Industrial Instrumentation
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Lecture - 15
Flowmeter - IV

This is lesson 15 of Industrial Instrumentation, we will continue with the flowmeter. So, this lesson 15 and we will basically discuss the Flowmeter IV, we have given the name like that.

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So, in this lesson we will cover, the contents of the lesson - electromagnetic flowmeter, ultrasonic flowmeter. These two basic flowmeters we will discuss in this particular lesson. Now, let us speak about what the viewer will know at the end of this lesson.

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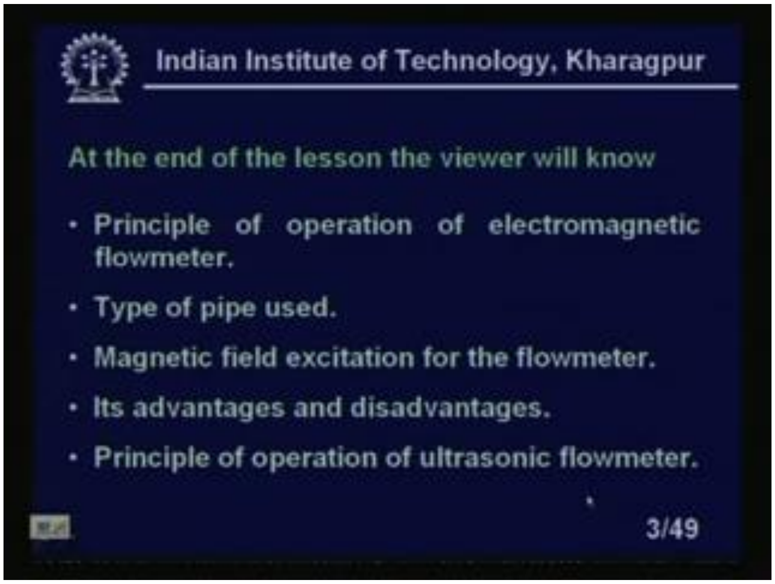

At the end of the lesson, the viewer will know principle of operation of electromagnetic flowmeter, type of pipe used, because various types of pipes you have to use, then magnetic field excitation for the flowmeters which will cover, because electromagnetic flowmeters in needs of magnetic field excitation, then we have its advantages and disadvantages. Principle of operations of ultrasonic flowmeter, this also … We will discuss the ultrasonic flowmeters in details. So, it will come one by one.

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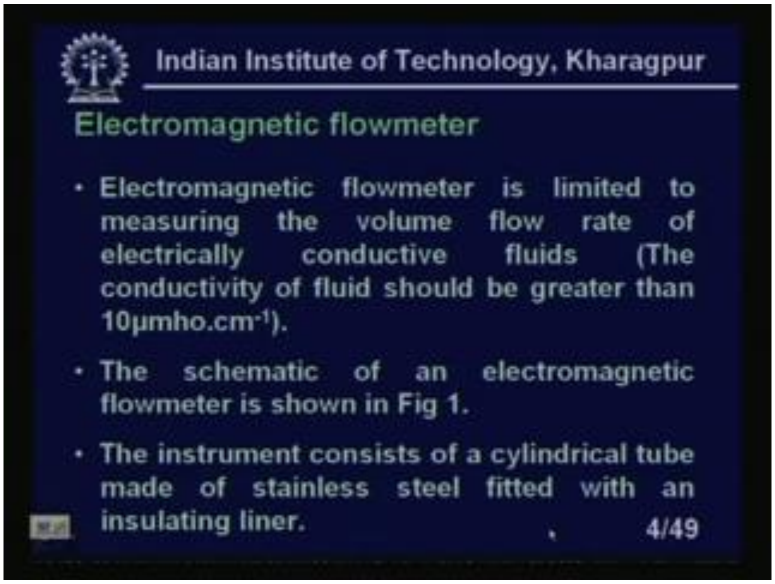

Now, let us first start with electromagnetic flowmeter. Electromagnetic flowmeter is limited to the measuring the volume flow rate of electrically conductive fluids. The conductivity of the fluids should be greater than 10 micro mho per centimeter. This is a typical restriction of the electromagnetic flowmeters and if it is less than this, so this flowmeter will not work. However, there is no higher limit on the, on the greater conductivity of the flowmeter. That you will see that in some situations the, the pipe as well as the electrode installation will be different if the conducting liquid is very, is very good conductivity of the fluid which is flowing through the pipe.

The schematic of an electromagnetic flowmeter is shown in Figure 1. Let us look at. The instrument consists of a cylindrical tube made of stainless steel fitted with an insulating liner. So, there should be insulating liner, because if it is a metal tube, so the, it will have a short circuit pulse. So, for that reasons what will have that we should have insulating liner.

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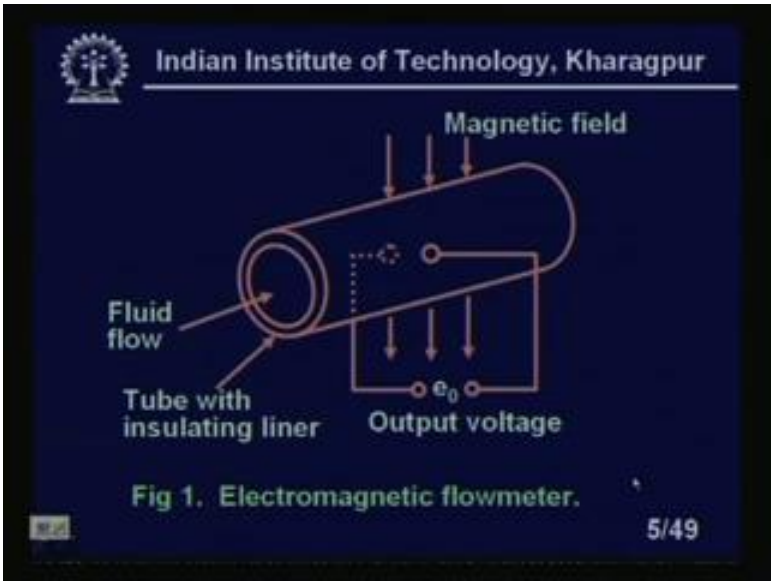

Now, typical you see this is the electromagnetic flowmeter. It looks like this. You see, if I have a camera on this side, camera on this, it looks like this, right? So, the liquid is flowing in through it and then it is coming out; flowing in, coming out. So, there is a magnetic field. So, if there is a coil on top and a coil at the bottom, so it will produce magnetic field which acts perpendicular to the flow of direction, direction of the flow of the fluid and we will put two sensors on both the sides - one sensor here or electrode, another electrode here. So, you will see that due to Faradays law of electromagnetic inductions, some voltage will be developed across this electrode. That voltage will be carried by it in terms of flow.

Now, the flow of the fluid, this position of the electrodes, if the line connecting the two electrodes and the direction of the magnetic fields are mutually perpendicular to each other, right? You will see here fluid flowing is through the pipe. There is insulating liner, so we are producing magnetic field with proper coil and all those things and two sensors are there which are installed diametrically opposite side. One sensor is here, another sensor the other side. I am sorry, one sensor is in this side, other sensor on the other side, you cannot see that and we are getting the output voltage. This output voltage is to be carried by it in terms of the flow.

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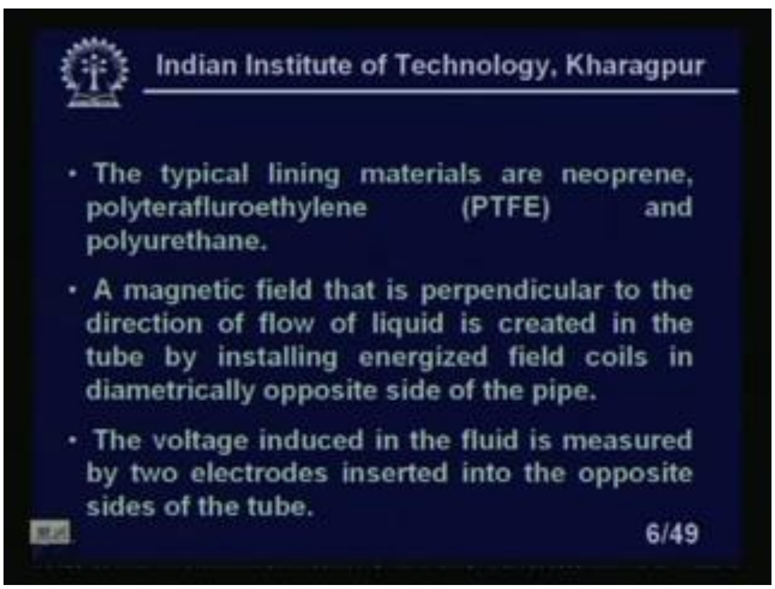

The typical lining materials are neoprene, polyterafluroethane ethylene, which is abbreviated as PTFE and polyurethane. A magnetic field that is perpendicular to the direction of flow of the liquid is created in the tube by installing energized field coils in diametrically opposite side of the pipe. This already we said. I mean two energized field coils are there. What type of I mean electric, what type of energy we will apply that we will discuss later on, but to produce magnetic field we must have some two coils which are diametrically opposite side. The voltage induced in the fluid is measured by two electrodes inserted into the opposite sides of the tube. We have shown just right now, right? Two electrodes are there. These are also installed in diametrically opposite sides, but all are mutually perpendicular to the, each other.

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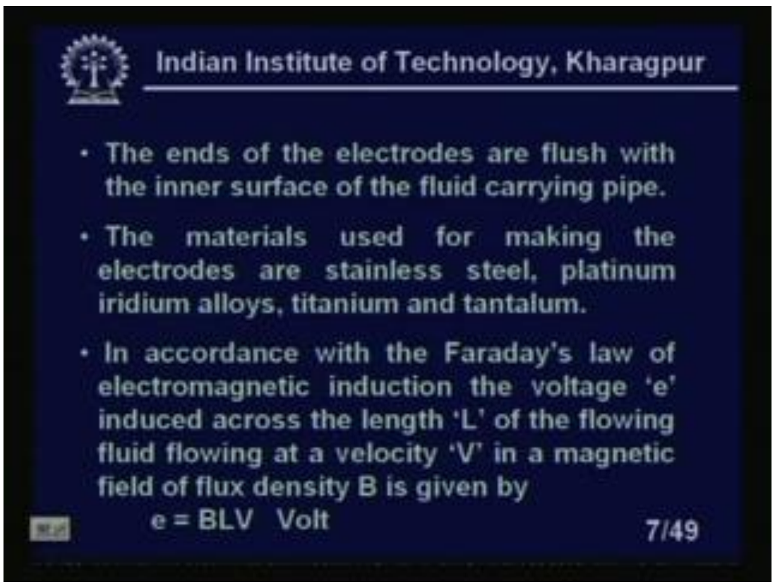

The ends of the electrode are flush with the inner surface of the fluid carrying pipe. This is important for the magnetic flowmeter, specially if the conductivity of the fluid is not very high. If it is very highly conductive, then it is not necessary to put it, to be flushed with the pipe, right? The material used for making the electrodes are stainless steel, platinum iridium alloys, titanium and tantalum. You can see thus electromagnetic flowmeter, though it has many advantages that we will discuss what are the advantages later on, but it is not very cheap instrument. It is quite expensive instrument in the sense that the type of electrodes you will use, the pipe you use and the pipe is not expensive, but inside the pipe you should have a liner. So, those are quite expensive. That cause, that makes the instrument very expensive. Moreover individual calibration of the instrument is necessary, very precise calibration.

To make this, if you add all these things, you will find that the initial installation of this tube is quite expensive compared to the other flowmeters like differential pressure flowmeters and all those things. But, in some situations we cannot afford to have a differential permanent pressure drop. In that type of situation, this magnetic flowmeter is used. The material used for making the electrodes are stainless steel, platinum iridium alloys, titanium and tantalum. In accordance with the Faraday's law of electromagnetic induction, the voltage e, induced across the length L of the flowing fluid at a velocity V in a magnetic field of flux density B is given by e is equal to VLB volts, right?

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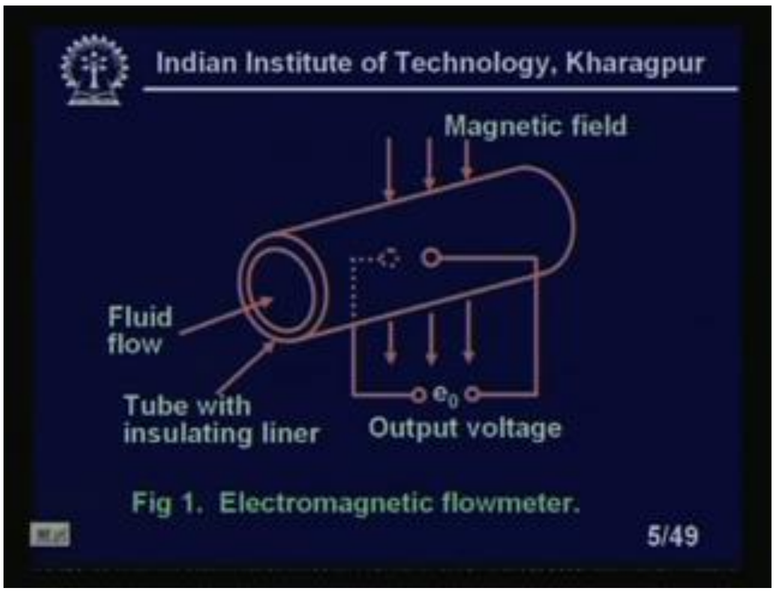

So, let us look at, what is this. This is our pipe, so you see what is capital L? Capital L, basically if you look at here capital L will be the, if I take some pen, so capital L will be the diameter of the pipe, is not it, inner diameter of the pipe, capital L. V is the flowing, velocity of the flowing fluid and B is the magnetic field which is magnetic field intensity or flux density which is working on the conductivity fluid, right? So, we you see the, in accordance with the Faraday's law of electromagnetic induction the voltage e induced across the length L of the flowing fluid flowing at a velocity V in a magnetic field of flux density B is given by BLV, where you can find this is in volts, obviously. See, this is in volts, right?

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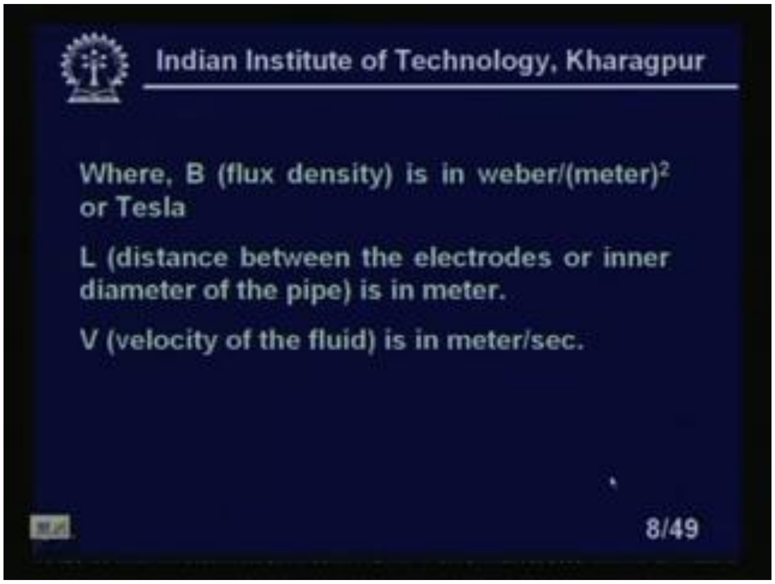

This output voltage is in volts provided that where B is the flux density is in weber per meter square, which is in Tesla, L is a distance between the electrodes or inner diameter of the pipe which is in meter, V the velocity of the fluid that is in meter per second, right? See, if you use all these notations, we will find that the velocity of the, I mean the output voltage of the fluid will be in volts and you can see here if BA and L remain constant for a particular liquid, obviously e will be directly proportional to the flow velocity. See, if you now multiply that velocity with the area of cross section or the inner area of cross section of the pipe, we will get the volumetric flow rate, is not it?

Now advantage; there are several advantages of this type of flowmeters.

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Number 1, there is no obstruction of the fluid flow. Therefore, there is no pressure loss associated with the measurement, right? This is very important. Then we have, it is suitable for installation that can tolerate only a small pressure drop. In many situations you see, this pressure drop cannot be allowed when the liquid is flowing in a slow moving velocity and pressure across is very small. We will find it is, we cannot afford to have this type of pressure drop, right? So, in that type of situations, this magnetic flowmeter is quite popular.

The absence of any internal part is very attractive for measurements of velocity of corrosive and dirty fluids. You will find that in the other type of flowmeters, whether it is electric, whether it is differential pressure flowmeter, turbine flowmeters, everywhere we have to install all the systems inside. In the case of turbine flowmeter, entire turbine is to installed inside the pipe in the, though in the case of orifice meter, Venturimeter, the, there is no such installation. But there is, orifice plate is there and also in the case of Venturimeter there is a slight deductions of the pipe diameters which is actually the throat of the pipe that also makes problem. So, the absence of any internal part is very attractive for measurements of velocity of the corrosive and dirty fluids.

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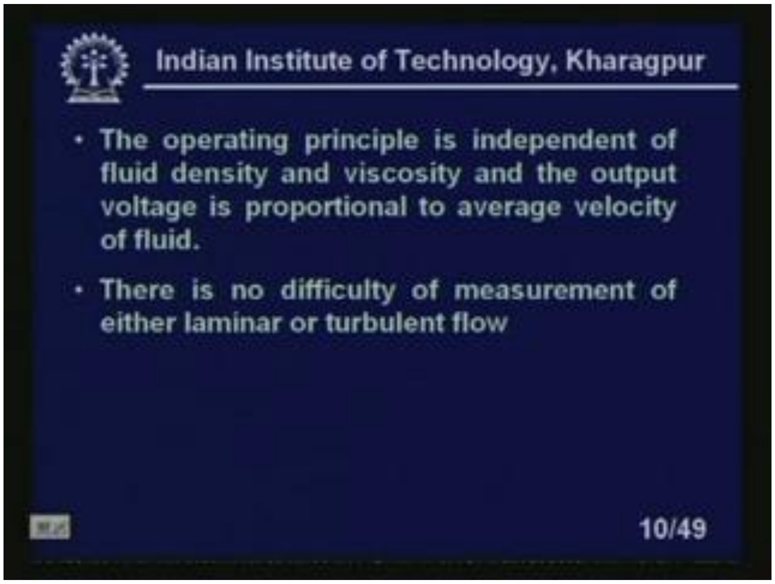

So, the operating principle is independent of fluid density and viscosities are very important and the output voltage is proportional to the average velocity of the fluid; this average velocity of the, this is very important point. Please note the voltage is proportional to the average velocity of the fluid. The operating principle is independent of fluid density and the viscosity, right? That what does it mean that is it independent? For all the liquid, the output voltage will remain same if the velocity is same? It is not true. Why? We will explain after some time. Got it, what I am saying?

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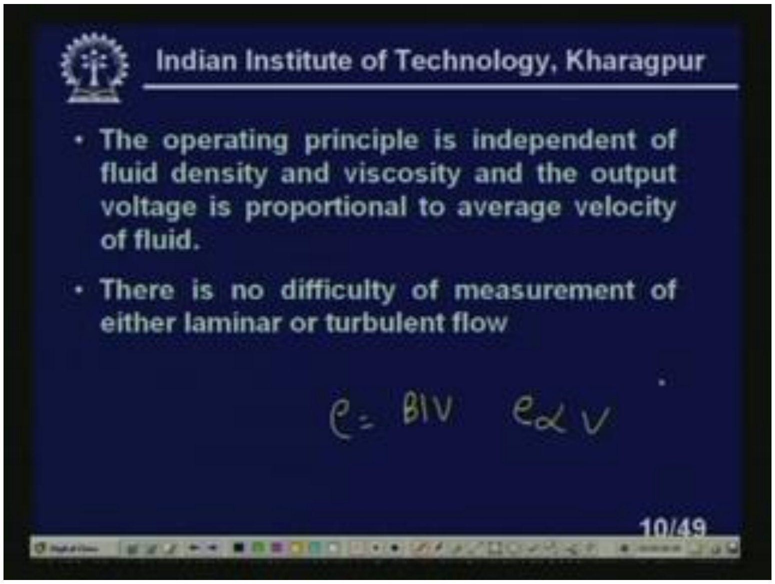

That means I am saying that our equations, if you remember, is e equal to BLV. So, we are saying that e is proportional to V. So, for all liquids, if the velocity is same will I get the same value of the output voltage? Not true; you won't get the, why? The reason is L will remain fixed that is the inner diameter of the pipe, because we will install, this is a basically distance between the pipe. It assumes like this one. You can assume the, like this one. If I again take this example that a conductor is moving inside a, conductor of length is moving inside a magnetic field, if I assume it is of, of length L, so that conductor of length L is moving inside this pipe with a velocity V that we can assume.

Now, we apply the Faraday's law of electromagnetic induction also by using that principles; the conductor of length L which is the inner diameter of the pipe moving with a velocity V on that the flux density B, clear? So, there is no difficulty of measurement of the either laminar or turbulent flow. So, this is very important. Since it is independent of viscosity and density, so obviously we can measure both laminar and turbulent flow.

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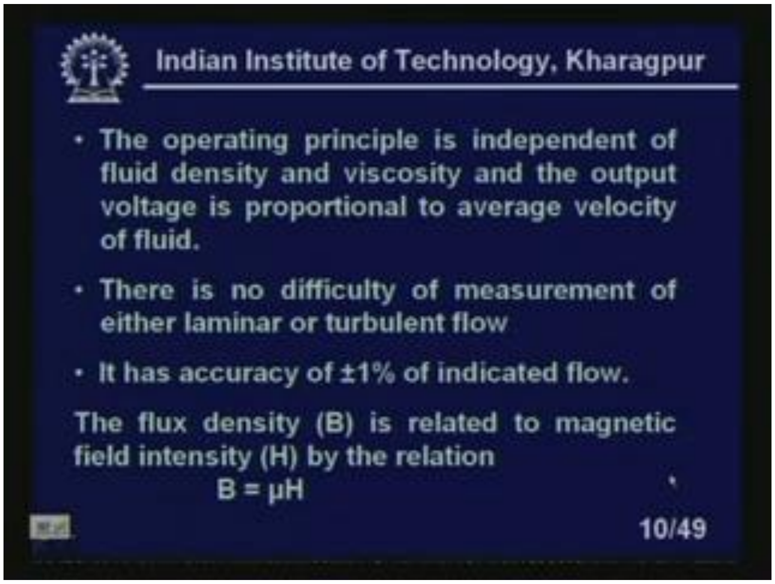

It has accuracy of plus minus 1% of indicated flow. This is also quite high, I should say. The flux density, now what I said sometime back that the, whether for the same velocity I will get the, for the different liquids will I get the same value of the voltage? No, that is not correct. Why, it will be clear now. You see, the flux density B is related to the field intensity H by the relation B equal to mu H, right?

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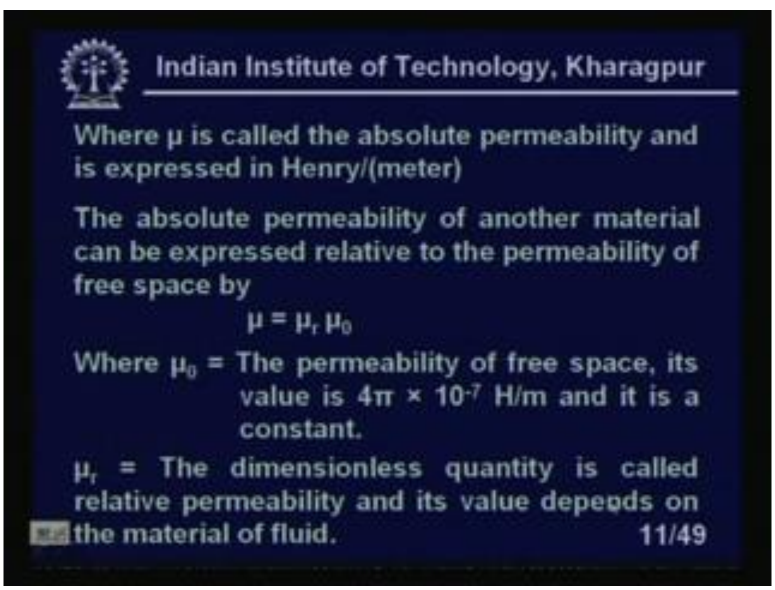

Mu is called the absolute permeability and is expressed in Henry per meter and the absolute permeability of the another material can be expressed relative to the permeability of the free space by mu equal to mu r into mu naught, where mu naught is the permeability of the free space. Its value is 4 pi into 10 to the minus 7 Henry per meter and it is a constant. The mu naught is a dimension, dimensionless quantity and it is called the relative permeability and its value depends on the material of the fluid, right? So, as the material of the fluid changes, value of the mu R will change. So, value of mu will change. So, that will lead to the value of B will change, so the output voltage also will change, right? So, for different liquids I will get different outputs depending on how much the value of the mu for the particular liquid.

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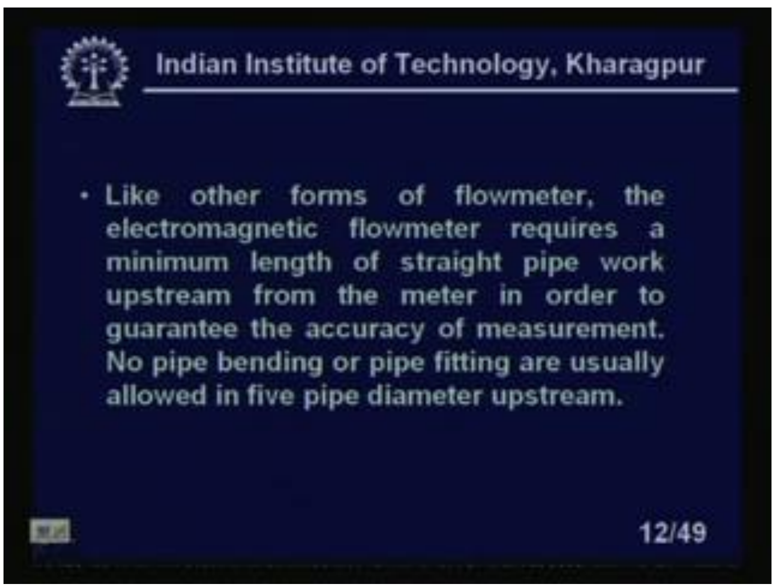

Now, the other forms of flowmeter, the electromagnetic flowmeter requires a minimum length of straight pipe work upstream from the meter in order to guarantee the accuracy of the measurement. We have seen that this type of restrictions we have especially in the differential pressure flowmeter. That means we have 20 upstream pipe diameter. There should be no obstruction, no pipe bendings, that type of things also here saying that like other forms of flowmeter, electromagnetic flowmeter requires a minimum length of straight pipe work upstream from the meter in order to guarantee the accuracy of the measurement. No pipe bending or pipe fittings are usually allowed in 5 pipe diameter upstream. So, it is quite less compared to some other flowmeters. We have seen that in many flowmeters it is 25 diameter upstream. Please note that one thing is important, it is measuring the average flow velocity, right?

Now, disadvantage is, one of the greatest disadvantages that the conductivity should have some minimum value. If it goes below that magnetic flowmeter cannot work. So, this excludes by this all the hydrocarbons. That means electromagnetic flowmeter is not suitable for measurements of the fluid in any petroleum industry. There is some restriction. We have restriction of the petroleum industry of using any electrical type of system, because it is hazardous and I mean it is inflammable. But still, if you do not consider that part you will find that electromagnetic flowmeter will not work for the hydrocarbon, because hydrocarbons conductivity is much less prescribed for the electromagnetic flowmeter. So, that I will discuss one by one.

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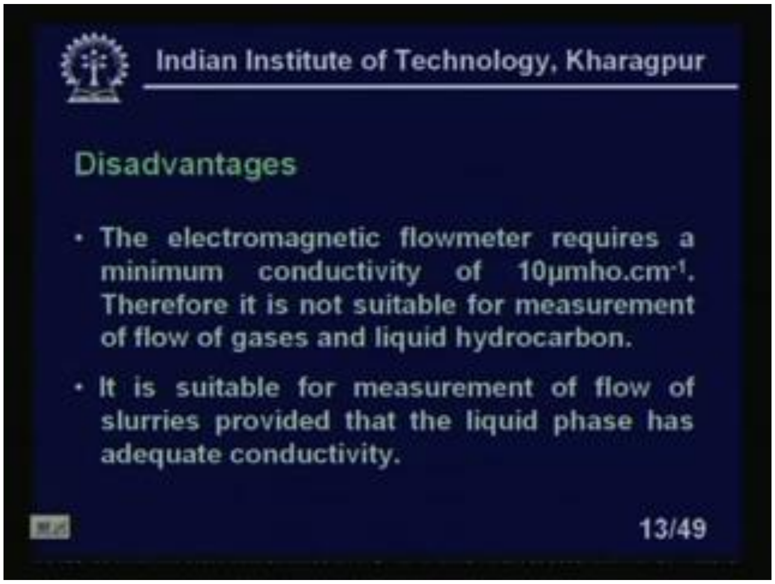

The electromagnetic flowmeter requires a minimum conductivity of 10 micromho per centimeter, right? Therefore, it is not suitable for measurements of flow of gases and liquids, of liquid hydrocarbons. So, it is not suitable for measurements of liquid, any oil industry or petrochemical industry, right? It is suitable for measurement of flow of slurries provided the liquid phase has adequate conductivity. Adequate, liquid phase must have adequate conductivity, then only the measurement is possible, otherwise it cannot be. So, that restriction is there, micro mho per centimeter, it should be there, right?

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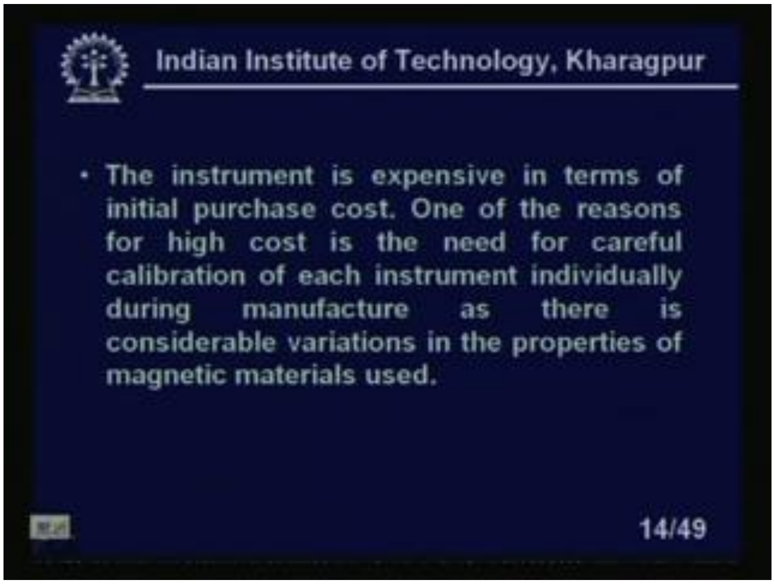

Now, instrument is expensive, as I told you earlier, in terms of initial purchase cost, because I told that the cost of the inner liner of the pipe, cost of the electrode, these are causes of expensive and cost of calibration is also quite high. So, one of the reasons for high cost of the need, is a need for careful calibration of each instrument individually during manufacture as there is considerable variations in the properties of magnetic materials used. You see, that is very difficult to get very, actually predict the B, I mean the amount of value of B you will get. See, it will slightly vary depending on, even though you are giving some coil a slight reorientations of the, slight misalignment of the coil will give you different value of B, so your output voltage. So, each and every meter should be calibrated on the site and separately it is to be, that is the one meter you are calibrating you can say the other meters are of same calibrations value that is not correct, right? So, these are the difficulty along with the initial purchase cost.

That means the, your pipe is quite expensive as well as the electrodes are also expensive. So, keeping these three in mind and keeping these three points electromagnetic flowmeter more expensive than the other conventional flowmeter. But, there are some advantages, as I told you. One is the greatest advantage that it does not create any pressure loss, right? That is the greatest advantage of this electromagnetic flowmeter. The field excitations, what type of field I will give, because I need, I have to give some field excitation for the, this electromagnetic flowmeter to work, right?

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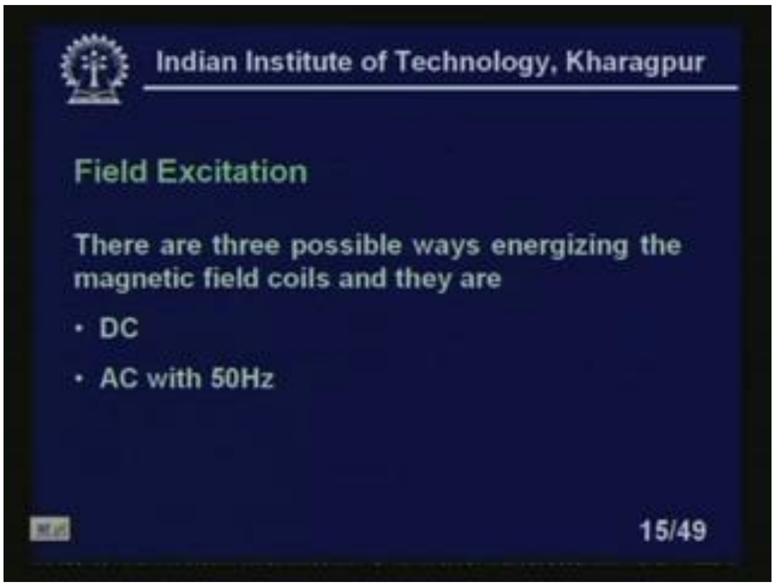

There are three possible ways of energizing the magnetic field coils and they are DC, by, you can direct current you can give to the field coil. It will produce some DC voltage. It does not matter; the pipe is, they have a DC magnetic field and the fluid is moving inside the pipe. So, there is no harm. I will get Faraday's laws of ……, so there is rate of change of flux, so that will be converted into the voltage. We can, as well as AC, with 50 Hertz AC we can have also. That is another way of energizing the magnetic coils.

Two magnetic coils, one on the top, other at the bottom, right? So, what type of electric energy we will give? Either DC or 50 Hertz AC or pulsating DC or interrupted DC. This is another method. So, we will discuss this pulsating DC in details, right? Because, that is the most modern method of energizing the field coils for an electromagnetic flowmeter.

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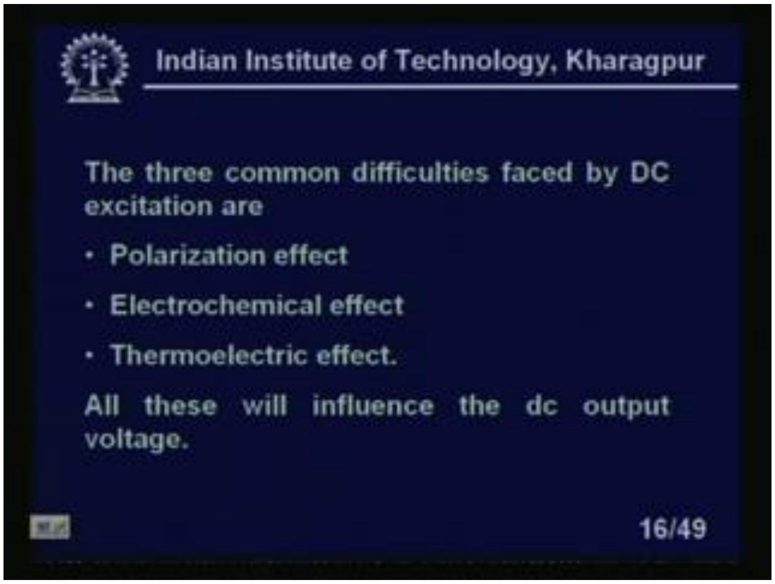

The three common difficulties faced by the DC excitations are polarization effect, any DC has the polarization effect we know, because any DC has the polarization effect. This is a very typical problem whenever you use any DC. There is a electrochemical effect, because there is a, if there is a liquid there is a chance of electrolysis. So, the positive ion moving one side, negative ion moving another side, so all these problems will be there and also thermoelectric effect, because there is a DC wire metals. So, whenever you apply DC, see if there is difference of temperature, so I will get a different, will get a additional voltage for which we have not accounted for, accounted for, right? So, that will give some error in the measurement.

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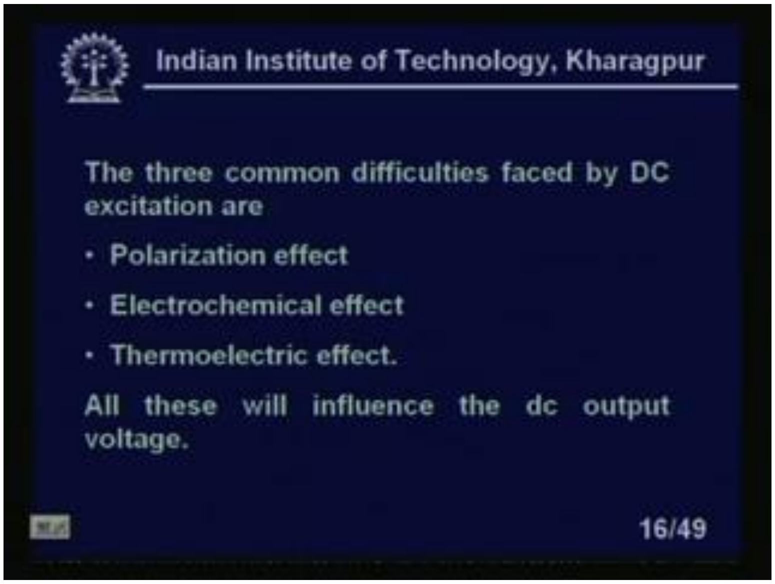

So, all these will influence the DC output voltage. So, what is the solution?

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Solution - these effects can be overcome by energizing the field coils with alternating current of 50 Hertz. We can apply a 50 Hertz signals, alternating signals, right, so and it is used for over the years, right? For many years AC excitation was most common. That signals can be easily amplified by high gain AC. This is another advantage of the AC, because DC amplifier was not popularly available sometime back also. So, now DC amplifiers are available, but as you know op amp has some restrictions of the currents and how much maximum voltage we will get that type of things are there. But, if we have AC amplifier, it is easy to amplify the signal.

Now, the major disadvantage of AC energized field coil is, the output voltage is subject to 50 Hertz interference voltage generated by the transformer action in a loop consisting of the signal leads and the fluid path, right? Signal leads are there, we have a fluid path is there, so in between there is a transformer action that will create problem in the case of AC magnetic field, whenever we are using AC 50 Hertz.

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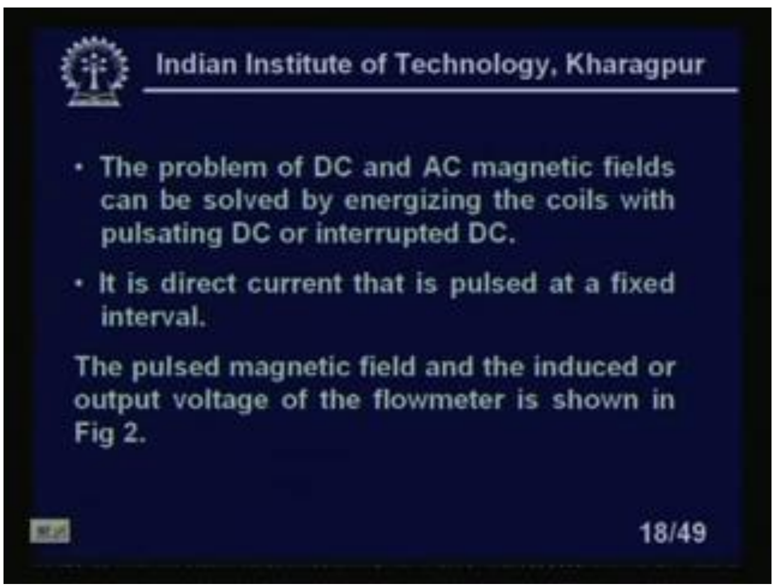

The problem of DC and AC magnetic fields can be solved by energizing the coils with pulsating DC or interrupted DC. We will use some interrupted DC, right, so that to solve this type of problem. Neither there will be any DC problem polarization effect, then electrochemical effect and then thermoelectric effect where those transformer feedback action which is common in the case of 50 Hertz AC energized magnetic field. So, this can, we can discuss in details.

It is a direct current that is pulsed at a fixed interval, right? The pulsed magnetic field and the induced or output voltage of the flowmeter is shown in Figure 2.

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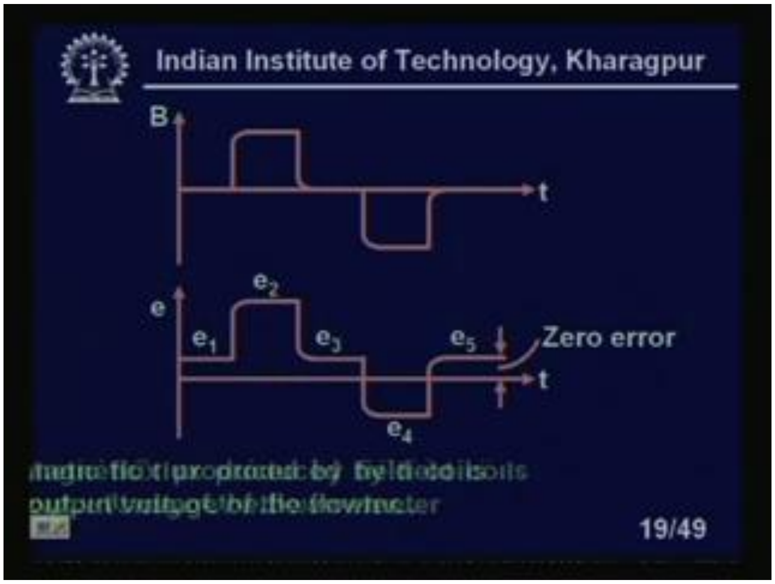

This is Figure 2, we can see here. So, magnetic flux produced by the field coils and the output voltage of the flowmeter. There is a non-zero voltage here, so that is called the zero error in the case of electromagnetic flowmeters, we will discuss this.

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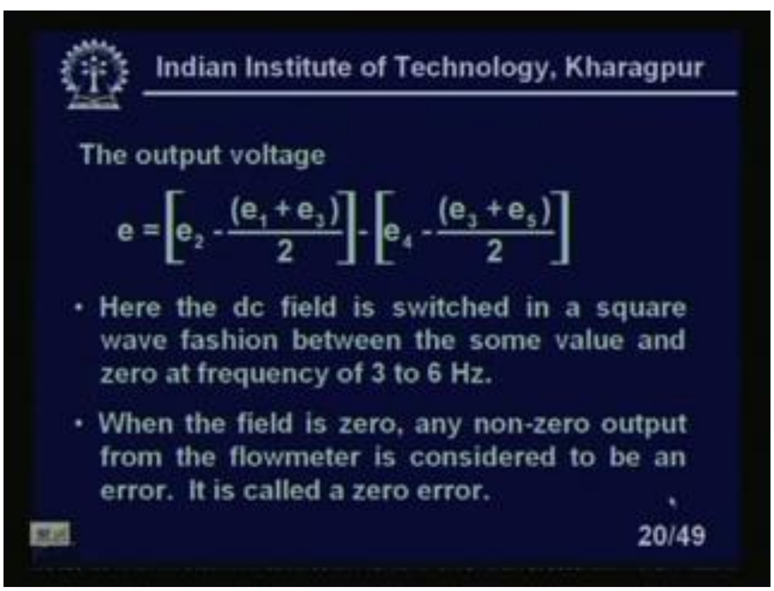

So, the output voltage I can write e equal to e 2 minus e 1 plus e 3 by 2 whole minus e 4 minus e 3 plus e 5 by 2, right? Here, the dc field is switched in a square wave fashion between the some value and zero at a frequency of 3 to 6 Hertz, right? When the field is zero, any non-zero output from the flowmeter is considered to be an error. It is called the zero error. When the field is zero, you see here when the field is zero, so we have some non-zero output voltage. When the field is zero we have a non-zero output voltage, when the field is zero we have a non-zero … So, these are the zero error, clear? When the field is zero, any non-zero output from the flowmeter is considered to be an error. It is called zero error, right?

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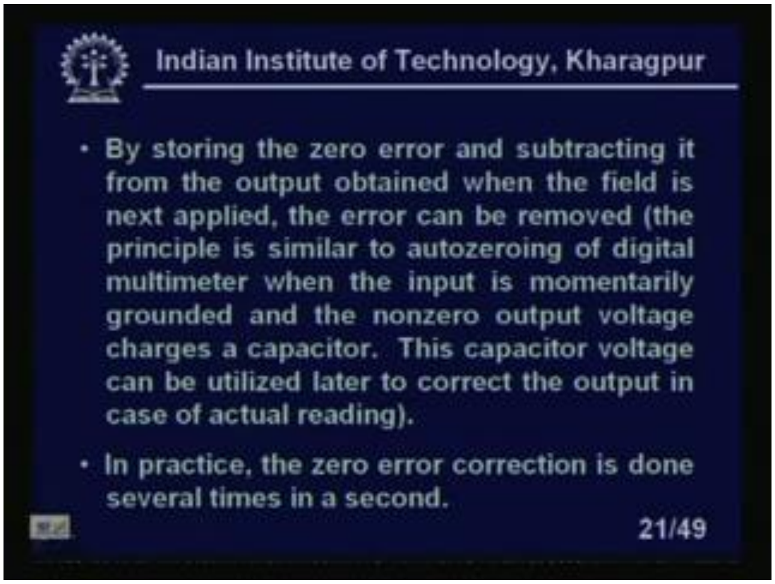

By storing this zero error, the storing the zero errors and subtracting it from the output obtained when the field is next applied, the error can be removed and the principle is similar to the autozeroing of digital multimeter when the input is momentarily grounded and the non-zero output voltage charges a capacitor. This capacitor voltage can be utilized later to correct the output in the case of actual reading, right? In the case of digital multimeter, as you know also we have A to D converter in other type of situation. So, we will find that even though if I short the output, I will be getting some display on the meter, so which is undesirable.

So, what they do actually in the case of digital multimeter, the same principles we are utilizing here also. They are charging one capacitor by this offset voltage by shorting the input. So, that voltage will remain intact. So, whenever I will make the actual measurement, so we will add algebraically that voltage to the measured voltage. So, it will be either subtracted or added, so I will get the actual reading. In practice, the zero error correction is done several times in a second, in the case of flowmeter electromagnetic flowmeter.

Now, there is situations when the electromagnetic flowmeter you can have metal pipe also. You do not need lining, all these things which is expensive. That type of situation will arise when, when the, the, the velocity of the fluid you are measuring and the fluid has a very high conductivity. One of the good examples is suppose you are measuring the fluid velocity of mercury. Mercury may flow through a stainless steel pipe that is quiet desirable it should flow through a stainless steel pipe. In that situation you do not need any liner, any lining, inside lining, because that the conductivity of the mercury is so high, it is higher than the stainless steel. So, even if you put some, I mean sensor outside, the probe outside, so it will pick up the signal that shortest path, right?

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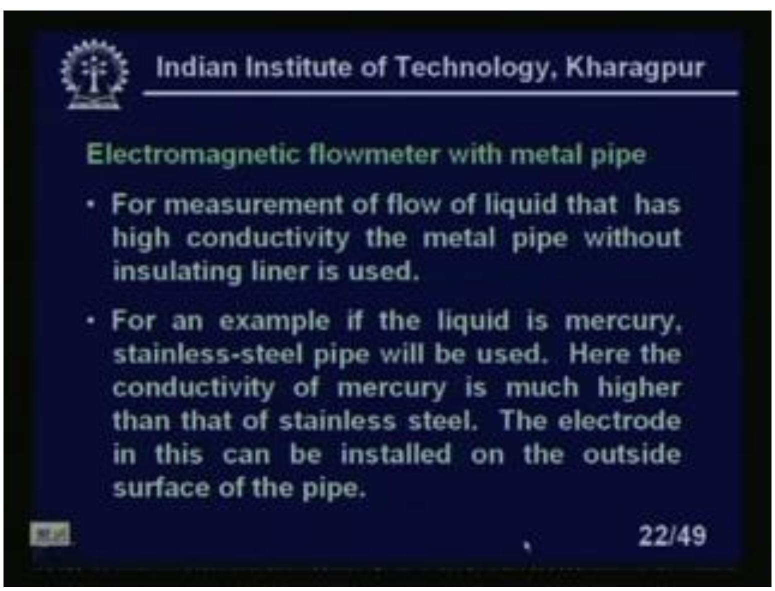

For measurement of flow of liquid that has high conductivity the metal pipe without insulating liner is used that I said. For example, if the liquid is mercury a stainless steel pipe will be used, where the conductivity of the mercury is much higher than that of the stainless steel, right? The electrode in this can be installed on the outside surface of the pipe that is very important. You can install the electrode just outside the pipe, right, because it won't shorten, right? So, that is the, I mean we talked about the electromagnetic flowmeters, their advantages, only disadvantage that it cannot measure the flow of the hydrocarbons and all those things. Other thing is, it is expensive also. Well, how much it is rugged that depends. Obviously, it will not be as rugged as the differential pressure flowmeters which is used over the years. It will need, I mean it need very little attention also.

So next flowmeter, also nonlinear … type, we will discuss is ultrasonic flowmeter, right?

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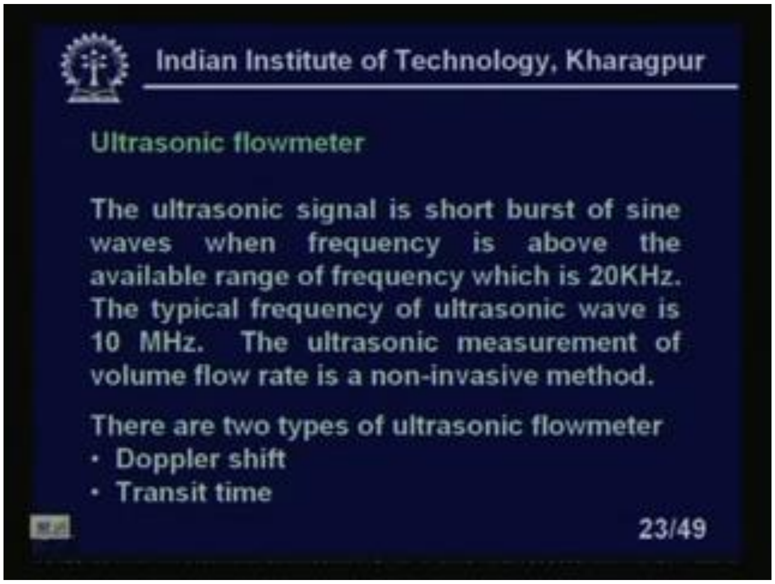

We will go to the board, digital board, yes ultrasonic flowmeter. You see, the ultrasonic signal is a short burst of sine waves when the frequency is above the available range of the frequency which is 20 kilo Hertz. This is non audible range, right? So, above 20 kilo Hertz even we have to use …. So, above that frequency we call it ultrasonic frequency.

Now, typically the ultrasonic frequency may be around 10 mega Hertz, but we will see that we can have frequency anything between 0.5 mega Hertz to 10 mega Hertz.

The ultrasonic measurement of the volume flow rate is a non-invasive method. This is again a non-invasive method of measurements. This is a great advantage of this type of method, we will see, I mean later on. There are two types of ultrasonic flowmeters, so basically. They are Doppler shift flowmeters and there are time shift, transit time measurement flowmeter. One is Doppler shift flowmeter that is another is transit time measurement type flowmeters. We will discuss both the case. There are some and situation where you have to use Doppler shift, in the some situation we have to use transit time, transit time measurement technique.

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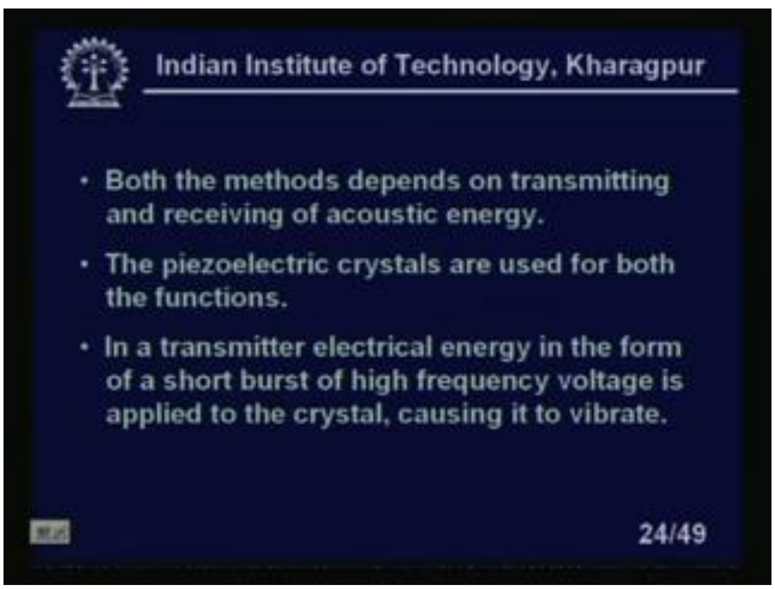

Both the method depends on the transmitting and receiving of acoustic energy. Acoustic energy is to be transmitted and received and usually we use piezoelectric crystals for that. The piezoelectric crystals are used for both the functions. In a transmitter, electrical energy in the form of a short burst of high frequency voltage is applied to the crystal causing it to vibrate. But, vibration now communicate to the, through the liquid and it ends the, another diametrically opposite side of the pipe where there is another sensor which will pick up the signal or receive the signal, right?

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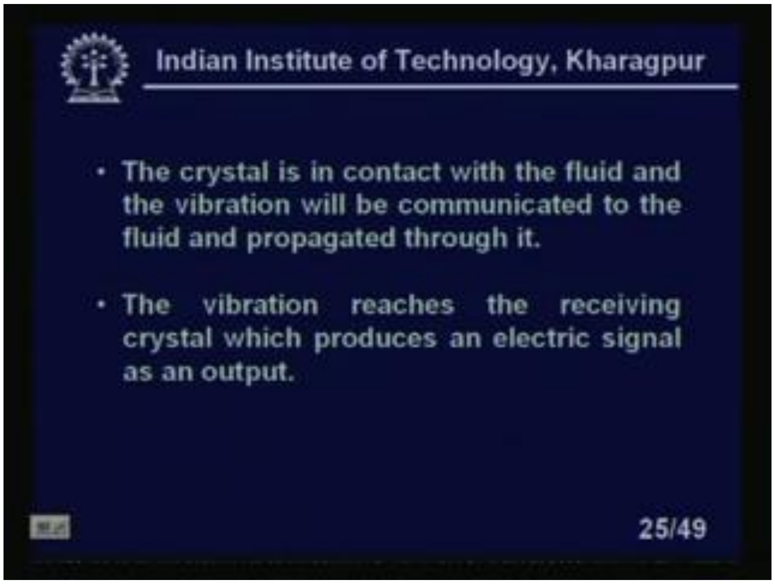

The crystal is in contact with the fluid and the vibration will be communicated to the fluid and propagated through it to, what far? To the point, where the other sensors are there, diametrically opposite side. The vibration reaches the receiving crystals which produces an electric signal as an output, right?

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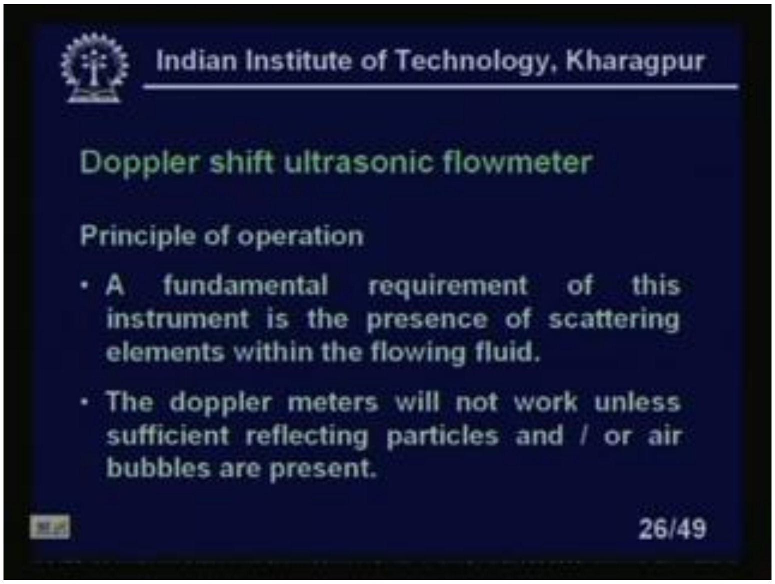

Now let us, this is the basic principle so far I have discussed about the, I mean both the case of Doppler shift ultrasonic flowmeter and transit time measurement flowmeter, this is the basic principle. We will use some ultrasonic piezoelectric crystals. We will transmit the signals and we will receive the signals. The Doppler shift ultrasonic flowmeter, it looks like this, principle of operation let us look. The fundamental requirement of this instrument is the presence of scattering elements within the flowing fluid, very clean fluid.

If the liquid is very clean, if the gas or gas we cannot make the flow measurements, in that type of situation what I am saying, the Doppler meters will not work unless sufficient reflecting particles and or air bubbles are present in the fluid itself, which, in which we are interested in measuring the, because it is to be reflected, right? We will show that thing in the figure.

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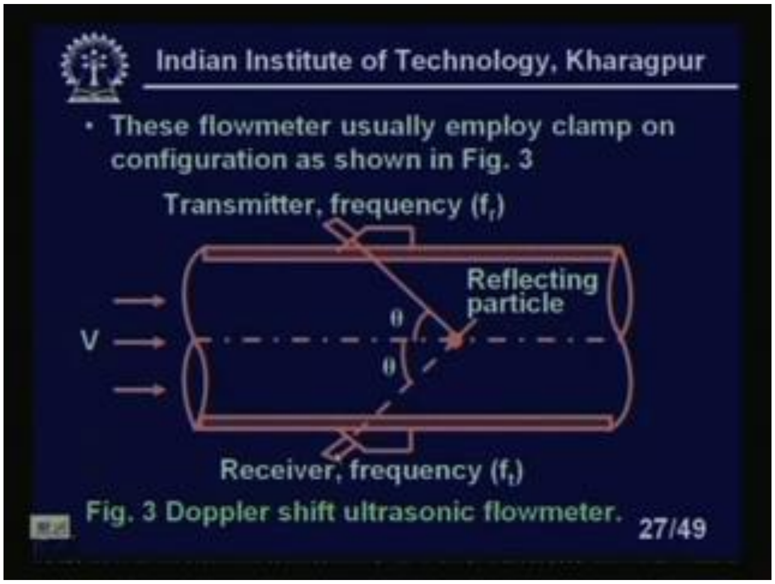

These flowmeters usually employ clamp on configuration as shown in Figure 3. You see, this is our configurations. I have a, I am transmitting the signal from this, right? You see here I am transmitting signal from, this is coming down here. This is reflecting particles, so it is getting reflected with an angle theta and I have a receiver here, right? So, there is a change of frequency. We will measure that frequency and calibrate in terms of flow. So, fluid is going through velocity V, right and this is a clamp on measurement. That means you can externally clamp on these meters. Even though, we are showing the, there is some deviations, some refractions that is I am not showing in details here, right? This is Doppler shift ultrasonic flowmeter.

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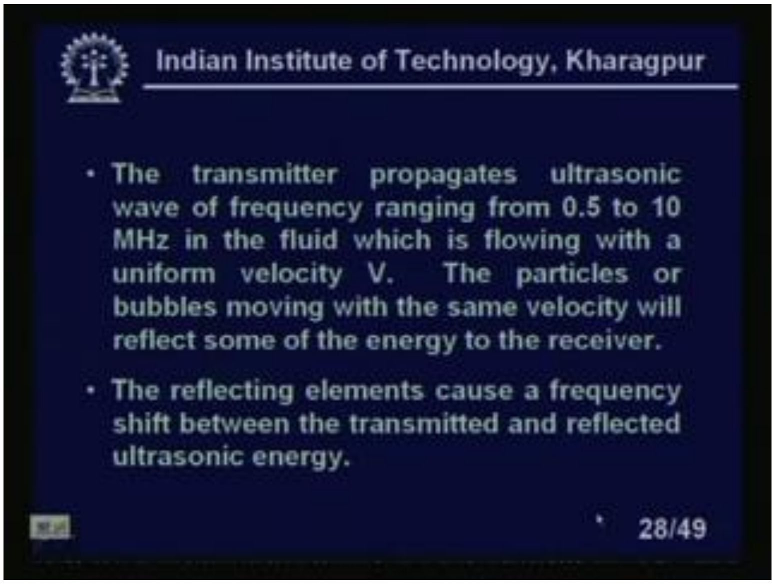

The transmitter propagates ultrasonic, ultrasonic wave of frequency ranging from 0.5 to 10 mega Hertz in the fluid, which is flowing with a uniform velocity of V. The particles or bubbles moving with the same velocity will reflect some of the energy to the receiver, right? Some of the energy will be, I mean received by the receivers which is again are piezoelectric crystals. The reflecting elements cause a frequency shift between the transmitted and reflected ultrasonic energy.

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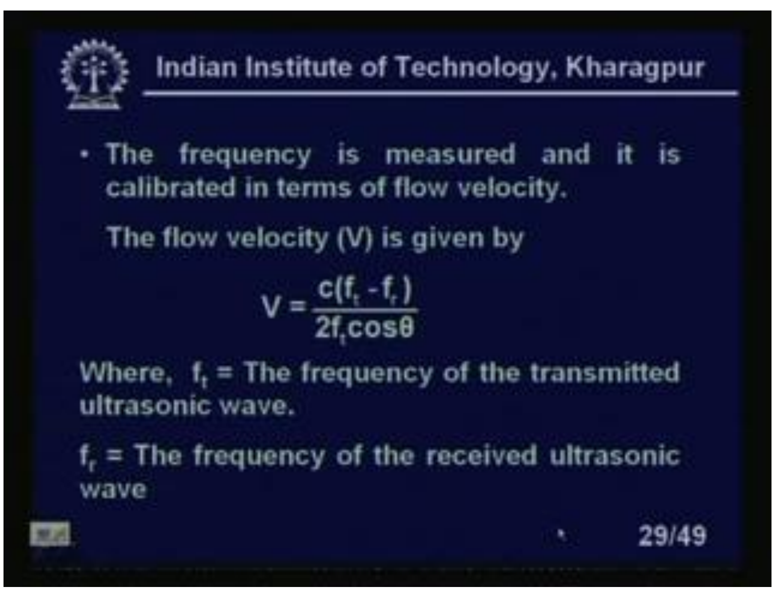

The frequency is measured and it is calibrated in terms of flow velocity. It is calibrated in terms of flow velocity and the flow velocity V is given by c f t minus f r 2 f t cos theta. What are those legends? f t is the frequency of the transmitted ultrasonic wave, f r is the frequency of the received ultrasonic wave or reflected ultrasonic wave.

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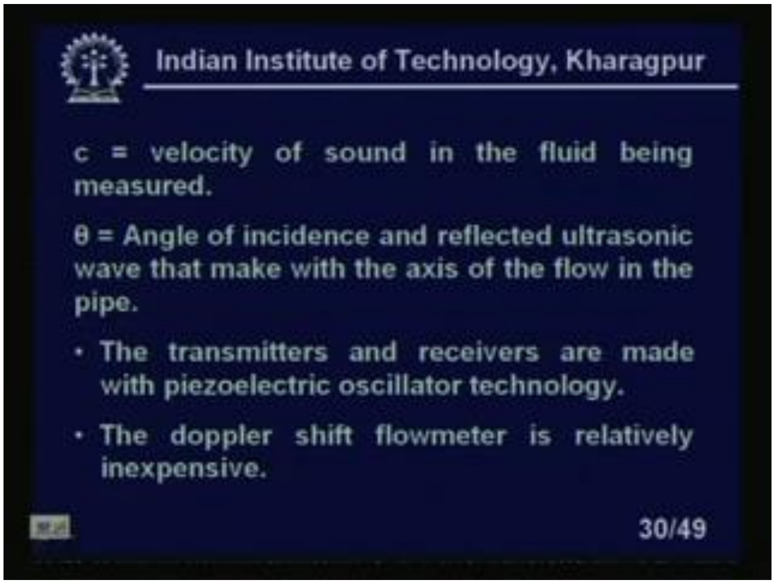

c is the velocity of sound in the fluid being measured, theta is the angle of incidence and reflected ultrasonic wave that make with an axis of the flow in the pipe. c, now you see here the, we have to know the c very accurately in the medium itself, because your accuracy of the entire measurement depends on how accurately you know the velocity of the sound wave, ultrasonic wave in that particular liquid, right? That is true, if, I mean found earlier, then only you can find the velocity, but whereas you will see in some other methods this is not necessary. It will cancel out, right? That is in those methods are preferred. Transmitter and receivers are made of piezoelectric oscillator technology. The Doppler shift flowmeter is relatively inexpensive. This is quite inexpensive instrument.

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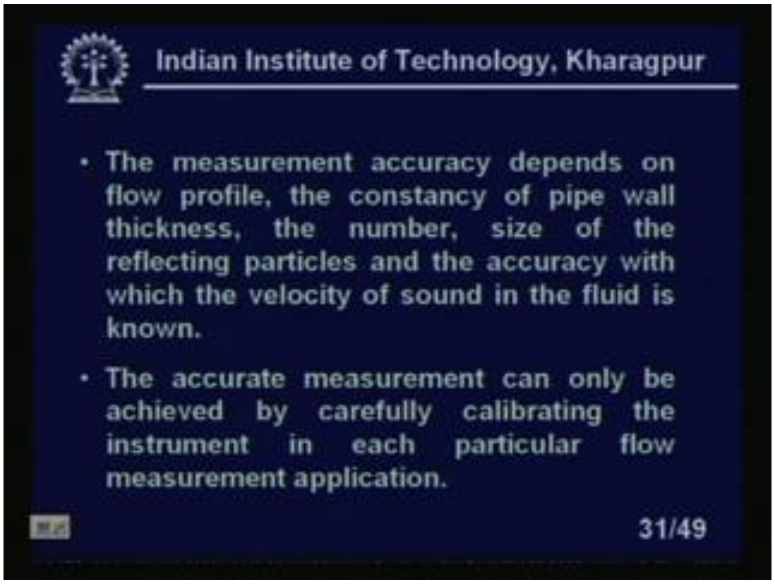

The measurement accuracy depends on the flow profile, the constancy of the pipe wall thickness, the number, size of the reflecting particles and the accuracy with which the velocity of sound in the fluid is known, right? So, these are the all things which will be necessary for measure, accurate measurements of the fluid velocity in a pipe by ultrasonic method of Doppler shift. The accurate measurement can only be achieved by carefully calibrating the instrument in each particular flow measurement application, right? That is also in, see you have to again like electrometric flowmeter we have to calibrate individually in all cases. That restricts the use of these instruments a lot, but it is, is quite popular for some other application, because it is totally non-invasive technique.

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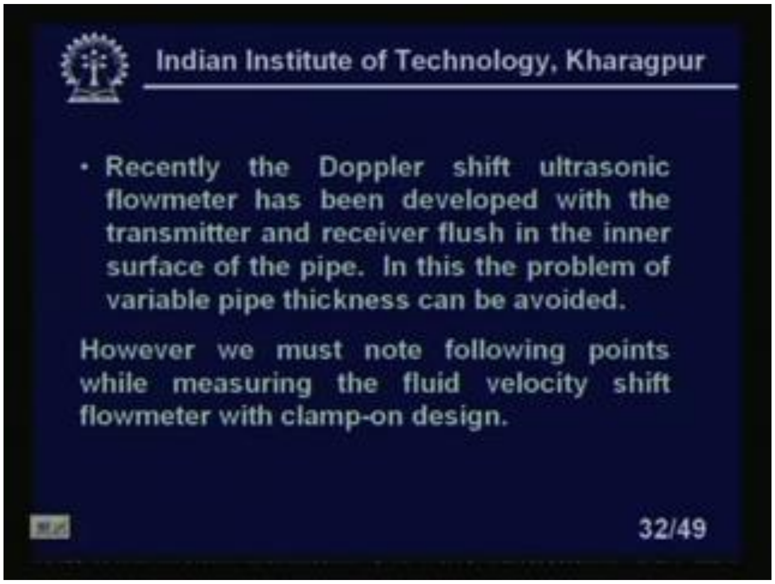

Recently, the Doppler shift ultrasonic flowmeter has been developed with the transmitter and receiver flush in the inner surface of the pipe. In this, the problem of variable pipe thickness can be avoided, because in the clamp on method you have to install the ultrasonic flowmeters from the outside, right, ultrasonic flowmeter outside the flow pipe. But recently, the Doppler shift flowmeters has been developed with the transmitter and the receivers flush in the inner surface of the pipe. In that type of situations, the variable pipe thickness cannot be avoided, because you see the, if there is a variation in the pipe thickness that will cause the problem, because you will ….. the ultrasonic waves outside. So, it is coming through some wedge, then it is coming to the liquid.

But, this type of problem can be solved if we install the, the, if the, if the, if the sensor, ultrasonic sensor is flush with the liquid itself, right? However, we must note following points while measuring the fluid velocity shift, velocity shift flowmeter with the clamp on design.

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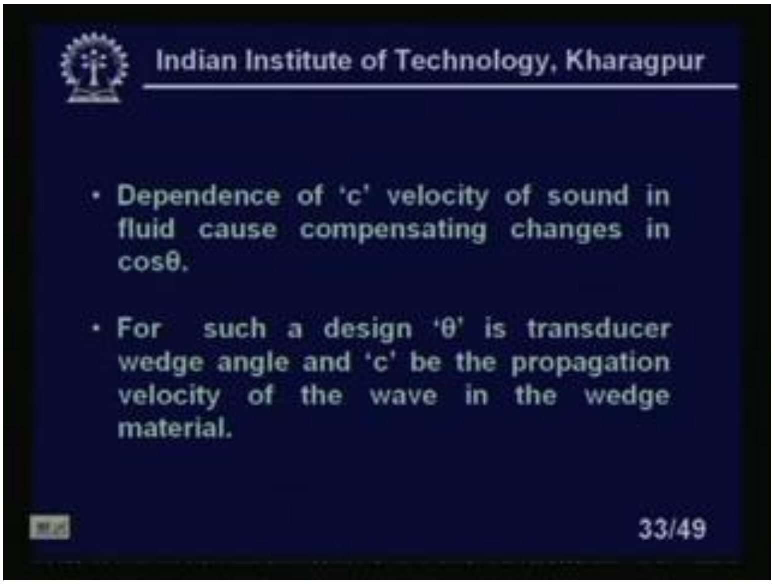

Dependene of c, velocity of sound in fluid cause compensating change in cos theta. For such a design, theta is transducer wedge angle and c be the propagation velocity of the wave in the wedge material.

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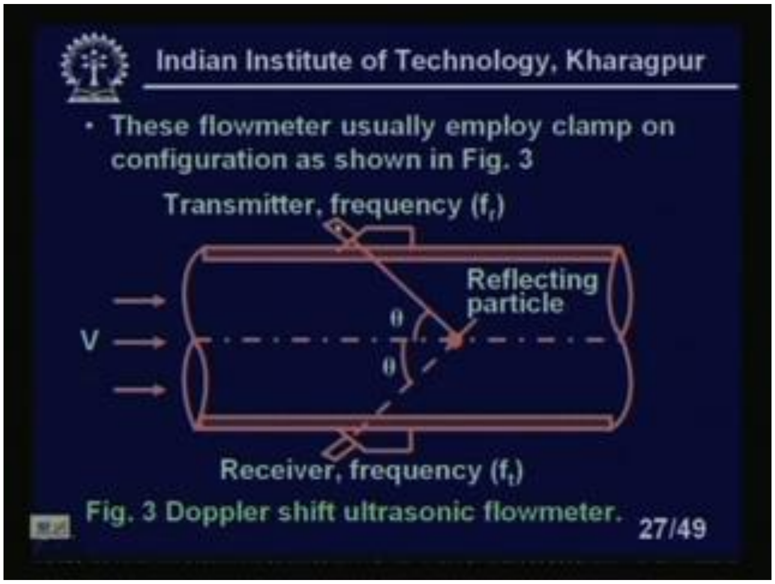

What is that to we can look at that if I look at ultrasonic flowmeter, it will, this is here. You see here, this is the wedge inside which we have put. So, the velocity of the fluid in the, inside of the ultrasonic, in the wedge is more important ………. We must know that accurately also, right? So, those are the problem with the ultrasonic flowmeter. That is people now, because there is a reflection also of the ultrasonic wave, so if they want to flush it with the liquid itself.

Dependence of c velocity of sound in the fluid causes the compensating changes in cos theta. For such a design, theta is transducer wedge angle and c is the propagation velocity of the wave in the wedge material.

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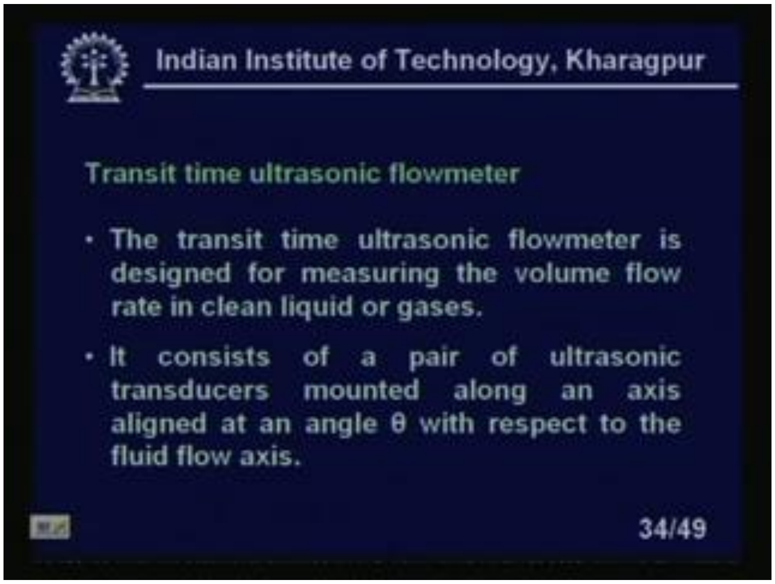

Now, let us start to discuss the transit time ultrasonic flowmeter. This flowmeter has some tremendous advantage over the or conventional Doppler shift flowmeter. So, let us discuss that. The transit time ultrasonic flowmeter is designed for measuring the volume flow rate in a clean liquid or gases. This again the problem, in one case you need dirty liquids and another case you need a clean liquids or gases. If the liquid is dirty, we cannot make the measurement. It consists of a pair of ultrasonic transducers mounted along an axis aligned at an angle theta with respect to the fluid flow axis, right? It will be more clear once you see the diagram of this.

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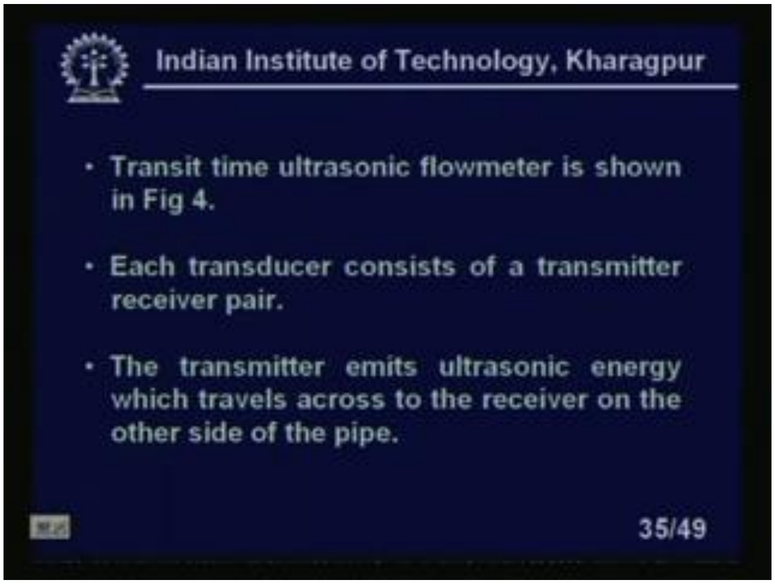

Transit time ultrasonic flowmeter is shown in Figure 4, next figure. Each transducer consists of a transmitter receiver pair. So, each transducer is a transmitter receiver pair and transmitter emits ultrasonic energy which travels across to the receiver on the other side of the pipe, right?

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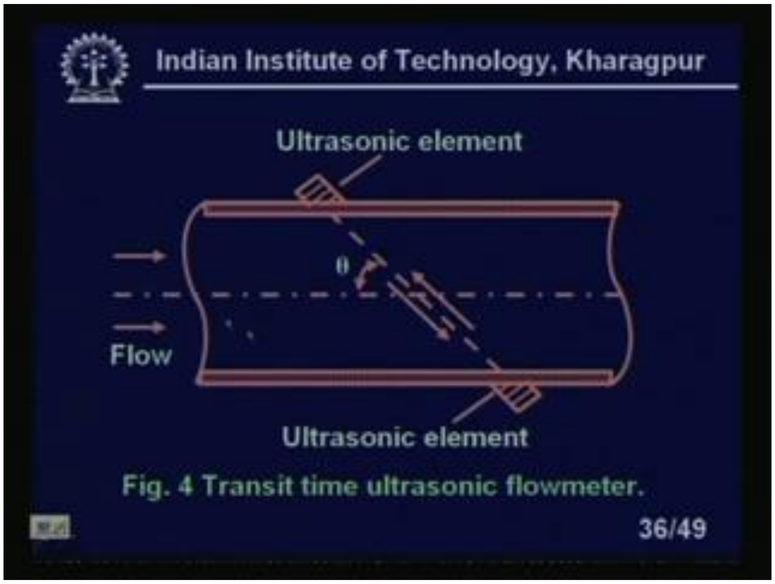

You can see here, so this is a transmitter and this is also a receiver. So, this comes here, receives and it again transmits, right. Fluid is flowing through the pipe. This is angle theta.

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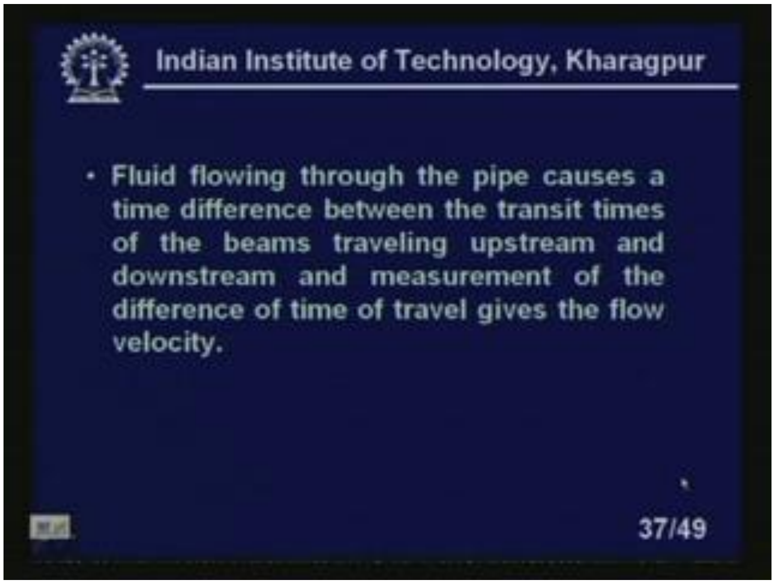

The fluid flowing through the pipe causes a time difference between the transit times of the beams traveling upstream and the downstream and measurement of the difference of time traveled gives the flow velocity. What is that?

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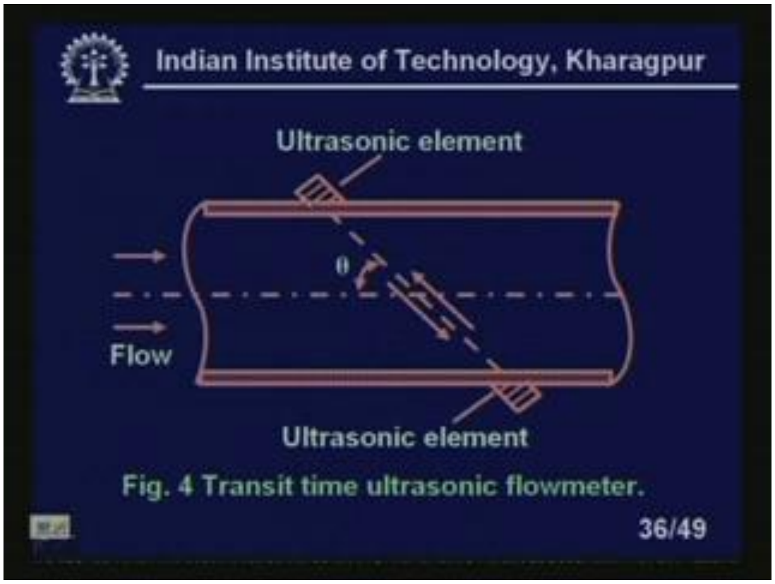

So, when the liquid is coming, when the, I mean this ultrasonic wave is traveling in this direction, this upstream direction, because it is moving and when it is flowing the, when the ultrasonic waves it is coming back which is in the opposite side of the beams, so there is a time shift between the two, right? Received signal transmitting between the time lapse between the signal transmitted and the received it will be different in two cases, right?

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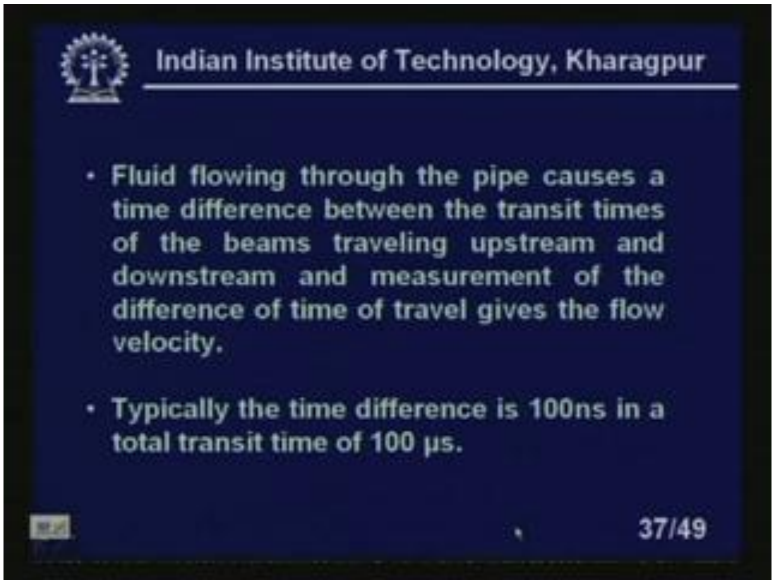

So, using that principles I can measure the, you see here the fluid flowing through the pipe causes time difference between the transit times of the beams traveling upstream downstream and the measurement of the difference of time travel gives the flow velocity. Typically, the time difference is 100 nanoseconds in a total transit time of 100 micro seconds. There is again a problem. How you will measure such a small value of time? We have to measure it …. very accurately, right? So, accuracy of the measurement of fluid velocity comes down, falls down for the measurement of time difference of 100 nanosecond.

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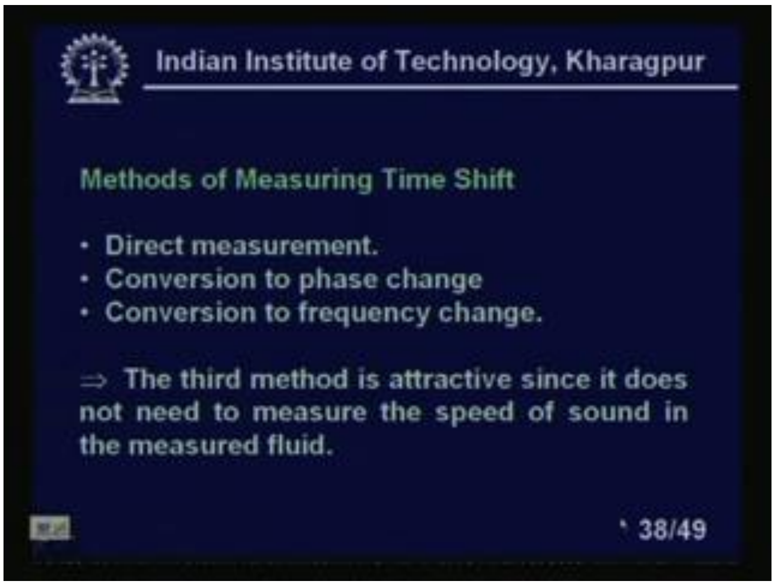

So, how will you measure this time shift? So, methods of measuring the time shift - there is direct measurement, conversion to a phase change, you have a conversion to a frequency change. We will discuss the frequency change in more details. The third method is attractive since it does not need to measure the speed of the sound of the measured fluid, because in previous case, in Doppler shift flowmeter we have seen that we need the, we have to measure the fluid velocity which is not necessary in this case, right?

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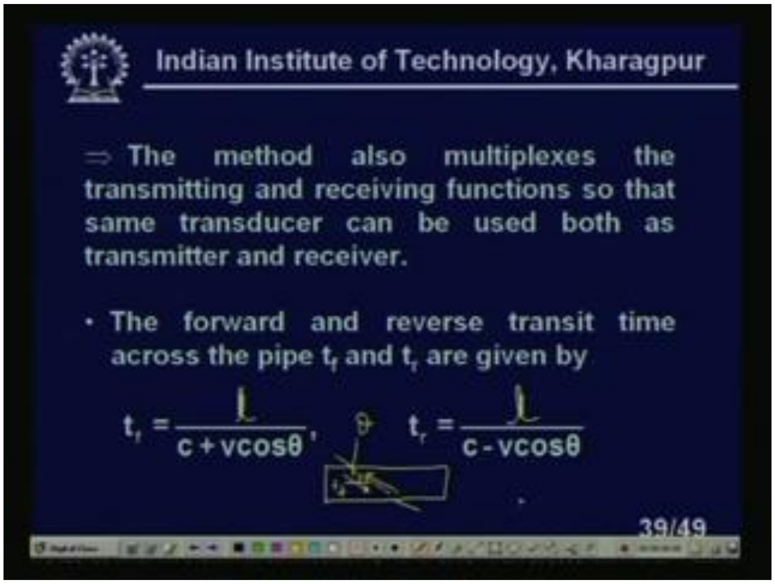

The method also multiplexes the transmitting and receiving functions, so that some transducer can be used both as a transmitter and receiver. So, multiplexes signal should be there. When the transmitter is working as a transmitter, during that time you should not receive any signal, right? So, some multiplexing functions your transmitter …., I mean you have to make; we should say again the cost of the signal processing circuitry of this type of transducers. The forward and reverse transit time across the pipe is t f and t r are given by c plus v cos theta, right? If I take this, I can draw it here nicely and I have a pipe here, have a signal here, we are receiving the signal.

So, this is the transmitter. When it is going back, forward and reverse …., so how much it will be? This is the l, is the length between the two sensors is l actually. Please note, this is l, small letter l. This is small letter l, right? This difference between the positions of the two sensors is the velocity of sound plus v cos theta, because this is cos theta we have shown, is not it? So, this is theta, right? So, this is cos theta, so v cos theta, so that is a time. Similarly, here also it will be c minus v cos theta, right? Because in that case, what will happen? In case of return, because signal is going in this direction, is not it, it will take more time obviously to reach the transmitter here itself.

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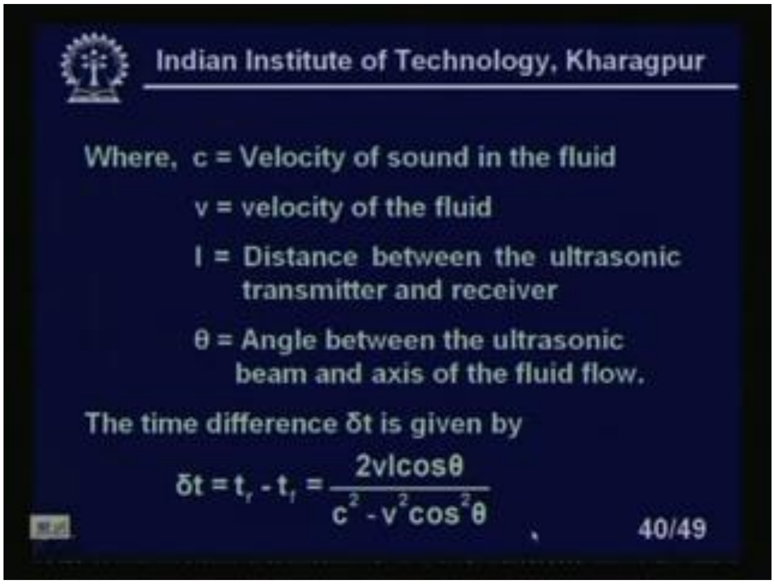

c is the velocity of sound in the fluid, v the velocity of the fluid, l is the distance between the ultrasonic transmitter and receiver, theta is the angle between the ultrasonic beam and the axis of the fluid flow, right? The time difference delta t is given by delta t equal to t r minus t f. If you subtract 2 vl cos theta upon c square minus v square into cos square theta, clear?

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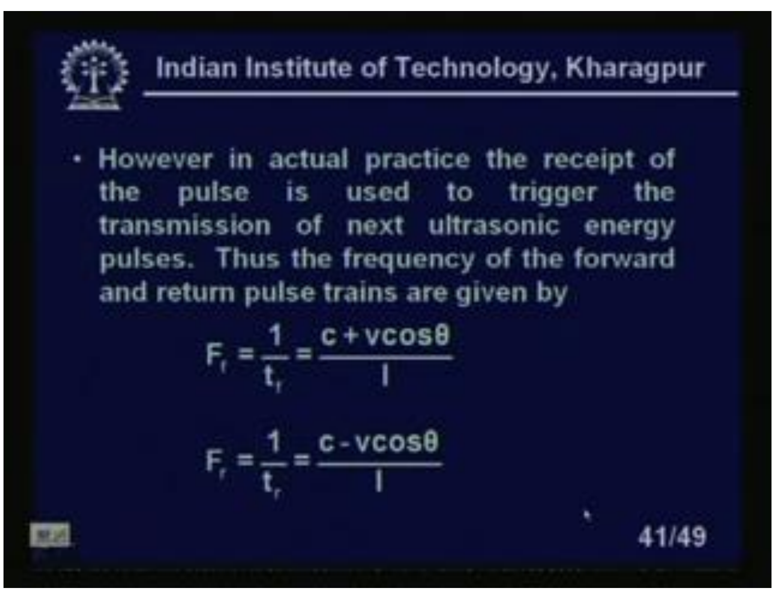

However, in actual practice, the receipt of the pulse is used to trigger the transmission of next transmits, ultrasonic energy pulses. This is ……, otherwise how will have a machine will know? So, the receipt, whenever we will receive the pulse we will trigger some signal conditioning, so that it will launch the next ultrasonic pulses to the transmitter itself. Even that time it is a transmitter and the transmitter where I have received the signal from is actually now receiver. Thus, the frequency of the forward and return pulse trains are given by inverse of F f is equal to 1 by t f c plus v cos theta by l, F r equal to 1 by t r c minus v cos theta by l, right?

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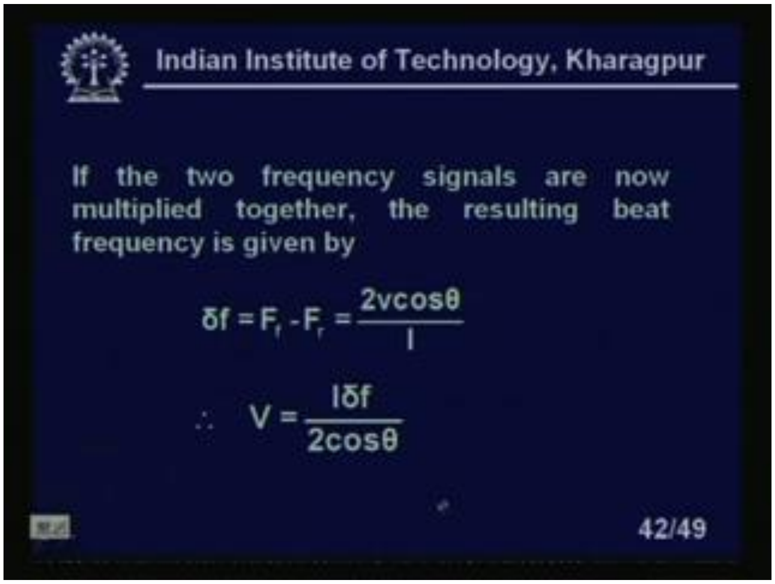

See, if I take this frequency shift, thus the frequency, I mean if the two frequency signals are now multiplied together, the resulting beat frequency is coming, difference and the sum frequency will …. 2 v cos theta by l if the difference frequency, so v is l delta f 2 cos theta. If l and 2 cos theta are same, fixed, so delta f we can see is directly proportional to the velocity of the fluid flow, right which is flowing through the pipe.

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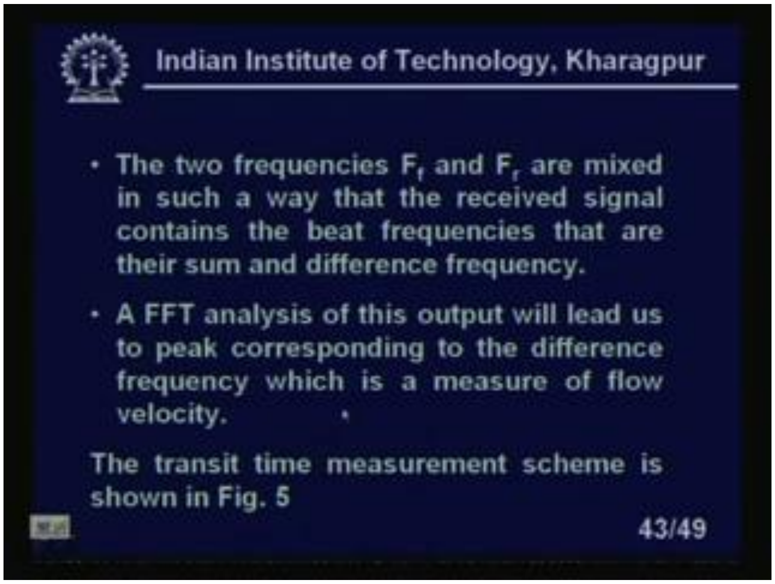

The two frequencies F f and F r are mixed in such a way that the received signal contains the beat frequency that are their sum and difference frequency. So, that difference, sum frequency we can easily, I mean, I mean pass through a low pass filter, so only the beat frequency will remain, difference frequency will remain. The other frequency will go away, right and FFT analysis of this output will lead us to a peak corresponding to the difference frequency which is a measure of the flow velocity, right? FFT analysis we will do, so we will get a peak. So, that will give you about the flow velocity.

Peak corresponds to the difference frequency, so we will get a peak corresponding to the difference frequency which is the measure of the flow velocity. Now, transit time measurement is shown in Figure 5 that we can see.

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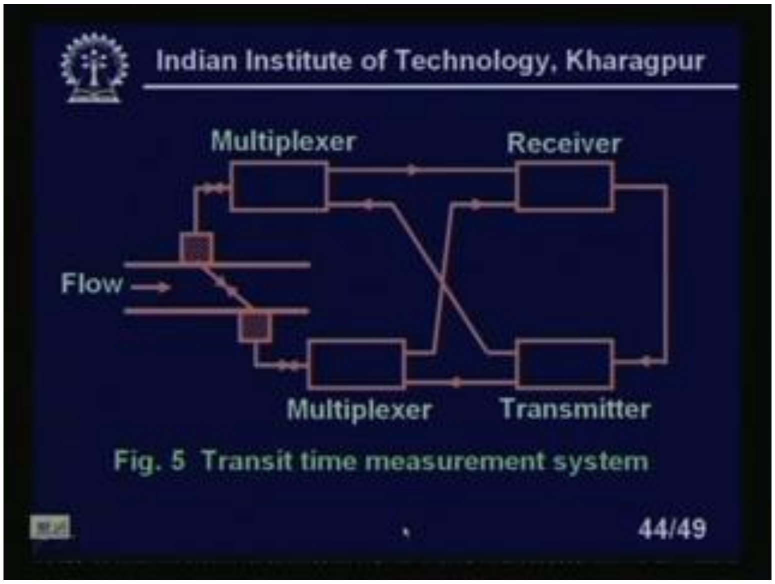

So, this is our transit time measurements. You have multiplexer. It will activate whether this will be transmitter or receiver and this is the receiver signals and we will have a circuit.

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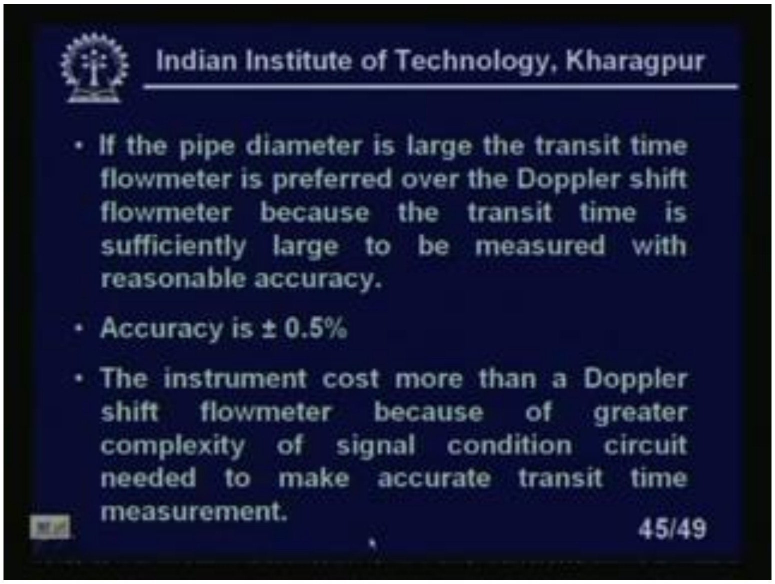

If the pipe diameter is large, then the transit time flowmeter is preferred over the Doppler shift flowmeter, because we are, at that time the transit time will be large and it will be easy to measure the large time difference. That delta f also will be large in that case, because we are not measuring the time. Ultimately we are converting to frequency and time, frequency and then measuring the frequency. So, if the transit time is large, so obviously what will happen? Your delta f also will be large. The accuracy is typically 0.5%. That is a typical accuracy of our, our flowmeter.

The instrument cost more than a Doppler shift flowmeter, because of the greater complexity of the signal conditioning circuitry, right? The circuit is more complex than the Doppler shift, but the advantage that we do not have to measure the velocity of sound in particular liquid. So, that is I am saying the instrument cost more than Doppler shift flowmeter, because of the greater complexity of the signal conditioning circuit needed to make accurate transit time measurement, right?

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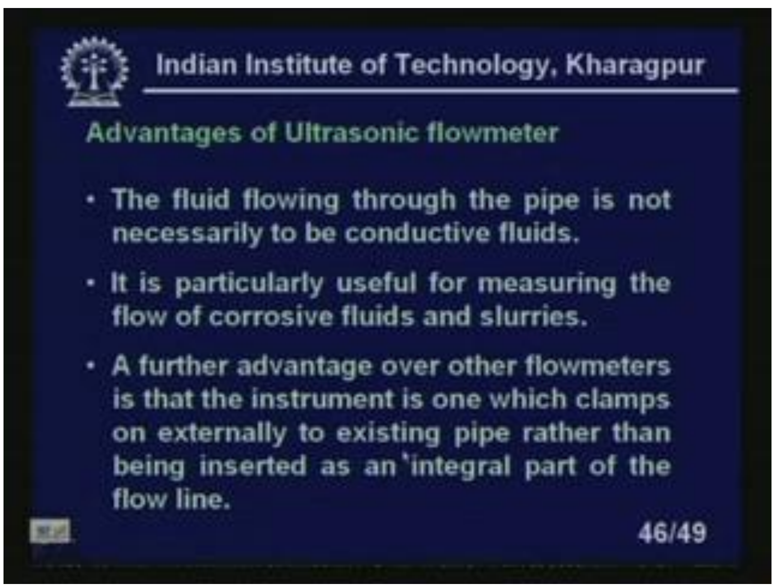

Now, advantage of this ultrasonic flowmeter, let us look at one by one. This is in general; I mean not only the, the flowmeter, Doppler shift flowmeter or transit time measurement flowmeter, I am talking of the general advantage of the ultrasonic flowmeters, right?
There are several advantages of the ultrasonic that is the reason it is, slowly it is coming up. You can say now the market share is around 10%; market share of the flowmeter in

the processing industry, you will find it is 10%, right? The fluid flowing through a pipe is not necessarily to be conducting fluid. This is very, I mean important advantage you should say that, because in case of, you will see that electromagnetic flowmeter it must be a conducting fluid, that restriction is not there, right?

It is particularly useful for measuring the flow of corrosive fluids and slurries, right? See, we have corrosive fluids and slurries. Even though it is not conducting, because in the case of fluids, I mean slurries we have seen that in the case of magnetic flowmeters, the liquid portions of the slurries should be conductive, otherwise you cannot use the flow measurement of the slurries by the electromagnetic flowmeter. Now, in this case any slurries, if it is conductive, non-conductive it does not matter, I can make the measurements, right, by the ultrasonic flowmeter.

A further advantage, again I can repeat this is ultrasonic flowmeters advantage in general, right? A further advantage of the, over other flowmeter is that the instrument is one which clamps on externally to existing pipe rather than being inserted as an integral part of the flow line, right? It happens in the case of electromagnetic flowmeter also. You see here also you do not have to install inside like orifice meter, turbine flowmeter, all the type of flowmeters, you do not have to install anything inside the pipe or rotameter also, the bob is there which is inside. So, further advantage over other flowmeters is that the instrument is one which clamps on externally to existing pipe rather than the being inserted as, excuse me, as an integral part of the flow line.

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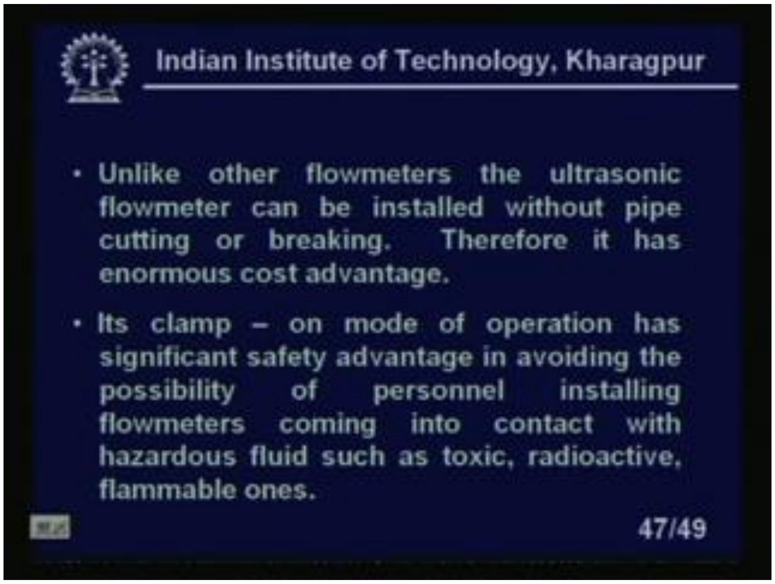

Unlike other flowmeters, the ultrasonic flowmeter can be installed without any pipe cutting and breaking, you see that previous slide, to existing pipe rather than being inserted as an integral part of the … It is a clamp on. You have seen the Doppler shift flowmeter it is a clamp on system we can have. Just outside you install the two sensors, it will through the wedge, so the ultrasonic signal will enter the pipe. So, it is totally clamp on system. That means outside of the pipe you install the two ultrasonic sensors. Even though there is some problem created because of the pipe thickness and all this …. non uniform pipe thickness that creates the problem.

So, for that reason people started to make the ultrasonic flowmeter Doppler shift where the sensors are flushed with the liquid. But if you consider only the clamp on method, so it is more advantageous that it is nothing to be installed inside. So, it is a totally non-invasive technique. There are some advantages of this type of flowmeters, because of non-invasive method. Unlike other flowmeters, the ultrasonic flowmeters can be installed without pipe cutting or breaking. Therefore, it has enormous cost advantages. The cost advantage is also there.

Its clamp on mode of operation has significant safety advantages in avoiding the possibility of personnel installing flowmeters coming into contact with a hazardous fluid, such as toxic, radioactive and flammable ones. If you have that type of liquid flowing through the pipe, so the person who is working on this one, so this is also advantageous that means if it is clamping on outside, just have a pipe, have a pipe and you just, I mean installing outside like this to clamp on. So, it has the advantage that the person also may be not exposed to this hazardous environment, right, where the fluid may be toxic or radioactive, inflammable ones.

There is another advantage of this one type of meter also in food and drug industry.

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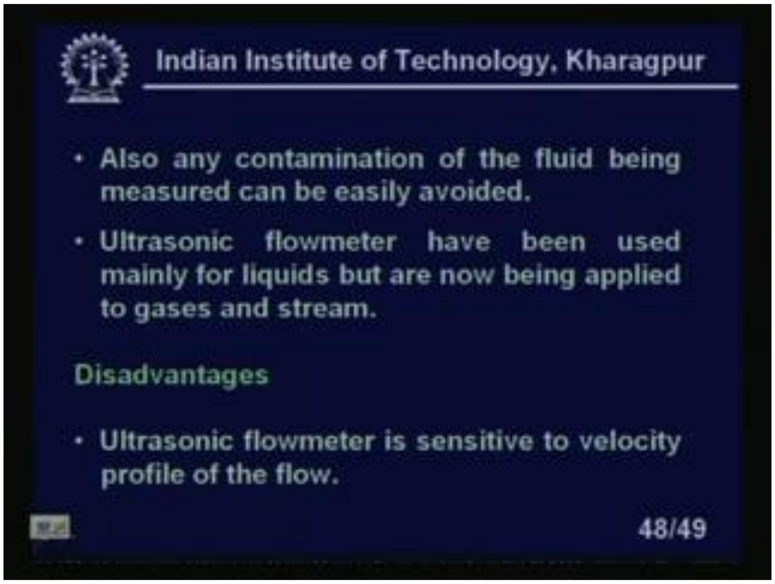

So, also any contamination of the fluid being measured can be easily avoided. In many situations, I have to measure the fluid of the, suppose in the case of beverage industries, soft drink industries, where the liquid, the beverage or soft drink are flowing in the pipe, so any installation of the, any meter outside that is you have to, I mean, I mean sterilize the sensors and all those things you have to …. you have to do. But, if it is clamp on the outside, especially in that case of ultrasonic flowmeter it does not matter whether it is conductive or non-conductive, I can make the measurement very easily, right?

So, in that sense it is also very popular in the food and drug industries. Ultrasonic flowmeter have been used mainly for liquids, but are now being applied to gases and streams also. Basically it was previously used for liquids, but it is used for gases also and streams. Now, there are, obviously you cannot say everything is very, I mean shiny and very good. So, there are many disadvantage of this type of systems also.

What are the disadvantages? Ultrasonic flowmeter is sensitive to velocity profile of the flow, right? In the case of electromagnetic flowmeter it measures the average flow velocity. But, the ultrasonic flowmeter is not doing actually that, right? That means what will happen? If the velocity profile changes, for the same average velocity I will get different output. This is the problematic case, excuse me, right?

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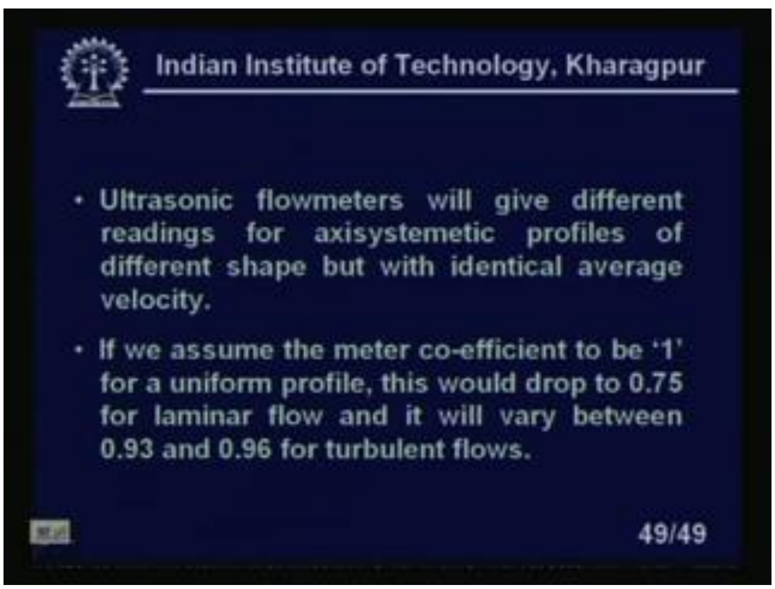

So, ultrasonic flowmeters will give different readings for axi, axisystematic profiles of different shape, but with identical average velocity. If the average velocity is same, but the profiles are not same, so obviously what we will find that the, you will get different value of the reading, right, the output, which is undesirable. If you assume that the meter coefficient to be 1 for uniform profile, this would drop to 0.75 for the laminar flow and it will vary between 0.93 and 0.96 for turbulent flows. So, these are the two typical disadvantage of the ultrasonic flowmeter, which is not there in the case of the electromagnetic flowmeter, but for the non conducting fluids we have to use ultrasonic flowmeter, because of its typical or invasive type of techniques of measurements, right? So, with this, I think I, today I come to the end of the lesson 15 of Industrial Instrumentation.

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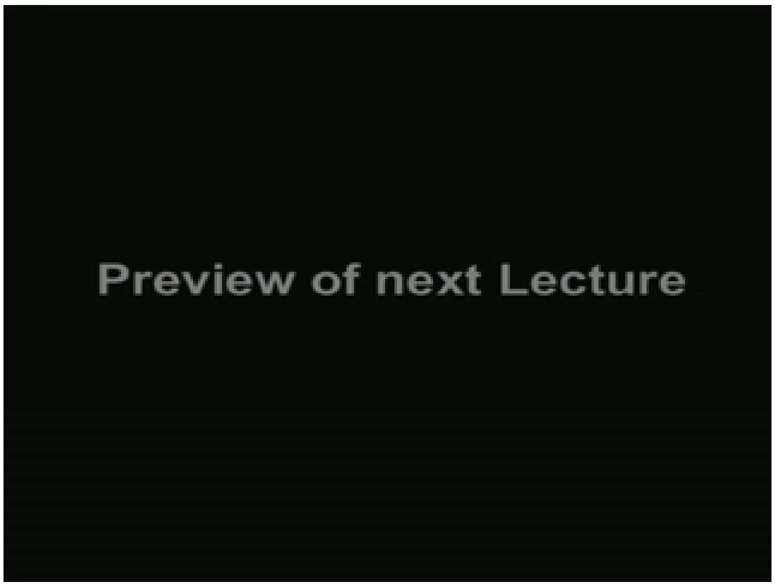

Welcome to the class of Industrial Instrumentation. So, this is lesson 16.

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In this lesson we will consider flowmeter, because we are continuing for last several lessons flowmeters, this lesson also will cover basically the flowmeter and the contents of this lessons.

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Hot wire anemometer one of the most widely used industrial flowmeter both for the liquids and gases that we will discuss in this particular lesson. Also, we will solve several problems on the flowmeter, various types of flowmeters. We will solve problems, we will give the problems and also we will provide the solutions to these problems.

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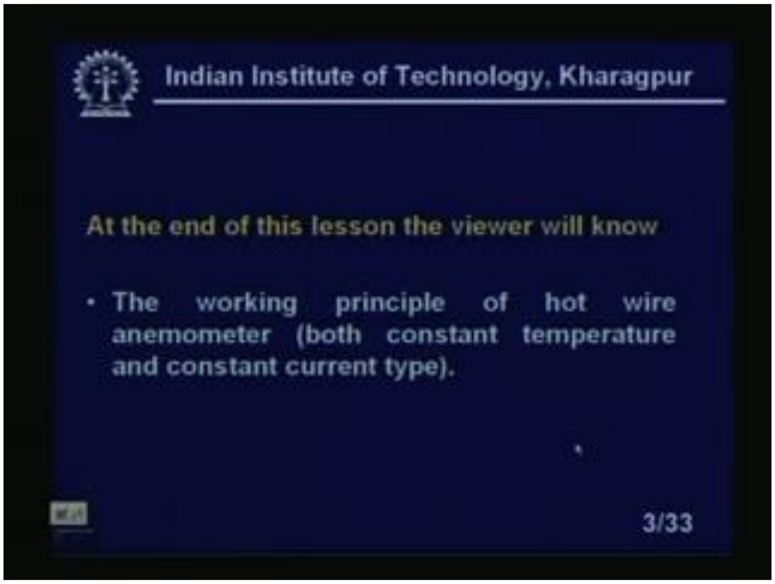

Obviously at the end of the lesson, the viewer will know the working principle of hot wire anemometer, both constant temperature and constant current type. This is a basic two types of hot wire anemometer you will find, so we will cover both. How it works, what is the signal conditioning circuitry and advantage, disadvantage everything to be covered in this particular lesson, along with the problems and solution to the different flow meters.

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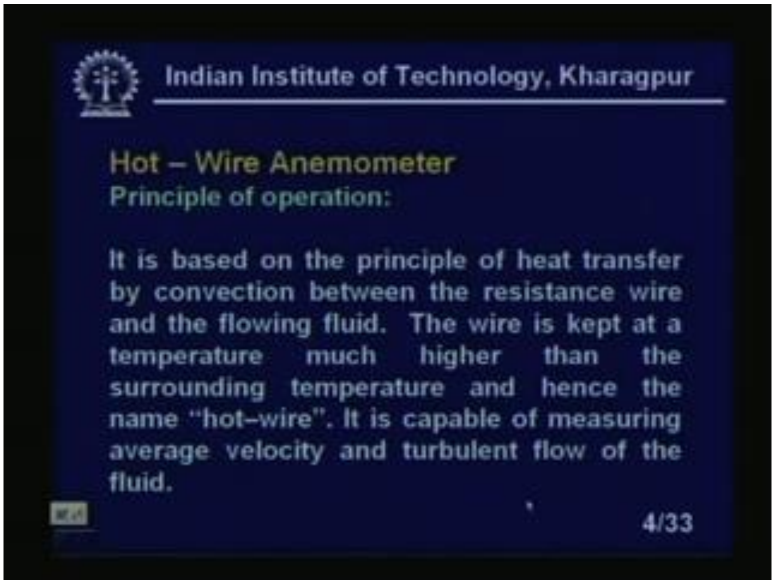

Now, hot wire anemometer if I look at, the principle of operations it is based on the principle of heat transfer by convection between the resistance wire and the flowing fluid. The wire is kept at a temperature which is much higher than the surrounding temperature and hence the name hot wire is given. It is capable of measuring average velocity and turbulent flow of the fluid. It can measure both, I mean average velocity as well as turbulent flow of the measurement. This is a great advantage of this particular flow meter.

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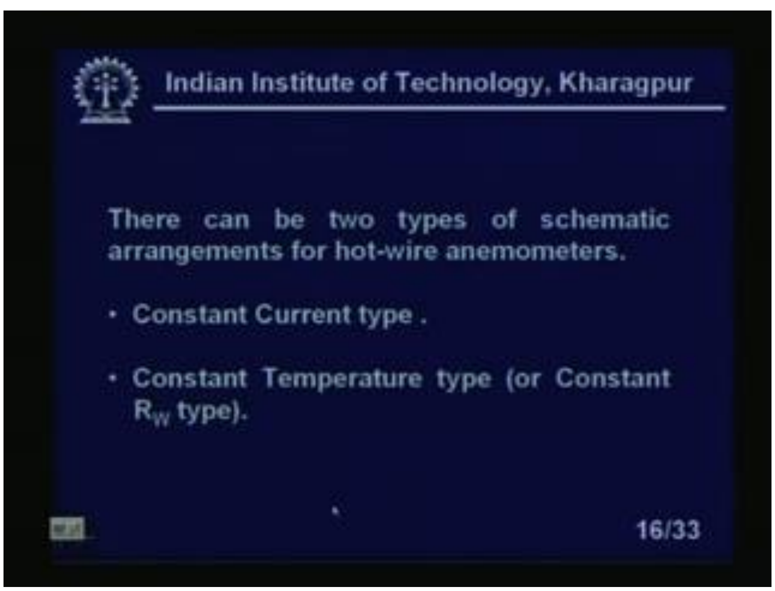

So, there can be two types of schematic arrangements of hot wire anemometers. That is I am telling either it will be constant current or constant temperature, right? So, constant current type and constant temperature type or constant R w type.

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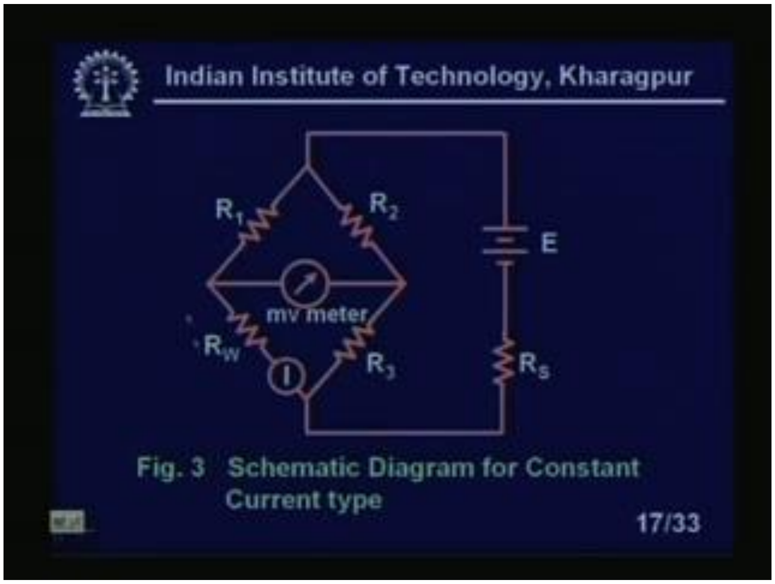

A schematic diagram of the constant current type, you see here actually what we are doing that initially we are taking all the resistance equal. R 1, R 2, R 3 and R w and this R s is quite high, right and we can measure, we can see the current which is passing through the, through this hot wire. Now, this resistance is so high compared to this resistance, you will find due to the change of flow, the resistance even the resistance will change, the change of current will be insignificant, right?

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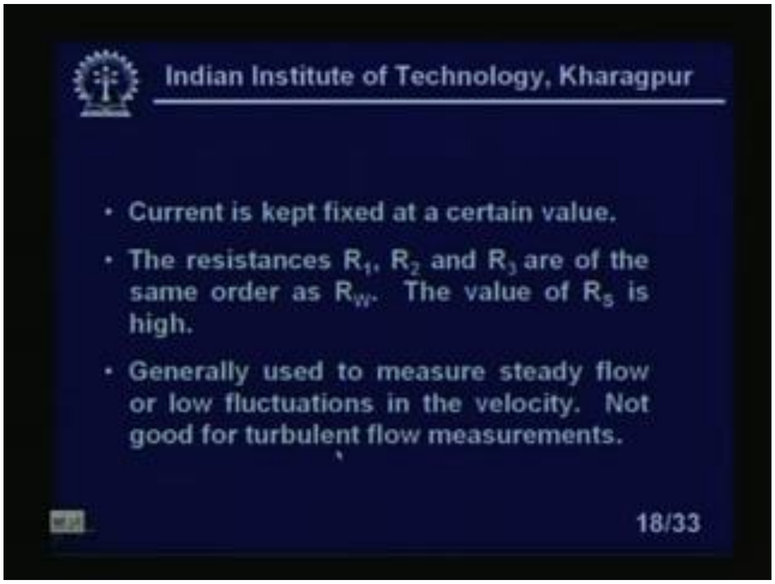

So, current is kept fixed at a certain value that can be measured by that resistance that by the ammeter. What is that ammeter? This ammeter, the, with the ammeter we can see whether the current is getting or remaining constant or not. The resistance R 1, R 2, R3, are of the same order as R w. Typically it should be quite small compared to the R, R s and the value of R s is high, right?

Generally used to, this is, this constant current type is generally used to measure the steady flow or low fluctuations in the velocity. Not good for very high frequency turbulent flow. We need some compensation. If you do the compensation, then it is possible to that mean lead lag network using I can make the circuit in such a way, so that the, I can measure the much higher frequency. Otherwise, normally it is not suitable for the low, high frequency fluctuations. So, high frequency turbulence, turbulent of the flow.

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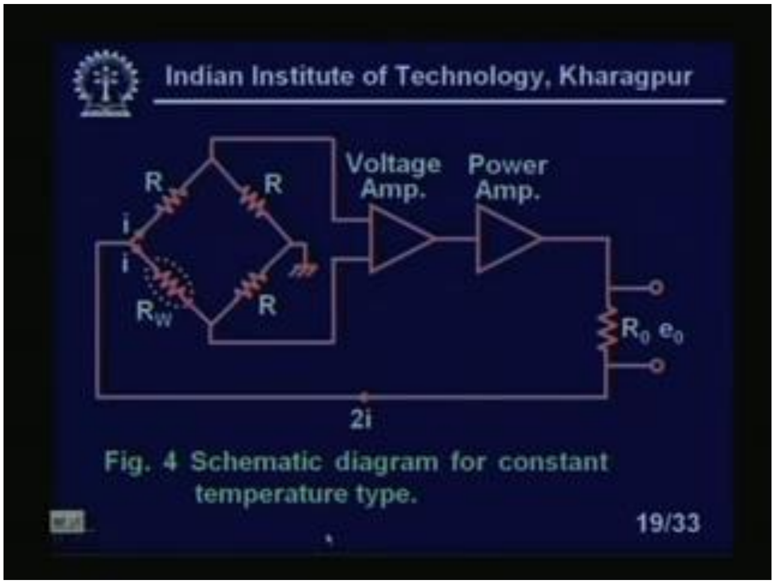

Now, this is the schematic diagram of a constant temperature type of a hot wire anemometer. You see the, here it is a auto balancing system. This R w is put on a one arm of a bridge, which is a our hot wire and all other resistance are put, all are same. Now see, what will happen that if there is a, if there is a unbalance that means suppose due to resistance change, then what will happen? You see that if there, if there is a unbalance, so you will get a, initially it is balanced say there is no output voltage, no error voltage, but some steady state current will flow through this resistance. Now, what will happen you see that if there is a change, so that change will be a, if the, there is the unbalanced voltage here and that will amplify this voltage amplifier and power amplifier. So, it will give a current, so it will change the current through the, through this bridge and it will continue till we achieve the balance, right?

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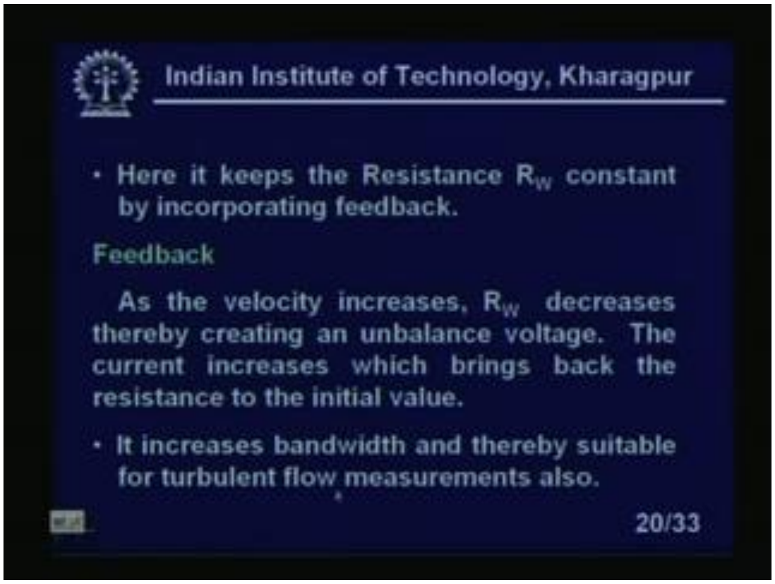

So, it is auto balancing systems, we can see here. Here it keeps the resistance R w constant by incorporating the feedback. Now, as the velocity increases R w decreases, thereby creating an unbalance voltage and the current increases which brings back the resistance to the initial value, right? It increases the bandwidth and thereby suitable for turbulent flow measurement also. So, it is also for increasing, since we are using feedback, so it is a, it is suitable for measurement of the high frequency swirls and turbulent flow.

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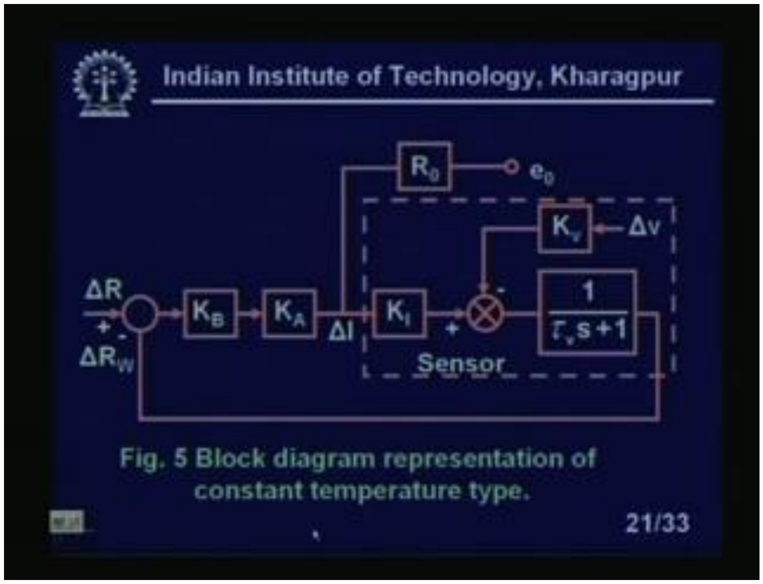

Fig. 5 Block diagram representation of constant temperature type.

Now, this is a block diagram of a constant temperature type of sensors, we can see. We have K B K, inert is going out. So, this is our typical systems.

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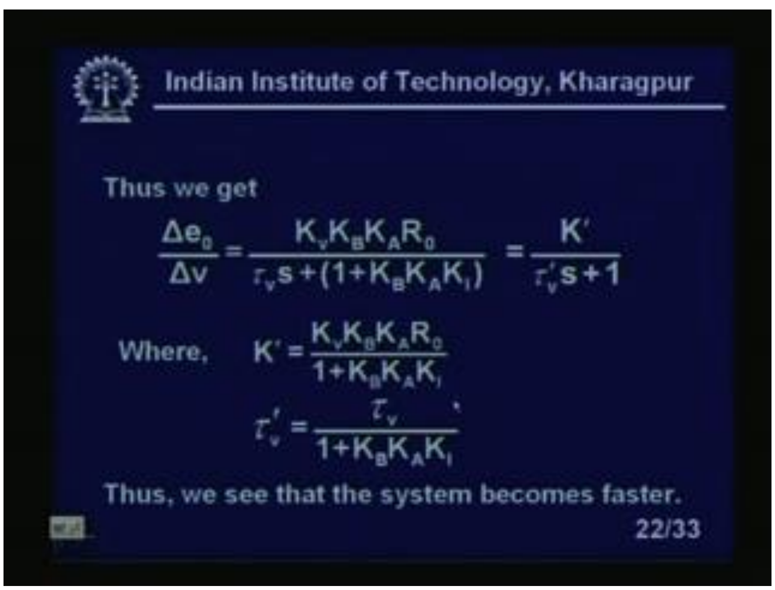

Thus we get, you see delta e naught by v, this output voltage divided by change of output voltage due to the change of velocity K V, K V, K B, K A, R O, tau V S plus 1 plus K B K A K I which is equal to K dash equal to upon tau dash v S plus 1. Previously it is only tau V S plus 1. So, what is tau, tau dash v, let us look at. So, K dash equal to K V K B K A R O 1 upon 1 plus K V K A K I and tau dash v is equal to the, previously we have tau v S and naturally, what will happen if I decrease a time constant of the system? All my frequency responsible increases, is not it? You have the time constants, I can measure the high frequency. This is the basic, fundamental, I mean fundamental equations of any, any instruments or any systems.

Even if the …. time constant is large, I can measure the response very fast for a step input. If the cyclic, obviously also that advantage is there. Thus we see that the system becomes faster, since we are dividing this tau v by this factor, so obviously what will happen, by this factor what will happen? This frequency is tau, tau dash v will decrease and I can measure the higher frequency.

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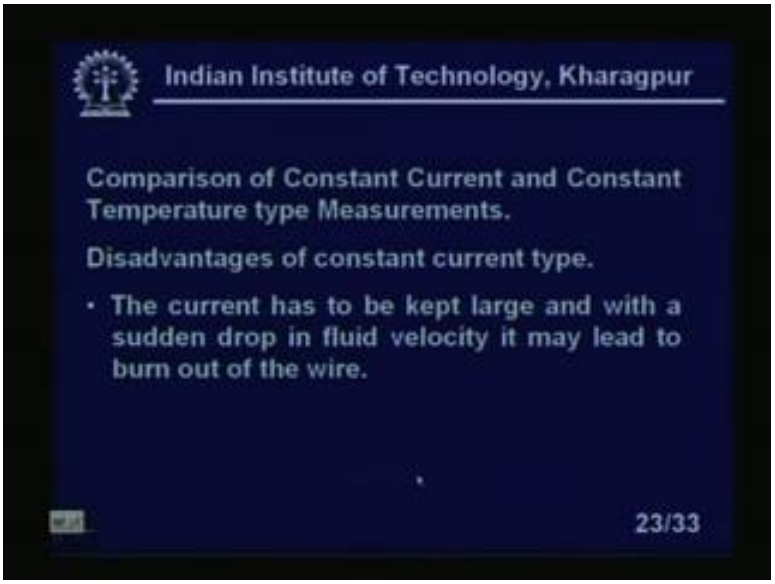

Now, comparison of the constant current and constant temperature type measurements, disadvantage of the constant current types, the current has to be kept large and with a sudden drop in fluid velocity it may lead to the burn out of the wire. So, this is a typical problem of the constant current type. That means the current has to be kept large, otherwise what will happen? So, usually it is large and if there is sudden fall in the fluid velocity, so temperature may rise. Because it is constant temperature, some constant current must flow through these ones, it will burn out the wire. For dynamic measurement, separate compensation networks are required. That means I need a lead lag network, as I told you earlier, to make the phase compensation, so that I can go for the higher frequency of measurement.

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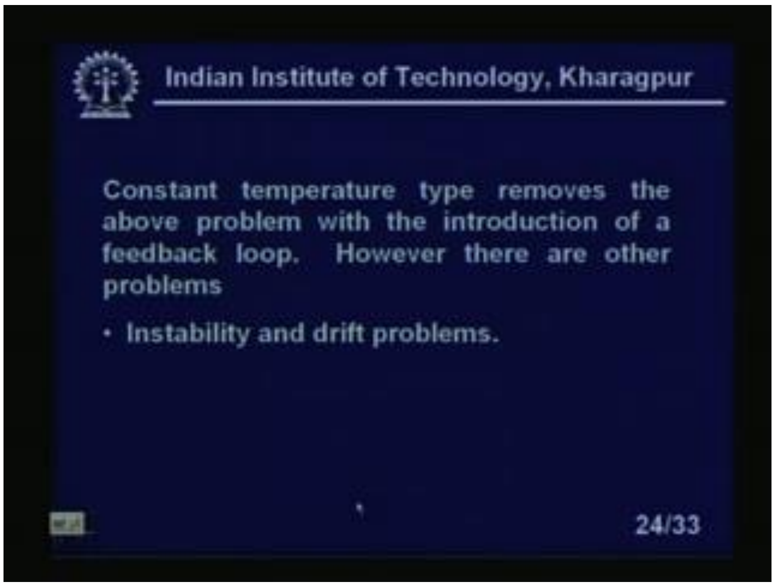

Constant temperature type removes the above problem with the introductions of the feedback loop. However, there are other problems. Instability and the drift problems of the there, because drifts of the amplifier will come in picture, right? With this, I come to the end of the lesson 16 of Industrial Instrumentation.