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**Lecture - 7**
**Flow Measurement**

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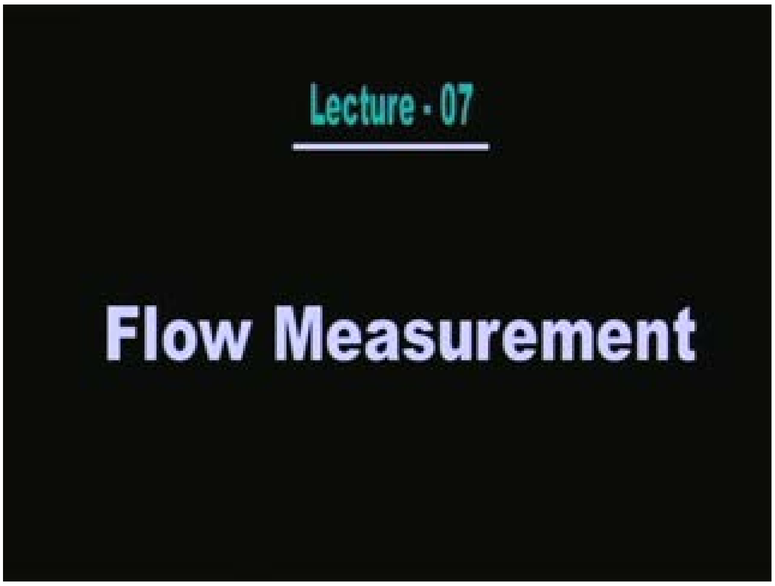


Welcome to lesson number seven. This lesson is on flow measurement. So, what are we expecting to gain from this lesson, let us see the instructional objectives.

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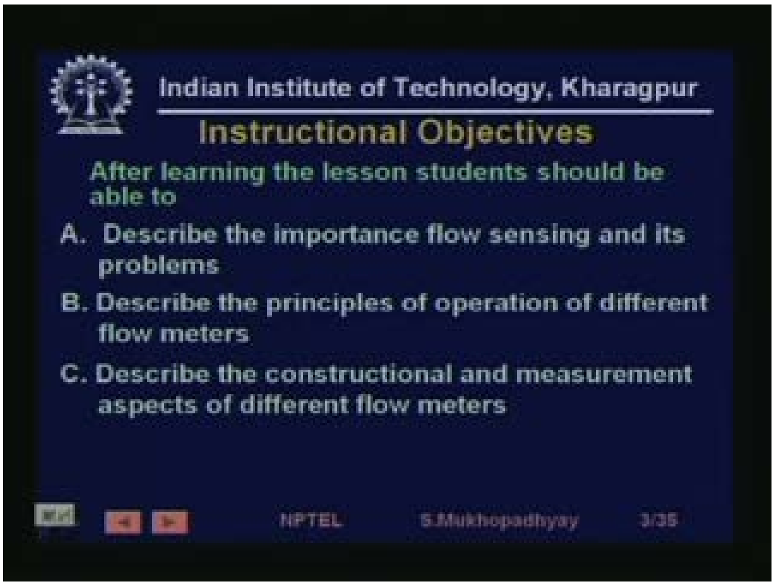

So, after learning the lesson the student should be able to, number 1 describe the importance of flow sensing and it is some of it is problems. Everybody describe the principles of operation of different flow meters, actually there are various principles we have selected some based on their industrial applicability. So, they will be able to familiarize themselves with these principles of operation, how they basically work. They will be able to describe the basic constructional features how it, what it looks like what are the different parts how they are made and the different measurement aspects.

What affects measurement when the measurement is good when it is bad. Finally, they will be able to see the merits and demerits and probably also compare when which particular flow sensor is to be used. So, these are the things that we expect to gain from this lesson. Now, let us go on into it.

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First the need for flow sensor. Flow sensors are needed flow is a very basic process parameter and it is needed flow measurement is for flow control and for flow metering. So, we need to know how much of a particular material has past sometimes. We also need to control the flow and it turns out that flow control is a very, very, very important particularly flow control is a very common and important control loop because of the fact that every other control. For example, temperature control or composition control in a reactor.

Temperature control in a heat exchanger, level control in a tank or pressure control in let us say an accumulator, where you know various time we accumulate hot gas. So, that you can use that gas to preheat. So, we can do pressure control. So, for doing pressure control we actually, I mean how do we control pressure, we actually open and close the inlet valve and for controlling that inlet valve we sometimes have a flow loop. As we will see when we will enter see the various process control loops in our process control module will see that how that is to be done.

So, it turns out that flow measurement is becomes an integral part of these. This apart from the fact that operators apart from flow metering and flow control just flow monitoring is important because operators need to keep an eye of them. So, there are whole arrays of instruments which will display simply display or log the flow.

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So, having said that, let us basically try to characterize flow meters. So, flow meters can be characterized in 2 ways. The first is obstructive or you know intrusive measurement. So, intrusive means that the instrument or the sensor will be put in the flow. So, it will affect the flow in even if in a small way, but it will affect the flow, it will obstruct it.

So, under the under this obstructive head we have, various kinds of flow meters and today we are going to look at differential pressure flow meters. Under that 2 major categories orifice meters and venturi meters.

Then rota meters which are also very, very common in the industry. Turbine flow meters and well there is a variant of turbine flow meters called paddle wheel meters which are also similar. So, we are going to look at only turbine flow meters. Then among the non-obstructive ones or the non-intrusive ones where the big, the medium is utilized for sensing, but as such the instrument is not placed in the flow.

So, you are doing the measure if it is flow in a pipe we are typically talking about flows in pipes we here we are not talking about open channel flows. So, if it is flow in a pipe then we have we are going to make the measurement from outside the pipe we are not going to put anything within the pipe. So, we have among that we have electromagnetic flow meters, we have ultrasonic flow meters and we have cross correlation flow meters. So, these are the various types of flow meters that we are going to look at today. Start with differential pressure flow meter.

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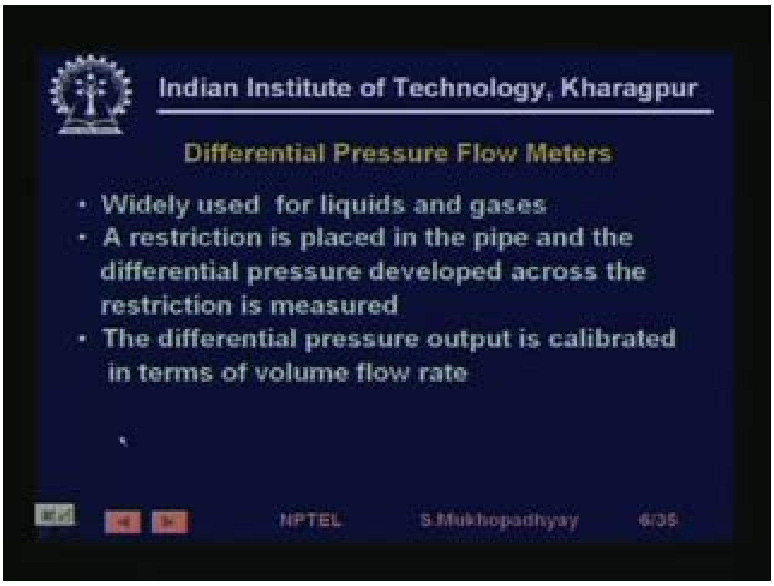


These are the most common and widely used for liquids and gasses in the industry and basic idea is that you place we will see it very soon. Basic idea is that you place a restriction in the pipe. That is the pipe is flowing at some point you obstruct the flow and you make a hole. So, now the liquid which was coming from this side, upstream when it meets the obstruction and the hole it has to flow through the hole.

So, in flowing past that hole where when the flow area is reduced it will develop a pressure across this obstruction. It is this pressure, which is measured and then calibrated in terms of the flow. So, this is that is why is called a differential pressure flow meter. So, basically we are obstructing the flow creating a differential pressure across the obstruction. And then measuring the differential pressure using some differential pressure measurement scheme which we see in the pressure measurement module right.

Then the then the differential pressure output is to be calibrated in terms of the volume flow rate. Incidentally in this particular case, we are only we are basically talking a volume flow rate. We are not talking of mass flow rates. Mass flow rate measurement requires 2 things. Firstly, it requires measurement of volume flow rates and it could also require measurement of density or sometimes it is done like that sometimes it is done directly. So, in this case we are talking about volume flow rates. We are also not talking of measuring linear velocity profiles where the velocity profiles are varying at different points of the flow field.

So, there are there are actually various kinds of flow measurement applications, but the vast majority of industrial applications require to measure the volume flow rate. So, we are going to concentrate on that. This pressure development when a flow is restricted is actually based on a principle called the Bernoulli's principle. So, what is that principle.

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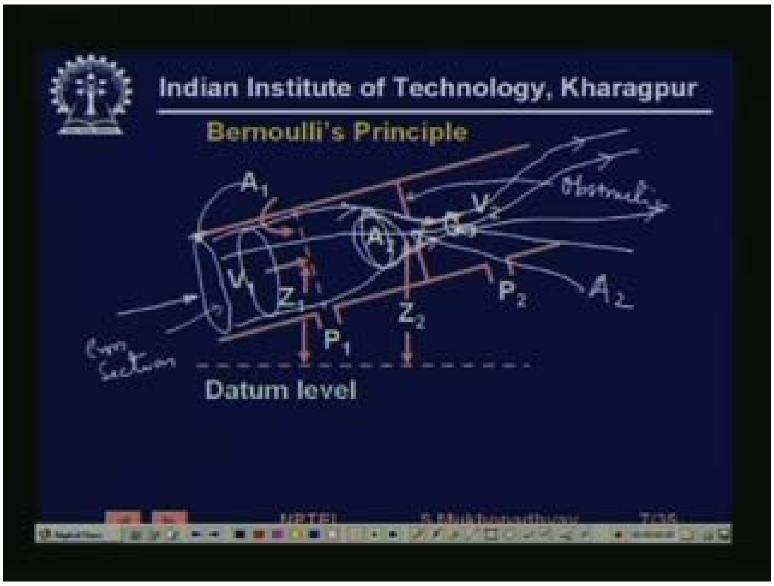


So, that principle says that if you have a pipe which is, this is a pipe through which the liquid is flowing let me select a pen here. So, the liquid is flowing this way. So, initially when it is flowing, it is flowing through this area cross section then at this point. This is cross section A 1 at this point there is an this is the obstruction it is simple, it can be a simple plate or the pipe itself can be made such that the such that diameter reduces.

So, this is the obstruction. So, now, the liquid which is coming will pass through like this and will again feel and go like this. So, these are the you know the liquid if you draw the set of so called stream lines although this is not laminar flow. Then the liquid flows like this. Now, So, you see that the area effective area of cross section on the 2 sides this is the obstruction or continuously changing. Here it is A 1 here it is slowly changing here it must flow through A 2, this is A 2 or A 2 here. Then it can it can get further reduced and will reach a minima. This position where the minimum area is reached is sometimes called the vena contractor.

Vena contractor and then it again spreads out and feels the pipe right. So, this is what is going to happen and Bernoulli's principle says, that if you have a fluid going, that is you know kind of it says that essentially there are three forms of energy in flowing fluids. One is it is kinetic energy which is due to it is velocity another is it is potential energy which is depending on at what height it is with respect to some daytime level, in this case this is the daytime level.

The third one is the pressure energy, which is which dependent, which depends of the pressure that exists in the fluid at that point of time. So, Bernoulli's principle says that if you assume that there is no friction loss then this energy is conserved. So, anywhere the some of these three energies are going to be the same.

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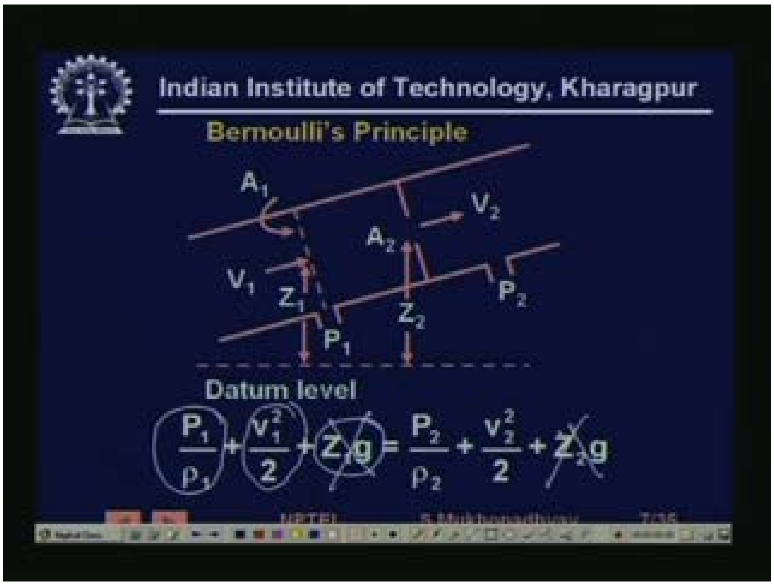


So, it says that this is the pressure energy, pressure energy is P by row. So, this is the pressure energy, this is the kinetic energy and this is the potential energy. So, it says that at any 2 points these are going to be conserved roughly. So, you get this equation if generally in our situation pipes are horizontal. So, if they are horizontal then Z 1 equal to Z 2 and you can ignore these 2 terms generally.

So, then you have this equation that P 1 by row 1 plus V 1 squared by 2 equal is to this. It also often happens if it is a liquid that the liquid is incompressible, and if it is a single phase liquid then it is density will also be same at 2 point. So, this does not change. So, then you have. So, this is the basic principle. So, then you have and this V 1 is obviously related to the volume flow rate because A into V 1, the A into V 1 will give you the volume that. So, basically V 1 is Q by A where A is the cross section right and Q is a volume flow rate. So, you can relate this V 1 with volume flow rate. So, that is why how this the volume flow rate is actually related to the pressure right. So, let us see how this principle is used.

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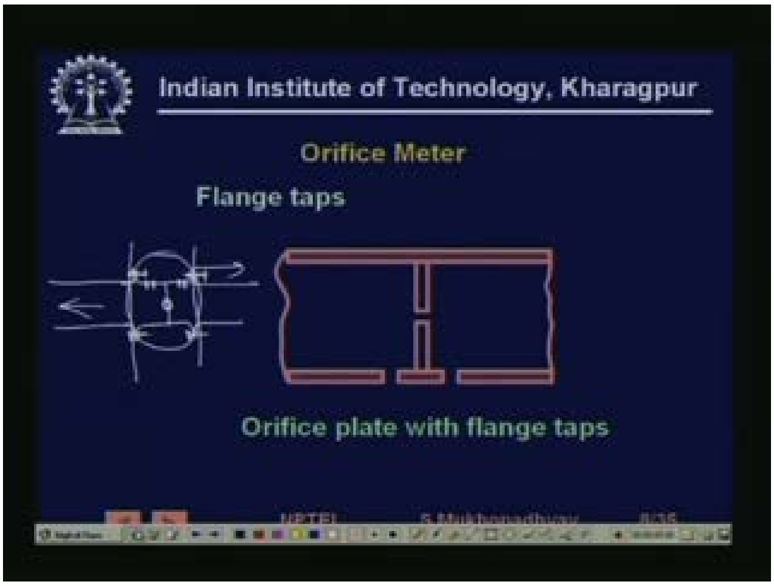


So, now we have an orifice meter which uses this principle. So, what. So, orifice meters can have basic idea is same that we have a pipe, in the pipe we are going to put a plate with a hole it that is all. We are going to measure pressure difference across this plate. So, depending on where we measure the pressure there could be a different types of these you know these are called the pressure taps.

So, this is one pressure tap this is the upstream and this is downstream tap. So, depending on the pressure tap positions you can have some variations. So, in this case we have flange taps. So, which means that basically how it is done is that, there is there is actually a flange. Flange means that there is a pipe section coming here. So, you have. So, here actually somewhere here you have that hole.

So, actually this is the pipe upstream pipe section this is the downstream pipe section and in between you connect this plate. You connect it and you bolt it here, this plate place you bolt it such that it stays. On this flange you have this pressure taps. So, you have flange taps, similarly you can have various other positions of taps like you can have what is known DD by 2 taps where the position of the taps are related to the pipe diameter. So, on the upstream side you have if the diameter is D, then you have a tap at distance D from the plate and the downstream side you have at D by 2. So, these are all you know could you have.

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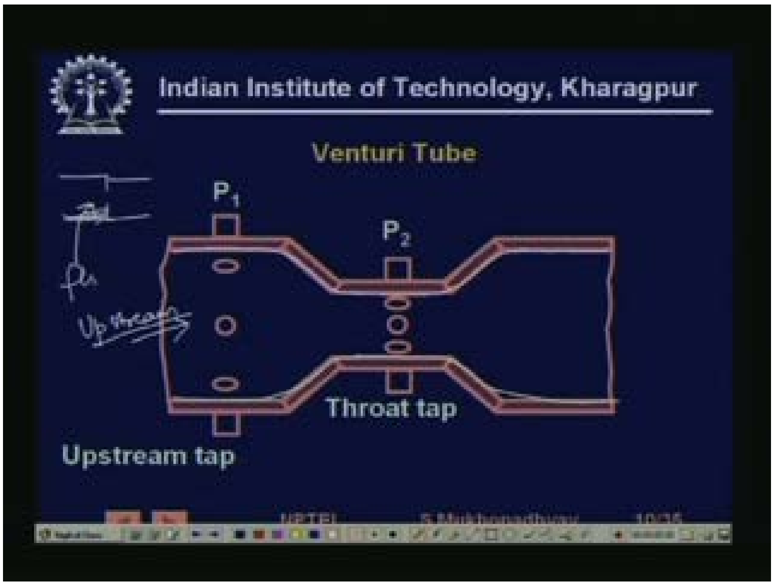


So, you can have various other kinds you can have vena contractor taps that is the put the tab where the area becomes minimum right. So, you can have corner taps. So, with the there are various tapping conventions you can adopt 1 anyone of them the other case is venturi tube. So, in the orifice plate we are we have pipes and we put a simple plate inside while in the venturi we actually have a pipe section, where the diameter gradually reduces right.

So, here we have the venturi. So, what happens here is this is the upstream side. This is the upstream side and these are you know actually do not have a single tap you can have you can have taps all across the periphery. So, that you can take this measurements. You have flow measurement one thing must be understood that flow measurement because of turbulent this Bernoulli's principle, this uses turbulent flow conditions. So, because turbulent there is always a pressure fluctuations. So, measurements are generally tent to be noisy. So, it is a good idea to you know make this pressure measurements and average them. So, that is why people can use different ((Refer Time: 17:11)), you can if you have if you have a number of taps along the periphery.

Then you can use it for averaging and you will get noise reduction. So, you have this taps on the upstream side and this is called the throat of the venturi. So, the diameter here the pipe section is made such that the diameter reduces and sometimes it is smooth also this looks sometime this is made smooth. So, that you do not have energy loss and then. So, principle is the same again measure pressure here measure pressure here and then apply Bernoulli's principle.

So, there are some advantages, if you have a smooth surface, first of all there is no you know if you see the other one. In the other one you have in the pipe you have certainly have an obstruction. So, you have if you have any kind of you know particulate matter suspended matter in the thing, this creates an obstruction all of a sudden this is if the flow is not smooth. So, what happens that you can have metal material deposition around this point because the suddenly the fluid comes and fills the obstruction.

Here there is I mean there is there is a point where things tent will tent to settle and that will change the flow properties, this will change flow properties such things can happen. While they do not happen in the venturi. In the venturi the things smoothly flow out and the pipe diameter is reduce. So, therefore, there is no such material deposition and even if you have venturi can measure flow even for in whatever is known as dilute slurries. That is I mean liquids with some suspended solid particles, while orifices can also do that, but they are not generally use for doing that. So, this is the basic principle and if you see the flow measurement law.

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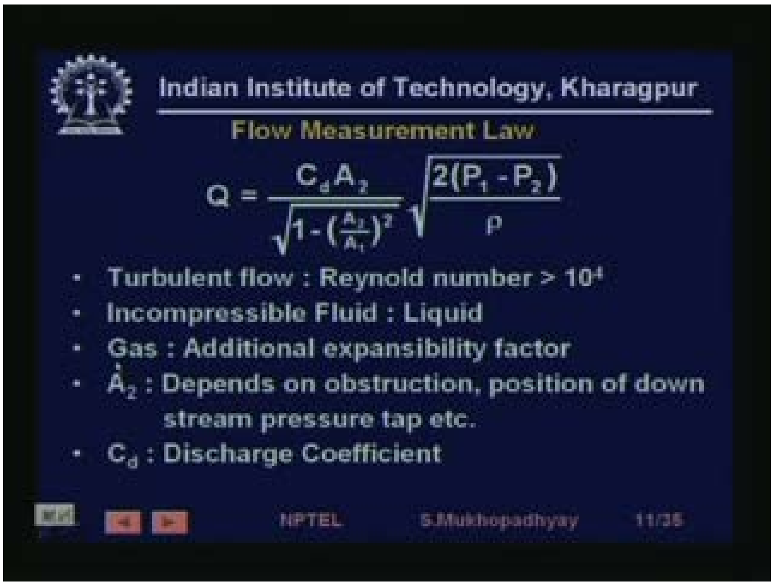


It turns out that the flow is actually related to, this is the pressure right, this is the P 1 minus P 2 is delta P which is the pressure difference across the obstruction. So, if you take one of the taps the upstream taps will have pressure P 1 the downstream tap will have pressure P 2 and the flow will be related to this thing, A 2 and A 1 we have all ready seen they are diameters of, they are cross sectional areas of the pipe upstream and downstream.

It turns out that if you take Bernoulli's law and actually derive the flow rate, then you will get this part. If that is, if you measure the pressure exactly at the plate at that point, but it turns out as we have seen that we are actually measuring the pressure elsewhere. Slightly away from the plate. So, therefore, we have to it should actually A 2 should stand for the area where you are making the pressure where we are measuring the pressure.

So, now since this is a sort of geometric parameter, you have designed the plate. So, you know it, but therefore you need to add a factor. So, this is the ideal one would have given, if I measured the flow right at the plate, but I am not doing that. So, therefore, I will apply a correction factor and this correction factor I will experimentally determine right.

So, first of all we must know under what condition this this law is actually used for the measurement with some CD value which have to be chosen based on manufacturers guidelines given. So, we have to know when this is valid. It is valid on a turbulent flow when the Reynolds number which is again parameter, which can be calculated based on density, viscosity, velocity of the fluid and some dimensions of the place, where it is flowing in this case the diameter.

So, based on that we calculate a parameter called Reynolds number and when the Reynolds number becomes greater than ten to the power four evaluates too, we can assume that the these measurements equations will hold. These equations are actually given for incompressible fluids, that is a liquid. While if we have if you use we can use it also for gas this kind of measurement is also can be used for gas.

Only thing is that the assumption of a constant row will not hold in that case. So, therefore, we have to apply corrections further corrections. So, we have to add which is called an expansibility factor which it depends on various things like CP by CV pressures etcetera. So, we now this A 2 is actually stands for the cross sectional area for the fluid flow where we are making the measurement P 2. So, that depends on various kinds depends on the obstruction depends on the position of the downstream, pressure tap.

Sometimes depends on the obstruction that is whole parameters. So, they have to be there. So, based on this, but. So, actually we do not we do not use that value. So, we actually use the whole value, whole parameter and instead apply a correction factor called the discharge coefficient. Which is experimental determine by the manufacturer. So, from manufactures tables we can get this value.

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So, value of discharge coefficient depends on various things. It can depends on the type of flow meter there is an orifice or venturi and each manufacturer for each model will give you a detail description of how to obtain the discharge coefficient. Reynolds number and diameter ratio that is, what is the diameter of the upstream pipe and what is the diameter of the hole you are using.

So, the ratio which is often called beta that is this refractors primarily determine the discharge coefficient also the fluid type. That is obviously there and experimental or values or regression equations for CD are available for various flow meters over a wide range of fluid velocities. So, we can use them.

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So, this is the basic principle. Now, if we what are the plus points no moving parts robust, very cheap you are just putting a plate. Of course, venturi is not that cheap maintainable, very well established had been used in the industry under various flow condition for long long times and good very good amount of data is available found on CDs and the various things that happen. So, no problem in getting information. This is the point that these meters because they create an obstruction they actually create a.

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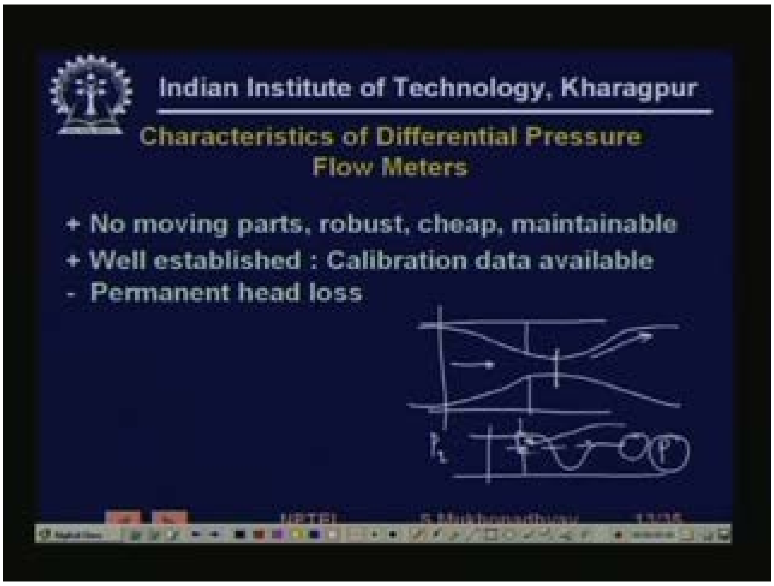

They actually create permanent head loss actually what happen this needs to be understood is that, suppose you have a pipe and if you have an obstruction here then liquid flows out like this. So, what happens that here suppose you have P 1 as you are going down area is decreasing. So, velocity is increasing the same volume of liquid is flowing through a smaller area. So, velocity V is increasing. Therefore pressure is falling actually.

Here the pressure will be minimum, because the velocity is the maximum and then it will again rise, but it turns out that it cannot rise fully. So, the pressure curve actually if you see down the pipe stream suppose the pressure was here the pressure will fall and then it will rise, but it will not rise fully. So, there is a permanent pressure loss which is to be, which is shown in terms of the pump energy loss. So, actually suppose you need a pressure P it is the down side that you have putting an equipment.

So, you need to create a certain amount of fluid pressure there. So, if you need a fluid pressure of P here, then you have to create a pressure which is on the upstream side by using a pump which will compensate for this drop. Therefore, you we are going to lose some energy. So, this is the price that you pay in these flow meters. In certain cases this could be significant.

So, this as we have seen that the flow is or other the pressure is actually proportional to the square of the flow right it is root over delta P is coming is K into root over delta P. If we assume that that constant proportional defector is constant. Then you have an equation which is K into Q is equal to K into root over of delta P. So, what you are measuring is delta P. So, the delta P is again some K 1 into Q square. So, it is actually square relationship which means that, suppose the flow becomes 0.25 times or twenty five percent of the rate in flow.

So, then the pressure measurement pressure drop will become point zero. So, about 5, 6 percent of the flow and this pressure sensors, when the instruments operate at very low range they actually become, I mean they actually become inaccurate because there are some fixed errors.

So, as percentage of readings they you will have lot of errors. It turns out that because of this non-linearity these instruments are not very good at measuring low flow rates right. So, range ability is the ratio of maximum value of the measurement to minimum value of measurement or other minimum value of measurement to maximum value of measurement. So, this is not very high this ratio. This ratio is rather low because you cannot have very low measurements. So, that is another problem.

Discharge coefficients can change with where, actually you have the in the orifice plate the sharpness of the edge it is flowing through the hole and the edge of the plate which is made. So, the edge of the plate is made like this. The edge of the plate on the. So, you have plates with edges like this. So, you have a sharp edge here. If this edge due to use this edge gets rounded, then the discharge coefficients will change and your flow measurements can become erroneous. So, it needs maintenance.

It generally applicable for clean fluids, although some amount of suspended particles can be used for especially for venturi. There are sometimes installation constrains in the sense that it is required that, suppose if you place the meter in a position where just upstream of the meter there is a there is a bend then this meters will not read correctly. So, there are restrictions that is the upstream and an especially upstream there should be straight pipe lengths. So, there are installation constrains.

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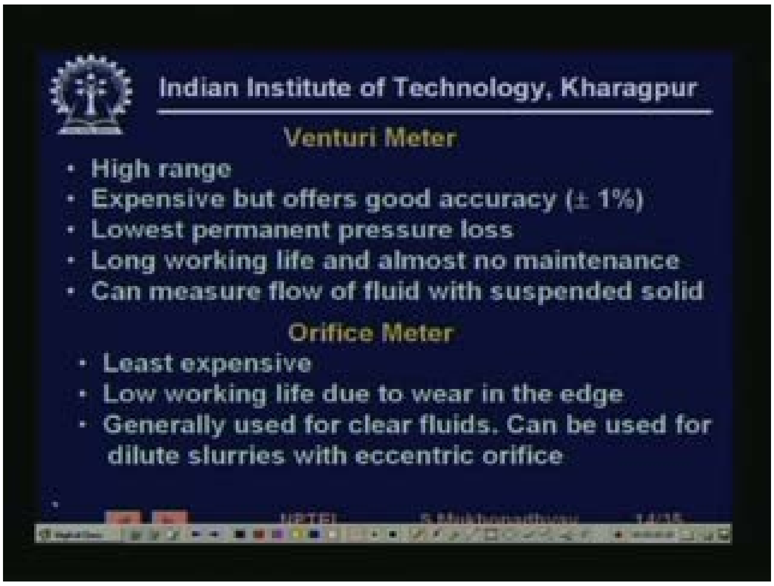


If you compare venturi meters with orifice meters turns out let us see, what is happening here. So, you have venturi meters can work with or work on very high ranges. You can have very big venturi. They are expensive compare to orifice meters because you need to make the whole pipe section they are nicely machine not just a plate, but they are definitely offer good accuracy and lowest permanent pressure loss.

So, even if cost you are going to make up some of that costs by wasting less energy, less pump energy. So, that is a good thing about venturi they are long working life because they are smooth and the liquid passes. So, once you install it very little maintenance is required and it can also measure flow of fluids with suspended solid. On the other hand, orifice meters are the least expensive, but they have lower working life. Due to where in the edge and generally they are good for clear fluids not for with. So, fluids with particulate matters, although sometimes it is used with an eccentric hole that the hole is not placed in the center, but in the bottom. So, that when the fluid passes it actually it will wash away any suspended particle that that can accumulate all right. So, next we have the rota meter.

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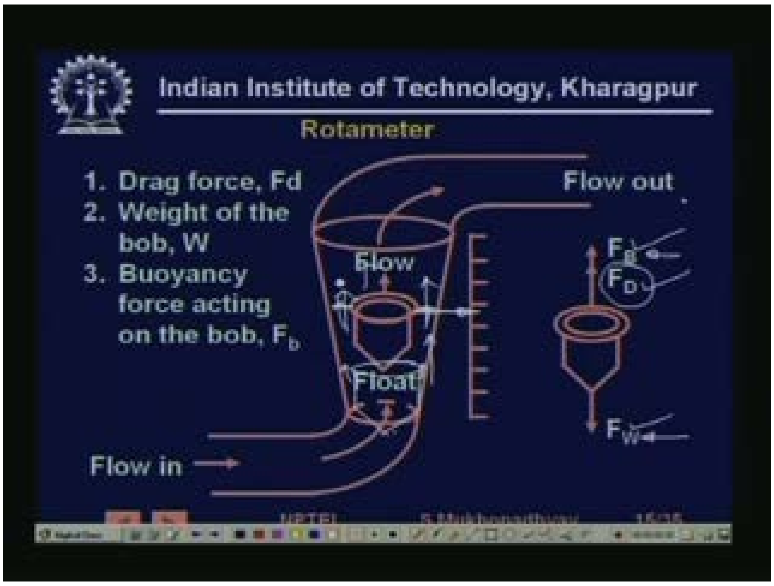


So, in the rotameter is sometimes called the variable area of flow meter. So, you might have seen this. So, what happens is that you have a tube right. This tube can be made of metal this tube can be made of glass generally made of glass in the common case. So, the fluid is coming in and flowing out. So, you will there are there all there always to be installed in the upright condition because the use. So, they cannot be installed horizontally, they have to be installed vertically all the time and the fluid will flow this way and go out this way.

So, let us if you see the force is acting on the fluid. There is what is known as a float or a bob which in if the flow is not there than this bob will actually sit here. This in this bob will actually sit here. So, it will sit here. So, as the as the flow increases gradually the bob will rise. So, at various flow rates the bob will actually settle at a certain position. If you readout from a scale where is the bob is settling at the present time, then this scale is sort of calibrated in tube.

So, this will directly give a readout of the fluid flow rate. It is called the variable area of flow meter because the area through which the fluid flows here and the area which through which the fluid flows here. This area through which the fluid flows continuously varies as the float goes up and down. So, the flow area is vary, I mean contrast this with the venturi. There the flow areas are constant right. It is the pressure, which is vary why here what is going to be the pressure. See a free body diagram or forces then where will the float be stationary. The float will be stationary when the force is on it will, actually balance out. So, when will it balance out. So, what are the forces. So, the forces on these are the buoyancy force which is upward. Then there is the weight, it is wait which is downward and it has a you see what is happing here, is that again the pressure on this side there is actually a the pressure you see here the liquid is actually flowing through a constriction right.

So, it is velocity is. So, what is going to happen is that there will be drag force. There will be a force which will be this side. So, this is buoyancy force, there will be force due to the due to the flow, flow fluid will try to drag it up and there will be a force on the weight. So, when these will balance out the float will be stationary right correct. So, now, it turns out so that means, that see, the drag force that is developed must always be the same that is it is the difference between the buoyancy force and the weight which are constant for a flow. So, it is the force which is constant, but at different flow rates to achieve this force, the float must settle at a different position.

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So, now for example, this is what it looks like. So, you see that this is the pipe actually this taper is actually see can you make out the taper, probably you can make out the taper see here the diameter is less and here the diameter is more. This is the float and there is a guide rod given. So, that the float does not mover here and there in the within the tube and the calibration here in this case is made directly on the glass. So, you can and this is the input port and this the output port. So, this is what it looks like and it comes in a wide variety of sizes when. So, it could look different ways.

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So, this is the principle operation, that the float remain stationary when the weight for the float is balanced by the buoyancy and the drag force. The annular area between the float and the vertical tube varies continuously. Actually that is why you must have a taper. The rotameter would not work if you made a cylindrical tube. Although the taper is very low to have a large range, but it is varying. So, when the float is in a particular position for a flow rate the differential pressure varies with this square of the flow rate. This we have seen this is this is from Bernoulli's principle right. So, the pressure across it will actually vary will actually vary because in relationship with the flow.

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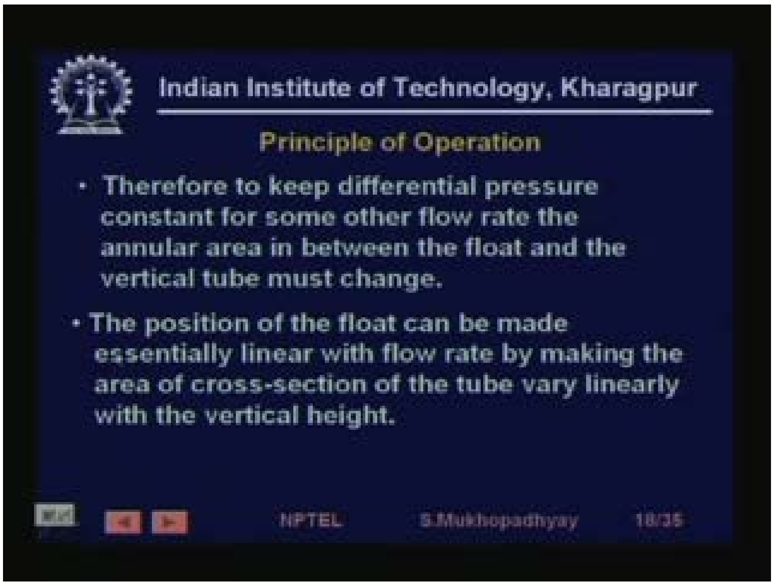


So, therefore, to keep differential pressure constant for some other flow rate, the area must vary. So, the flow rate is if the flow rates changes basically it depends on the velocity. So, therefore, if the flow rate changes then that area must also as the flow rate increases. So, the area must also increase to have a certain velocity because we need a constant velocity to be reached. So, that the differential pressure develop due to this velocity can balance between balance the difference between the buoyancy and the weight.

So, therefore, as the float rate increases the area must increase to keep the velocity constant. So, when does a area increase when the when the bob goes up. So, as the flow rate increases the bob will now go up up and settle at a higher position. So, therefore, to keep the differential pressure constant for some other flow rate, the annular area in between the float and the vertical tube must change. This is the principle of measurement and the position for the float can be made.

Now, if you carefully fabricate, the tube in such manner that the area varies linearly with position. Then as Q varies A must vary K, K must track if Q become double A must become double to keep V 1 constant and therefore, if A becomes double when the height becomes double, then you have linear measurement of Q with X right. So, you have to make the tube such that the area where is linearly with height.

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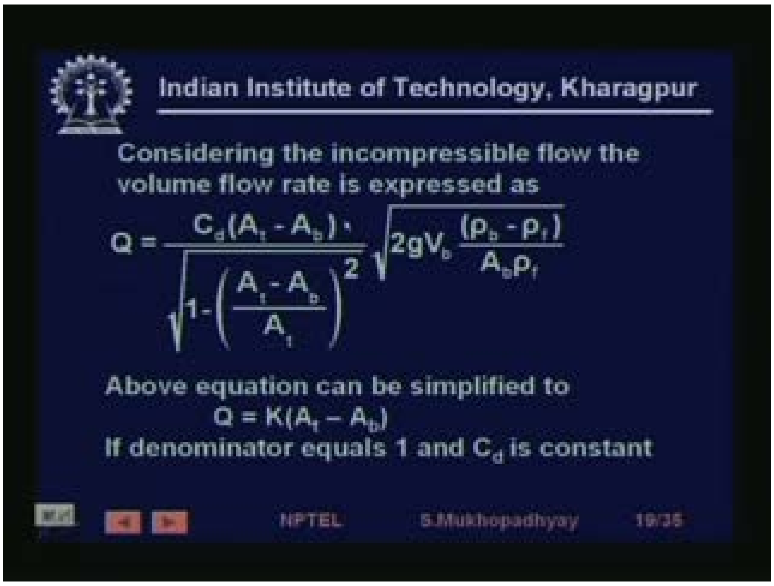


So, typically the volume flow rate is given as again in using Bernoulli's formula. In this case if we do that weight balancing then you find out, this is bit of manipulation which we can find any standard instrumentation book. It turns out that this AT minus AB, AB is the area of the bob, AT is the area of the tube at a particular height, CD is a discharge coefficient, VB is the volume of the bob row B is the density, row F is the density of the fluid. So, it turns out that, the flow rate is given like this and if you have...

So, you see this part is constant because if we assume that the fluid density is constant. So, this part is a constant here if you have AT minus AB is much smaller compared to AT. If this factor you can be neglected it is actually small. So, then if you assume it to be 1 then what happens is that, you can have, you have actually Q is proportional to AT minus AB. So, the annular area AB is the area of the float AT is the area of the tube. So, that. So, AT minus AB is actually.

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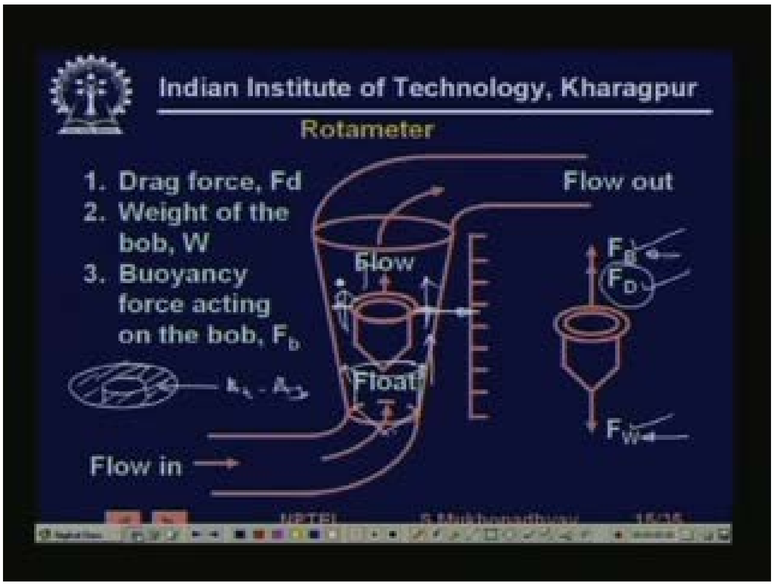


So, let me draw it here itself. So, this is AT this is AB float. So, this is AT minus AB, this part, this annular part, this is the area through which the fluid flows out. So, if the denominator equals 1 and CD is constant then you can have. So, you have proportionality there that is what is used for measurement.

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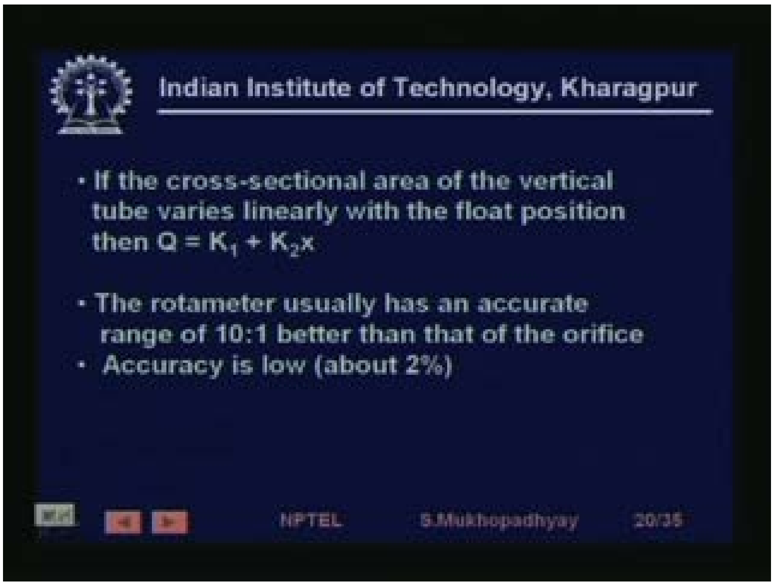


If you if you vary AT minus AB proportional to X, then you have a measurement Q is equal to K 1 plus K 2 X. The rotameter is usually accurate and you can see that, here the measurement is linear with X and you have better range ability than that of the orifice.

You are not measuring pressure drop here. So, there is no square relation, there is a linear relation and accuracy is not that high for a rotameter, but some it is a very simple instrument nothing is there just a tube. You can just put in and you will get a reading. So, that is why it is quite widely used. Sometimes you can have automated float flow detection using magnetic methods or using optical methods.

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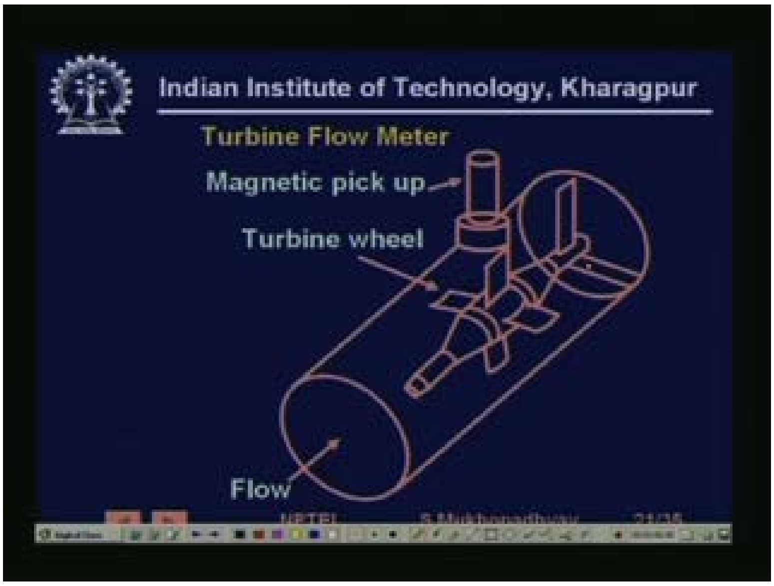


Next we have turbine flow meters. These are, here the idea is simple, the idea is that you put a small turbine within the pipe and the turbine is made, in such a manner we will see how it is made that as the fluid flows it keeps pushing the blades. So, it keeps pushing the blade. So, the turbine start rotating and if we analyze the mechanics, then you will find that the rotational speed because it is done by momentum transfer. So, the linear momentum of the flow some of it gets transferred to the angular momentum of the turbine.

So, therefore, the flow rate becomes proportional to rotational velocity of the turbine and this rotational velocity of the turbine must be sense from outside the pipe. The turbine is placed inside. So, therefore, people use either use optical means where as the blade rotates some light beam is going to be obstructed or they use a magnetic means, where there will be magnet and as the as this metallic blades pass. There will be electric pulses or voltage or current pulses generated. So, you count the pulses then you know at what speed this turbine is rotating. This is the basic principle of operation and if you see the cross section area.

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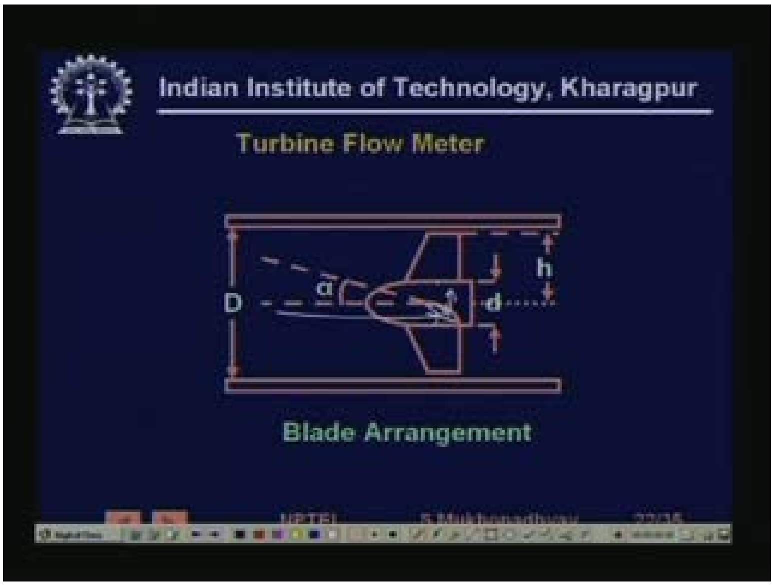


You will find that this is the blade. So, you see this is the blade and actually it is not properly drawn if the blade is like this. So, when the liquid passes it actually pushes the blade it pushes the blade. So, the turbine rotates right. It actually the blades are made slightly slant right. So, when they are made slant when the fluid will pass it will push the blade this. So, that is how it rotates.

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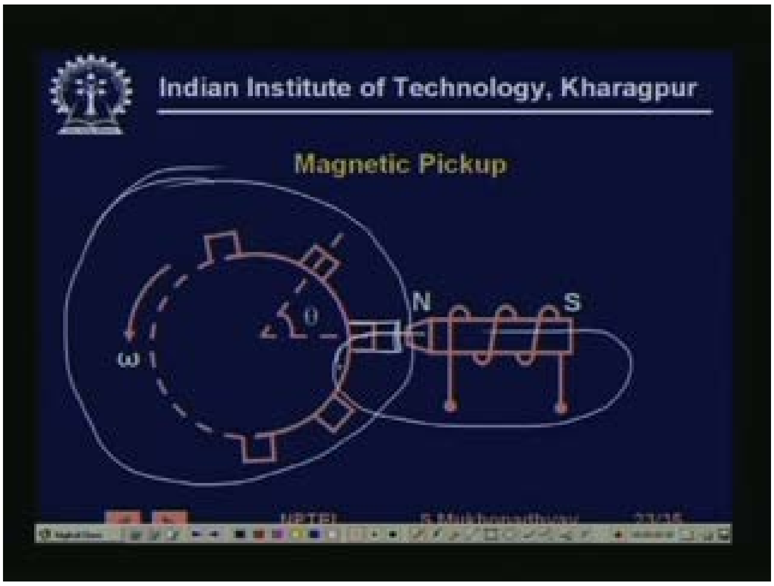

If you see the magnetic pickup principle, it is simple that you have a magnet, which is outside the pipe right. So, you have a pipe here. So, the pipe is inside, the turbine is inside and the magnet is outside. So, now, as it rotates what will happen is that, this is an electromagnet. So, the flux lines will pass like this, actually this blades are actually should must be exaggerated, that is they come actually quite near they should come near it. So, as you can see that if the blades are facing the magnet then there reluctance path of this path is iron. So, therefore, the reluctance path is somewhat reduced.

While if this point is facing the magnets then the reluctance of this path is not, it is still here. So, therefore, more reluctance. So, what happens is that as the wheel rotates the reluctance of the magnetic circuit periodically varies. As the teeth comes close it become small as the teeth goes away and the space between the teeth come facing the magnet the reluctance grows large.

You have a certain MMF because you are driving certain current into this coil. So, the flux also flux is MMF by reluctant by reluctance. So, therefore, the flux also keeps oscillating. So, when the blades come close the flux increases because reluctance is lower and vice versa. So, now, if you.

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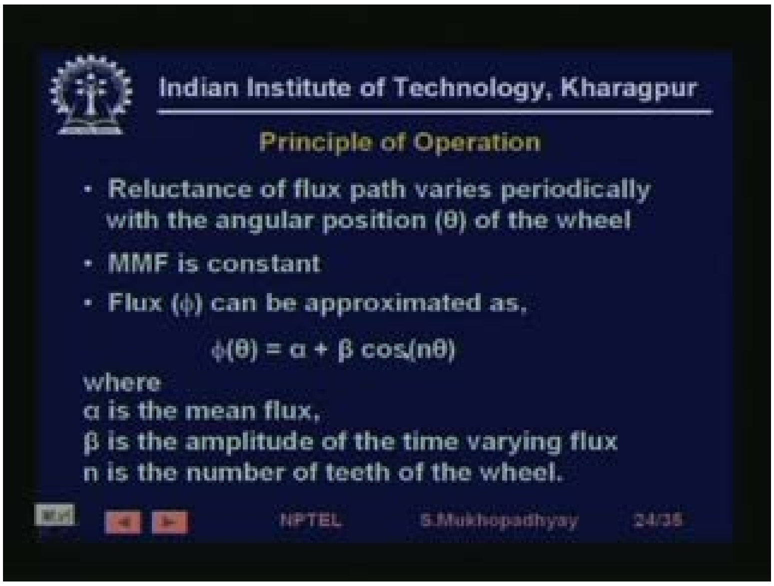


So, basically and what is this frequency of oscillation. This frequency of oscillation is actually n times, that is n times the rotational speed because once the turbine rotates n teeth will pass at this flux pulsation will go through n cycles. So, actually this flux pulsation is an n times higher frequency of that of the angular velocity, that is what I should be realized. So, this phi as if matter of theta is can be expressed as in this term alpha plus beta cause n theta. So, you see that it varies if the as theta varies from 0 to 2 phi this go through n pulsations this phi.

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So, now we can it is a simple matter to calculate what is e, what is the induced EMF in the coil that is nothing, but we have we actually have a permanent magnet. So, permanent magnet means the magnetic strength is constant and we have we have put the coil across which an EMF is induced as flux pulsates. So, that is given by simple d phi d t and it turns out that this is simple calculates will tell that it is beta n omega sign omega T.

So, what do we see where omega is rotational velocity. So, therefore, what do we get, we get actually a sine wave if we see the EMF e will get a sine wave whose amplitude will also vary with omega and will frequency will also varying with omega. So, both are increasing with omega as we can see here. So, we can for signal conditioning we can either try to detect the amplitude or try to detect the frequency. So, now this will as we have said that it turns out that the angular velocity raised again proportional to Q. So, therefore, the frequency is also proportional to Q and the amplitude is also proportional to Q.

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So, that is what we do. So, we measure either the frequency or the amplitude. It turns out that these are to be used mainly in clear fluids, but they can give you quite accurate readings. Although they cause a permanent head loss and if there are not so rugged and reliable as you know orifice meters there also more expensive. So, they are typically you know it can be used in things like you know acids, which are single phase clear fluids with low viscosity and they are available in various ranges for liquids and gases. This is a typical picture of thing.

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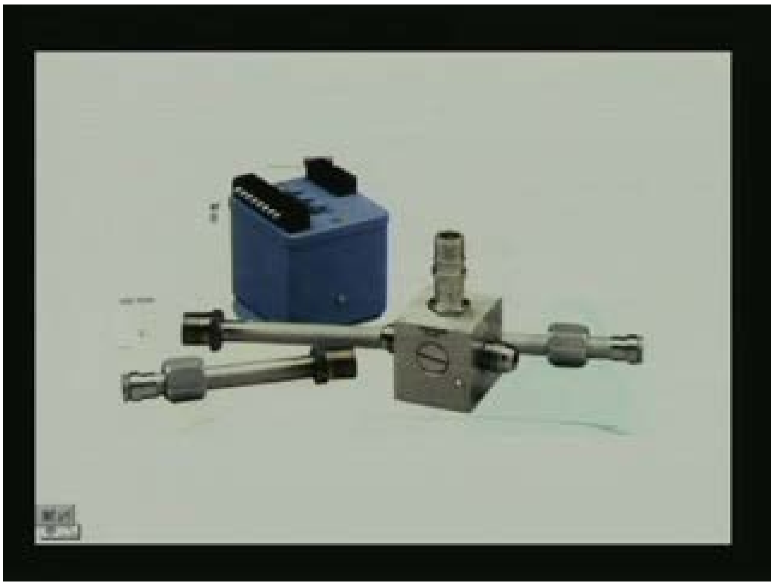

Of such a meter, you can see that this is the magnetic peak off and these are the pipe sections which you can connect with it and this is meter. So, you have connect the pipe section the turbine is already put inside it. So, this completes our obstructive flow meters and we take a quick look at the un-obstructive ones. For example, electromagnetic flow meter.

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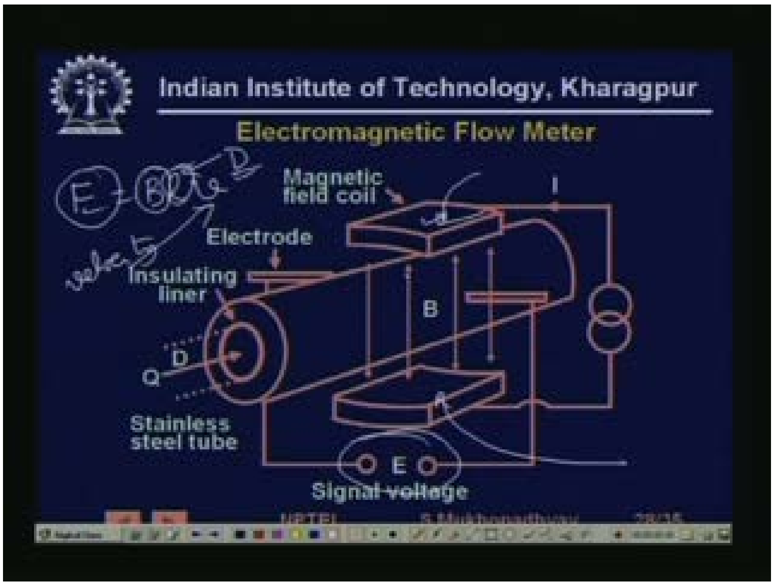


So, here what we are is let us see the parts we have a pipe. So, there is a pipe this is a pipe line, the actual flow is through this part. So, what we have created is that we have created a magnetic field these are coils. These are coil assemblies, these two. So, we have created a created a magnetic field by sending through this coils. These are actually schematic connections, when there is just shown that this is they actually connected to 2 sources.

Now, if you have. So, here is a magnetic field and if a fluid with some conductivity that is some free charges. If it flows past it then what will happen is that is that by the Hall effect we will generate some voltage across the electrodes. So, Hall effect says that if you have a magnetic field and if you have conductor conducting current through it, then across the 2 sides perpendicular you will actually develop some voltage and that is. So, it is like you know e is equal to BLV kind of thing.

So, these coils will cut the flux and there will be some EMF generated. So, it is this EMF which is actually sensed using these 2 electrodes and this is the signal that you are going to get and the magnitude is given by something like BLV. So, B is constant B is constant by excitation, and L is the L is the length which is which in this case is actually the diameter. So, it so the EMF is actually proportional to the velocity or the volume flow rate.

So, this is the simple method. There are some measurement issues involved in the sense that you should use the excitation of this V and some bit of signal processing is required because there are some you know you can have thermoelectric potentials etcetera. So, you can have drift if you use DC. So, pure DC should not be used and some you can use fifty hertz DC also, but fifty hertz DC has some fifty hertz interference problem sometimes. So, you can use where we have current excitation and then generate. Take many samples and then average. So, any offset will go away. So, such simple signal processing is possible after that. So, you see that this is completely from outside the pipe.

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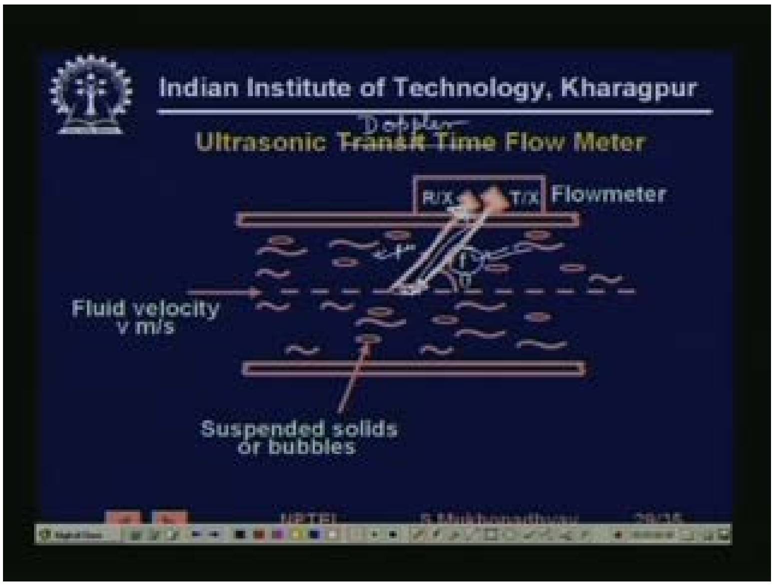


Similarly, we have we have an ultrasonic, this is not a transit time flow meter this is actually, this is wrong title that we have got, this is a Doppler flow meter here is a. So, what we are doing is, this is use for particulate. So, you see in the fluid we have some solid suspended particles right. So, you have an ultrasonic transmitter and you have an ultrasonic receiver. So, at this transmitter is transmitting an ultrasonic pulse which is sound pulse in this direction.

So, what will happen is that at frequency F. So, it turns out that by Doppler effect, the frequency that will appear to, suppose and it will come to the, it will hit some particulate matters and this particulate matters will actually scatter it. When they scatter it some of that scattering will get back to the receiver. So, we are going to transmit it is going to be scattered by the various particles. Some of that is scattering we are going to receive using another piezoelectric twister and from.

So, now, we are going to measure the frequency that with which we transmitted and the frequency which we receive. Now, it terms out that if we transmit with frequency F, then to this scattering particles this is by Doppler effect. This appears the frequency will be proportional to the relative velocities. So, what is the relative velocity, while it is going this way, suppose the velocity is this way. So, it has a component this has a velocity component this way and what is that velocity component, that velocity component is V cos theta, this is theta.

So, the relative velocity is C plus V cos, this is the relative velocity of sound with respect to this particle. So, it will now see a corresponding frequency F double dashed F dashed. Now, so it will when I see a frequency F dash it will also scatter that frequency back, but that frequency will now appear to the receiver of a certain other frequency which is F double dashed. What is the relative velocity between when it is transmitting back, the relative velocity is actually C minus V cos theta. So, therefore, what will appear, this receiver will now see a totally different frequency because the relative velocities in the 2 direction are different. So, now if you see because of these suspended solids. So, if you now see the…

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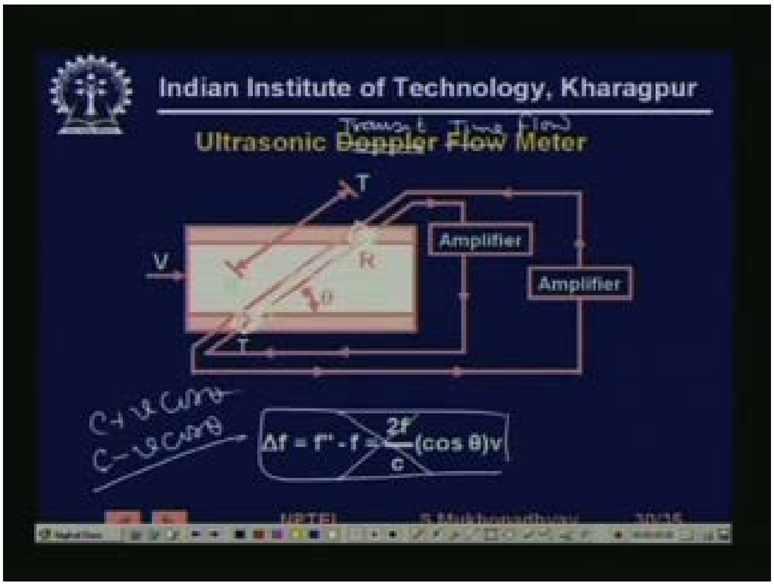


So, if you see the, I am sorry this I do not know it is creating a bit of problem. This diagram is to be ignored. So, if you see the frequency difference. If you see frequency difference between these 2, then you will find that the frequency difference will actually with this F is constant, this is the transmission frequency, theta is also constant depends on the angle which we have put the transmitter in the receivers, C is constant velocity of sound in the medium.

So, therefore, it will be this frequency difference is going to the proportional to the velocity which is again volume flow rate. So, this is the principal of Doppler flow measurement, then we also have, actually that is a slide mix up about transparence is here. Let me tell you that this is now in this slide let us ignore this. You can also measure by having what is known as transit time flow meter in a transit time flow meter, what you do is here you have 1 here ,you have 1 piezoelectric crystal here you have another one.

So, you transmit from here and receive here and you measure the time. When you see you are you are corrected to electronic. So, at the same precision time you transmit a sound pulse and count the time after which you receive it. So, then what is the transit time T, T 1 will be given by the relative velocity of sound in this direction, which is actually C plus V cos theta. If you see similarly, if you transmit in the other direction then you will get C minus V cos theta.

So, therefore, the transit times are going to be different in the 2 cases. If you measure delta T, you will again find that is the difference between the transit times in the 2 directions, then you will again find that is proportional to velocity. So, this is the principal of measurements in transit time flow measurement. So, we are going a little fast now. So, with the…

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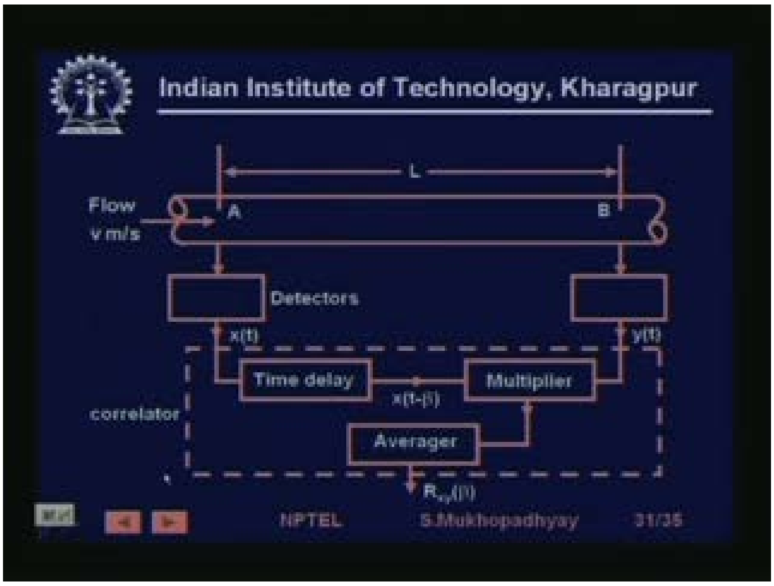


So, the last we will actually the last one is correlation flow meter. I will just explain the basic idea without going into details because there is lack of time. So, the idea is that if you want to this is typically used in situations where you have 2 phase flow that is you have bubbles in a gas or you have sand in air or you have line dust in air. You want to measure the measure the volume flow rate.

So, now what happens is that it is rather difficult to measure these things using for example, orifice meters are not good for having this kind of you know, gas bubbles right. So, what will happen is that, what you do there is that you measure the flow at 2 different points. You measure some properties for example, you can measure capacitance or you can measure charge collected at these 2 points. If the fluid flowing then actually this because of because the because the sands suppose the sand is being carried through air.

So, the sand particle will actually form clouds when they are when they are passing through air. So, each cloud will have a signature, will have a signature kind of signals. So, then you first obtain the signature in terms of capacitance or in terms of charge from this point. If and then you obtain the signature from another point. Then you try to find out the time difference between these signatures by some numerical technique which is called cross correlation. So, once you can find this time, then you know that it travels this distance over this time and therefore, you know the velocity. So, these you know some kind of what is known inferential or numerical techniques. So, I am going to skip this because we do not have time.

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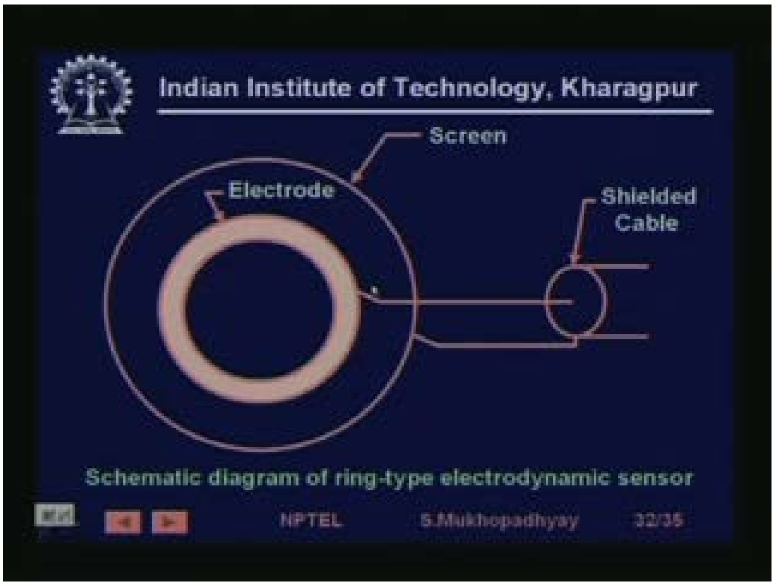


So, you can put electrodes on the pipe and from this electrode, for example, in this case it will collect charge. So, you collect charge from this point and you collect charge from this point and then you correlate these 2 charges. That way you can measure the velocity. So, we are going to skip this.

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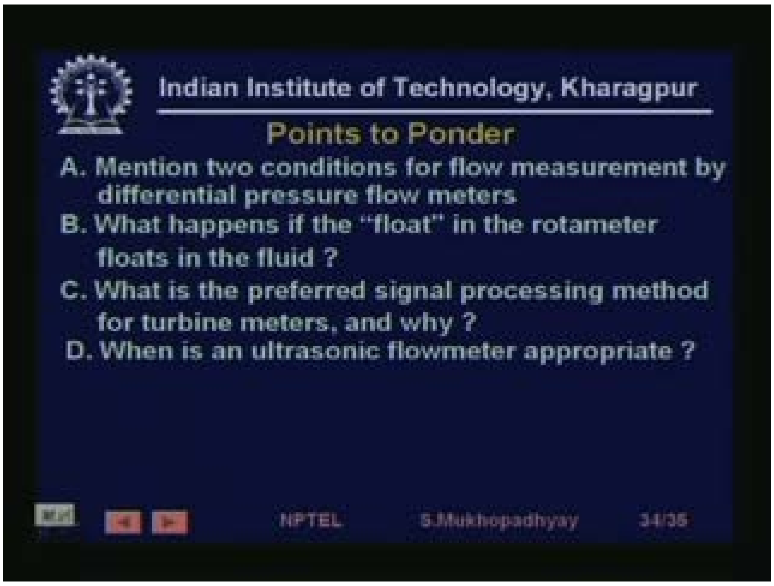


We finally, come to the points to ponder which is. So, there are several questions which you can think of for example, can you think of two condition for flow measurement by differential pressure flow meters right. So, think of two conditions under which, they are applicable. One of them is that the flow must be turbulent, it is not applicable for laminar flows. So, can you think of another point.

What happens if the float in the rotameter floats in the fluid. Obviously, you are not going to get a ready why. So, the float must be generally heavier than the float density. What is the preferred signal processing method for turbine meters and why. So, you have two choices, one is amplitude measurement another is frequency measurement, which one do you prefer and why do you prefer it. When is an ultrasonic flow meter appropriate. So, when should you use an ultrasonic flow meter, other than an obstruction flow meter. When can you use a cross correlation flow meter. And finally, when should you use an electromagnetic flow meter. These flow meters are use useful under certain conditions. So, which is apprehend from the principles. So, study the principle and try to find that condition. So, that is all for today.

Thank you very much, see you in the next lesson.