Industrial Instrumentation
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Lecture - 14
Flowmeter – III

Welcome to lesson 14 of Industrial Instrumentation. In this lesson, we will continue with the flowmeters. As I told you repeatedly before that the number of flowmeters are huge in, in numbers. So, we have to continue on several lessons and we have to discuss details, in details all the flowmeters. So, in this lesson, basically we will cover the one open channel meter which is very widely used for irrigation purposes that is weir and also we will discuss direct electrical output flowmeter that is turbine flowmeter, right? So, let us look at the contents of this lesson, Flowmeter III as it happened.

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Now, we will have contents, so we will first discuss the weirs, its principles, its application, what are the different types of weirs that also we will discuss and then we will discuss the, a variable reluctance tachogenerator, because the, using that principle we will use, we will make the turbine flowmeter. Turbine flowmeter advantage is the direct electrical output. So, in many applications it is popular and moreover, it is unlike differential pressure flowmeters, you do not, we do not need any conversions and square rooting, all those problems are not there in this type of flowmeters. We will also discuss the turbine flowmeter.

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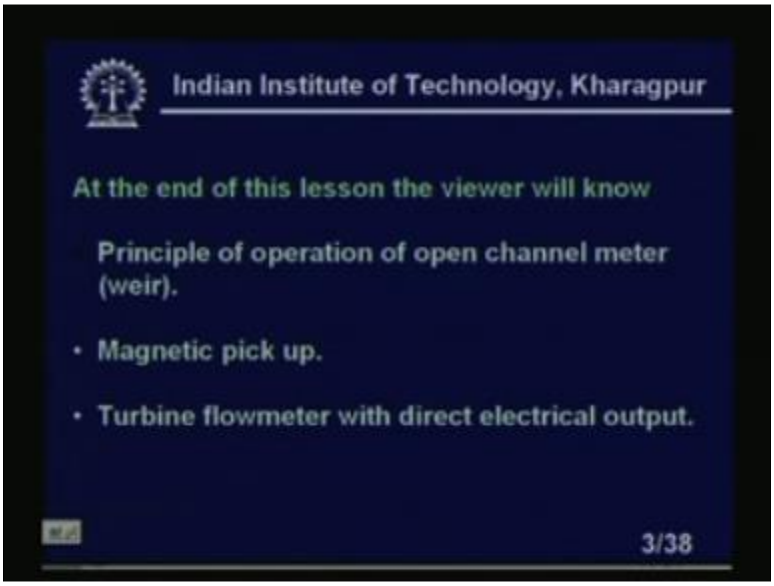

Now, at the end of this lesson, obviously the viewer will know that how to use the weir in the systems, I mean how the person can be, the person can use the weir for measurements of water flows, especially mostly it is used for water flow in an open channel like canal or duct, right? That means principles of operations of open channel meter that is weir. Open channel meter, we have already discussed the, not only weir, we have, actually pitot tube is also used. But pitot tube as you know it is mostly used for the, used for the gas and it is not suitable for the dirty liquids, because when we are talking of the measurement of the flow of water in a canal or river, you cannot except that it will be very clean. So, it will be extremely dirty in that sense, so we need some other rugged flowmeter.

So, in that sense, whereas no other, there is no other alternative than weir to use the measurement of flow in open duct, I mean open channel, right, like canal, river, like that. So, we will also look at the magnetic pick up, because this magnetic pick up, we will find that we will use in many applications for measurements of velocity and all those things. So, the principle is same, whether I, suppose if I want to know that an RPM of a motor, so that can be utilized and the magnetic pick up is also used there and also if I want to know the, the liquid flowing in a pipe, so what is the liquid flowing in a pipe, if I use some magnetic pick up, so that is also, I mean that is the part of the turbine flowmeter that is the reason we will discuss magnetic pick up also; also, the turbine flowmeter with direct electrical output. So, these three things we will discuss in, I mean people, I mean the viewer will know the details of these three components.

Now, let us look at the weir.

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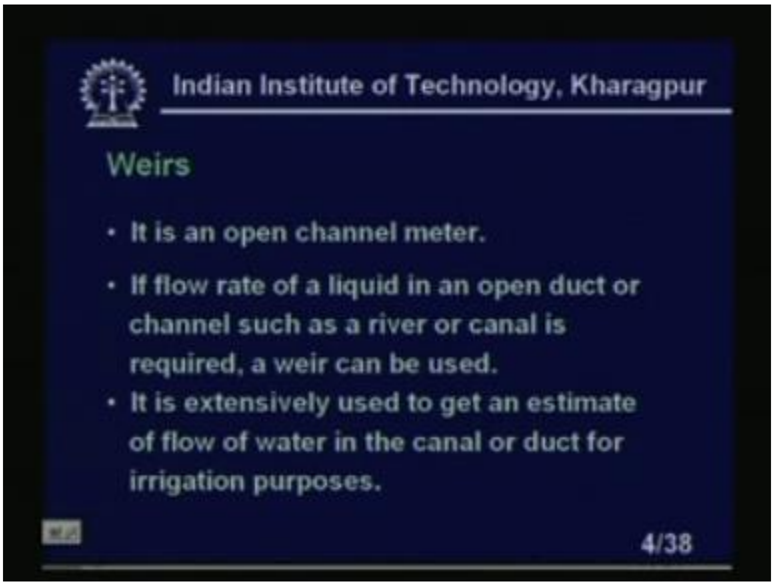

Weir, you see, it is an open channel meter, first of all. That is I told you repeatedly it is an open channel meter, it is not a closed channel meter. Now, if the flow rate of a liquid in an open duct or channel such as a river or canal is required, a weir can be used. There is no other alternative. As I said it can be used, but in fact actually there is no other alternative than using weir. It is extensively used to get an estimate of flow of water in the canal or duct for irrigation purposes. So, whenever there is irrigation, so how much water is to be given to a particular land and all those things, details I mean, this estimate is only possible by, if we use weir, right?

So, it is very much suitable for measurements of the liquids in the open. It is not for gas. So, it is only for the liquid, mostly for water and principle operation of weir and moreover one thing I forgot to tell you that it is, you see that it does not depend on the, depend on the temperatures and all those things. Many other sophisticated, as you know there are many complicated, as you know flowmeters are there, so but it does not depend on the temperature. Suppose if the water is coming out of a boil or if I want to measure or if you are discharging that water somewhere, so that type of measurement is also possible in, by the, by means of weir, because the, if the temperature increases it hardly matters to the weir or the flow coefficient also does not change much.

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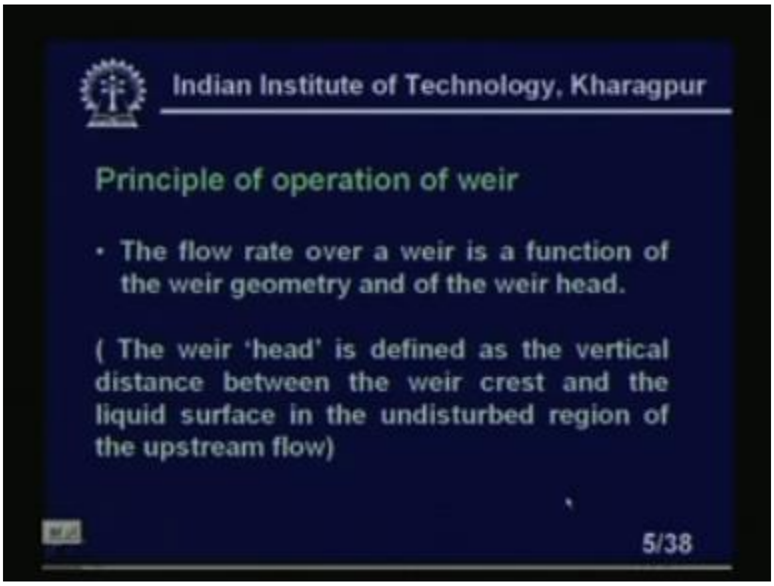

You see, the flow rate, excuse me, the flow rate over a weir is a function of the weir geometry and the weir head. You will see that basically there are two types of weirs used. One is rectangular weir and the V notch weir. Usually the rectangular weir is used for the large flow measurements and the V notch weir is used for low flow measurements and however, we will find that the V notch weir is actually more accurate than the, more accurate than the rectangular weir. In this particular lesson, so we will discuss or we will derive the flow velocity as well as upon volume flow rate for the, in the case of rectangular weir, but we will give the expression for the volume flow rate, whenever we are using the V notch weir, anyway. So, it depends on the weir geometry, right, geometry and weir head.

What is wire head let us look at. The weir head is defined as the vertical distance between the weir crest and the liquid surface in the undisturbed region of the upstream flow. So, these terms we will use repeatedly, the undisturbed region of upstream flow. So it looks like this, we will discuss.

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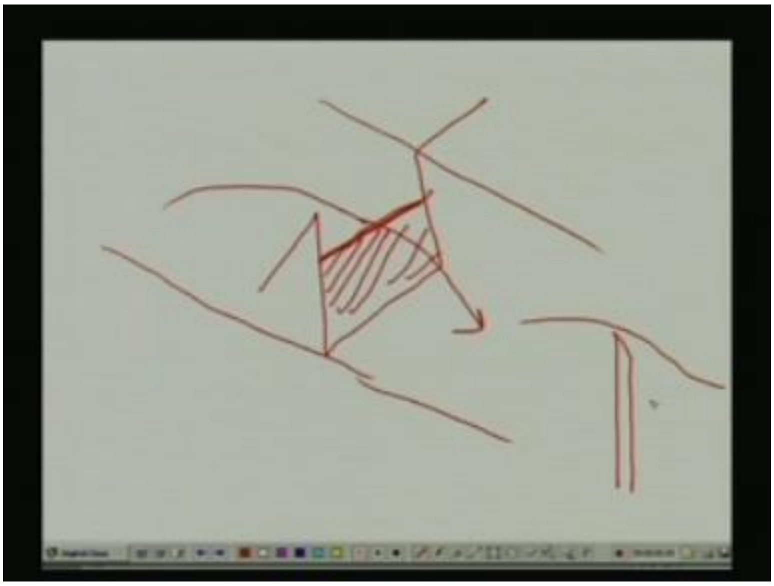

We will see here, if I take a blank page you will see the weir, actually in that is a restriction like, see it is a restriction like this. We will give the figure, so water is flowing through this side. There is a channel, right, so water is flowing from this side, right? So, if it is closed on this side suppose, so liquid will flow over this one, right, this. So, this is called the crest of the weir, right? If you look at, it is, I mean if I take a side view, it will look like this, sharp edge. So, water is falling over this liquid, right? So, this is the ….. In fact actually, I mean you, you will see that this will be like this one.

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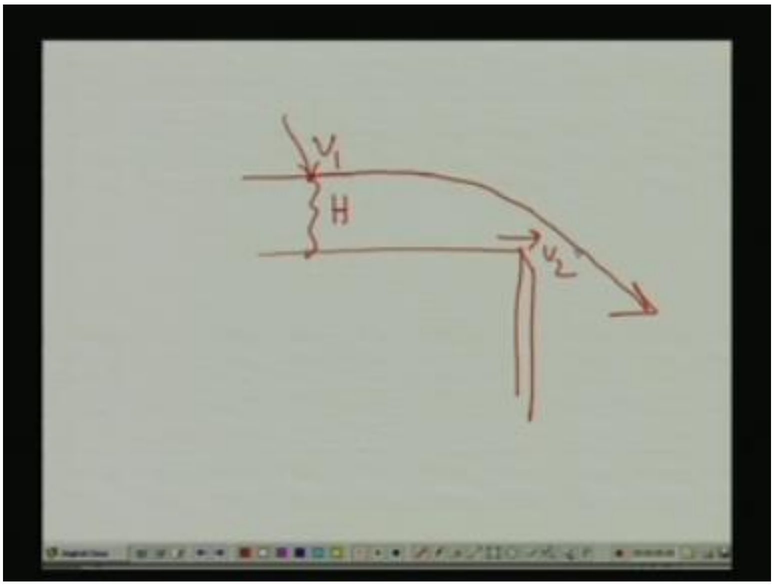

That means I have a vertical side view, so the water is falling, so falling like this. So, this is our undisturbed region of the upstream, right? So, this will be our H, which will be shown in the next figure, right? So, here if I take the velocity V 1 and at the crest if I take the velocity V 2, then we can easily write the Bernoulli's equations, right? Our goal is to measure this height, H by any means. So, what are the different means that I will show you later on. So, by measuring H, I can calibrate this instrument in terms of flow. That means H can be calibrated in terms of flow and mostly it is indicated type of instruments or monitoring type of instruments. It is hardly used for transmission purpose, right?

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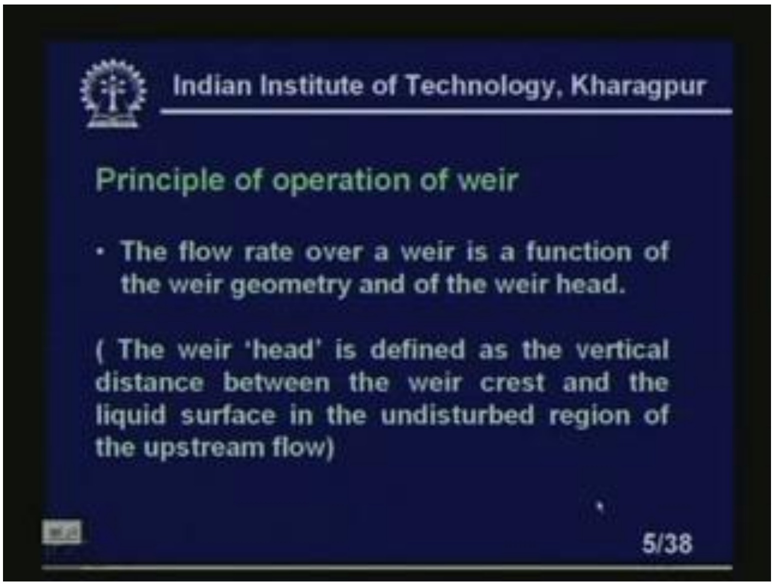

So, that is I am saying, the weir head is defined as the vertical distance between the weir crest and the liquid surface and the liquid surface in the undisturbed region of the upstream flow, right?

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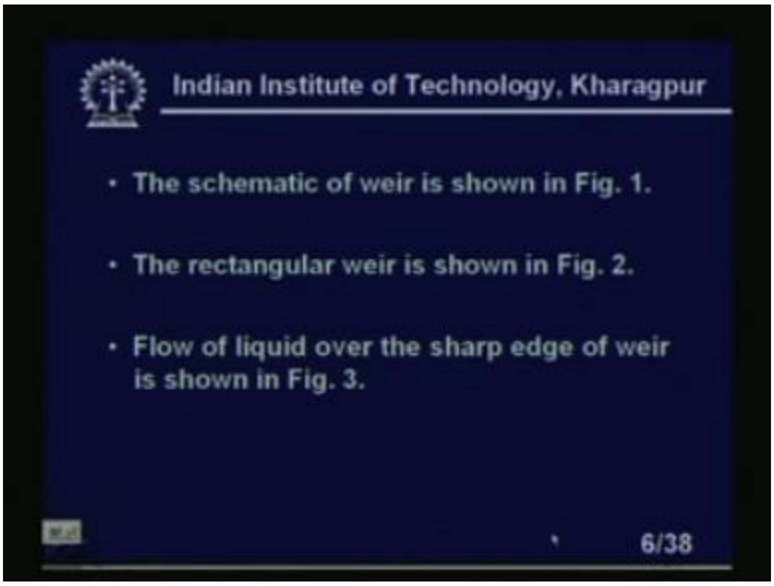

The schematic of a weir is shown in Figure 1. The rectangular weir is shown in Figure 2 and flow of liquid over the sharp edge of weir is shown if Figure 3. So, in subsequent three slides, we will find that, we will show you the weir geometry and rectangular weir and flow of liquid over the sharp edge of the weir. So, these are all in Figure, Figure 1, 2 and 3, respectively.

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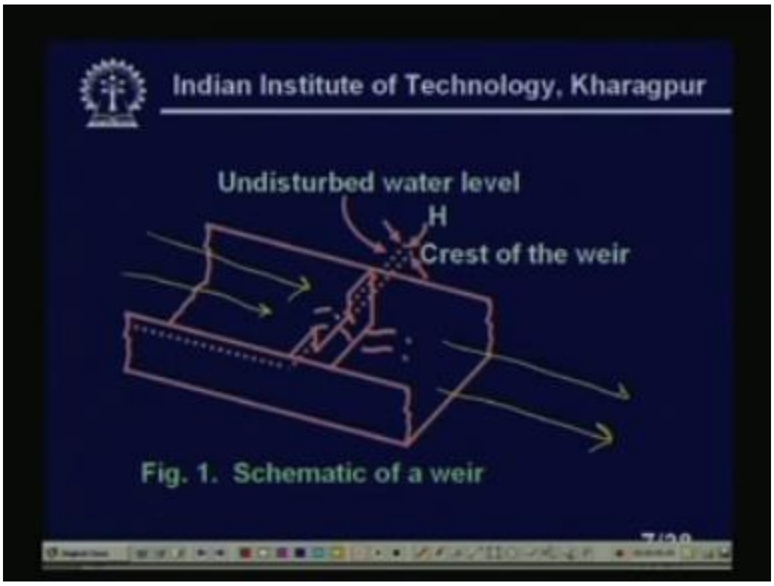

Now, you will see that it is the schematic of a weir, as I have shown you. So, this is the duct and assuming that this is a river or a canal, so the liquid is, if I take a different pen, if it is flowing in these directions, right and flowing out in these directions. So, restrictions we have put like this, right? So, in a college dictionary you will find the meaning of the word weir is basically a dam, but it is, actually it looks like a dam, I mean restrictions, but so there is, as it happened in the case of dam there is a level of difference in the upstream and the downstream, the similar thing is here also, right?

Let us look at very carefully. You see this is our crest of the weir, right? Liquid is coming here and falling down, right? Now, if I put a float on this side which can move only in the vertical direction, then what will happen? This, according to the, if the flow velocity is high, so this height will go up, right? This H, if you look at H, because liquid is, suppose the liquid is in this, up to this level, right, so from the crest to the undisturbed water level that is the H or head of the weir. I repeat that from the crest that means the sharp edge of the weir to the level which is undisturbed water level is the capital H that is the head of the weir. Actually, we measure H, right by some means. So, this is the schematic of weir.

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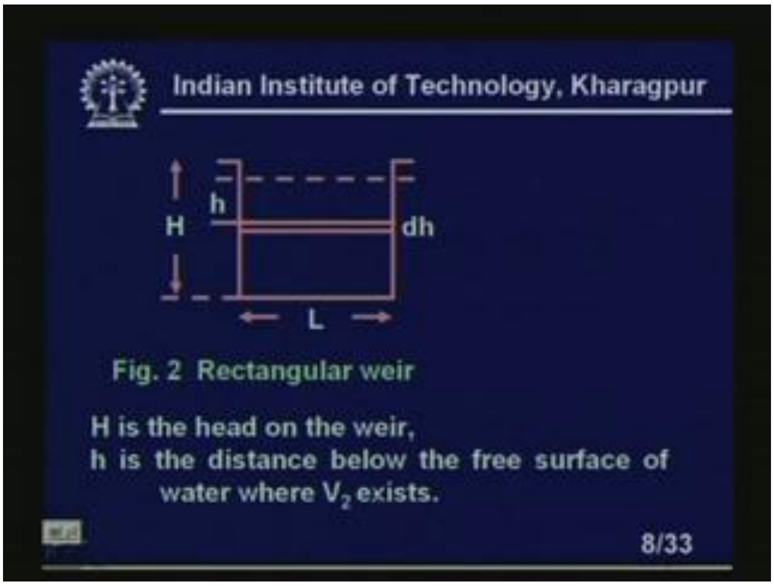

Now, you see, this is a rectangular weir. So, this is, we will discuss later on what is small h and what is dh. So, this is our crest of the weir, right and this is the water level. Not necessarily it will go to the top, right? Water level may go up to this position. In fact, this should be not up to this, this should be, should be, it should end here, right? So, this is the water level, this is h, right? So, from this crest to the upstream, undisturbed upstream, water flow level that is the capital H, not this part, right and for derivations, later on we will see we take a small section dh at a height of h, right, from the top of the undisturbed flow level, undisturbed flow level upstream that we have taken. So, at a distance h from the undisturbed upstream flow level we take a section over width d. This will be needed for, later on to find the total volume flow rate or volumetric flow rate in the rectangular weir, right?

Now, let us look at, let us look at how the weir, how the water is flowing on this weir, where H is the head on the weir, as we told and L is the length of the weir. It is basically length of the crest of the weir and small h is the distance below the free surface of water where V 2 exists. That will be shown in the, more clearly in the next, next slide, right? You see here, yes it is clear now.

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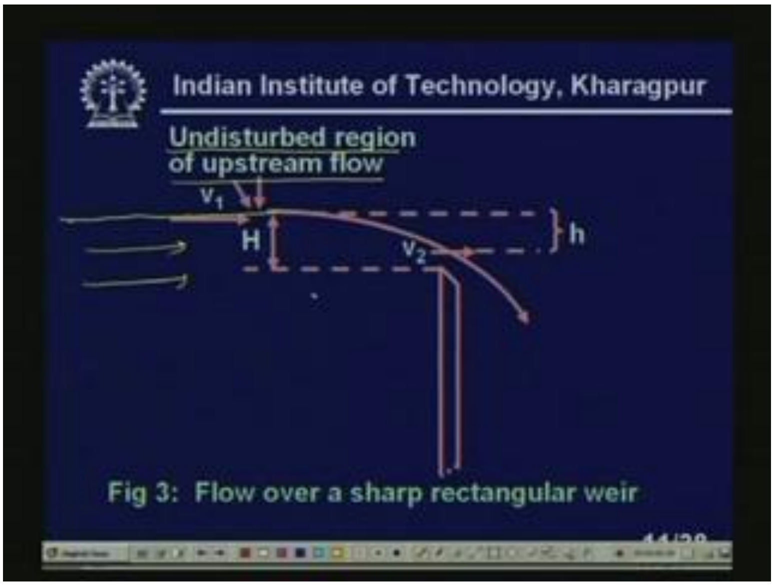

You see, this is the upstream, undisturbed region of the upstream flow, right? This is the water level, this is the undisturbed region of the upstream flow. If I take a pen, this is the undisturbed region of the upstream flow, so this is, everywhere this is same, because water is, I mean coming like this one, so this level, so it is undisturbed, so after that you see that water height start to fall, right? Now, in the previous slide if you see, what we have seen, here you see what will happen? Let us go back, anyway, see this is the distance h. In the previous slide you see here, h is a, we have taken a section of, small section dh, of height dh at a height from the undisturbed region of the upstream flow of h.

That means if you look at, so this our h, this is from the upstream. This is from the undisturbed region, right? Fine. Now see, what will happen? So, this is h and the velocity above the crest is V 2 and velocity upstream is V 1, clear? If it is there, so I can immediately, so this sharp edge is very important, we will discuss later on, because if it is not sharp the calibration constant will be modified. So, we can, usually after certain months we can just change the weir keeping all other dimensions constant, so that the, our flow coefficients will remain same as before. Let us look at weir.

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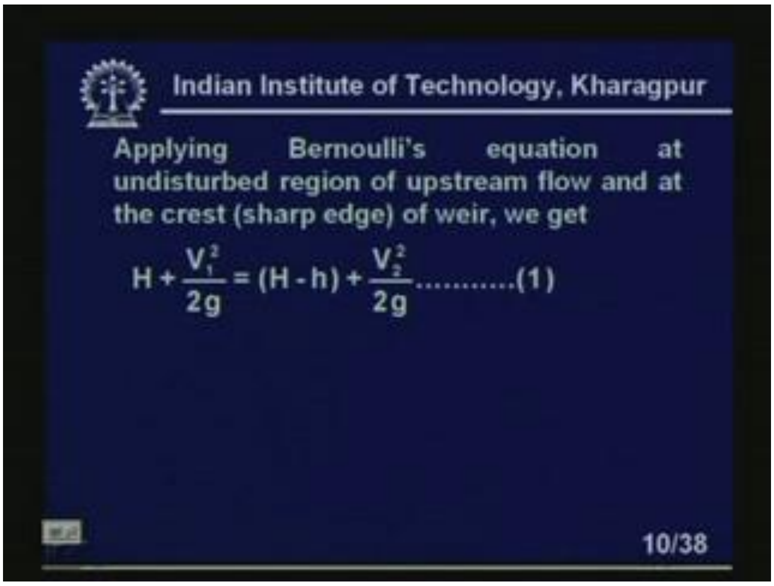

Now, if I apply the Bernoulli's equation at the undisturbed region of upstream flow and at the crest that means the sharp edge of weir, we can immediately write H plus V 1 square by 2 g capital H minus h plus V 2 square by 2 g is not it, because the height is, if I take from the datum level it is H minus small h, right?

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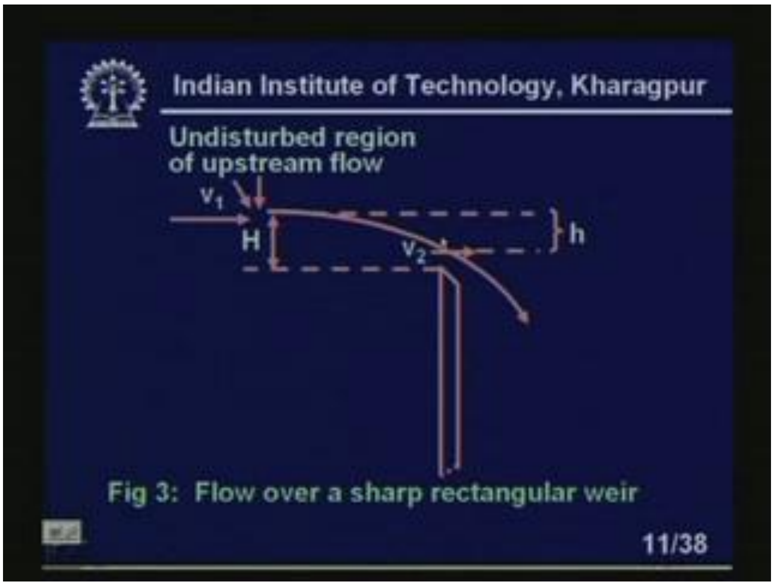

If I go back, you see H minus small h. At this position, my V 2 exists and H is existing. In that this case we are taking this one as the datum level, is not it? You see, this is we are taking as datum level. So, this is H height plus V 1 square by 2 g, so add. This one is V 2 square by 2 g plus if I take this one as a datum level, so it is H minus h where V 2 exists, is not it?

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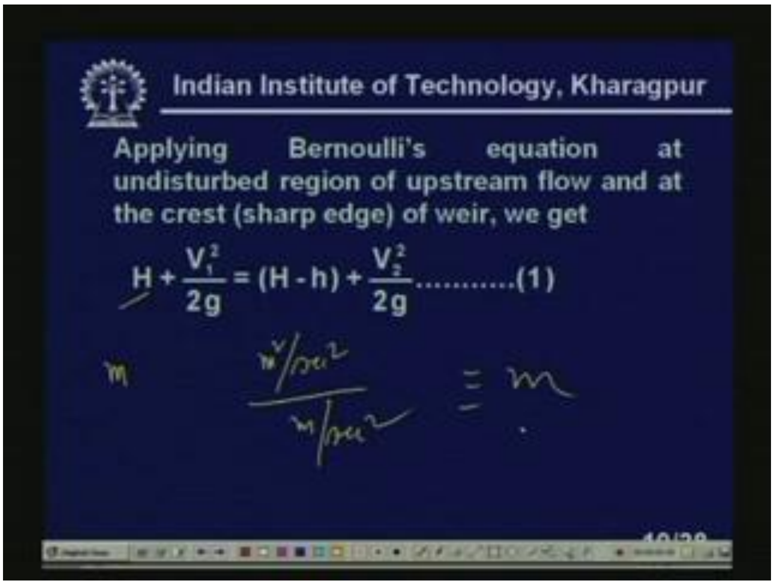

So, if it is there, so I can write these equations. You can, interestingly you can see here that all are dimensions of height, because if this is in meter, so this will be in meter square per second square. So, g is meter per second square, so obviously it will be in meter, clear? So, no problem in that side, so dimensionally it is correct, right?

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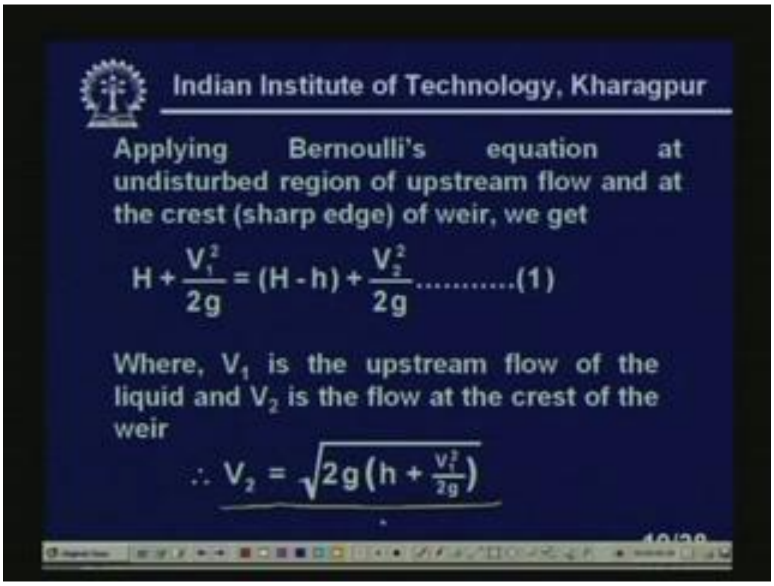

Where, V 1 is the upstream flow of the liquid and V 2 is the flow at the crest of the weir that we have told one, once we have shown in the diagram. So, obviously if I manipulate the equations, so the equation number 1, so it will come as a, come up as V 2 equal to, because we say H and h will cancel out, V 2 root 2 g h plus V 1 square by 2 g, right? Now, in most cases we will find that the V 2, the speed at the crest will be always very, very large that we have seen. Those who have visualized near the dam we will find that whenever in a lock gate, especially we will find that the, when the water is flowing just over the lock gate, the speed of the water is very high compared to the, I mean calm upstream flow, right? So, in that cases, so I can obviously tell that the V 2 will be much higher than the V 1. In that case what will happen you see, we can simplify this expression like this.

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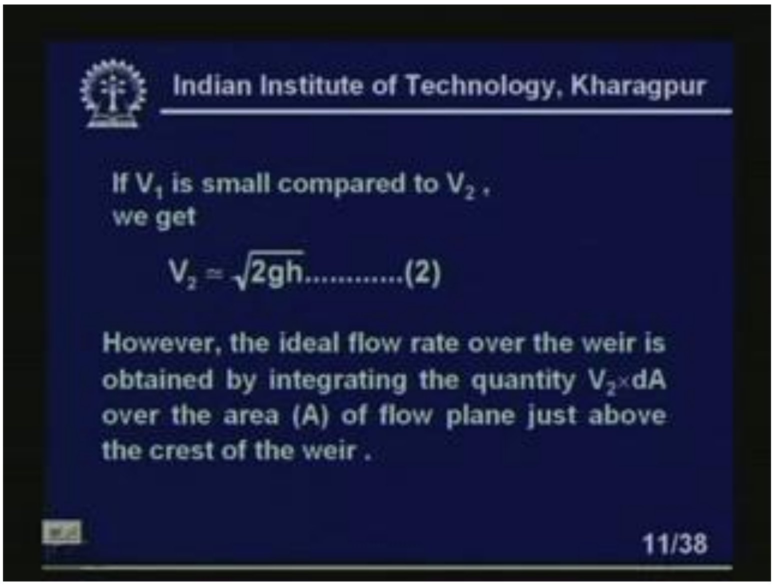

If V 1 is small compared to the V 2, then we can write V 2 equal to root over 2 g h, right? This is equation number 2, right? However, the ideal flow rate, if I want to now find the ideal flow rate, because this is the velocity at, because it is not very easy to measure the H, right, because this is the, we are getting the flow at the crest, so it is, please remember another thing whenever it crosses the, if I take a blank page it is easy to understand. You see here, what will happen?

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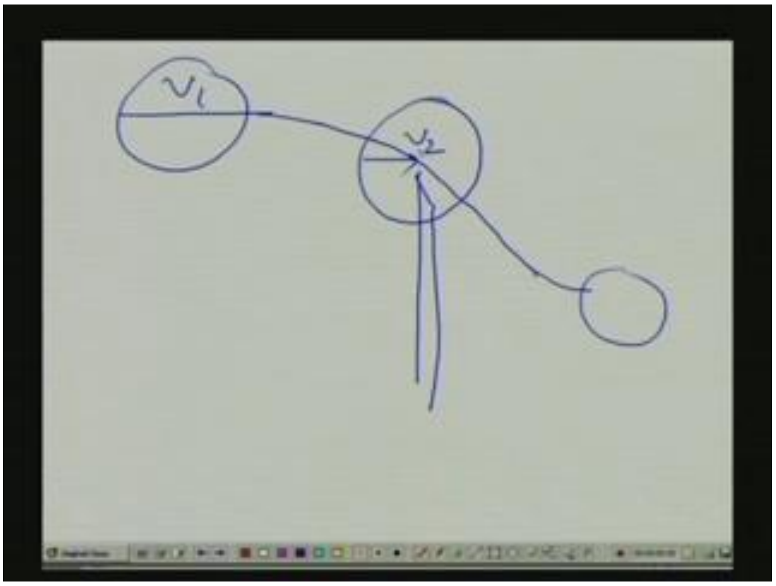

Whenever the liquid, I have a crest here, so if I take some other pen, so you see here, so here the velocity is V 1. Some liquid is falling down here is V 2 at the crest, right? So, here you see the, again the velocity will reduce. So, at this position only the velocity will be high. This velocity will not be maintained. Once it falls down, the velocity will also be reduced in this region. It is already less than V 2. Here also this velocity will be less than V 2, right? However, the ideal flow rate over the weir is obtained by integrating the quantity V 2 into dA. What is dA? over the area A of the flow plane just above the crest of the weir? What is dA, let us look at. What is dA?

You see, dA is, actually we are finding dh multiplied by L that is the dA. So, dh multiplied by L will be the dA. So, we will integrate over the height, h. So, we will get the total flow of velocity.

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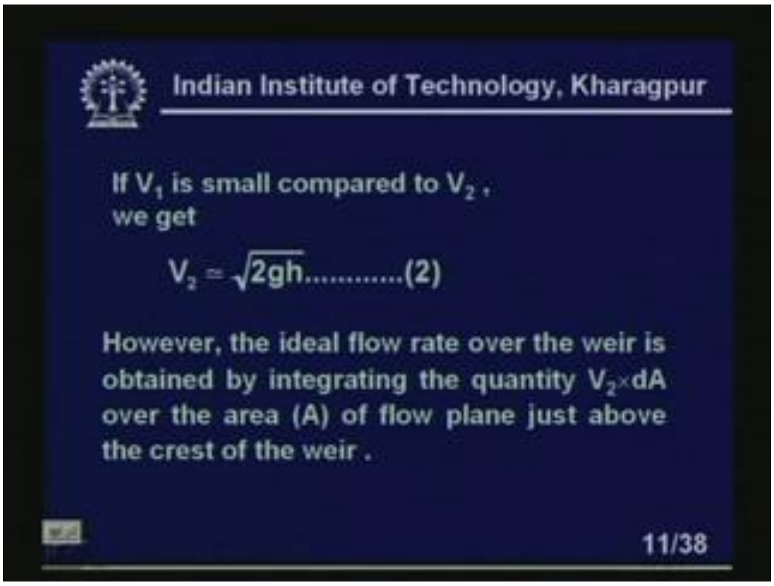

If I come down here, now you see, so theoretically what we can write that if I go back, so however the ideal flow rate over the weir is obtained by integrating the quantity V 2 into dA, velocity at the crest multiplied by the dA, dA is the small h section at the height h from the top, small h of width dh, so dh into L will be the dA, over the area A of the flow plane just above the crest of the weir, right?

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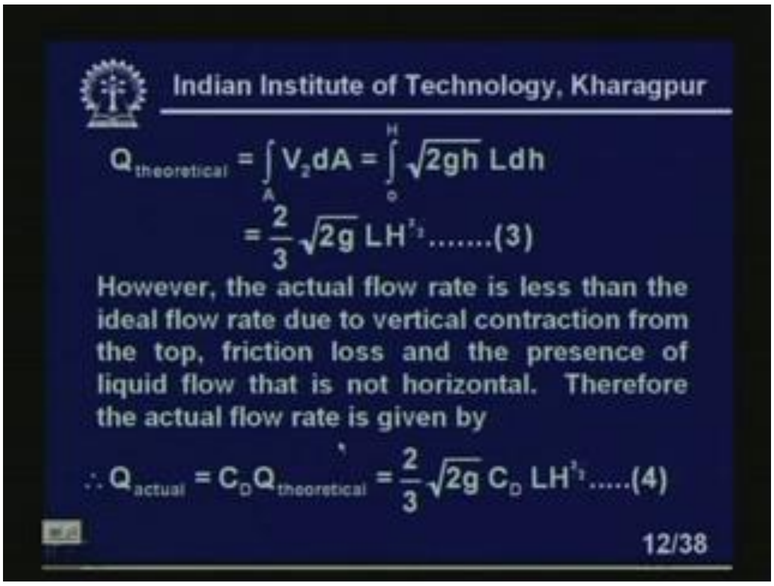

So, we can write Q theoretical that means theoretical volume flow rate equal to V 2 into dA. So it is meter, meter cube per second, because this velocity is meter per second, it is in meter square. So if I, that is if I convert, so it will be 2 g h, right, root over 2 g h, already we have seen, multiplied by, what is dA? L dA that I told you earlier. So, this will be equal to, integrated over instead of A will be from, since it is all converted, L is constant, only H is the variable, so I converted this integration values from zero to H. So, if I do it, so I will get the expressions equal to 2 by 3 under the square root 2 g into L H to the power 3 by 2. Please note, it is H to the power 3 by 2, this is equation number 3.

Now, however this is, as it is happened in all the flowmeters, so you see that every time we have to multiply by a flow coefficient. Sometimes we call flow coefficient, sometimes we call discharge coefficients. So, it is very, sometimes it is very difficult to measure actually, to find theoretically the value of all the discharge coefficients. The best thing is to find experimentally with some standard flowmeters, right? So, however as it happened in any other flowmeter, the actual flow rate is less than the ideal flow rate due to the vertical contraction from the top and the friction loss and the presence of liquid flow that is not horizontal. Therefore, the actual flow rate is given by, so vertical contraction this is the slow contraction from the top. If you look at, you see here, so there is a slow contraction from the top, right?

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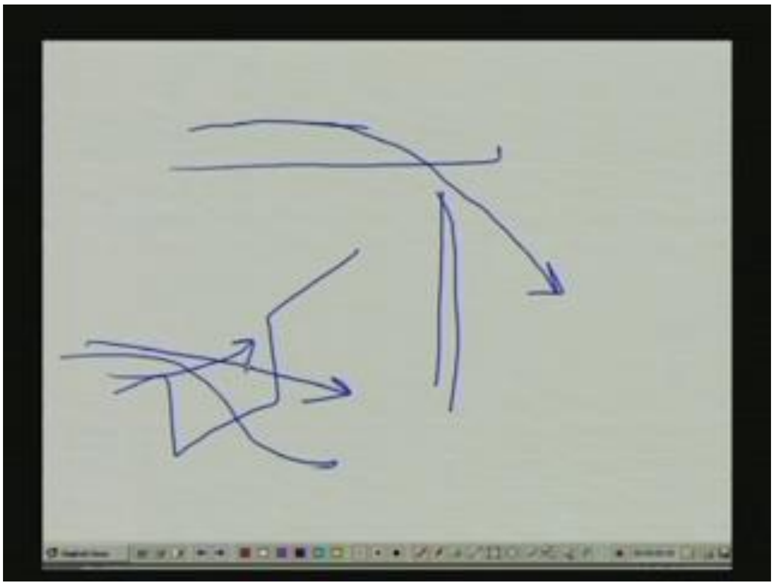

I have a weir, so there is a, it is not that suddenly it is coming, so it is a slow contraction from the top and we are assuming that all the flow velocities is like this one, right? If I have a weir, we are assuming that all velocities is in this direction. This is not necessarily true. Velocity will be in this direction, some velocity will be in these directions also, right?

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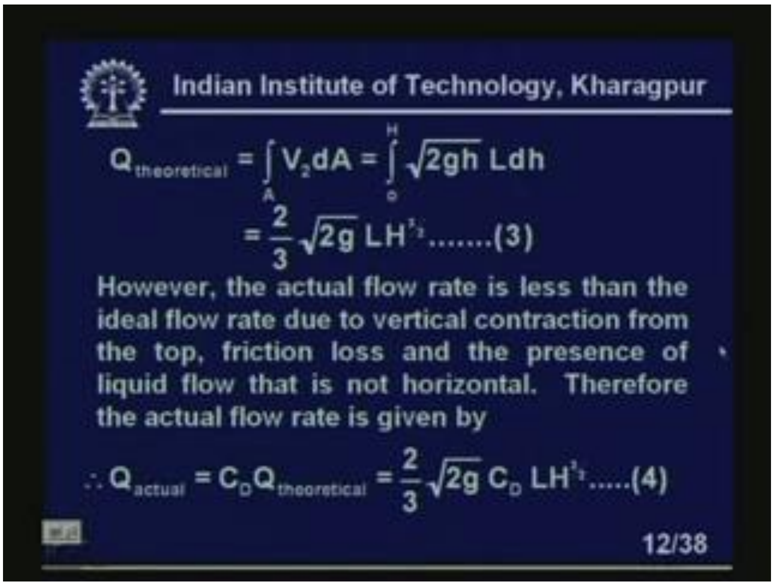

So, we have to take care while we are making the, if you, if we are interested to find the actual flow rate, right, for that reasons we are telling, you see, however the actual flow rate is less than the ideal flow rate due to the vertical contraction from the top and the friction loss and the presence of liquid flow that is not horizontal. Therefore, the actual flow rate is given by Q actual equal to C D Q theoretical 2 by 3 square root of 2 g C D LH 3 by 2.

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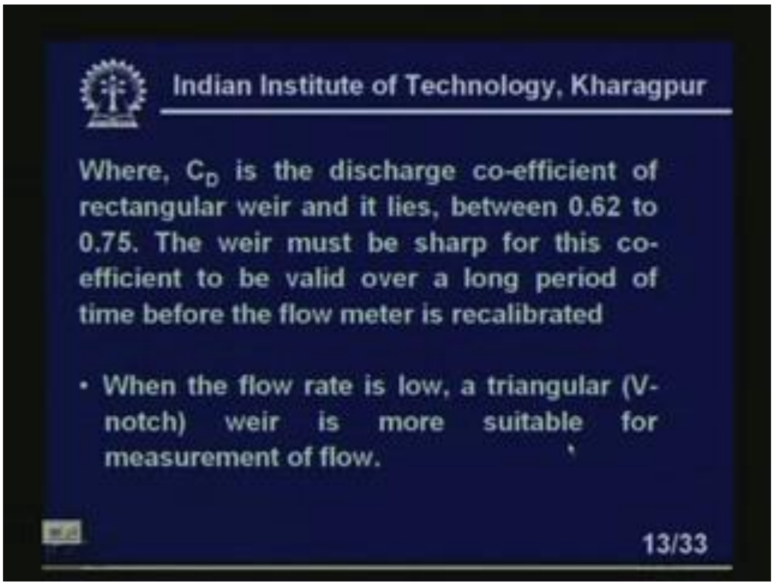

This is equation number 4, where C D is the discharge coefficients of the rectangular weir and it lies between 0.62 to 0.75 and the weir must be sharp for this coefficient to be valid over a long period of time before the flowmeter is recalibrated, right? This I told you earlier also. That means this H should be very sharp, otherwise what will happen? You see that this, the calibration constant or discharge coefficient will be modified. That happens in all the instruments. So, most of the instruments like, you see in the case of Venturi, when we discussed the Venturi meter, in the case of Venturi meter this type of calibrations is not necessary. But, we have seen in the case of orifice meters this, the H is not, is not 90 degree rectangular orifice we will find that the discharge coefficients will be modified.

So, the best way, during the routine maintenance you change the orifice. If you know the thickness and everything is same, dimension is same, the orifice hole diameter is same, you do not have to recalibrate, right? Similarly in the case of discharge coefficients or in the case of weir also, so during the routine maintenance, suppose after using 1 month or so or 2 months, depending on the how much …., how much is the corrosion in water and all those things, we can just change this weir. Weir, it is not very expensive equipment. That is also you must mention, I mean this is to be, I mean this is to be explained, because it is not expensive compared to the, I mean if you look at the other open flowmeter it is not very expensive. So, in that sense it is, replacing a weir, it is not very expensive affair, right?

So, when the flow rate is low, now we talked about the rectangular weir. But, there is another type of weir, as I told you, this is called V notch weir. When the flow rate is low, a triangular or V notch weir is more suitable for measurement of flow.

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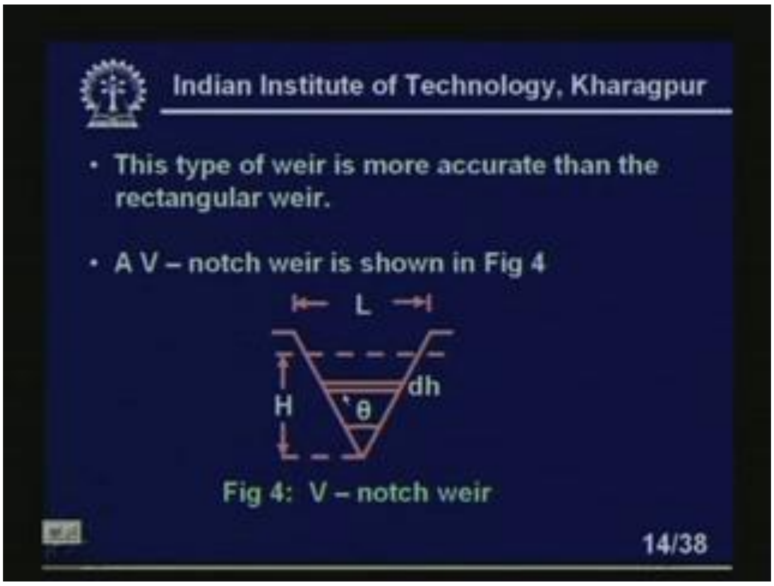

This type of weir is more accurate than the rectangular weir, right? It is for the low velocity flow rate, but it is more accurate, right? A V notch weir, as you can see, is shown in figure 4, right? You see here also, so this is the length of the V notch weir. This is also restrictions. Instead of rectangular, this type of weir we will put it and so this is, it is slowly increasing. This is the included angle theta. As before, we have taken a section dh from the top of, from top of the undisturbed flow region, h and H is the height head of the weir. As the liquid flow increases, this head will increase, will go up. H will increase, please note because in the previous case also we have seen that this H has increased, right?

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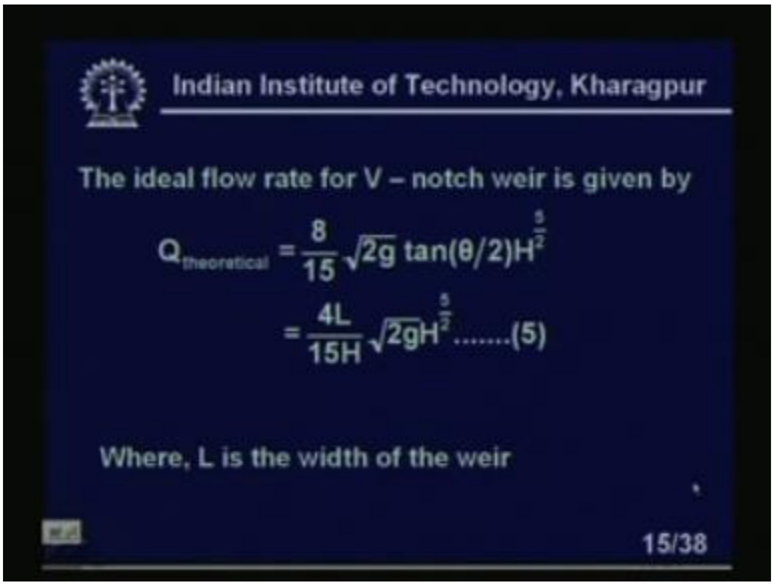

So, total, excuse me, the ideal flow rate for V notch weir is given by Q theoretical equal to 8 by 15 under the square root of 2 g tan theta by 2 H to the power 5 by 2

4 L by 15 H. If I replace tan theta by 2 under the square root root 2 g H to the power 5 by 2, this is equation number 5, where L is the width of the weir or length of the weir or width of the weir; whatever you say, it is same thing, right? So, it looks like this you see. We have seen that, anyway. You see here.

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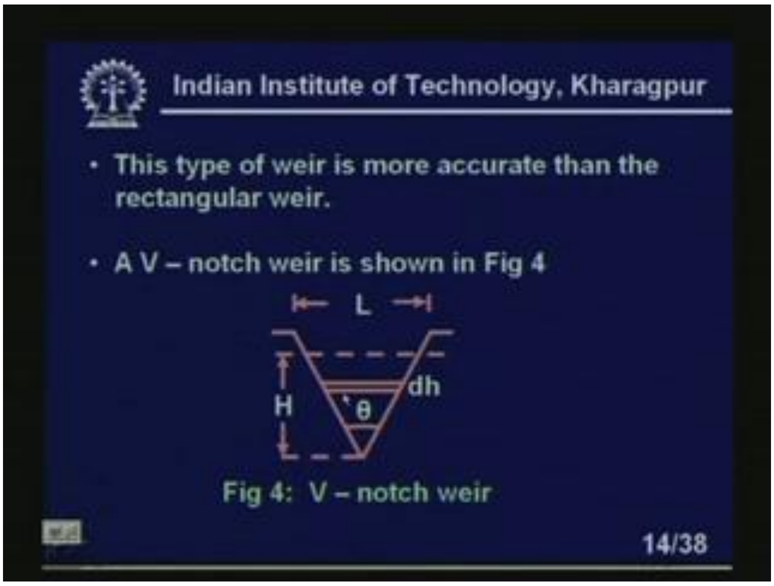

So, this is included angle theta, so tan theta will be how much? Tan theta will be L, L by 2. This total is L, so it is L by 2 divided by H, if I take the tan theta.

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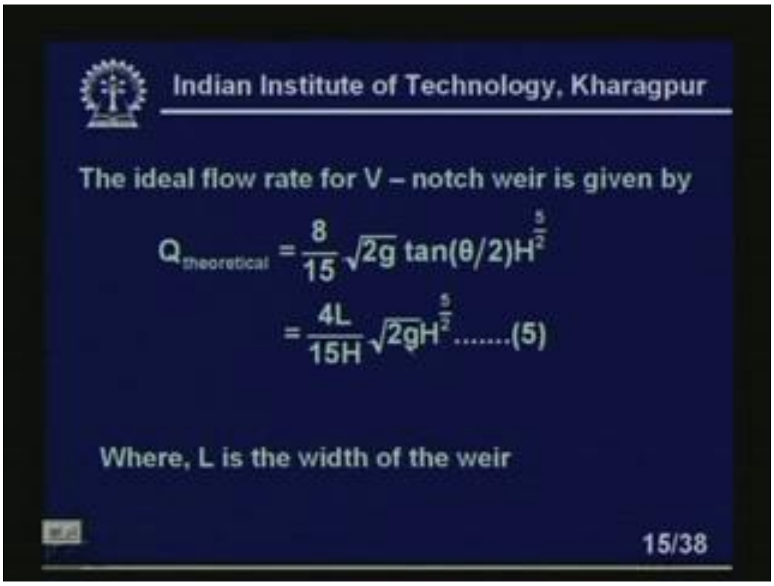

So, exactly that thing I did in the next slide. So, tan theta by 2 is replaced by, I mean L by 2 divided by H. So, it will get 4 by 15 H root over 2 g H 2, where L is the width of the weir. So, what is the variable here? In the Q theoretical also you see H. As the liquid flow, volume flow rate increases, H will increase, right? The height or head of the weir is increased. This H is to be measured by some means or the other, right?

All other things are constant, L are constant, g is also constant, so it is quite nonlinear, as you can see. So, this H is to be measured and this height is calibrated in terms of the volume flow rate.

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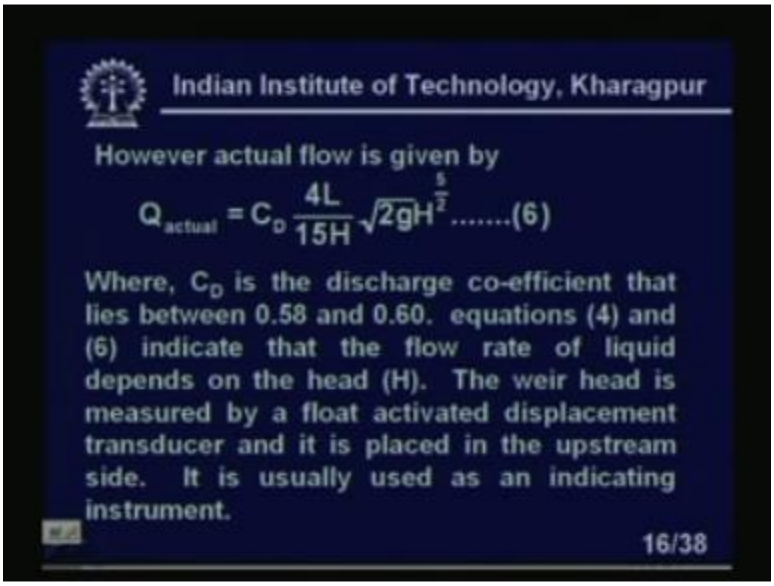

However, the actual flow rate, as it happens in the case of the rectangular weir also, we will find the actual flow rate will differ from the theoretical flow rate. So, it is to be multiplied by discharge coefficient C D 4 L by 15 H, so under the square root 2 g H to the power 5 by 2, equation number 6, where C D is the discharge coefficient that lies between .58 to .6, because this is experimentally found. It is very difficult to find the theoretical value of C D. So, what the people did, they have taken some standard and compared and found the C D value.

The equations 4 and 6 indicate that the flow rate of the liquid depends on the height or the head capital H, right? So, that capital H is to be measured. What is the capital H? That is the upstream height of the, upstream flow from the crest of the weir, right? What is that? Very clearly, let us quickly look at. H, I have to measure, some way or the other.

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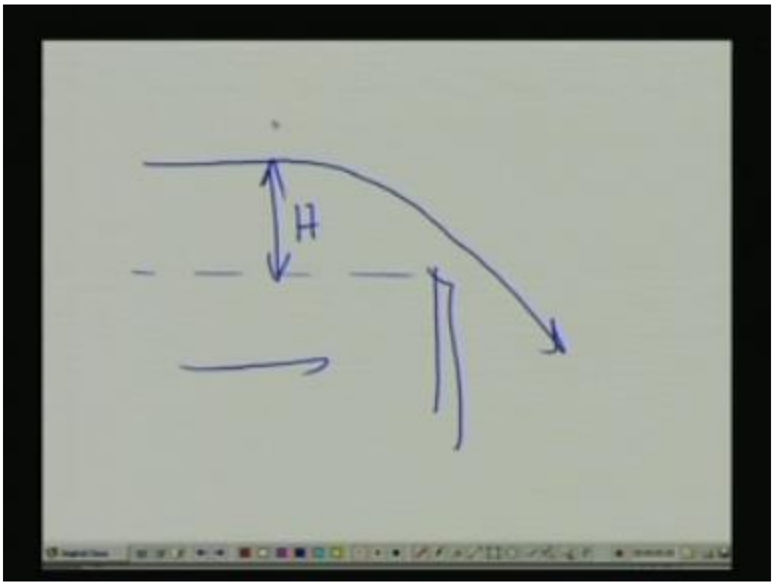

What is that? That means I have, a liquid is flowing, right? So, I have a liquid flowing like this one, undisturbed. So, this H is to be measured. As the flow rate increases, this H will increase. If the flow rate decreases this H will decrease, right, clear? Even though it is nonlinear, I mean, relation but if the flow rate decreases, this H will decrease, if the flow rate increases this H will increase, right? So, I will measure the H and calibrate H in terms of the flow rate, fine, right?

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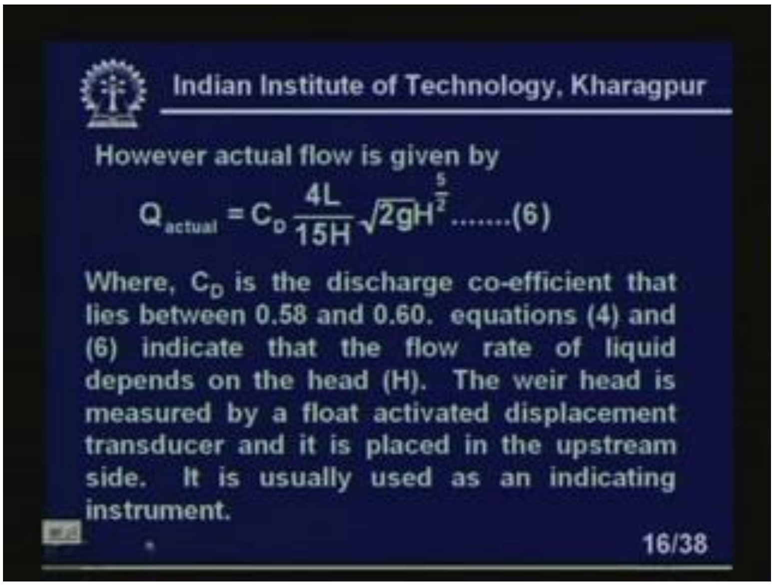

Now, as I told you earlier also, you see, the weir head is measured by a float activated displacement transducer and it is placed in the upstream side and it is usually used as an indicating instrument. It is not for the, I mean transmitting instrument. People tried even though, I mean transmitting, but it is not for the, I mean actually it is indicating or monitoring instruments.

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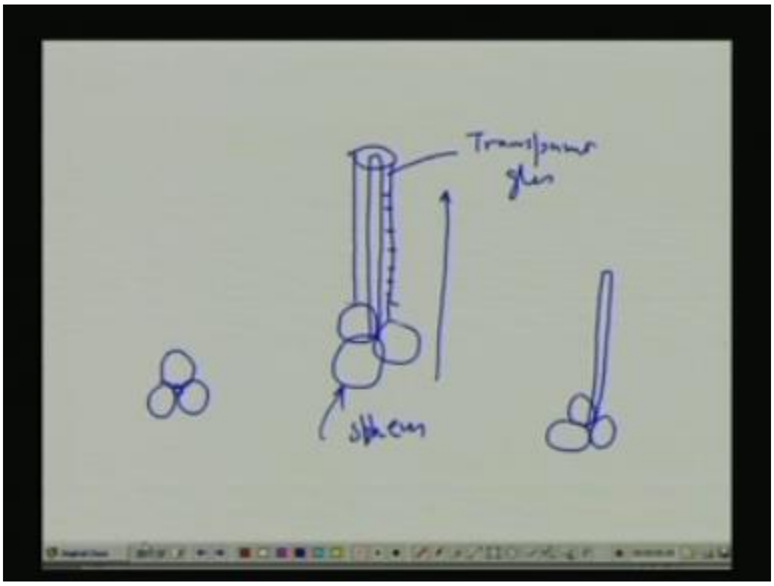

Usually what they do, you see, in the upstream sides, I mean they are making a, sometime they are making a float like this one, right? So, one like this one, so there is a, it is put on a cylinder, right, a transparent glass. This is actually spheres which act as a float. So, what will happen? So, this is put on the upstream side, right? What will happen? If the water level increases, so this float will go up. This float will go up like this one, right? This float will go up like this one and if you have a graduated scale here on the glass itself, so I can measure this height and calibrate the height in terms of the flow.

So, these are basically, for balancing if you use single that …. problem of balancing, so they use three. Actually if we take a top view three spheres like this one, 120 degree apart, three spheres made of plastics and put. If I take top view you cannot see. So, I take like this one, right? If I take a side view, it will be like this one; three spheres, so one float. So, as the liquid, I mean if the flow increases this will go up. So, this is calibrated in terms there, so this is all about the weir.

Now weir, as I told you, there is no other alternative for irrigation purposes for making the and it is quite robust. It is not that accurate obviously, but it is to get an estimate of the flow of the fluids especially in the irrigation purposes, right?

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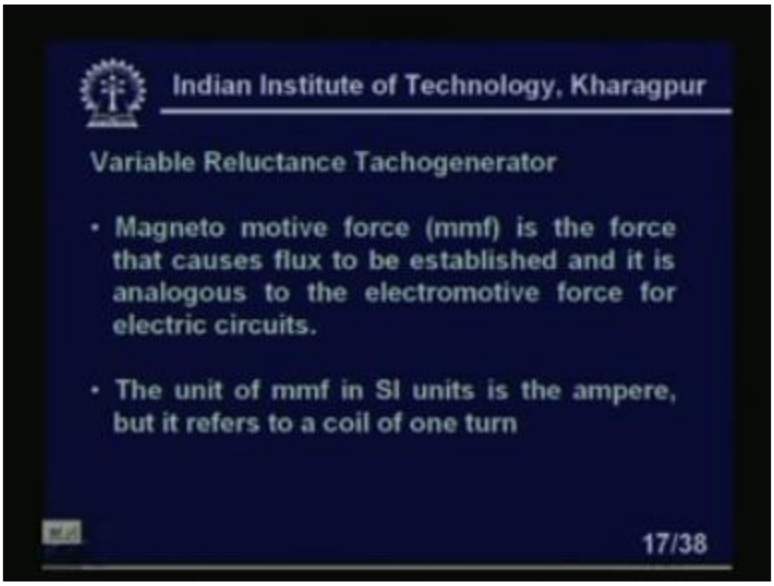

Now, our next transducer which we will discuss is the, basically we will discuss the turbine flowmeter which is direct electrical leading flowmeter. But, to know the turbine flowmeter we must first look at the variable reluctance tachogenerator and what is the, some basic terminology of the reluctance and magnetic force we must tell in brief and its units in SI, then we will go for turbine flowmeter. First we will look at the variable reluctance tachogenerator, because exactly that principle is used to make the flowmeter.

So, let us look at magneto motive force. Magneto motive force is a force that causes flux to be established and it is analogous to the electromotive force for electric circuits, right? The unit of mmf, we write, magneto motive force we write mmf in SI units is the ampere. It is actually ampere turns, but it is actually telling about the single turn, but it refers to a coil of one turn, right?

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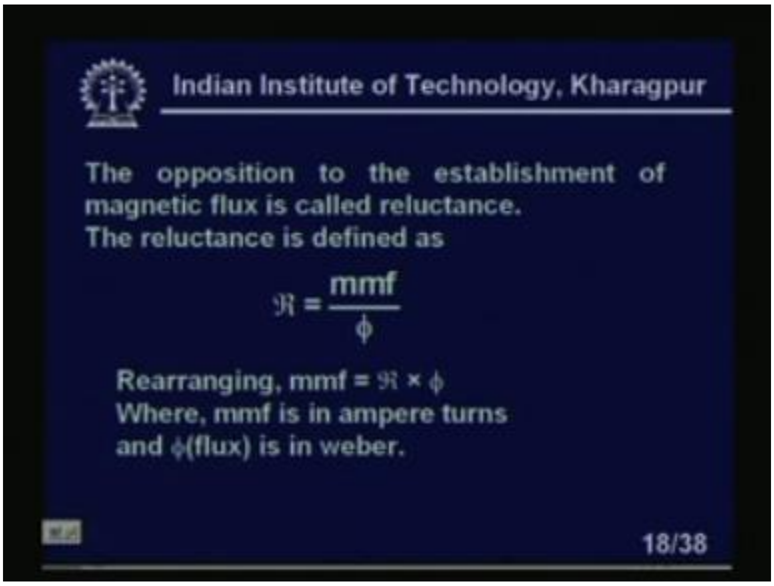

The opposition to the establishment of magnetic flux is called the reluctance. Now reluctance, whenever reluctance increases your flux decreases. If the flux increases reluctance decreases, right? So, the reluctance is defined as R equal to mmf, magneto motive force divided by the flux phi, right? Rearranging, I can write mmf equal to R multiplied by phi, right, where mmf is in ampere turns, if the number of turns is more than 1 and phi is the flux, is in Weber.

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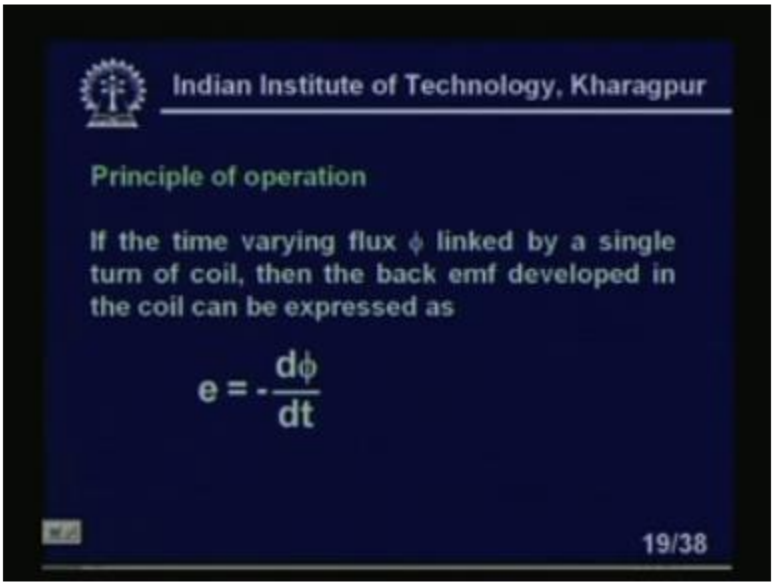

Now, principle of operations of this variable reluctance tachogenerator let us look at. Now, if the time varying flux phi linked by a single turn of coil, all of you know now the basic principle, then the back emf developed in the coil can be expressed as e equal to minus d phi by dt, right?

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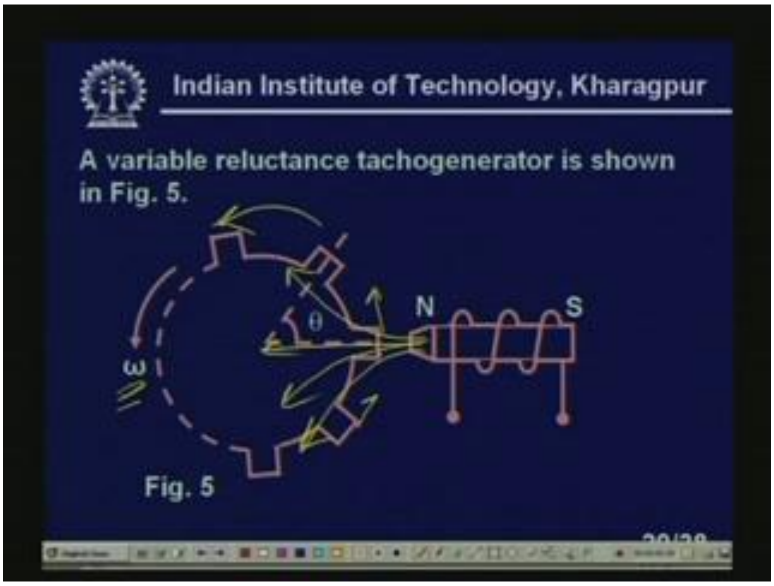

Here you can see the variable reluctance tachogenerator shown in figure 5. You see this, we are showing a wheel with teeth or blade, whatever you say. There are several teeth you can see or blade, several teeth here and this wheel is made of, this teeth actually is made of ferromagnetic material. Please note, this is made of ferromagnetic material and a coil is wound on a permanent magnet and this pole piece is made up of soft iron. So, what it that? This coil is wound on a permanent magnet. This pole piece is made of soft iron and this teeth is made of ferromagnetic material.

Now you see, what will happen? There is, a flux will be developed, is not it? How it looks? You see, the flux will just go like this one. Sorry, if I take a new page, I think we must go back, so if I take some other colour, I think let me choose this colour, so the flux will look like this one. So, it will go like this, go like this, go like this, go like this, in this …., is not it? Then, what will happen you see? You see, what will happen that when the, when these teeth or blade comes to the, very close, actually this gap is very small. Just for, I mean sake of understanding we have drawn in such a, I mean larger gap. Theoretically this, I mean actually, in the actual, in the variable reluctance tachogenerator this gap is very small.

Then, what will happen? In this case whenever it comes to, very close to this, reluctance will be small, flux will be high and in between the teeth. Suppose this is, this wheel is rotating in a direction, in a, in a, in an anticlockwise directions with an angular velocity of omega, you see this one, you see this is the angular velocity. Wheel is rotating with an angular velocity of omega, right? Now, what this angle is theta. What will happen? You see if this rotates, if the wheel rotates like this one, right, then what will happen?

If it rotates, so whenever this wheel, I mean in between the two teeth, suppose the teeth has gone down this direction, this teeth has moved to this, now this pole piece faces the, the gap in between the two teeth. Then, what will happen? The reluctance will increase. So, there is a change of magnetic flux, right, right? So, what will happen? This output voltage, there will be variable output voltage. Time varying output voltage we will get if it rotates with the speed of omega, right? So, using this principle we will find, we have made the turbine flowmeter. So here, again I will repeat this is made up of permanent magnet, right and this pole piece is made up of soft iron and this teeth is made of the ferromagnetic material.

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Now, the teeth of the wheel moves in close proximity to the pole piece. It is, I mean very close to each other as I told you, because for the sake of understanding we have drawn that much of gap, but it is, actually there is no gap.

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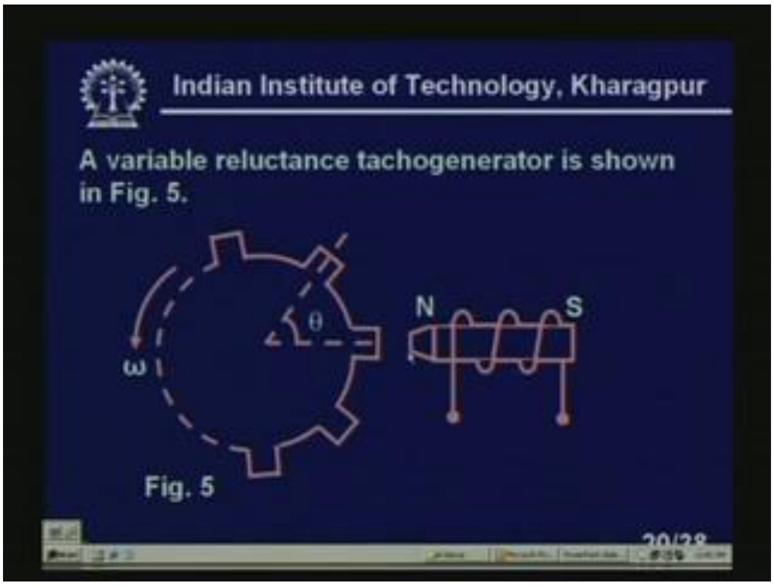

This gap is very, very small, right? This gap is ultimately, there is no gap at all, so it should come very close to this, right? This will come very close to this. That means if

I take it, so this will come very close to this, right? That you please note. So, it should come very close to this like this one anyway.

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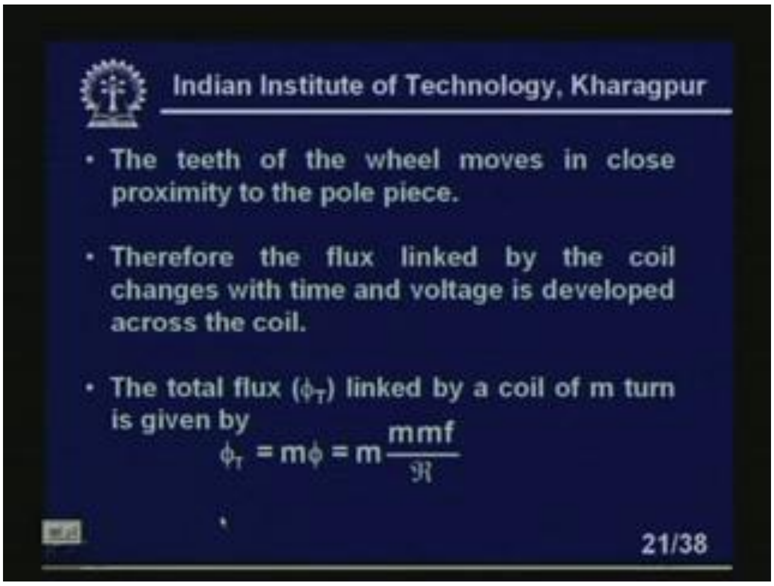

So, the teeth of the wheel moves in close proximity to the pole piece, as I told you. Therefore, the flux linked by the coil changes with time and the voltage is developed across the coil. The total flux phi subscript capital T linked by a coil of m turn is given by phi T equal to m phi m mmf into divided by R. R is the reluctance, the number of turns of the coil is m. So, it will given by m into mmf by R.

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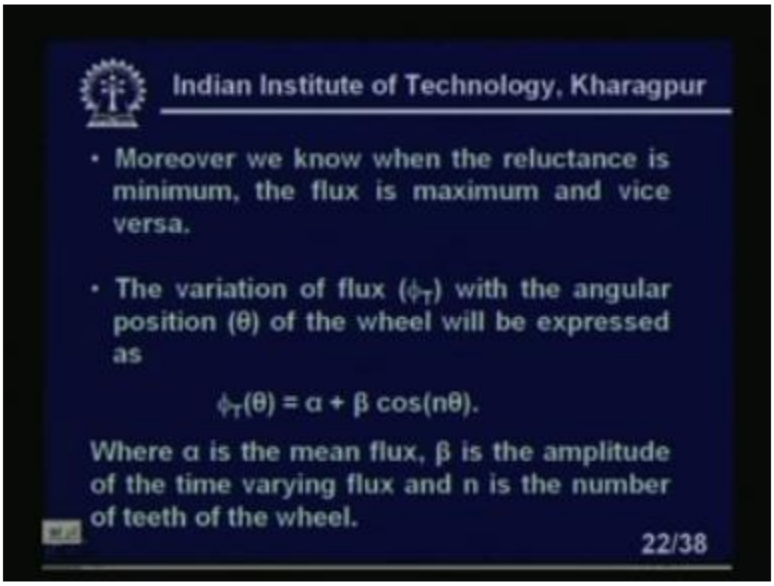

Moreover, we know that when the reluctance is minimum the flux is maximum and vice versa; that I have explained to you already. The variation of the flux phi T with the angular position theta of the wheel will be expressed as, this will be expressed as, since it is a sinusoidal variation, we can express as phi T theta equal to alpha plus beta cos n theta. What is this abbreviation let as look at, where alpha is the mean flux and beta is the amplitude of the time varying flux and n is the number of teeth of the wheel. There might be 4 wheel, there might be 4 teeth, there might be 8 blade. So, here in this case we assume that the number of, number of teeth is n. So, we can write phi T theta is time varying, theta total flux with respect to the angular position of the wheel is equal to alpha plus beta cos of n theta, clear?

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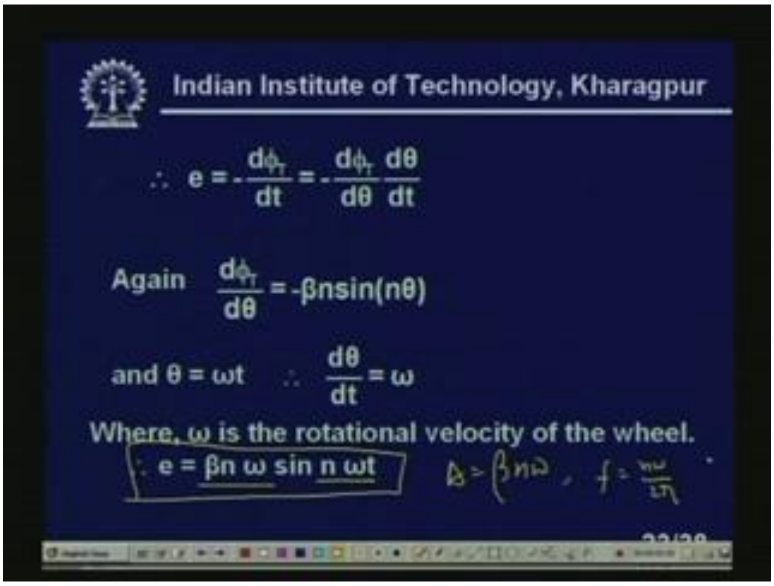

So, e the output voltage which we will receive at the coil is given by minus d phi T by dt. Total flux equal to d phi by minus d phi T by d theta into d theta by dt; that always we can write, is not it? So, again we know that the d phi if I differentiate by previous expressions that means if I differentiate this expression, so I will get, if I differentiate this expression I will get d phi T by d theta, minus alpha will cancel, alpha, d alpha by d theta is zero, so minus beta plus into n sin of n theta.

Now, theta is the, omega is the circular frequency and theta is an angle at instant of time. So, if we multiply by, omega by t, I will get theta. Obviously, theta should be in radiance. So, d theta by dt equal to omega. Quite obviously, if I differentiate this with respect to t, I will get omega. So, I will substitute all these in this equation, in this expression, right? In this expression, I will substitute this value of d theta d phi T by d theta and d theta by dt I will substitute in this expression. So, I will get, where omega I should say is the rotational velocity of the wheel. Now e equal to beta n omega sin n omega t.

What does it mean? It means, you see that the output voltage from the variable reluctance tachogenerator is a function of the angular frequency, amplitude of this. It is sinusoidal signal, the output voltage. If it rotates at a constant velocity of circular frequency omega that means the wheels rotate at the constant velocity of circular frequency omega, then you will find that the output voltage is expressed as beta n omega. So, this is very, very important expression. So, I should write, so what is amplitude? Amplitude is beta n omega of this output signal and with the frequency of n omega. That means I can say the amplitude of this signal that means I will get an output voltage if it rotates at a constant angular velocity beta n omega and a frequency. This is amplitude that means A and the frequency is equal to n omega by 2 pi, is not it, I mean a linear frequency. So, output voltage depends on both.

So, later on we will see that, we will little, make some little manipulations of the or little signal processing by which I want to make that output voltage will be only proportional to the frequency of rotation; that the frequency increases our output voltage also increases. But here it is not, because if the frequency increases amplitude also increases. You have your, the, I mean flow velocity, if the, if the number of rotation increases, number of the wheel rotating that is increases, this omega increases your output voltage also increases. But that does not depend directly only on the omega. Your amplitude increases your frequency also changes. So, two are changing simultaneously. That is not very desirable property, right?

Now, in turbine meter exactly this principle is utilized, right? This principle is utilized in turbine meter.

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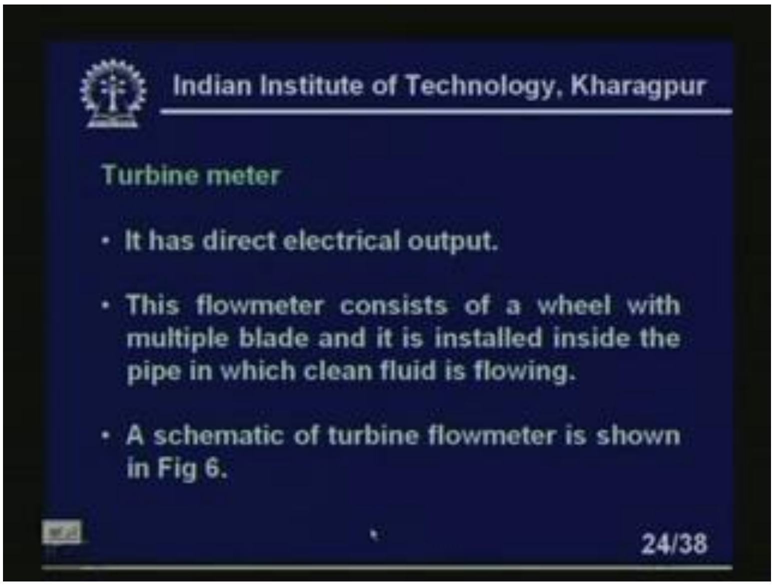

You see, what will happen? It has direct electrical output. It is a great advantage. In the, the other flowmeters we have seen that we have to make, lot of manipulation of the signal processing we have to do, like differential pressure flowmeters, rotameters, we have seen that there is a lot of, pitot tubes or we need a different lot of signal conditioning. Sometimes it is not signal conditioning circuit, in that sense it is a electrical. Sometimes you will find this pneumatic signal is coming. You have to convert with DP transmitter and so many things are necessary which is not necessary in the case of this type of direct electrical reading meter.

No, it is not much in use, because of some disadvantages anyway. It has a direct electrical output. The flowmeter consists of a wheel with a multiple blade. Now, I am telling here blade, because the shape is like a blade in the case of turbine meter. But the blade, whatever I am talking now it is similar, exactly similar to the teeth in our wheel of the just discussed variable reluctance tachogenerator, right? So, there is no distinction between the blade and the teeth, please note it and it is installed inside the pipe in which clean fluid is flowing. This clean fluid, the term clean is very important, you see it should be clean. Liquid should be clean, otherwise there is a problem. That we will discuss later on.

So, the flowmeter consists of a wheel with the multiple blades and it is installed inside the pipe in which the clean fluid is flowing. A schematic of turbine flowmeter is shown in Figure 6. I will show you the turbine flowmeter.

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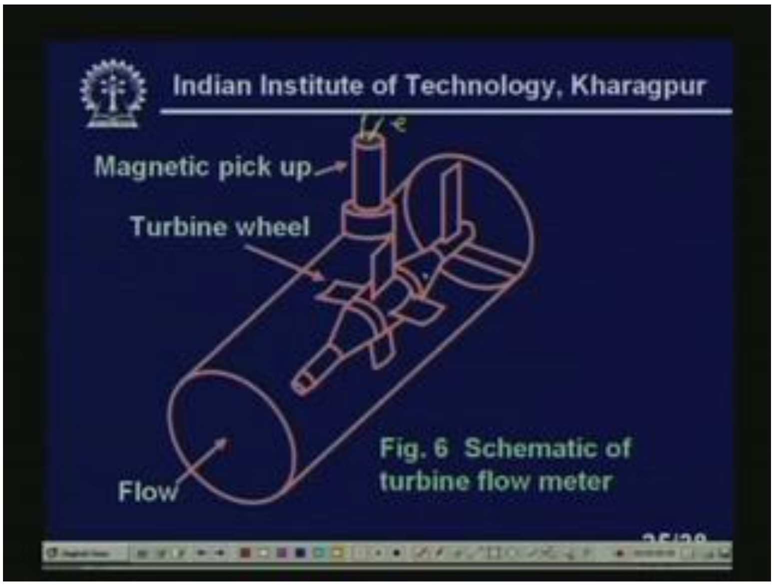

You see, this is our turbine flowmeter. So, we have a magnetic pick up. What is that magnetic pick up? This is a permanent magnet on which the coil is wound. In fact, there should be a, two terminal should come out. So, two terminal will come out, right? These two terminals we will measure the voltage E, right?

What is this inside the magnetic pick up? This is the magnet. These blades are, are made up of ferromagnetic materials. We have shown the 4 blades, right, 4 blades. You see, these are in angle, little angle, so the, when the flow is, when the liquid is flowing, it is impinging on the blade. If it impinges on the blade, so this, this will start to rotate. If it starts to rotate, then what will happen? If its angle is like this one, if it is like this one, then what will happen?

If I take a camera like this one, you see here if the blade is slightly like this, likely it happens in the case of, so liquid will flow over this one, right, in this direction. So, what will happen? You see here in this direction, so it will start to rotate, right? So, similar thing, So, this is made of ferromagnetic materials. I have a magnetic pick up here. What is that magnetic pick up? It is made up of permanent magnet on which the coil is wound with soft iron of pole pieces. Since it is a ferromagnetic material, whenever it rotates, for each rotation or whenever this blade passes this permanent magnet, I will get a pulse at the output or I will get a time varying signal at the output. So, that will be calibrated in terms of the flow, right?

Let us look at the details of this one.

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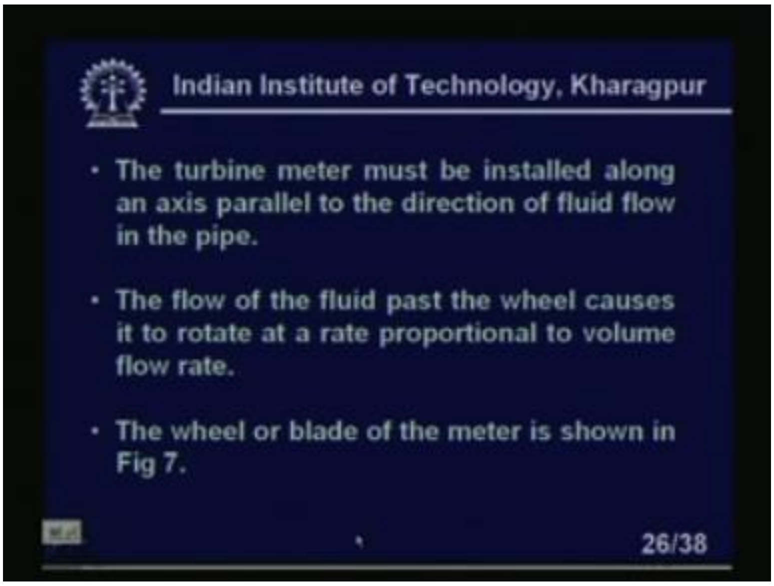

The turbine meter must be installed along the, along an axis parallel to the direction of fluid flow in the pipe, right? The flow of the fluid past the wheel causes it to rotate at rate proportional to the volume flow rate. It should be proportional to the volume flow rate. The wheel or blade of the meter is show in Figure 7.

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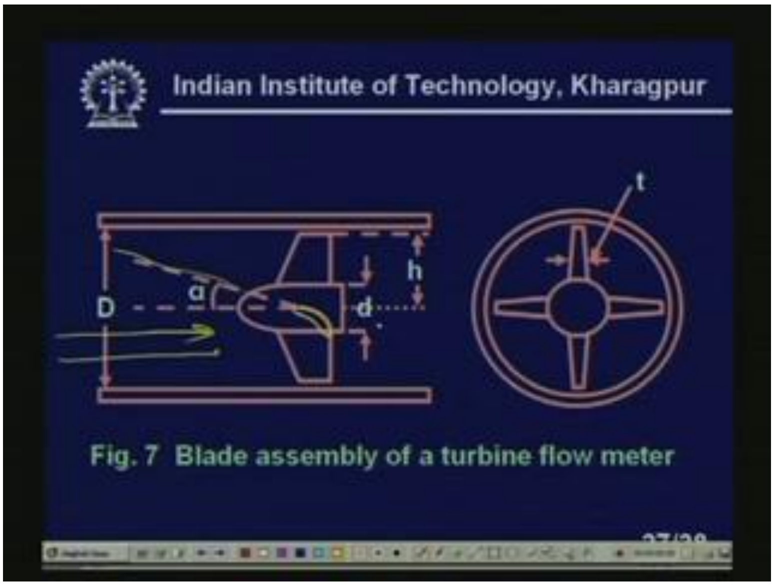

You see this little bit, this, each wheel causes an angle of alpha, right, angle of alpha and you see here the wheel. Actually if I take from the, along the axis of the pipe, the wheel will look like this one. This blade will look like, …. the thickness t and it has an angle alpha. It is actually, it looks like this, so that it will have an angle like alpha, like this one, right? So, this is angle alpha, right? So, the water is, water or liquid is flowing like this one. It is hitting this blade, so it starts to rotate in this direction, right?

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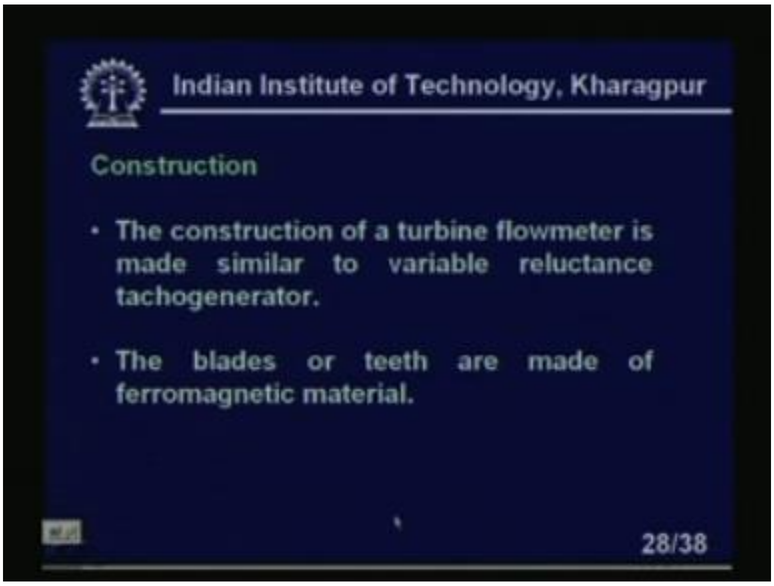

Construction, you see the construction of a turbine flowmeter is made of, similar to variable reluctance tachogenerator, no difference. The blades or teeth are made or teeth are made of ferromagnetic material.

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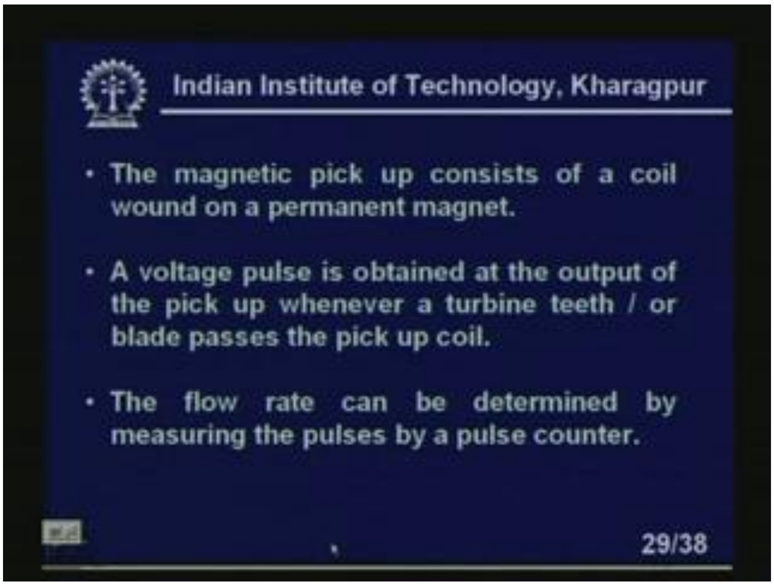

The magnetic pick up consists of a coil wound on a permanent magnet. A voltage pulse is obtained at the output of the pick up, whenever a turbine teeth or blade passes the pickup coil, as I told you. The flow rate can be determined by measuring the pulses by a pulse counter. So, if I can measure the pulse count, I can measure the flow rate, as simple as that. Moreover, I can find the total volume flow rate if I count the number of pulses over a certain period of time. That is the great advantage of the turbine flowmeter that means the total volume of liquid flown over a certain period of time, ….

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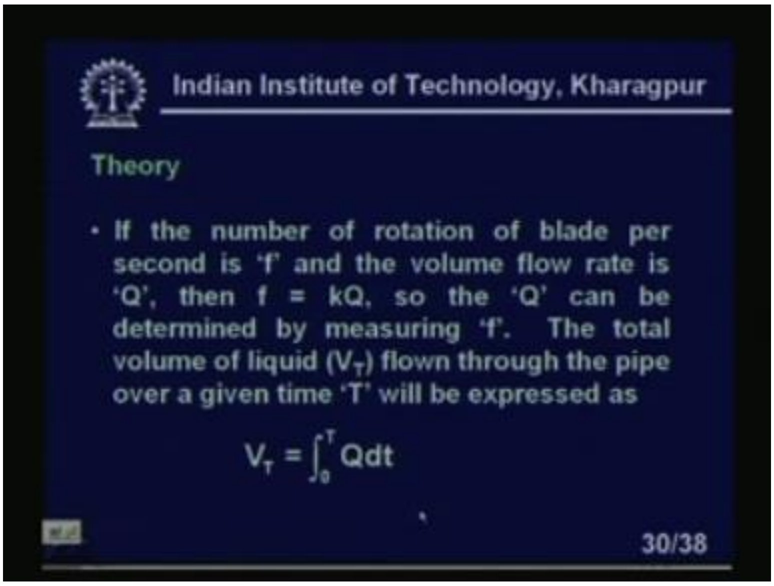

If the number of rotation of blades per second is f and the volume flow rate is Q, then we can obviously write f equal to k into Q, so the Q can be determined by measuring f. The total volume of liquid V T flown through the pipe over a given time T will be expressed as V T integral zero to T Qdt.

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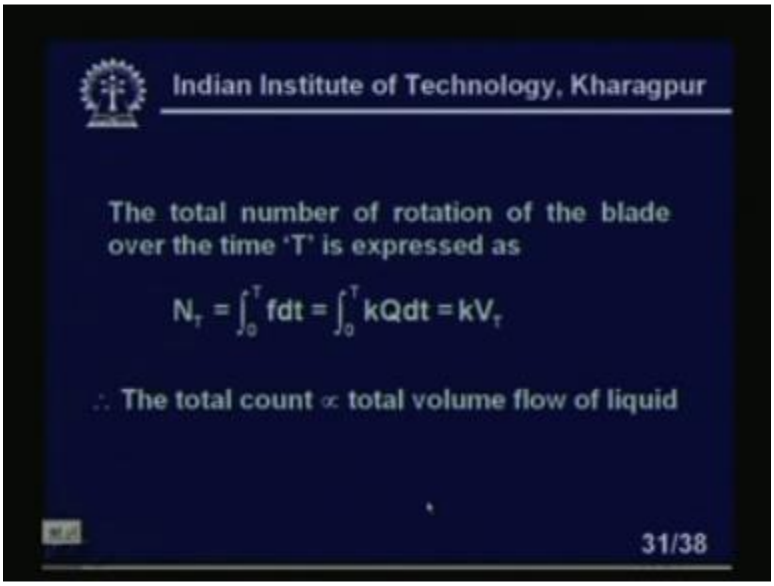

The total number of rotation of the blade over the time T is expressed as N T. Now we have, total number of count we have expressed T to zero f d t k Q dt into, so it is coming kV T, right? So, Q dt, so we are getting kV T, right? The total count is proportional to total volume flow of the liquid. Obviously, this we can measure by some counter, so which will give me the total volume flow of the liquid, right?

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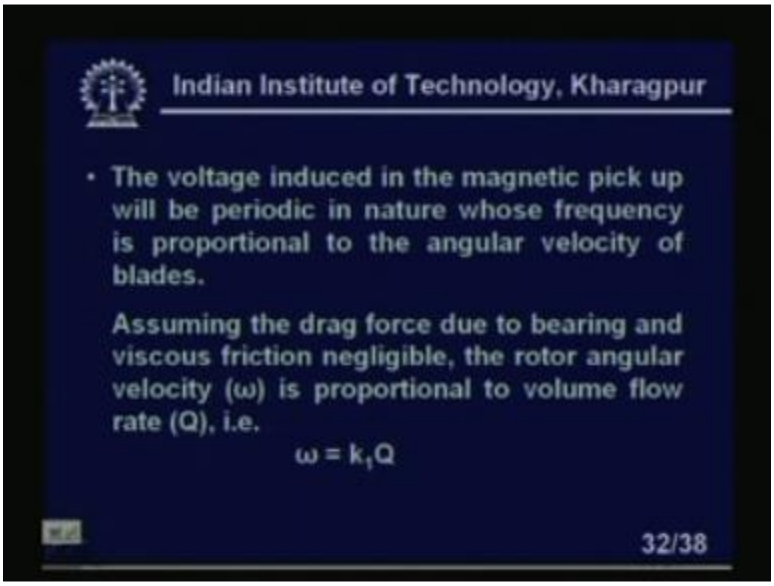

The voltage induced in the magnetic pick up will be periodic in nature, whose frequency is proportional to the angular velocity of blades, right? So, assuming the drag force due to bearing and the viscous friction negligible, the rotor angular velocity omega is proportional to the volume flow rate given by, obviously what will happen? As the volume flow rate increases, your, the velocity increases, obviously the omega also will increase. Omega depends on what? The omega depends on the velocity of the fluid flowing through the pipe. So, in turn if I, velocity if I multiplied by the A, the area of the cross section of the pipe, so obviously, I mean, I mean minus the area taken by the hub and all these blades and all those things, I will get the flow velocity, I mean the angular velocity.

So, I can say that the angular velocity will be proportional, angular velocity of the turbine flowmeter is proportional to the volume flow rate. So, that is actually we have written.

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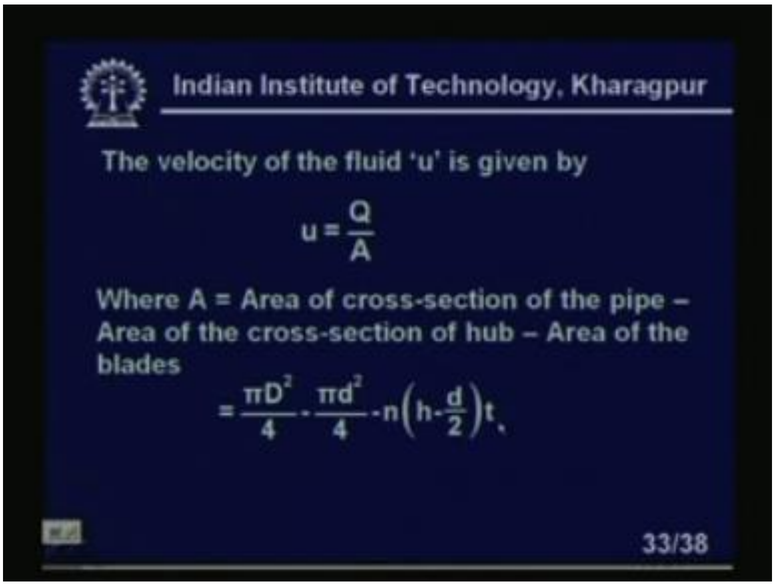

So, the velocity of the fluid is given by u equal to Q by A, right? A is the area of the cross section. Now you see, where A is the area of the cross section of the pipe minus area of the cross section of hub and area of the blades. So, that we have written pi D square by 4 minus pi d square by 4 n h minus d by 2 into t. So, this will be very clear, you see here. As you can see from the, I mean in the, in the, from the constructions you will see it is very much clear.

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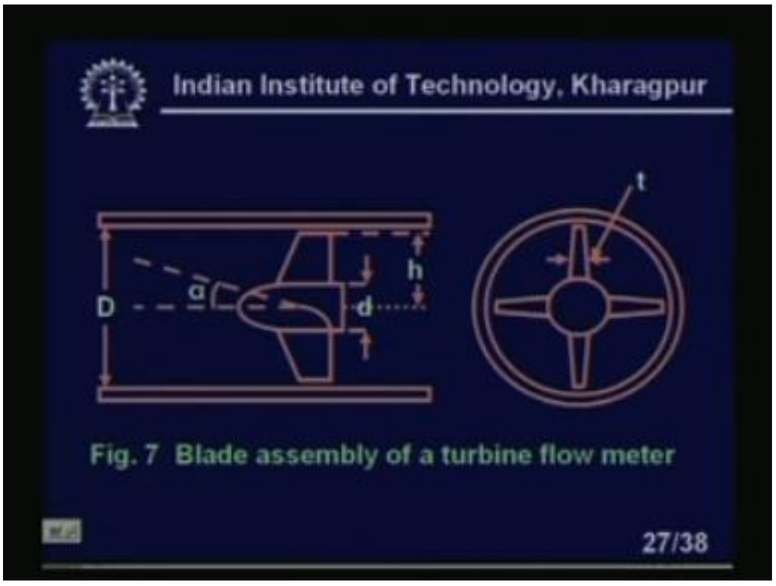

You see here, so this is h. h will not be exactly d by 2. Please note, h is not exactly d by 2, because there is a gap. There should some gap to, because you have to give some space to rotate, right?

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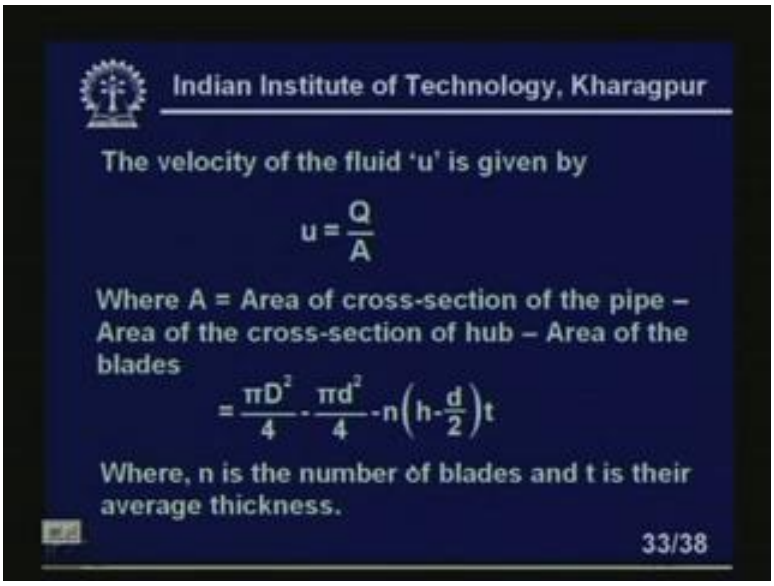

So, this is our expression. We have shown pi d square by 4. The total area of cross section of the pipe minus the hub, the area taken by the hub minus the area taken by the blades, right? So, all these things if I, so where n is the number of blades and it is and t is their average thickness.

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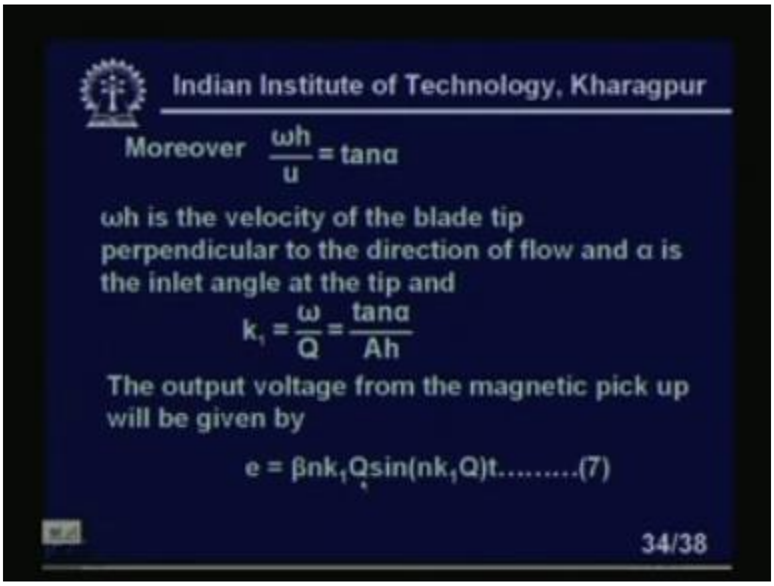

So, moreover we have seen that omega h by u equal to tan alpha by in fact, omega is equal to tan alpha, is not it? Exactly, so omega h is the velocity of the blade tip, because that is the circular cross section, circular frequency multiplied by h is the velocity of the blade, blade tip and is because h is the, actually if you look at, h is the, h is the height of the blade from its central position, is not it? See, if I multiply by the omega, so it will give the speed of the tip of the blades, right, per second. It is the velocity of the blade tip perpendicular to the direction of flow.

Obviously that is very much clear, because the liquid is flowing in this direction, so the blade is rotating in this direction. So, if the direction of the flow is this, the blade will rotate in this direction. So, I can write that alpha is the inlet angle at the tip.
So, k 1 equal to omega by Q equal to tan alpha by Ah, right? So, the output voltage from the magnetic pick up will be given by beta nk 1 Q sin nk 1 Q by into t, equation number 7.

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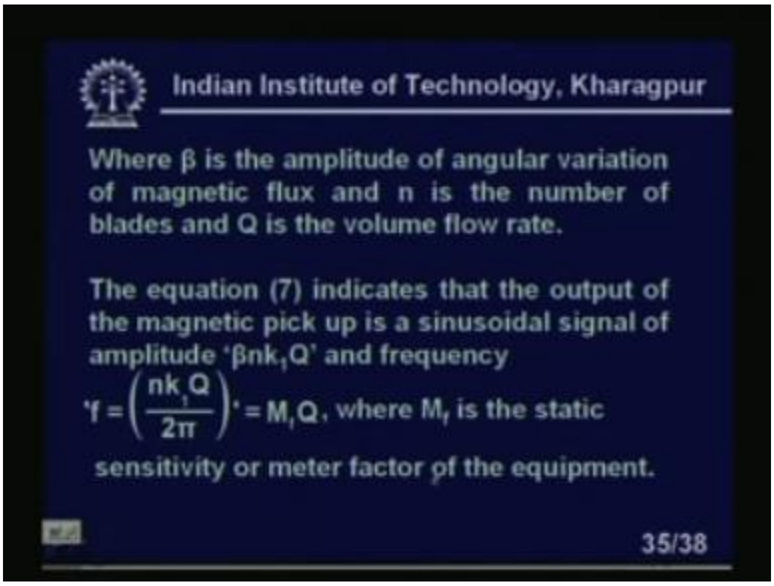

Beta is the amplitude of angular variations of magnetic flux and n is the number of blades and Q is the volume flow rate. The equation 7 indicates that the output of the magnetic pick up is a sinusoidal signal of amplitude beta nQ and the frequency is nk 1 Q by 2 pi, where, which can be written M f into Q, where M f is the static sensitivity or the meter factor of the equipment, right?

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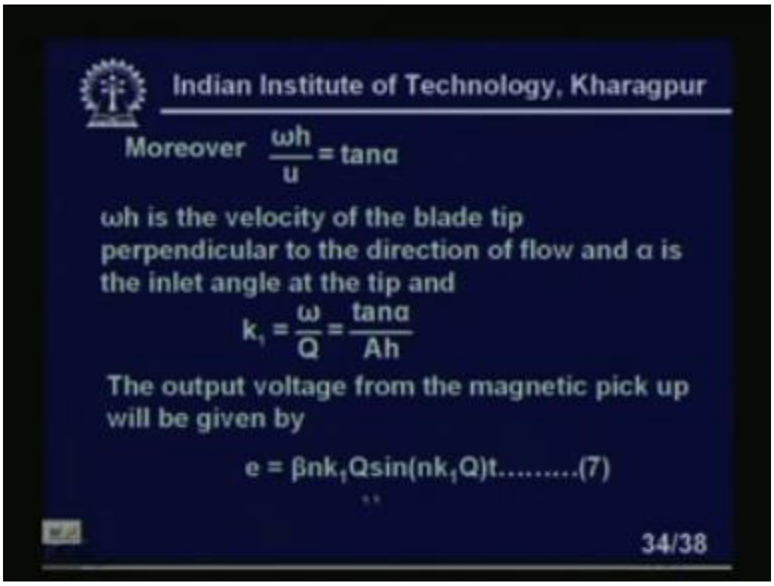

Now, you see, one thing you must note that if I look at here, if I look at in this expression, you will find this is a, again this is the expression what we are getting. You see that it depends on the frequency of number of, sorry, it is a, beta depends on what are the factor? Q. As the Q increases, this amplitude also increases. Q is the volume flow rate increases the amplitude increase. So, simply what they do actually?

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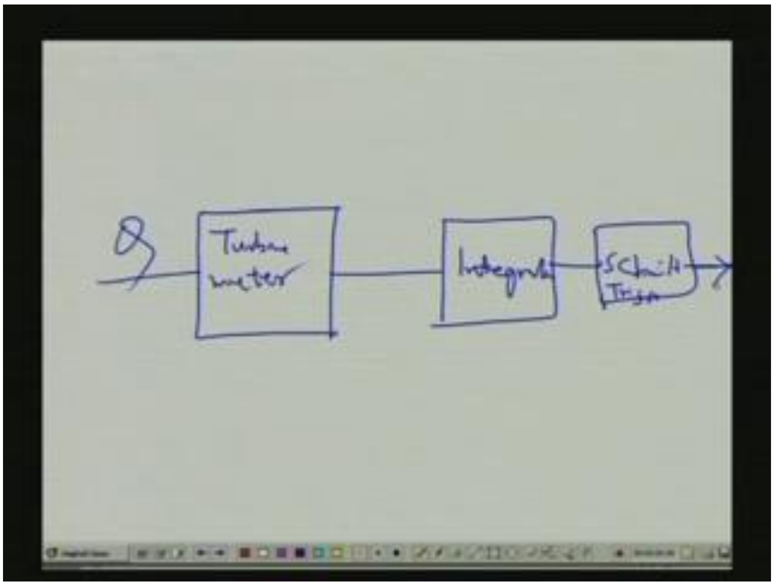

They take a, if I take, I have a turbine flowmeter, if I take a, sorry, so they take a meter then they pass through an integrator, our turbine meter. Then the integrator, then a Schmitt trigger. What will happen? You see, once you integrate, I will get a signal which depends, I will get a constant amplitude signal. I will get a signal which looks like this. You see here I will get a signal. This output of this Schmitt trigger is a constant amplitude signal, because Schmitt trigger is a pulse shaper, as we know. So, I will get a signal that depends only on the frequency. As the, that means that means as the flow velocity Q changes here both the amplitude of the signal also will change. Here it will not, because the …. of this amplitude will cancel out, flow will cancel out. The Q will cancel out.

So, at the output of the Schmitt trigger, I will get now only the frequency. So, the constant amplitude frequency I will get. So, that frequency can be calibrated in terms of the volume flow rate. Let us look at, let us go back again. So, that is actually they do in the case of meter.

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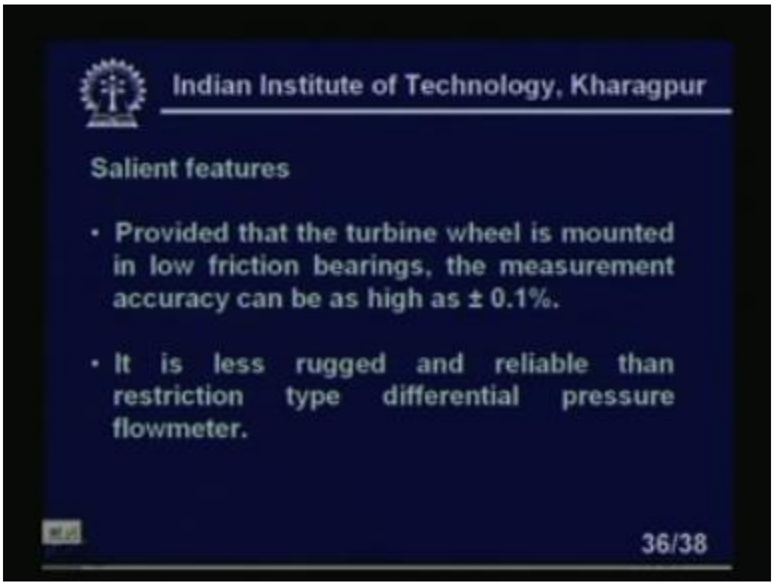

So, provided that the turbine wheel is mounted in low friction bearings, the measurements accuracy can be as high as plus minus 0.1%. It is less rugged and reliable than the restriction type differential pressure flowmeter.

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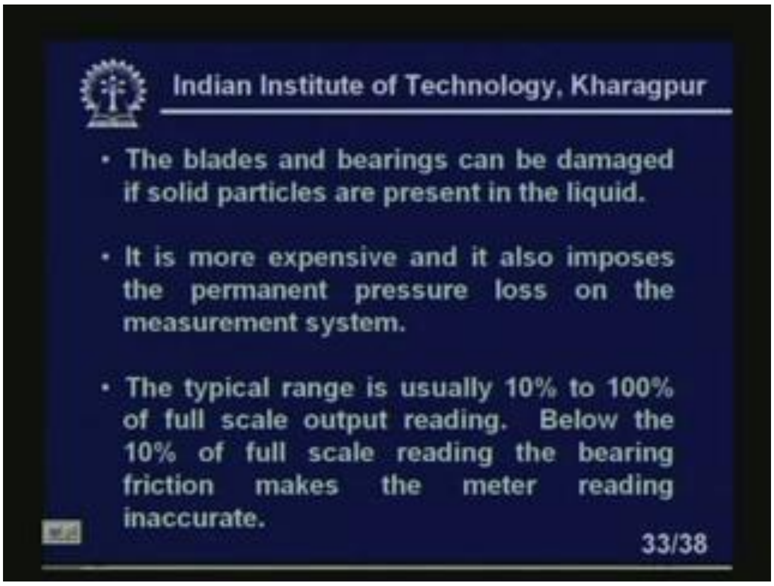

The blades and the bearings can be damaged if solid particles are present in the liquid. This is the most important point; liquid should be very clean, right? There is another problem. It is more expensive and it also imposes the permanent pressure loss on the measurement system. Even though it is not as high as, because we are, I mean putting some restrictions in terms of the blades and all these things, so extra pumping is here also, so it is not that it is totally open channel like, I mean it is not totally the permanent pressure loss free flowmeter.

So, there is a, some certain amount of permanent pressure loss in this type of flowmeter. So, the typical range is at usually 10% to 100% of full scale output reading below the 10% of full scale reading the bearing friction makes …

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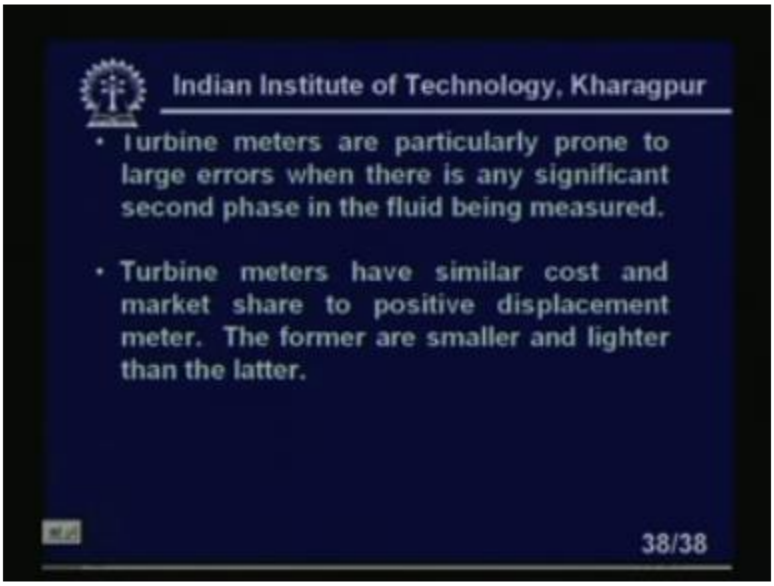

Turbine meters are particularly prone to large errors when there is any significant phase change in the fluid being measured. Turbine meters have a similar cost and the market share to positive displacement meter and the former are smaller and lighter than the latter, right? Now, this is the some advantage, but as I told you in the turbine flowmeter, the basic principle is that I am getting an output. The flow velocities which I am getting you see, it is I am getting a sinusoidal signal at the output of the turbine flowmeters. Since the basic means is similar as the tachogenerator, so as the flow velocity changes, amplitude changes as well as the frequency of the signal also changes, frequency of the sinusoidal signal.

Now, if I pass this signal through an integrator, then what will happen? So, this will cancel out. So, I can explain this again. Let us go back.

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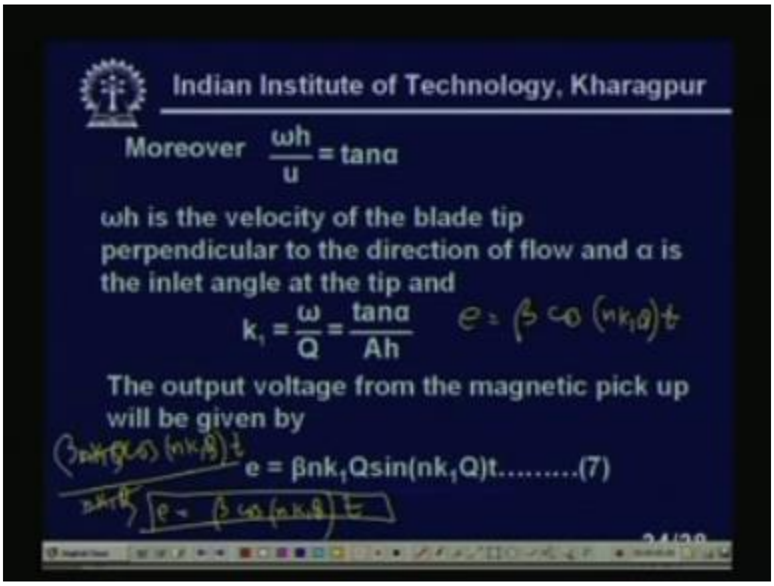

You see here, yes, here you see here, what will happen? So, if I integrate this signal, if I integrate this signal then what will happen, you see? So, I will get beta nk 1. If I take the different colour, please note so beta nk 1 Q cos of nk 1 Q into t divided by this nk 1 Q, so this nk 1 Q nk 1 Q will cancel out. So, after the integrations I will get, e equal to beta cos of nk 1 Q into t, is not it? You see here, right? I will write it clearly, e equal to beta cos of nk 1 Q into t. So, what does it mean? It means that you see that beta is a constant. It does not depend on the flow velocity. So, amplitude is directly proportional to the frequency.

Now, what will happen? It, I will pass that signal. After integration I will pass that signal through a Schmitt trigger. I will get a constant amplitude pulses, but the frequency will change as the flow velocity changes. So, if I measure the frequency, that frequency will be calibrated in terms of the flow, right? This is the advantage of this type of meter. So, with this I come to the end of the lesson 14.