to not only that because, some powerhouse to the tail water level again we should have another sign special arrangement.

That is not that may not be there in the case of impulse turbine, but that is there in reaction turbine that we should have a draft tube. I will discuss what is draft tube; because all the you know whenever pressure head is converted to the velocity head through nozzle maybe all the velocity heads is not utilised to; while rotating the runner. So, we may have certain amount of kinetic energy when it is coming out from the turbine that the turbine outlet.

So, to recover that you know kinetic energy in terms of pressure head again we should have a divergent part which is known as draft tube that is again an essential component for the reaction turbine. We will discuss this issue while we will be discussing about the reaction turbine ok. So, this we next move to discuss about the impulse turbine. So, as I said you that impulse turbine example is a Pelton wheel.

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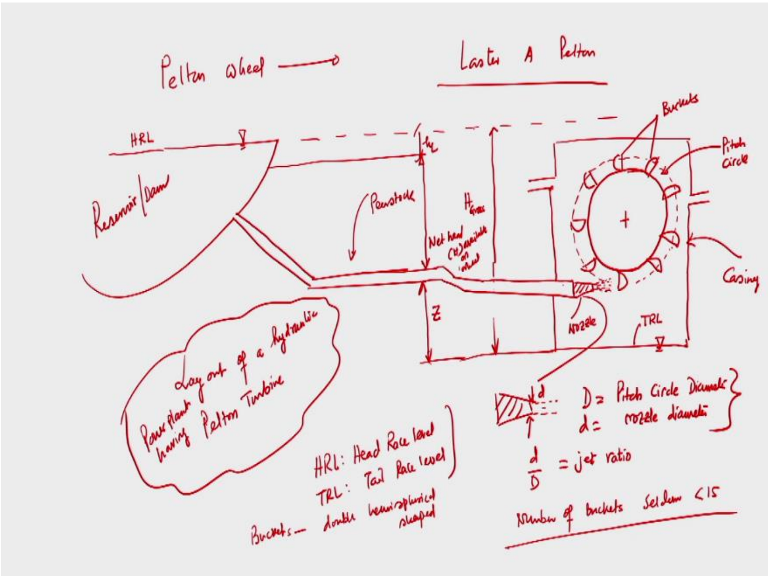

So, example is Pelton wheel which was you know first the name is given to one of the name of American engineer that is Lester Allen Pelton. So, Pelton wheel is an example of impulse turbine. So, if I draw the schematic rather it is very important to draw the schematic how it works. So, I will now draw the schematic. Suppose this is so this is known as head race level hl, hrl then we are having. So, then this is penstock and then this is allowed to take. So, if I now draw is again a schematic.

So, we should have; so, this is the wheel I mean we will discuss in details. And then we have a casing so, this is normally open to atmosphere. Then so, this is nozzle this is known as nozzle this is tail race level that is what we are talking about we are talking about. You know this is pitch circle, pitch circle and you know these are buckets call buckets and this is of course, casing.

So, we call it this is penstock through which we are taking water from the reservoir to the inlet of a turbine through nozzle. So, this is the gross head available because this is TRL. So, this is TRL and this is called h gross. Gross head available and we will have certain amount of loss. So, we will have certain amount of loss and this is net head net head say h available on wheel. Net head available on wheel and this is penstock, and this is h l so this is loss. And you know this is net head available on the turbine and this is z.

So, of course, this is reservoir or dam whatever you tell now there is a D is the pitch circle diameter. So, if I assume D is a pitch circle diameter as d is a nozzle diameter. So, capital D is the pitch circle diameter small D is a nozzle diameter because if I draw if I take out this. So, this is the nozzles that are actually nozzle diameter I mean. So, jet is coming. So, this D/d which is known as jet ratio this jet ratio. So, this is essentially a layout of a Pelton turbine plant Pelton layout; a layout of a hydraulic power plant hydraulic power plant having Pelton turbine. So, this is the layout of a hydraulic power plant having Pelton turbine.

Of course, we need to write HRL which is known as Head Race Level and TRL this is known as Tail Race Level. So now, only this two are used while we are discussing about the hydraulic power plant. So now, probably we need to our objective is to obtain the velocity triangles of course. And then from there we can so when water is coming from reservoir to the inlet of the turbine through certain arrangement like we are having penstock and then we are having nozzle of course, we may have more than one nozzles I mean it is of course, two. And the nozzle whenever liquid is coming put from the nozzle it is having some high velocity.

It is having high velocity and then it strikes the bucket and then it when it is striking bucket rather enter rotor rather than enter wheel will start rotating. The wheel is having some few number of buckets that will start rotating and if the shaft of that wheel is connected with the shaft or other. If the generator or alternator is connected with the same shaft then it will start rotating and we will get electricity that is fine. we need to find out the velocity triangles from where we can quantify what would be this two in two quantities are very important.

First of all what is the power transferred by the fluid to the wheel. Power transferred by the fluid to the wheel and then this a one important aspect, but maybe power input to the wheel is obtained power input to the wheel and power transferred to the wheel is not same, because there will be certain amount of losses that we will discuss. So, power input to the wheel that is the energy the kinetic energy of the fluid which is coming out from the nozzle itself that is the power input to the nozzle power input to the wheel. While out of that power how much power is transferred to the wheel that will be different because we need to take a few losses that we will discuss you know in our subsequently.

So, to obtain that we need to draw the velocity triangles at the inlet and outlet and that we will draw before we go to do so. Let us first discuss about let us first discuss a few important issues which are very important while we are talking about the hydraulic you know Pelton wheel note that we have a pitch circle over rather a wheel which is having a few buckets and then we have pitch circle. So, you know the buckets are usually placed or fitted with a number the number of buckets. The number of buckets here I can write number of buckets it varies, but it is seldom less than 15 less than 15 number of buckets seldom less than 15.

So, they are evenly spaced which are shape is you know double hemispherical shaped. So, bucket that we are talking about bucket these buckets are evenly spaced on a wheel and this buckets are double hemispherical shaped. So, buckets are placed on a wheel and it is having hemispherical shaped. And they are mounted in such a way that whenever jet is coming out from the nozzle, it directs the jet along the tangent to the I mean whenever jet is coming out from the nozzle; the jet is directed towards the bucket.

So, there might be more than 1 nozzles maybe 2 nozzles, 3 nozzles normally, so 4 nozzles. So, whenever jet is coming out from the nozzles 1 or more nozzles are normally mounted. So, that nozzle will directs a jet along the tangent of the circle which circle this is this is the pitch circle. So, along the tangent to the pitch circle the nozzle will directs the jet that is very important. Whenever jet striking the bucket shape of the bucket is something different, we will draw that. So, let us now first draw the shape of the bucket. Again so, if I try to draw shape of a bucket then the bucket shape like this.

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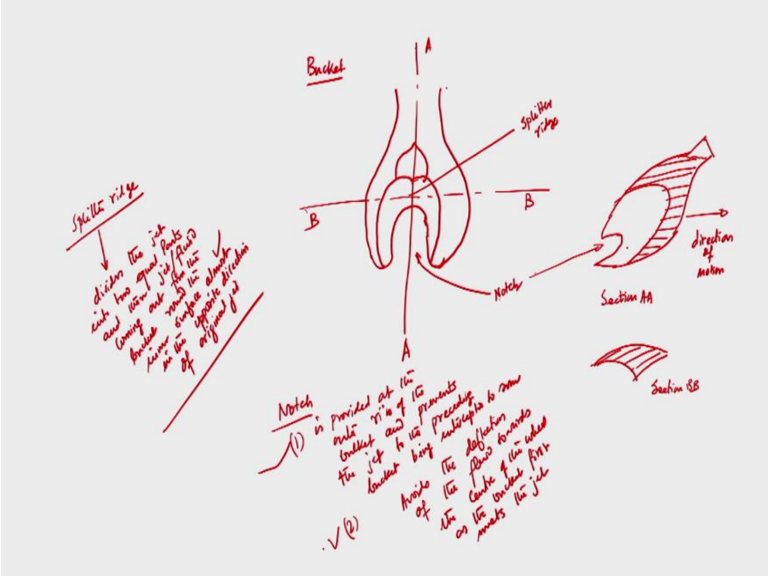

A particular bucket if I draw try to draw then bucket shape is like this So, now, if I take a section let us say this is BB, BB and this is AA. So, if I draw the section a section a look like this. So, this is the direction of motion so, this is section AA this is the direction of motion and section BB is like this. So, this is section BB; so, this is known as notch this is notch and we are having one splitter ridge. So, this is known as splitter ridge. So, this is the bucket shape bucket shape is a special type of shape. Now what we are discussing about that I said that; we have 1 or more than 1 nozzle maybe 1 or 2 nozzles or one or more nozzles which are mounted so that jet will strike you know it will strike the jet.

Now to along the tangent say it will strike the jet along the tangent of pitch circle. Now there is a splitter ridge at the down of the bucket down centre of the bucket each bucket we are having a splitter ridge. What is the function of splitter ridge? This splitter ridge allow water to you know rather splitter is divides it allows water to be divided the jet to be divided. So, at the down of the bucket down centre of the bucket there is a splitter ridge the function of the splitter ridge is to divides the jet on coming jet into two parts. And while it is dividing, and it will come out rather it the jet will proceeds along the two parts equal two parts and it will flowing round the inner surface of the bucket.

So, splitter ridge the function of the splitter ridge is to divides the bucket into divides the jet into two equal parts. And each part will try to follow the round shape of the bucket and it will come out just in the opposite direction of the jet. So that means, whenever nozzle is striking the bucket and there are 1 or more than 1 nozzles and is directed to strike the jet along the tangent of the pitch circle, and there is a splitter ridge function the splitter ridge is to divide the incoming jet into two equal parts and each part will try to you know flow rather it will come out from the bucket following the round shape and in the opposite direction of the incoming jet this is true.

Now there is a notch; so what is the function of notch is provided at the outer rim of the bucket which provides the jet to. So, as I said you splitter ridge very important splitter ridge what is the function of splitter ridge that it allows rather it divides the jet into 2 equal parts. And the 2 equal parts it divides, and then it the jet showing the jets then jet rather fluid coming out from the bucket you know round the inner surface, and inner surface and in the opposite direction of the bucket and in the opposite direction of the original jet rather inner surface almost in the opposite direction of original jet. So this is very important so, we have a splitter ridge function of a; so, we have said bucket is a special shape we have discussed here.

There are 1 or 2 nozzles which are mounted, and it will directs the jet along with tangent of the pitch circle diameter and which will strike the bucket. So, there is a splitter ridge in the bucket splitter ridge the function of the splitter ridge is that, the incoming jet which is coming from the nozzle it will try to device the incoming get into 2 equal parts. And then if jet will follow the round shape of the inner surface round. Shaft which is their inner surface of the bucket and it will try to come out from the bucket almost in the opposite direction of the original jet fine. And there is a notch watch is what is the function of this notch.

Notch is provided at the outer this is provided this is notch is provided at the outer rim outer rim of the bucket and prevents, this very importance prevents the jet prevents the jet to the preceding bucket being intercepted too soon. Not only that so, notch the function notch is that it is provided. So, whenever jet is coming out from the bucket one bucket we need to take into account that the out coming jet from the bucket it should not prevent it should not strike the bucket which is going to come because it is continuously rotating. So, may be as I said you that the jet which is coming out jet splitter ridge will divide the jet into two equal parts then it will follow the round shape which is there in the inner surface of the bucket.

And then it will come out almost in the opposite direction the jet, but we need to keep in mind that whenever jet is coming out from the bucket it should not it is should not strike the preceding bucket which is being intercepted soon, because it is continuously rotating. So, this very important not only that this notch is also provided it also avoids the deflection of the fluid towards the centre of the wheel as a bucket first meets jet; so, is the first function. Second function is this; a first function second function is that it avoids it avoids the deflection of the fluid towards the centre of the wheel as the bucket first meets the jet.

So, when bucket first meeting the first meets the jet the notch avoid; notch is provided that will have notch will avoid deflection of the fluid towards the centre of the wheel. So, it will not allow the fluid to go to the centre of the wheel. So, this is the function of a notch-notch and jet. Now question is the maximum change at momentum of the fluid and hence the maximum force driving wheel round we obtain. From this is clear that if the deflection angle becomes 180 degree. Then we have maximum change in the momentum of the fluid and of course, max maximum force that to drive the fluid. So, that is what I told you that if we can have that the in out coming jet the deflection angle then deflection. Say if the deflection angle is 180 degree; that is if it returns back from the wheel in opposite the exactly in the opposite direction it is almost in the opposite direction, but not exactly that is why I wrote the word almost, but not exactly.

So, if it is exactly in the original jet direction that we may have the maximum change of momentum of the fluid. And hence, the force working on the force driving the wheel will be high. But this is not the case because the deflection angle is limited to 165 degree maximum, because if it is 180 degree then the jet which is coming out from the bucket it may strikes the preceding bucket which is going to come. And it instead of getting higher you know rotation of the wheel it may try to resist the wheel rotation. So, these should not be the case. So, it is limited to the 165 degree.

We will discuss that what should be the maximum angle and then what is the maximum speed ratio and what is the maximum efficiency. Second thing that is what we have discussed that; we have a tail race level, now the tail race level is always located I mean the wheel should be located sufficiently away from the tail race level. So, that the water being collected the tail race level that should not be in touch with the wheel right. So, that is why the runner should be located wheel above the maximum tail race level. So, that it always rotate freely without touching the water in the tail race level.

That is important another important thing here I will discuss the schematic; what is the gross head of Pelton turbine? So, gross head that the difference between tail race level and the h head race level is gross head is it now what is the net head available from the schematic it is clear that net head available is the you know gross head minus z minus h l. So, this is very important that gross head available is not only exactly the you know total head I mean total jet plus something, because we need to take into account losses in the still you know penstock that is losses. So, h l is the losses in the penstock. So, if you take that effect friction losses into account then net head available is the gross head. So, if I write that here that what is the net head.

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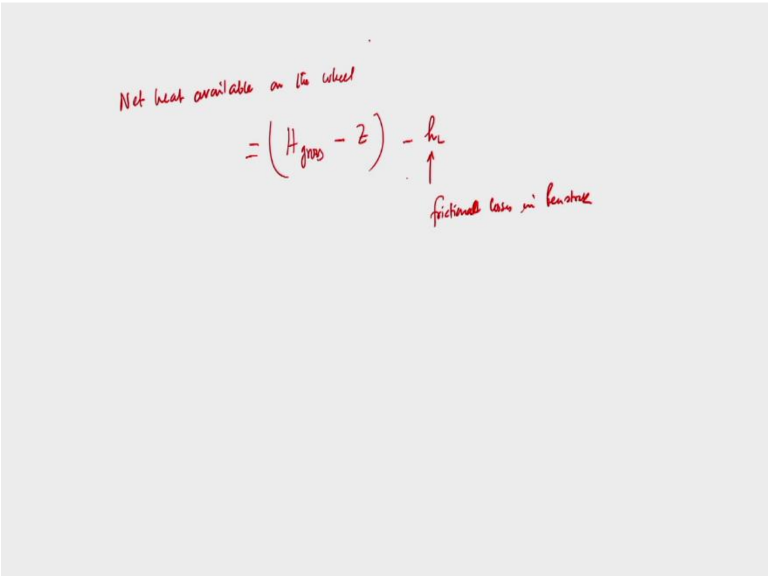

So, net head available on the to the wheel rather it is very important that net head available on the wheel = $H_{gross} - Z - h_1$ So, this is the frictional losses frictional losses in penstock. So, this is the net head available on the turbine wheel. So, we will see that out of this net head available how much energy you are getting. So, that is what is very important that I discuss that at the beginning that ok. We are allowing the liquid to flow through the nozzle.

So, jet we are getting so, we are get getting incoming jet. So, what is the power input to the wheel; that is obtained from the kinetic energy of the jet. So, power input to the wheel is the kinetic energy of the jet that is coming out from the nozzle, but out of this power input to the wheel what is the amount or the how much fraction of power being transferred to the wheel; that may not be different. So, the power input to the wheel and power transferred to the wheel is not equal because of some losses.

So, we will discuss that issue and also we will work out one example and we will try to give a mathematical formulation from where we can quantify what will be the efficiency of that Pelton wheel. So, we will discuss that aspect in the next class, I stop here today.

Thank you very much.