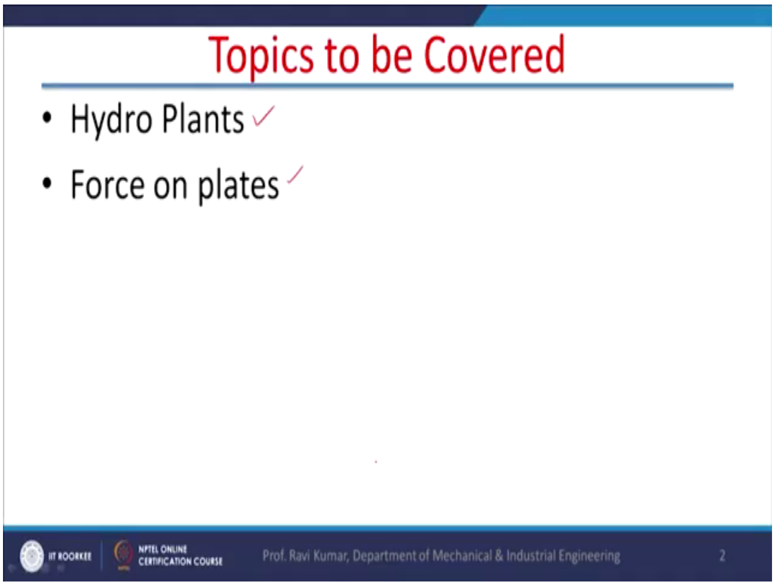
Power Plant Engineering
Prof. Ravi Kumar
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 22
Hydro Plants and Forces on Plates

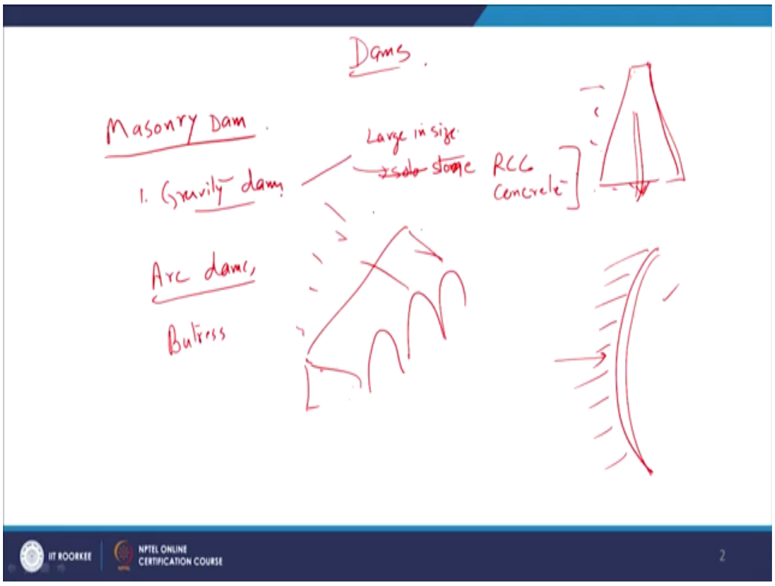
Hello, I welcome you all in this course on Power Plant Engineering. Today, we will discuss about the Hydro Plants and Forces on Plates due to impact of jet.

(Refer Slide Time: 00:36)



Before we start with the hydro plants, we like to discuss; I like to discuss the dams about the dams. There are different type of dams some of masonry, dams some of field dams.

(Refer Slide Time: 00:43)

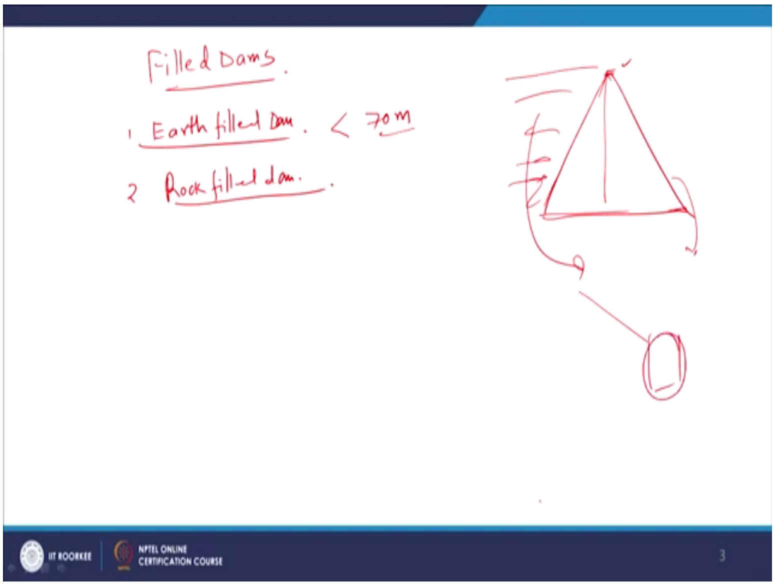


So, if you look at the Masonry dam. So, for example, Bhakra dam; Bhakra dam is a Masonry dam. So, one is gravity dam. Gravity dams are massive quite large in size and the thrust of the water because when the water is filled with the dam water on this side. So, thrust of the water is sustained by the gravity of ah this dam only, right.

Thrust and whatever force are acting on the wall are sustained by the gravity of the vent, then that is why they are quite large in size, they are built of stone, RCC, concrete, right. So, this is the material which can be used for the Masonry dam, there are certain arc dams also. The arc dams you must have seen some of the dam there is a arc, it is not a straight wall there is an arc and the convex side of the arc which is faces the water pressure.

So, water pressure is not as in the case of gravity dam it is by the gravity of the water which dissipates the water pressure, gravity of the dam which dissipates the water pressure; here, the pressure is dissipated by the arc of the dam, right. So, there are arc dams, there are buttress dams. So, in buttress dams you will find there are number of buttresses and they support the structure and on this side there are dams, there the water is storing is there, right.

(Refer Slide Time: 03:03)



In addition to the masonry type of dams are certain filled dams. Now, the filled dam is number 1 earth dam, but earth filled dam is good for maintaining nearby flora and fauna and the height is less than always less than 70 meters earth dam; you do not go beyond 70 meters and this type of dam it blends well with the surrounding of the dam.

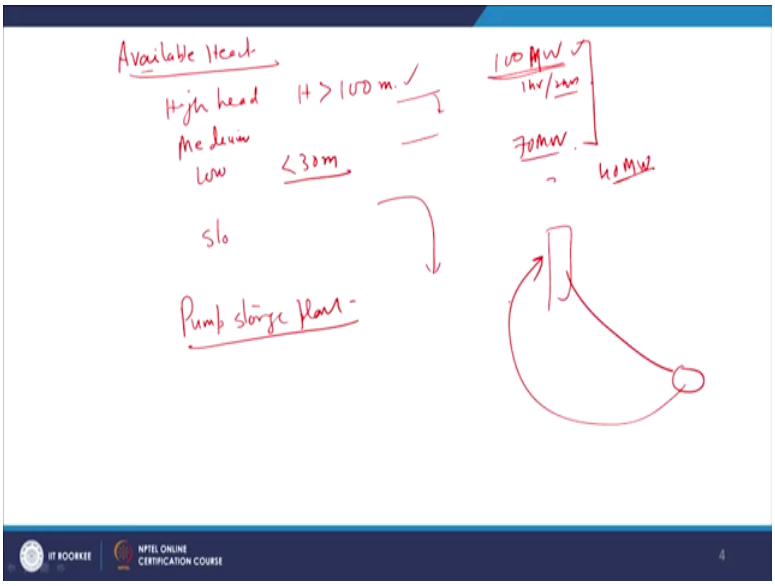
Natural surroundings of dam, it builds it blends with them in a proper manner and the structure is normally protected by the corrosion; corrosion much corrosion is not there, spillway cannot be made on this dam. So, a supplementary because arrangement has to be made a supplementary spillway is made for this dam, right.

And, the second one is rock filled dam. The rock filled dam is dam where the different shapes of the rocks, they are filled in making a dam it has a slope also, right and it is very robust will be a strong dam. And rock dam rock filled dams are suitable for a location which are prone to earthquake also because earthquake is major, is considered to be major threat for the existence of the dam or the life of the dam.

So, if it is a rock filled dam, it can sustained a high resistive scale; I mean, it can go up to 7 or may be it depends upon the design. So, it can sustain earthquakes, it is and the second thing is it will not if it is damaged for high at certain order of earthquake the dam will also get damaged, but it will not damage, it will not simply collapse like a concrete dam, it will go off in the stages. So, that will that also give sometime for saving. Though, for such high order of earthquake it will become human being also to survive and all those buildings will be demolished, right.

So, but rock filled dam is a is considered to be very good dam where the on the side where which are close to the earthquake and these dams are made using different size of rocks. And, the rocks are filled in this space and how the and they are compacted and this is how the rock filled dam is made.

(Refer Slide Time: 06:06)



Now, after the dam the water goes, because the water is stored in the dam and from the dam it goes to the power plant; hydro power plant, right. And, for hydro power plant we can classify the hydro power plant also. Hydro power plant can be classified as available height, if high head when height is greater than 100 meters like Tehri dam. Tehri dam height is around 262 meters. So, it is a high head plant, it is a rock field also medium; medium is always between high and low. So, low is less than 30 meters so, medium is between 100 and 30 meters, right.

The; power plant can be peak load power plant and can be base load power plant. Base load power plant means minimum power which is required and during the day time power consumption is not constant, it also varies, right. So, power plant can be made designed as a peak load power plant and the base load power plant. If you peak load power plant then it will always be underutilized, right.

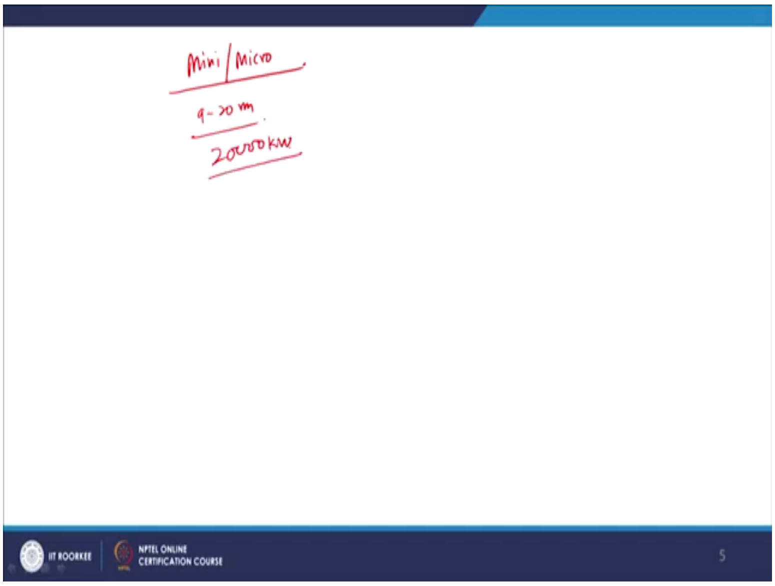
Suppose, peak load is 100 right, 100 kilo Watt or 100 megawatt and the plant you design plant for 100 mega Watt, rest of the day it will remain unutilized. Because, you will now never get 100 mega because 100 mega Watt you may be getting for let us say 1 hour or 2 hour, rest of the 23-24 hours it will remain unutilized, base load suppose is 70 mega Watt, right.

In that case; so, the plant; suppose, the plant is designed in such a way that the capacity remains between the peak load and the base load, right. And, plant with the storage is storage hydro power plant are without the storage if; suppose, there is a constant turn off we do not need the storage at all if throughout the year there is a constant turn off, we do not need the storage at all. If throughout the year there is for a small duration, there is a run off then we need huge storage ok, there is a pump storage hydro plant also.

Now, in pump storage plant what happens? During the off peak load, suppose you have you have plant is designed for 100 megawatt, power required is only let us say 50 megawatt or 40 mega Watt, right. So, what happens the excess power is used to run the pumps on the downstream side there are pumps. Suppose, this is a dam turbine on the downstream side, there are pumps and these the pump these pumps they pump back power to the reservoir.

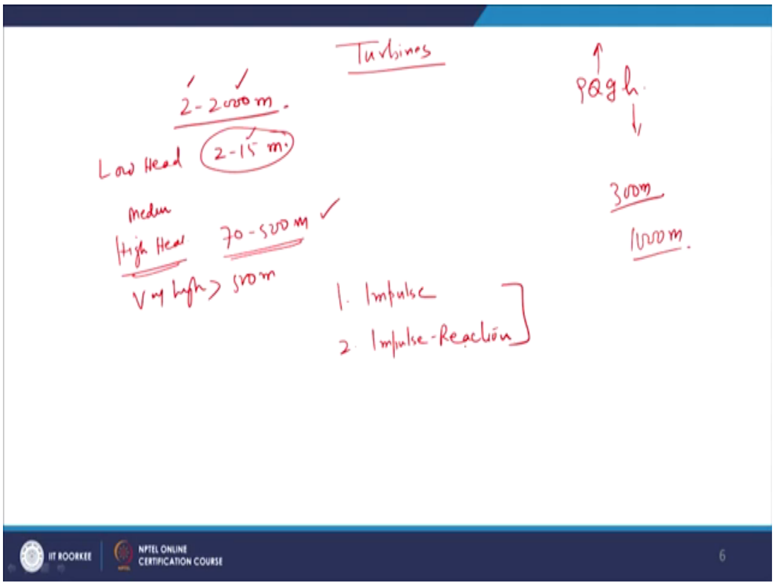
So, power is generated and that power is; so, instead of a very looks to be very efficient system, right. So, power is generated and this power is used for running a pump house, and this pump house pumps back the water in when the load is low on the power plant, right.

(Refer Slide Time: 09:17)



There are mini and micro hydro power plants also; mini and mini and micro where head is very low 9 to 20 meters, ok. In India you will surprise to know the potential for micro; mini micro is 20000 kilo Watts, it is quite high, right. So, we are number of mini and micro power plants which are producing this much of power.

(Refer Slide Time: 09:53)



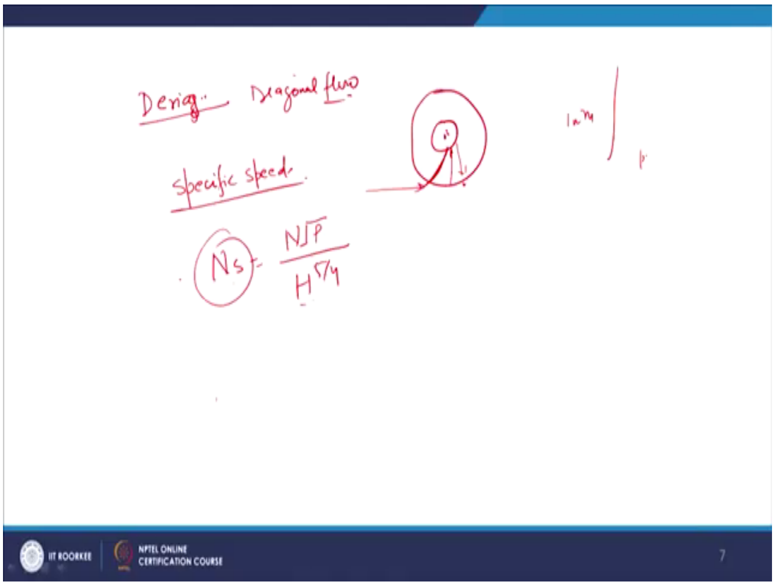
Now, we will go for the classification of turbines. Turbine is the main part of any hydro electric power plant because the power is produced inside the turbine, right. Now, turbine works between 2 to 2000 meter of head, there are turbines; there are turbines which are working under 2000 meter of head, there are turbines which can work up to 2 meters of head this is mini micro type of hydro power plant where they work for 5 meter head or 10 meter head or 7 meter head.

Now, low head turbine this is mini micro 2 to 15 meter. Now, when the head is low, definitely your energy is potential energy is rho Q and g h when head is low, Q had to be very high, right. So, for high head power plants; for high head power plants Q is less in order to generate same amount of power, the discharge will be less for higher, suppose higher is 300 meters, right. So, in that case discharge will be less if we compare with the 15 meters, when the discharge is less it gives mass flow rate of the fluid which is going through the turbine is less.

So, for in order to produce the same power, size of the turbine will reduced. So, try; size of the turbine is quite large when there are low head power plants. Now, high head we talk about high head it is between 70 to 500, right and very high 7 to 500 500 very high, greater than 500 meters and medium between, between these two, right. So, normally we have high head power plants in India we have number of high head power plants we have number of micro hydel power plants also.

Now, if these power plants, different we same type of turbine we cannot use in all type of power plants. For very high head power plants right where head is more than 500 meter or 1000 meters. In that case suppose head is 1000 meter, in that case you will have to go for a pelton wheel it is which is sort of impulse turbine, right. For very low head for example, 50 meters or let us say 70 meters we will have to go for impulse reaction turbines. So, there are two turbines like a steam turbines, here also there are two types of turbines one is impulse turbine and second is reaction turbine.

(Refer Slide Time: 12:55)



Now, direction of flow. Now, in turbines; in hydro turbines, suppose this is a wheel turbine wheel this is shaft. The flow can be tangential, there can be a tangential type of turbine, we have tangential type of turbine also. There are turbines which are radial where the flow is radial it flow in radial direction right, like Francis turbine.

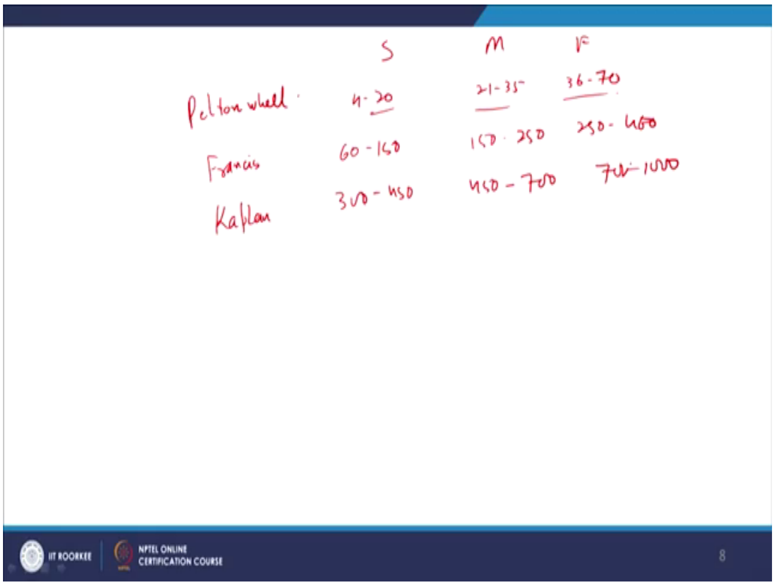
Now, in Francis turbine, there can be two types of turbine; two types of radial flow also entering from center leaving from periphery, entering from center leaving from periphery leaving from periphery entering sorry, entering from the periphery and leaving from the center. So, when the flow is in this direction it is known as inward flow turbine inward flow radial turbine, when flow is towards the periphery then it is outward flow radial turbine.

There is a another turbine we Daria's turbine which is diagonal flow which is diagonal flow turbine and every turbine has a speed which is known as a specific speed, right. Now, specific speed can be expressed as N under root P divided by, right. So, it is a speed of a turbine under unit head to produce unit power. Simply, we can take from the formula it is the steam speed of the turbine under unit head, head is 1 meter and power generation is 1 kilo Watt.

Now, through a specific speed if we decide which sort of turbine can be used because for different turbines there will be certain range of a specific speed. So, first of all if you simply how much power is required at what head suppose, we are designing a hydro power plant. So, what we have we have certain head and this from this head this is the flow rate and this much power is required.

So, we simply try to find out what is this specific speed required according to the specific speed the application of turbine will be done in hydro power plants. If; now, if you look at a formula if the head is very high carry high head will use Pelton wheels. So, if head is very high in that case you will have to go for Pelton wheels and we when the head is reduced then we come to the Francis turbine, right and then for further if the head is reduced we go for Kaplan turbine.

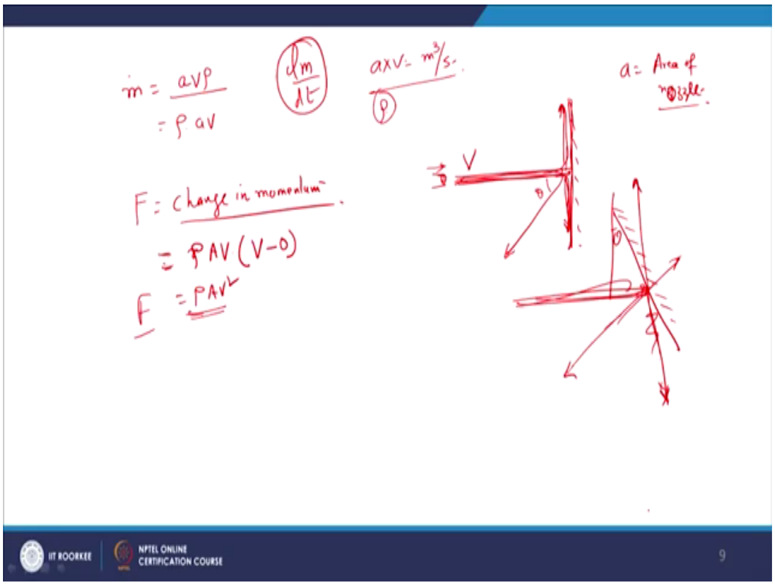
(Refer Slide Time: 15:48)



Now, if we want to have the range for Pelton wheels; suppose there is a Pelton wheel; slow, medium, fast 4 to 20, 21 to 35, 36 to 70. This is rpm, this is not specific speed if you go for the specific speed it will be lower than this. If I am just talking about the rpm Francis, it is 60 to 150, 150 to 250, 250 to 460.

Kaplan 300 to 450; Kaplan is the minimum head it requires the minimum head 300 to 450, 450 to 700 and 700 to 1100. Accordingly, there is specific speed will also vary for a particular application. Now, in the turbine before we go for the power generation in the turbine, let us understand the dynamics of the free jet.

(Refer Slide Time: 17:00)



Now, there is a free jet suppose there is a plate, right and the palette the potential energy of water which is stored in the reservoir is converted into the kinetic energy, and the jet strikes the plate so, it is in certain velocity. So, this is the plate and jet strike the replayed with a certain velocity v, right and there is an opening on the nozzle which has cross section area; a is the area of nozzle through which the water is coming and the plate is not moving at all place, plate is a static.

So, mass flow rate of water which is coming through the nozzle; mass flow rate of water which is coming through the nozzle is going to be area of the nozzle, velocity and density or density multiplied by av. v is the velocity cross section area because a and v will give you meter cube per second. Cross section area of the nozzle and the velocity of water which is coming out of the nozzle, if you multiply these two you will get volumetric discharge, and the volumetric discharge will is multiplied by density, you will get the mass flow rate.

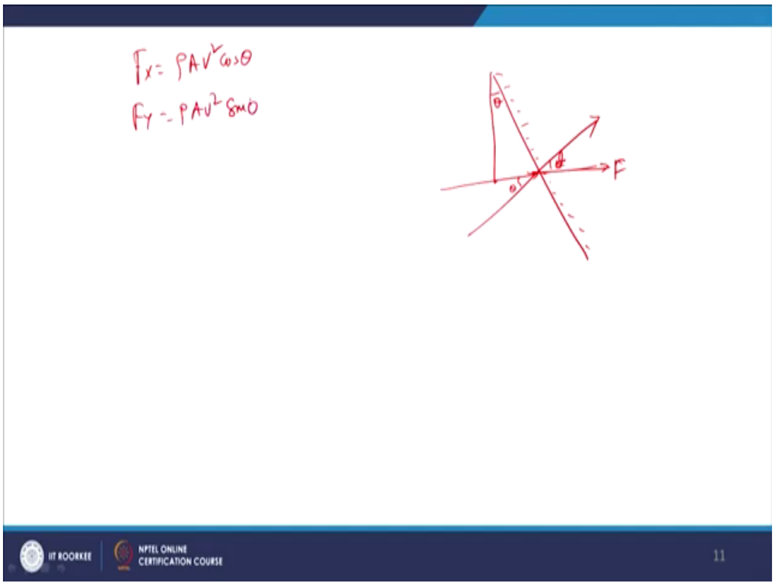
Now, after striking the plate there are possibilities. Possibilities are the water goes in two different directions, it is strike the plate and just simply fall from the plate. All the momentum is transferred to the plate, right or it the water jet strike the plate and it moves to the ninety degree. Water strike the plate it comes out at a certain degree theta right, water is strikes the plate and it is returned, it just strike the plate it is bounce back, right.

In the first case force on the plate; force on the plate and the water is striking the plate, force is going to be the change in momentum, right. Now, water is fluid is going in this direction and losing. So, all the; so, first of all rho AV multiplied by V minus final velocity 0 because all the momentum is just imparted. So, it is 0, it is rho AV square.

Now, this is remember this is mass flow rate d m by d t when we talk about when we say mass flow it means mass flow rate. So, mass flow rate, so it is rate of change of momentum it is not change in momentum, but this is rate of change of momentum; rate of change of momentum is force. So, this much force is exerted on this plate. Now, plate is inclined, plate is not a straight suppose plate is inclined from theta from the top, now this is the plate and jet is the striking like this, right.

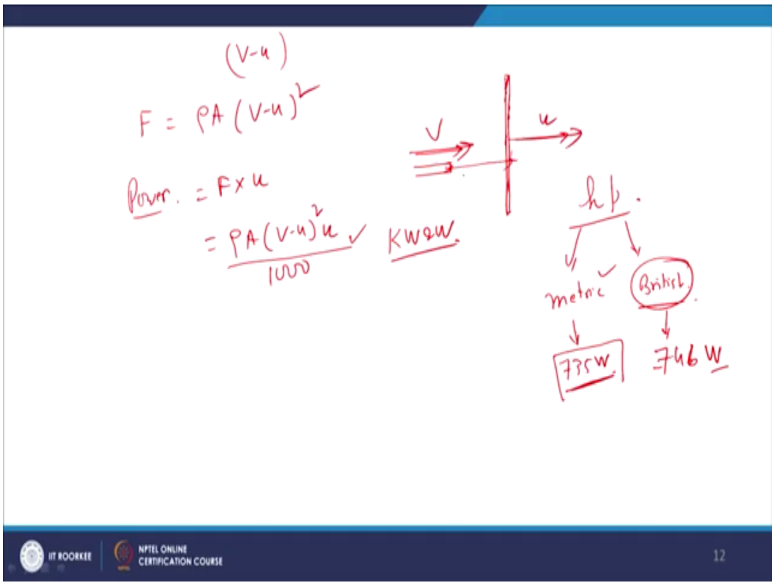
Now, the force jet is striking like this and then the force exerted in this direction and force exerted perpendicular in this direction has to be calculated. This direction and perpendicular to this direction is this direction, this direction or this direction, not this direction has to be calculated, right; I will draw another diagram.

(Refer Slide Time: 21:10)



This is like this jet is a strike like this, this is F force is this line suppose this is theta, let us take this is theta. So, this is theta, this is theta, this is 90 minus theta, this one is theta, now it is ok; this is theta, this is 90 minus theta, this is theta and this is force F. Now, force F in this direction is going to be F cos theta. So, F X is equal to rho AV square cos theta and F Y is equal to rho AV square sin theta.

(Refer Slide Time: 22:11)



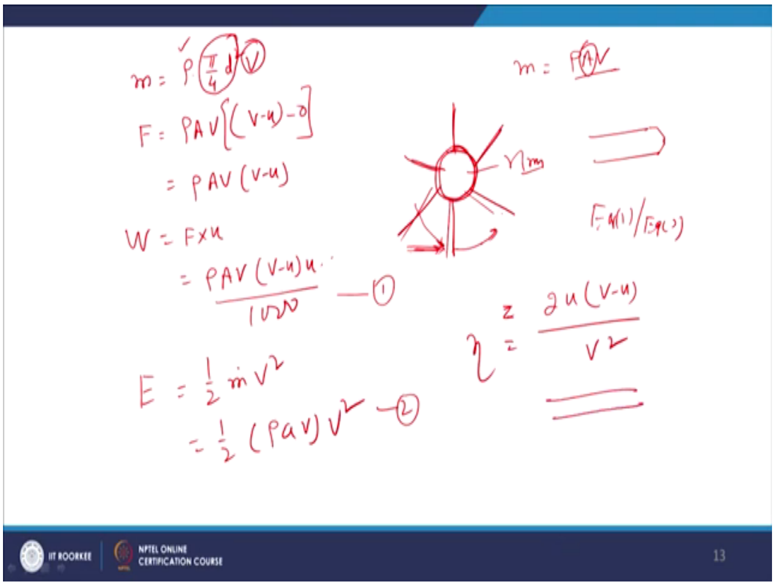
Now, suppose the blade is moving; blade is moving in a certain velocity because in turbines the blade does not remain; I mean, static, it does move. So, blade is moving now plate let us talk is to before talking to blade we will talk about the plate, plate is moving with a certain velocity u, now jet is also moving with a certain velocity V, right. So, then the relative velocity is going to be V minus u and the force will turn out to be ah rho A V minus u whole square and power in this case power will automatically come into the picture.

Now, the power is force into velocity is equal to rho AV minus u whole square multiplied by u, if you want to express power in kilowatts then it is going to be divided by 1000. Earlier, the power was if you go to the old power plants you will find power in horse power and there are two types of horse power one is metric horse power, one is British horse power or which is expressed in IP system.

Now, British horse power is 7 746 Watts, metric horse power is 735 Watts, right and if we normally go by the metric horse power, but and you if in the old machines you will find the British horse power. And, this British horse power has to be converted into the power because nowadays we are expressing in the SI units we are expressing power in kilowatts and Watts.

So, now, if we will after this because now what is happening this plate is moving in this direction, jet is moving in this direction, but practically it is not possible. Practically, it is not possible the plate and jet are moving in this direction, we cannot extend the length of the jet because this is a physical entity nozzle; the length of the nozzle with time, this is not possible, right.

(Refer Slide Time: 24:32)



So, what is possible? The possible is if we take a shaft and we put a number of plates on the shaft. If you put number of plates in the shaft and if the water is strike the shaft here, right then this plate will move in this direction and meanwhile another plate will take this place. And, again the water will strike this plate and this will ultimately transmit all the energy to this rotating shaft, the all the blades they will transmit energy to the rotating shaft and this shaft, it will start rotating with certain rpm, right.

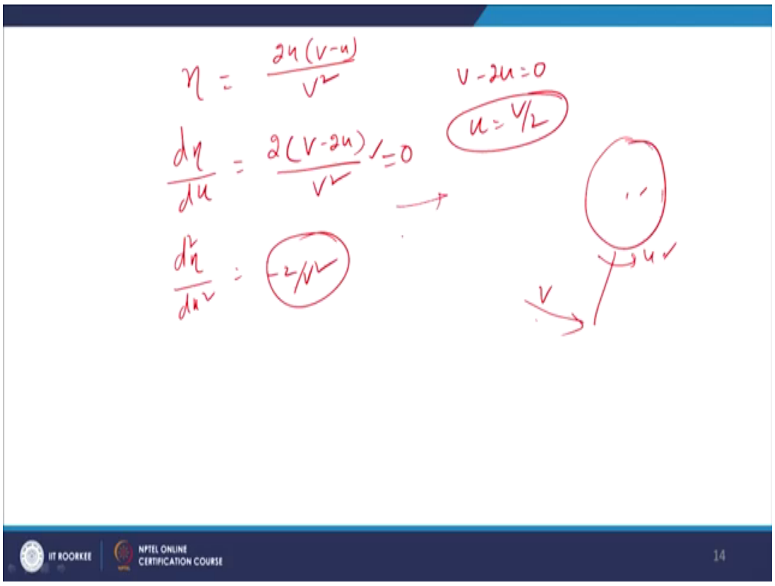
So, instead of having moving blade and the moving nozzle if we can have plates mounted not blades, plates mounted on a shaft these are very crude type of display of any turbine, rights. Plates are mounted on a shaft and the water jet is striking the plates and energy is imparted to the plates.

Now, if we want to do this if we want to represent this phenomena mathematically first of all we will have to calculate the mass flow rate. The mass flow rate is rho pi by 4 d square V. Now, earlier we calculated mass flow rate is rho AV, A is the cross section area of the tip of the nozzle not the body of the nozzle, it is the cross section area of the tip of the nozzle, right. So, this is pi by 4 d square multiplied by the velocity, multiplied by the density.

Now, the F force which should be exerted on this is going to be rho AV V minus u that is relative velocity and after that the velocity becomes 0 we assume; so, it is this. Now, it is rho AV V minus u. Now, we want to find work, work is going to be F into u is equal to rho AV V minus u multiplied by u divide this by 1000 you will find the output of the this wheel with the plates fixed on it. Now, kinetic energy of incoming fluid, but the kinetic energy of the incoming fluid is half m V square, m is the mass flow rate. So, it is going to be half rho a v into V square.

Now, if we want to have efficiency about this is equation 1, this is equation 2. Now, you want to have efficiency of this system because every machine you make right, we have to find the efficiency, how efficiently it is working. So, efficiency is the very important part of character characterizing any machine. So, here if you want to find efficiency you will divide this equation 1, divide by equation 2 and we if we divide these two equations you will get 2 u V minus u upon v square, this is the efficiency of this machine.

(Refer Slide Time: 28:01)



Now, efficiency we have noted that it is 2 u V minus u divide by V square. Now, I want to maximize this machine because at what peripheral velocity the efficiency is going to be the maximum. So, for this purpose we will just simply differentiate the this efficiency with respect to u. So, we will get 2 V minus 2 u divided by V square, ok. Now, this is going to give maximum because if you again d square upon d u square again we differentiate we are getting minus 2 by v square. So, it is a negative value.

So, once we have getting double differential negative value it means this if we put this is equal to 0 we are going to get maxima and that is going to be v minus 2 u is equal to 0 or u is equal to V by 2. So, if the; this is very interesting finding if the peripheral velocity is half is the peripheral velocity is half of the jet velocity; peripheral velocity is half of the jet velocity, the efficiency of the system is going to be the maximum. This is not about the output, output may be less, but efficiency of the system is going to be the maximum, right.

Now, with this is the process; I mean, this what I explained you this is the process of initiating design of any hydraulic turbine right, more on the hydraulic turbine we will discuss in the next lecture that is all for today.

Thank you very much.