Mechanical Measurement Systems
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Lecture - 28
Flow Measurement (2)

Hello, I welcome you all to the course on Mechanical Measurement Systems. Today we will continue to discuss the flow measurement in engineering application, and we will start with the introduction and the type of flow meter. We will take different type of flow meters in this discussion.

Regarding the introduction I have already give you introduction of the flow meters, but here we will be using different principles of physics in order to measure the mass flow rate or volumetric flow rate. We will be using, for example we will be using the faradize law for induced emf, we will be using coriolis component in for the flow measurement, we will be using the principles of Hall Effect, we will be using the principles of vertices or other principles of physics.

We will start with the rota meter rota meter is again a obstruction type of flow meter. So, in a rota meter which is normally used I think in many of the industries and it is used it used as a flow measuring device not only industries in the research labs in the research institutes also and it is very popular.

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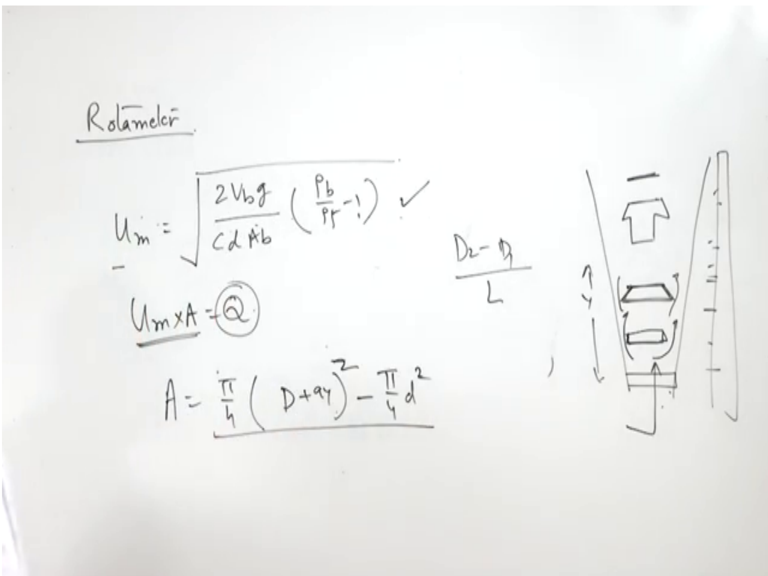

And the rota meter is very simple in restriction it has a tube and tube does not have a constant cross section. Tube does not have a constant cross section; the constant cross section of the tube varies from bottom to top. Let us say it is like this it has a Bob, Bob has a specific geometry and the fluid flows from the bottom, rota meter can be install in the when in the pipe the flow direction is vertical on the horizontal pipe it cannot be installed because we make use of the gravity force here.

So, this Bob is pushed by the water which is entering the flow meter right and as when the Bob is on the bottom most position there is no flow there is a marked scale here, in no flow condition it is at the bottom when the fluid enters. So, let us take water, water the working fluid water enters the flow meter it pushes the Bob it goes up when it goes up from the sides of the Bob the water is starts moving right.

It is further pushed when it is further pushed more space is available for the water flow and Bob retains suspended in the fluid and we can take either is a bobbed scalier from scale we can take the reading, but issue is what is the physics behind this because how does it come in to the equilibrium, and how the equilibrium is decided as we keep on increasing the flow rate the Bob keep on shifting the position in vertical direction for the highest flow rate it will be somewhere here right.

So, how the position of the Bob is decided and what are the force which act on this rota meter that we will discuss here. Now, in this rota meter there is the drag force, which plays a major part drag force is created due to presence of this Bob into the flow field and this drag force F d and the buoyancy force the buoyancy force also works in the in this direction drag force will work in this direction buoyancy force will also work in this direction.

So, buoyancy force is going to be the force equivalent to the mass or the force gravity force or the mass the fluid displaced by this Bob. So, mass of the fluid means volume and ht volume of volume of the Bob and density of the fluid sorry, volume of the Bob and density of the fluid right this is the mass of water replaced by this Bob right multiplied by g.

So, drag force and this is buoyancy force which is working on it is equivalent to the force and or the mass or the or the weight of the water which is replaced by this Bob that is volume multiplied by density multiplied by g. Gravity force on the Bob is volume of the

Bob density of the Bob and g now F d how to calculate F d drag force. So, for drag force we have the formula F d is equal to C d area of the Bob density of the fluid mean velocity of the fluid square divided by 2. This is drag force and this drag force is equal to V b g rho b minus rho f. So, definitely the rota meter will not work in under space or in 0 gravity, or if the gravity is changed the or in reduced gravity it will not function properly and 0 gravity it will not work at all because we are taking help of gravity force here for the purpose of measurement.

So, now, here if you do manipulation we will be getting u m square is equal to 2 V b g by C d A b or we can rho f rho b by rho f minus 1 this rho f you have taken here. So, 2 V b g C d A b rho f rho b minus rho f minus 1 that is u m square. And if we take the under root of this u m this case then we will get mean velocity.

Now, once we have the mean velocity then u m multiplied by the area will give the quantity of discharge q. And here also this rho f will not be there the u b u m will be going to the under root V b g by C d A b multiplied by the ratio of the density minus 1 right. And then once we have the value of u m that we can multiply by A then we will get the volumetric flow rate volumetric flow rate again multiplied by the density of the working fluid that is water here then we will get the mass flow rate.

Now, for area because area is very this variable area from the area is varying. So, in order to find area, but area is varying linearly, area is varying linearly A is equal to pi by 4 D plus a y. So, what is D plus a y? a is slope and y is the distance slope is suppose this is D 2. So, D 2 minus D 1 divided by L right, and if you multiply by y we will be getting D plus a y pi by 4 minus this is sorry pi by 4 D square minus pi by 4 D 1 or D square. So, this is the area which is available for the flow. D is the diameter of the Bob because it occupies certain cross section. So, area available for the flow is the cross section area of the tube minus area occupied by the Bob.

So, Bob the density of the Bob has to be as high as possible right for the good that is why it is made of only iron we take iron Bob we do not take plastic Bob. So, Bob and it depends upon the other factors also, but both of the flow meters you will find that the Bob is made of iron. So, there is a substantial difference between the density of the Bob and the density of the working fluid.

Now, after this obstruction type of flow meter we will be taking certain non obstruction type of flow meter, for example magnetic flow meter.

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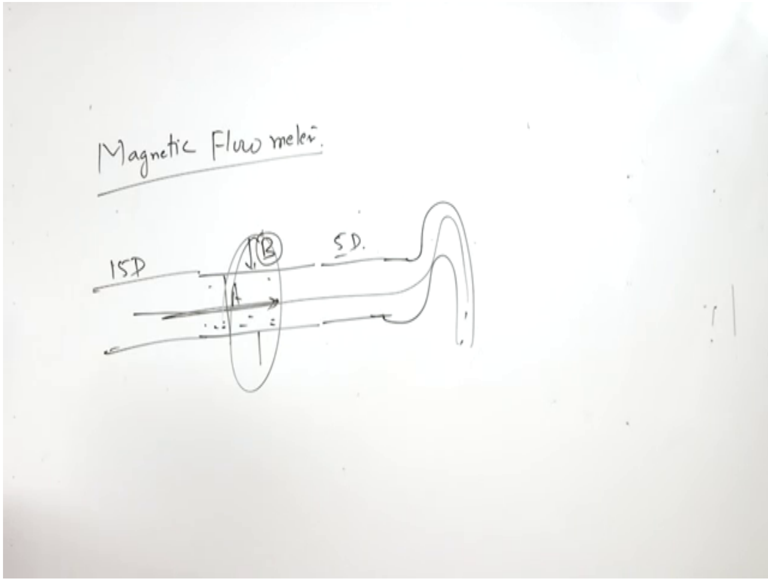

Now, in magnetic flow meter the principle of electromagnetic induction is used it does not have a moving part. First of all it is non obstruction type of flow meter it does not have any moving part in it. It has certain electronics which is used for the flow measurement, but the limitation of this flow meter is that it does not work with nonconductive fluids like distilled water.

The flow of distilled water cannot be measured with the help of magnetic flow meter hydrocarbons, hydrocarbons are not electrically conductive hydrocarbons flow of hydro hydrocarbons cannot be measured with the help of magnetic flow meter, but if there is a normal water because normal water has dissolved salts right. So, the flow of normal water we can comfortably be measured with the help of this type of flow meter and it works on the Faraday's law.

So, if the water is flowing a conductor suppose there is a conductor right perpendicular to it its is a there is a magnetic field suppose an conductor is moving in this direction and there is a magnetic field in this direction in the perpendicular to it on the third axis the emf will be induced. So, if you are putting magnetic b from top to bottom b electromagnetic field. So, perpendicular to this board emf will be generated and this emf will be proportional to the velocity, velocity of the water velocity of the charged particle right and this emf will be equal to B, L and V, this emf induced emf will be equal to B L V, V is the velocity of water, B is the strength of the electromagnetic field, L is the length right.

Now here, so V is equal to E by BL. Once we have the values value of V then multiply by cross section area if you multiply this by cross section area you will be getting Q and once the Q is with us we can find the velocity of mass flow rate through electromagnetic flow meter right.

So, it is the flow meter which is non obstruction type right, and this flow meter the limitation of this flow meter is that it cannot be used for the nonconductive fluids like hydrocarbons and distilled water, if their vibrations in the system installation then also this type of flow meter is not used. A coming reason has to be provided in this fluid type of flow meter it is approximately 15 d for upstream side and 5 d on downstream side. The flow meter has to remain fully flow rate this should not be something like it should not be stratified flow.

Now to ensure anything to be fully flow rate is difficult thing because we never no because types are not transparent. So, we never know whether it is fully flow rate or not fully flow rate. So, on the downstream side if it is possible sometimes it is not possible if a u turn is provided like this, so for any flow rate any flow rate it will be ensure that the fire pipe is fully flow rate for ultra low flow rate other issues will come in that case also this system may not work properly because in that case some scale fluid may remain there.

So, this flow meter is suitable when the entire flow in the pipe is fully flow rate and then the full (Refer Time: 14:44) flow in the pipe corning section has to be provided on the upstream side and downstream side there has to be no vibrations, it can be used for slurries also it can be used for the slurries also because there is no obstruction, so there is no issue of choking.

Now, after this magnetic flow meter there is another flow meter which is an obstruction type that is turbine flow meter.

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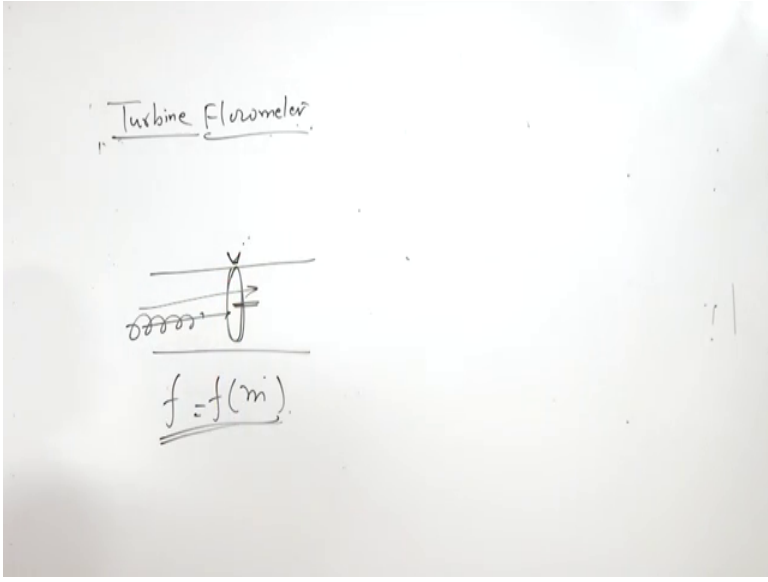

In turbine flow meter in the passage there is a turbine there is a disk containing blades and vanes right, water is a sort of axial turbine when the fluid flows over this turbine it is starts rotating. Higher the mass velocity or higher the velocity of the fluid higher the rpm of the disk right and higher the rpm of the disk; So, rpm of the disk can be related with the mass flow rate or the frequency of rotation can be related with the mass flow rate of the fluid.

So, there is a pick up here, there is a pick up here proximity sensor. So, proximity sensor sensors the pulse which is coming to the proximity sensor and this can also be used as totalizer. If a particular time duration if you count the number of pulses that will give the total flow and pulses per second will give you the mass flow rate per second or volumetric flow rate per second.

So, turbine flow rates are not very costly devices the flow should not have any swirl, if it is a swirl flow then first of all the pressure loss will be high and the reading we are going to get will not be proper from turbine flow meter. Otherwise cost wise is it is I mean it is not very costly device and it has some mechanical wear also because wheel is rotating on an axis. So, it has some mechanical wear also, but otherwise it is a very good device for the flow measurement.

Now, after turbine flow meter we will take vortex flow meter, vortex shedding, principles of vortex shedding, vortex shedding. Now, what is vortex shedding?

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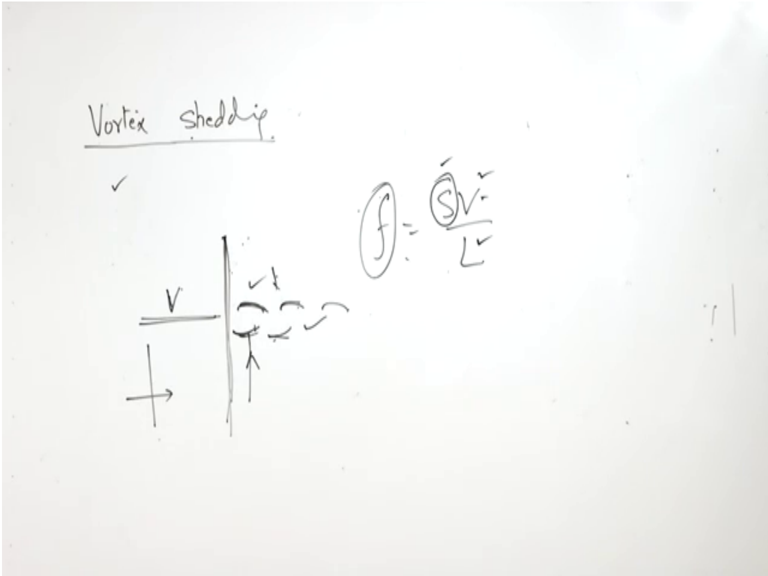

Now, suppose there is a bluff body bluff body a cricket bat is a bluff body a bluff body this duster can be a bluff body in a flow. So, when a flow bluff body is inserted or put in a flow then on the trading side of a bluff body suppose this is a bluff body on a trailing side of bluff body eddies will be formed.

So, when a bluff body is placed in the flow the vertices are formed on the downstream side or the other rear side of the bluff body. So, suppose this is a bluff body it is flat. So, a cricket bat is also a bluff body. So, when the flow is coming on this direction on the trailing side vertices will be formed. Now, these vertices can be counted with the pickups with the help of pickups and if you are able to count these vertices because number of these vertices is proportional to the velocity.

So, if you are able to count the frequency of these vertices we can find the velocity of the fluid and piezoelectric crystals are used a sensor of piezoelectric crystals is used on the on the trailing side of the of the bluff body in order to measure the vertices number of vertices and there is a number dimensionless number straw hall number. So, f is equal to S V by L, L is the characteristic length, V is the velocity s is the straw hall number and f is the frequency.

So, once we have the frequency with us straw hall number with us right it is essentially a constant this number is essentially a constant and it is dependent on the body shape of the body in certain operating limits. So, once we know the shape of the body straw hall number is with us, characteristics length is there, frequency is there we can always find the velocity. So, vortex shedding or vortex flow meters are also available in the market and they are a little costlier than these type of turbine type of flow meters or electromagnetic flow meters, for these flow meters are quite reliable and we can go for the low flow rate also or we can measure low flow rate also with the help of these flow meters.

Second thing is conductivity is an not issue here we can make, we can we can I mean measure the flow rates of any kind of fluid whether it is electrically conductive or electrically nonconductive.

Now, after this vortex flow meter there is another flow meter which is very popular speaking in oil industry that is ultrasonic flow meter.

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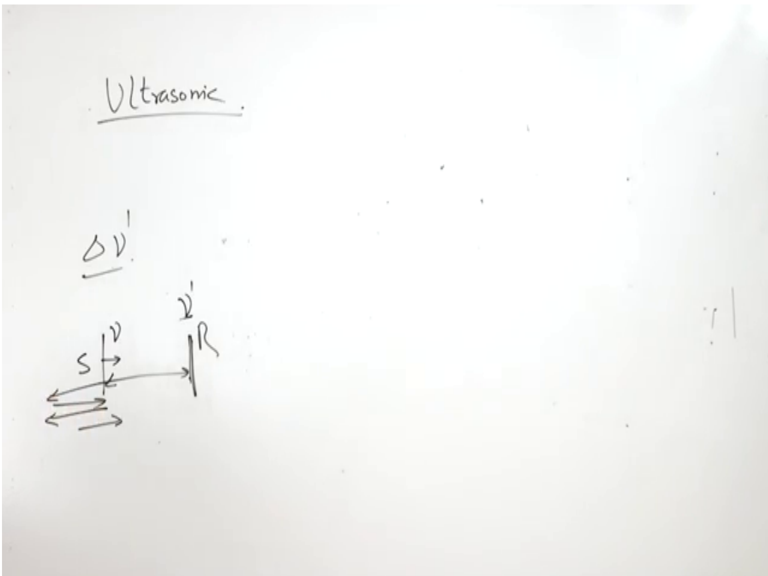

Now, ultra sonic flow meter works on the principle of Doppler, Doppler's principle. It is based on the Doppler principle of frequency shift. You must have studied in physics the Doppler effect when the receiver, when the source and receiver there is a relative motion between source and the receiver right in that case there is going to be shift in frequency by the receiver if the receiver is stationary source is moving in this direction or in this direction the receiver will receive a different frequency which it has emitted suppose it has emitted frequency mu.

So, the receiver will receive mu dash and the value of the mu dash will depend whether it is moving away from the receiver or it is going towards the receiver the same principle will be used here in the ultra sonic flow meter. First of all it is non obstruction type of flow meter and this flow meter can be used for the large diameter of the tubes right specially the oil industries for the transportation of oil large diameter of tubes are used.

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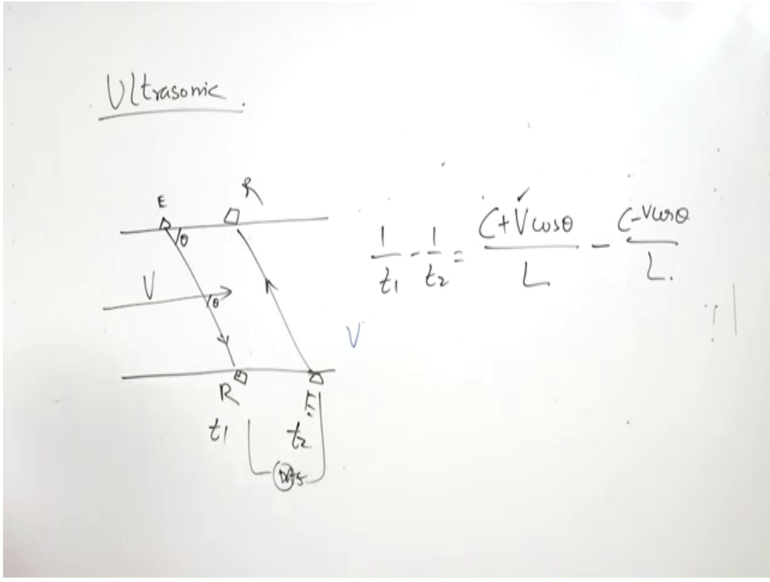

So, here in ultra sonic flow meter there is a emitter and receiver there are two things one is emitter and another is receiver and they are put in the flow at a certain angle right. Now, ultrasonic waves are emitted and received here and this is emitter this is receiver and this is emitter and this is receiver, and flow is in this direction right.

So, the time difference let us say this receiver receives in time t 1, this receiver receives the time t 2 right, then 1 by t 1 minus 1 by t 2, difference 1 by t 1 minus 1 by t 2 is going to be C suppose this is theta right. So, we will take horizontal component of this and this is going to be the C plus C plus this is V; So, C plus V cos theta divided by l whatever distance it is travelling and then here it is going to be C minus V cos theta divided by L.

Now, theta is known to us this is theta right and L is known to us t 1 and t 2 we have calculated just not calculated we have just measured with the help of data vision system right, and that we can always find the value of V. So, in a ultra sonic flow meter what is being done? On a pipeline we have just put, on a pipeline we have just put emitter and receiver at two places at a certain angle right. So, an using this equation using this equation, we can (Refer Time: 24:38) these calculation are also done in the hardware itself. So, simply you will get the flow display on the display screen that this is a mass flow or this is the velocity of the flowing fluid or if you multiply this by diameter you will all the cross section area you will be getting the volumetric discharge.

Now, after this ultra sonic flow meter we will take up the coriolis mass flow meter which is very popular in industries it is very popular because the metering through this flow meter is very accurate. So, it does the accurate measurement of mass flow rate and it is quite costly also, it is a very costly flow meter mass flow coriolis mass flow rate.

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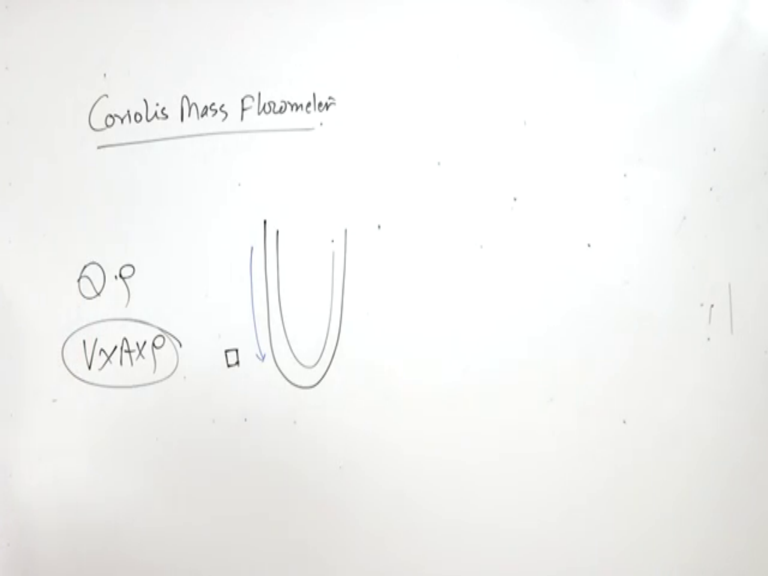

So, coriolis mass flow rate meter works on the coriolis effect coriolis effect can be visualized it is it will find many places in nature even though direction of ocean currents in the north hemisphere and the south hemisphere is decided by the coriolis effect. In our day to days life if you look at the flying aircraft is a is the best example. When you see a flying aircraft then aircrafts when it is taking either right turn or left turn either nose will go up or it will dip it will not remain in same plane.

So, when there is motion in two axis's. Suppose in aircraft let us take example of aircraft if you look from the rear from the aircraft suppose the fan or the impeller is moving in the clockwise direction, it is moving in the clockwise direction when it is moving in the clockwise direction will take this axis as this axis.

So, clockwise direction this finger index; finger than it is moving suppose it is moving left. So, when it is going straight and moving left moving left it is making curve it is making curve in anticlockwise direction it is something like opening the bottle. So, it will be represented by thumb. If these two things are there their precision will take a longer third axis and couple will work and couple will work by joining these two fingers. So, when it is moving left the couple will work like this it means suppose this is the aircraft the couple will work like this. So, nose will go up and rear will go down.

And just I am repeating if you are standing below behind the aircraft or on the rear side of the aircraft and looking at the front, and if the impellers are moving in clockwise direction then it will be indicated by this finger. This is how to find the coriolis component this is just to how to find coriolis component. And when it is moving in the left it is taking the left turn when it is taking the left turn then it is something like opening the bottle or counter clockwise movement. So, it will be denoted by thumb. If you connect these two and there is a couple will work in this direction it means the nose will go up and tail will go down.

Suppose impeller is not moving in clockwise direction it is moving in counter clockwise direction then the couple will be like this, when the aircraft is turning left than that nose will dip and the rear will go up something like that. Now, how we can use this principle precision in third axis in coriolis mass flow rate meter. In coriolis mass flow rate meter because first of all it is a mass flow rate meter, so we do not have to do the earlier flow meters you are simply finding the value of Q and then we are multiplying it by a sorry multiplying by the density.

So, and sometimes velocity multiplied by area multiplied by density then we are finding mass flow rate. But here in the coriolis mass flow rate we can straight away we can find the mass flow rate of the fluid.

And the working principle is like this if there is a tube and the fluid is flowing it is a u tube (Refer Time: 29:09) there is a u tube and fluid is flowing in this tube in a particular direction let us say in this direction. Now, I vibrate this tube perpendicular to this board. So, this tube does the vibration. Suppose this is a u tube and it does the vibration. During vibrations depending upon the direction of the tube the tube will get twisted and when we will when tube comes in opposite direction it will be twisted in another direction.

So, this twisting if we can measure this twisting angle with proximity sensor somewhere here, then twisting is comfortably related with the mass flow rate in the fluid because if there is no flow fluid flow in the tube, no twisting will take place. If the tube is empty if you vibrate the tube it will not twist, but the moment the fluid start moving in the tube due to coriolis component the tube starts twisting. And if we take two tubes together this signal will be amplified in some of the flow meter it is done, instead of taking two tubes they have taken two tubes.

So, that the this is amplified, twisting is amplified and this phenomenon is used for the mass flow rate and this coriolis mass flow rate meter and in this flow rate meter flow rate meter it is also used for two phase flow as well, in this two phase flow suppose there suppose I have to measure the mass flow rate of foam, foam is a mixture of gas and the liquid right homogenous mixture of gas and the liquid for that purpose this is the best flow meter which can be used for that purpose.

So, the beauty of this flow meter is it is used for the mass flow rate it does not depend it does not matter whether it is a liquid phase or the solid phase. But normally when the liquid phase is more than 10 percent or 20 percent this rote flow meter has to be re-calibrated. So, we have to have calibration curves for different fractions of liquid and vapour if you want to have truck measurement of the flow through this flow meter.

Now, another one is the Hall Effect flow meter, the Hall Effect flow meter.

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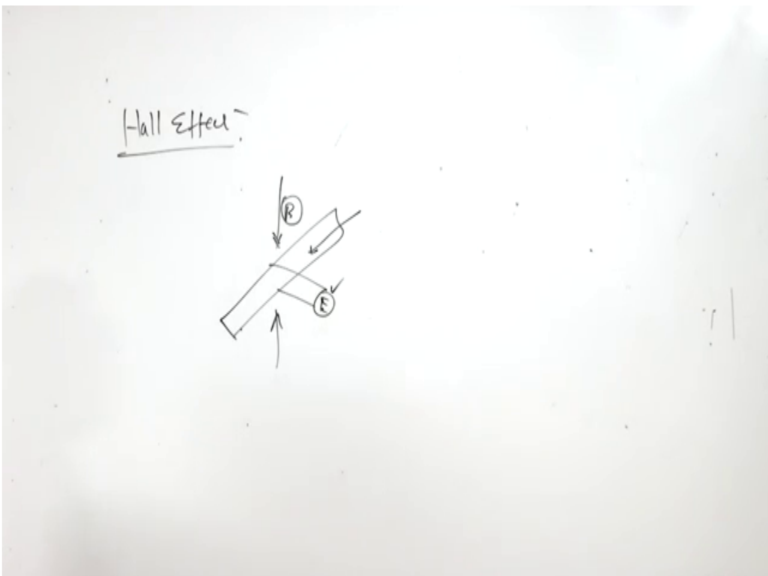

Now, in Hall Effect suppose there is a conductor and I should explain you first Hall Effect. There is a conductor and charged conductor and magnetic field is applied right in that case across the phases of the conductor emf will be generated. So, the moment we change V this emf will change.

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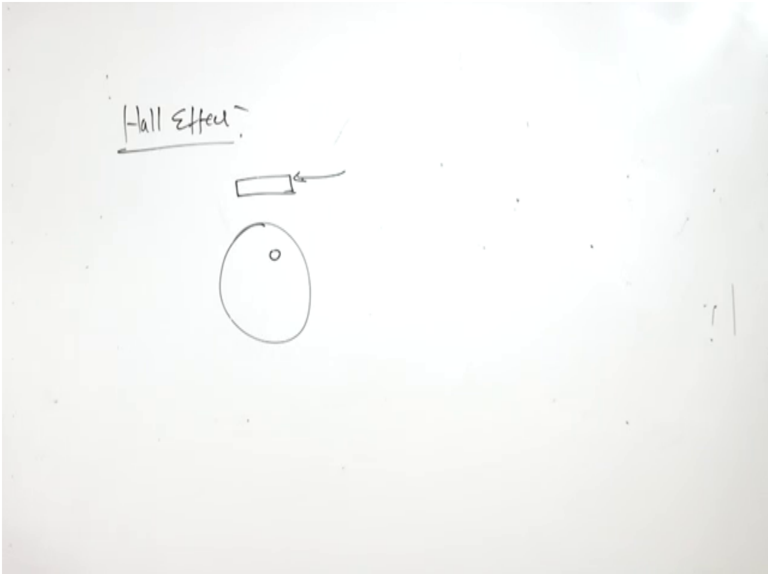

So, in hall effect type of flow meters in the rotor, in the vanes the magnet is fixed, in the rotor a magnet is fixed and when the magnet moves with the rotor the magnetic field associated with the rotor is changed, here there is a sensor right and electricity is passed through the sensor and due to this magnetic effect the emf of the sensor is measured.

So, this is a, this is the basic principles of the basic principle of the working of the Hall Effect flow meter.

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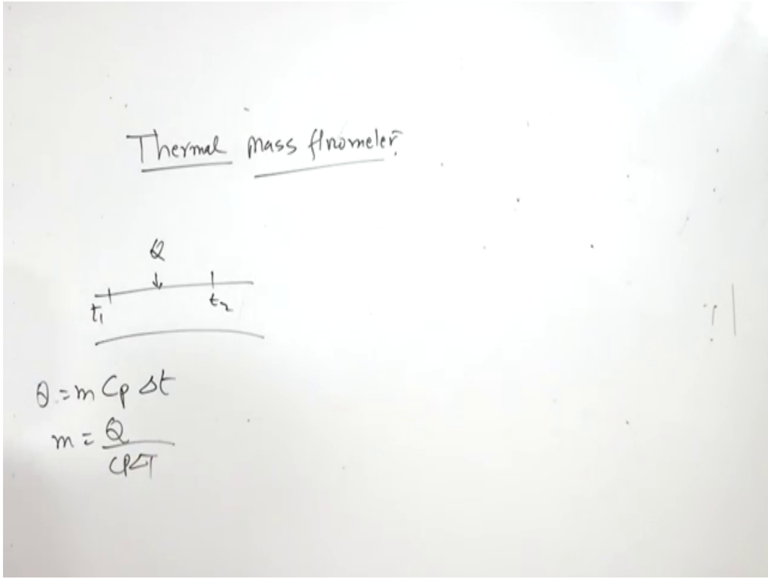

So, there is another flow meter which is known as thermal mass flow rate meter. Now, thermal mass flow meter we can have different type of arrangement one arrangement is Q is equal to m C p delta t, this Q is heat transfer Q right, Q is equal to m C p delta t.

Now, if we have C p for the fluid is known if we know the delta t and Q is the heating of the fluid, we can find the mass flow rate. This is the working principle. Now, this working principle is slightly modified or we can develop a flow meter based on this principle also Q is equal to m C p delta t.

So, in a tube heating is done Q this is t 1, this is t 2, right. So, what is the temperature rise in the tube right? This temperature rise multiplied by the a specific heat C p and Q is equal to m C p into delta t. So, m is equal to Q by C p delta t that is one thing.

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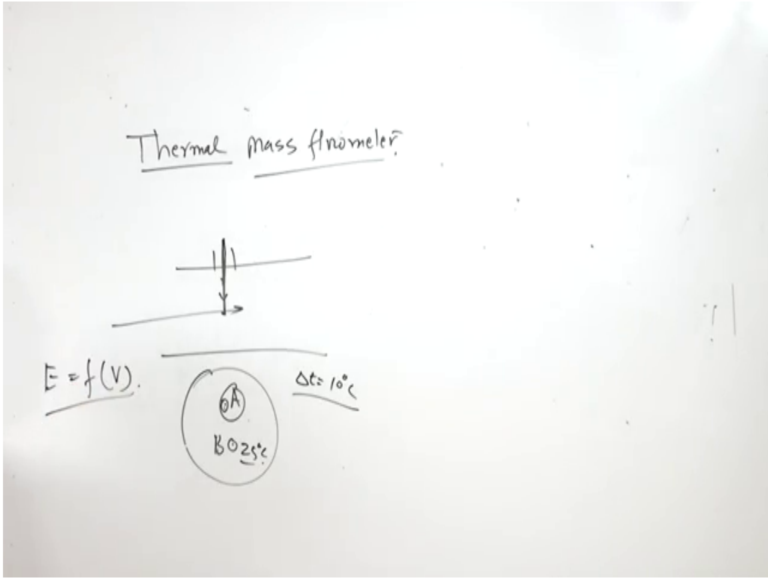

Second thing in a tube two electrodes are put, the two electrodes right, they are not I mean one after the another they are side by side they have been put. It is it is, the figure is something like this right.

Now, fluid flows over these electrodes. Let us say one electrode is at temperature of the water, let us say 25 degree centigrade. One of the temperature of water is it will require the same temperature of water and this electrode is heated and some energy is given electrical energy is given and it is heated and temperature difference of 10 degree centigrade is maintained.

Now, in order to maintain this temperature difference electrical energy input has to be given to let us say electrode A and electrode B. So, electrode a for electrode A electrical energy input has to be given. When the fluid flows over the a electrode it will take away the heat temperature will tend to go down, but we have the feedback control mechanics. So, the energy transmitted to this electrode will further increase or vice versa. If you decrease the velocity then energy transmitted to this electrode will decrease in order to maintain the temperature difference 10 degree centigrade.

Now, we can relate the velocity of the fluid with the energy supplied to the electrode and this energy supplied to the electrode is a function of a velocity of the fluid. And this is how we can find the velocity of the fluid in a in the thermal mass flow rate meter.

This is all for today. From the next class we will start with the temperature measurement.

Thank you.