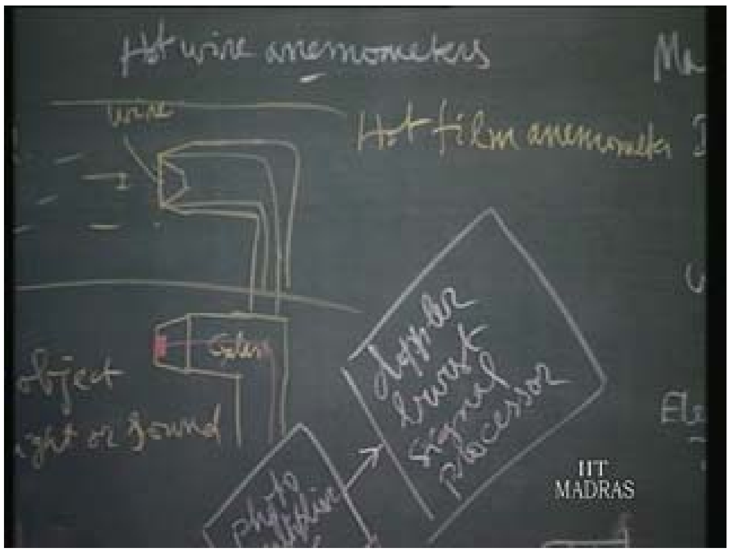
Principles of Mechanical Measurements

Prof. R. Raman
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture No. # 26

Yesterday we saw the hot wire anemometers in three modes operations. That is constant current mode of operation that is this is a hot wire anemometer where we have this wire here. This is the wire of few microns diameter this is taken inside, the connections are given inside. The wire is used to sense the flow.

(Refer Slide Time: 00:01:35 min)

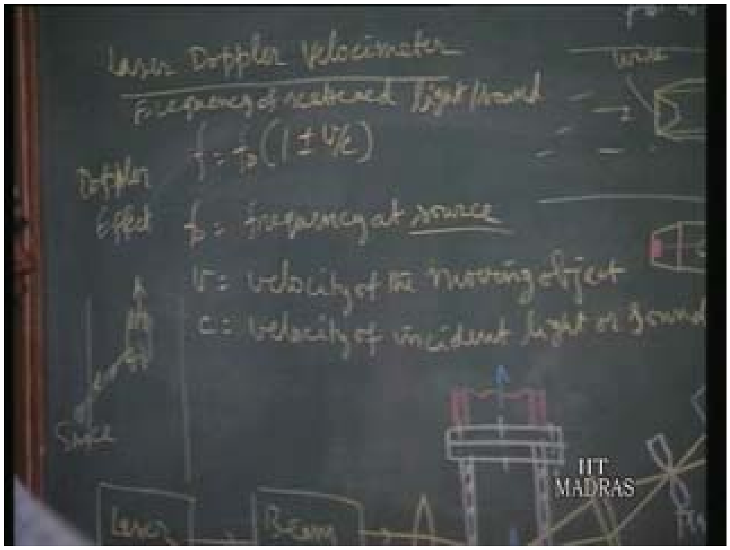


Here that is we saw three modes of operation, one is constant current mode of operation, constant temperature mode of operation and another one is automatic adjustments with automatic control that is with feedback. This is what we saw last yesterday. In maintaining such hot wire anemometers one is supposed to clean this wire periodically otherwise what will happen? The dust carried by the flue gas that is by the gas will get deposited and we will find the heat transfer coefficient h. We saw yesterday the equation i squared rw is equal to h into a into tw minus tg that is the heat transfer equation but factor h is affected if you allow the dust to accumulate on the wire. So what is to be done is it should be cleaned periodically. So that the calibration curve is valid, we also saw the calibration curves.

In doing so it seems the wire is so thin and short in length, it may break also while we handle it or if the gas flow which is there in the pipe may also contain some hard particles and due to high velocity when the harder particles hits the wire, the wire also may break. So in order to avoid this problem what is done is people nowadays use hot film anemometer, instead of hot wire anemometer they use hot film anemometer. They take a wedge type glass; this is made up of glass support. It’s a glass, here what they do instead of keeping a wire they paste on both sides, this is like wedge type and they paste the wire material, I mean they deposit the wire material on both sides it’s a wedge and then take the wire. This is front surface and from back surface another wire will be taken so now it’s a hot film anemometer instead of wire we are using hot film.

Now it is supported on the face of the glass support so naturally the breakage and all is eliminated. This is advantage of hot film anemometer over hot wire anemometer. So now we pass onto the next method that is the laser Doppler velocimeter.

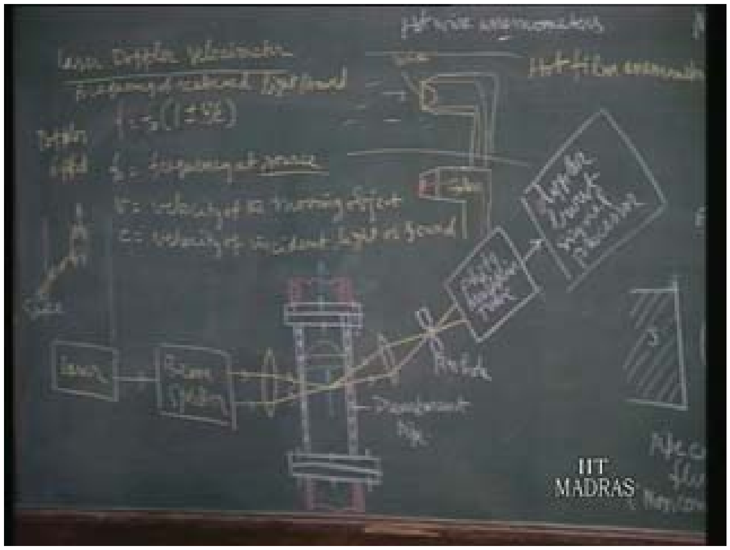
(Refer Slide Time: 00:04:20 min)



Here one can use either sound or light. The principle is making use of the Doppler Effect. What is Doppler Effect? Doppler Effect states the scattered light from any moving body contains the information about the velocity of the body. So the scattered source will be also, that frequency will be different from the source. So that is the Doppler Effect that is scattered beam contains information of the velocity. So that is expressed in terms of equation, frequency of scattered light or sound we can also use either sound or light for this measurement. So f is equal to that is scattered frequency is equal to f_0 which is the frequency at source 1 plus or minus v by c where v is velocity of the moving object and c is velocity of the incident light or the sound whatever we are making use of in a particular instrumentation. So plus we are using, when the object is moving towards the source this is the source from where we send a beam that is a source. So if the object is moving towards the source then we use plus and when the object is moving away from the source, for example this Doppler Effect again used for identifying the racing cars.

Suppose the police officer will be standing here and you will send the light source or laser beam whatever it is and you will collect it back. So now this is going away from this, this is source so by collecting this reflected light or laser, he will find out what is the speed whether it has more than the allowed speed in the road. That we will find out that is the Doppler effect, this is used by the traffic police officers to locate the racing cars or the over speeding cars or vehicles. So same principle here, it is because the moving vehicle contains velocity of it which is being obtained here. Similarly here the v is velocity of the moving object, now in any gas flow or any fluid flow that flow contains some foreign particles and we assume that the foreign particle moves with the same velocity of the velocity of the fluid.

(Refer Slide Time: 00:06:57 min)

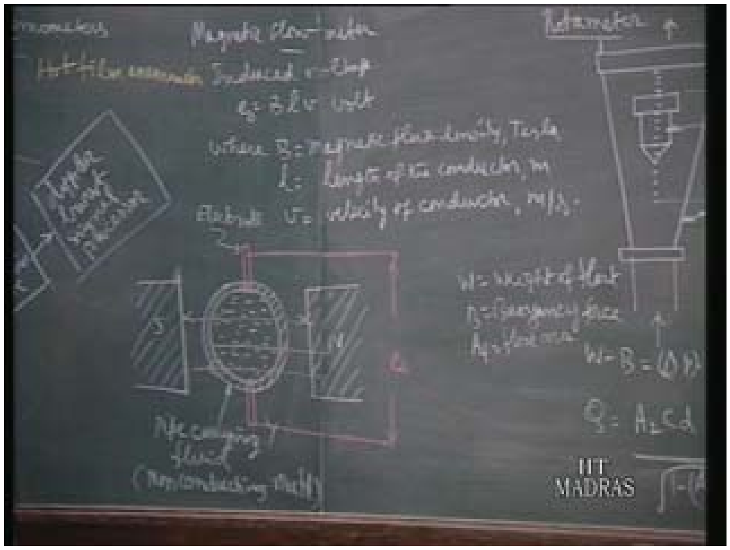


Under that situation we send a laser beam with beam splitter, it made into two and with the help of a lens we converge it within the diameter of the pipe. So where it converges there may be a particle flowing with the same velocity of the gas, so it scatters the light. So this is the light and this is scattered light collected by another objective lens and through a pin hole we can control the intensity and then it goes to the photo multiplied tube where the light is transduced into voltage, that voltage contains the information of the velocity of the object.

So being an electronic circuit which is according to this equation it will extract the information proportional to v and that is being depicted as velocity of the fluid here. That is the principle of this laser Doppler velocimeter. So by focusing at different points we can find the velocity of the fluid and then we plot the velocity profile and find out average velocity multiplied by area will give the flow rate. That is how the laser Doppler velocimeter is made use of. This has got one main difference, now we compare the pitot tube as well as hot wire or hot film anemometer. There the flow is obstructed, here you have got only less area so total area minus this area alone is available that is the flow pattern is disturbed by inserting the pitot tube or hot wire anemometer. That is not there in the case of laser Doppler velocimeter.

It’s an undisturbed flow, without disturbing the flow we are making the measurements that is the main advantage of this laser Doppler velocimeter. In aeronautics laboratories many places they use this laser Doppler velocimeter to find out the velocity of air particle in a channel, in a conduit. Next we go to the magnetic flow meter, one such magnetic flow meter principle the sketch is given here. This is a magnetic flow meter; it contains a pipe made up of nonconducting material. This is a pipe made up of nonconducting material, it carries the fluid. Here it can be slurries or the liquid containing some sediment also because we don’t have any obstructions. So slurries flow rate also can be made use of, that is the main advantages of magnetic flow meter.

(Refer Slide Time: 00:09:08 min)



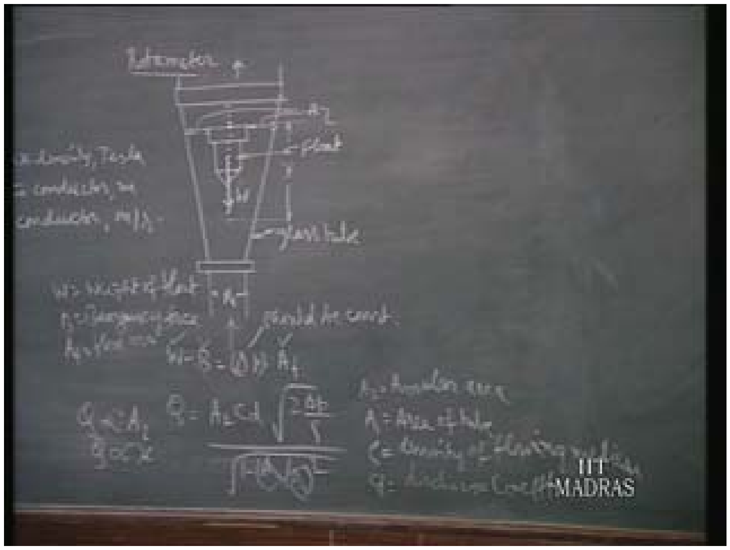
So we have got the nonmagnetic pipe carrying the liquid in the direction perpendicular to the board and by two electrodes we pick up the voltage developed in this fluid which is put across North Pole, South Pole of a permanent magnet. So magnetic lines are in this direction, magnetic lines are flowing in this direction that is Faraday's principle that is magnetic lines in one direction and the flow is perpendicular to the board and the electrodes direction is perpendicular to both of them. That is now to say if it is y direction, this will be x direction magnetic lines and the z direction is perpendicular to the board. These are the velocity of the conducting material. So the diameter of this pipe represents the length of the conducting material, each small strip can be considered as strips. So it flows in this direction, flowing direction is perpendicular to z direction; magnetic lines is x direction and the voltage developed is in the y direction.

So you have got this equation, induced voltage e_o is equal to that is e_o at the electrodes we pick up, b into l into v where b is the magnetic flux density in tesla and l is length of the conductor in meter and v is velocity of the conductor that is flowing speed that is of the velocity of a conductor meter per second. So the problem here is, it's not as a conventional conductor wire but the whole diameter is considered as the wire length, as wire is in terms of disc it moves so the developed voltage is picked here. So proportional to velocity we have got output voltage and the output voltage can be calibrated by sending known velocities and later on unknown velocities can be found out from this voltage developed between the electrodes.

Here in this case when the liquid that flows is nonconducting one, just like water; the amount of voltage developed is very very small then if you use the drift, drift is used in a dc amplifier to amplify this voltage. The drift problem will come. For that to avoid such problem what they do, instead of permanent magnet they put an electrode magnet of varying frequencies. Then the voltage developed also will be varying frequency at different frequencies and that can be amplified in an ac amplifier suitably. Suppose if it is a conducting material just like liquid metals then we don't require, even dc voltage itself is sufficiently large. We can measure it by an ordinary dc voltmeter.

It is to be noted since it is a nonconducting material, the electrode goes into the body and touches the liquid at the surface of the liquid then only the conduct the voltages can be picked up and then it comes down. So this is the principle of magnetic flow meter.

(Refer Slide Time: 00:12:41 min)

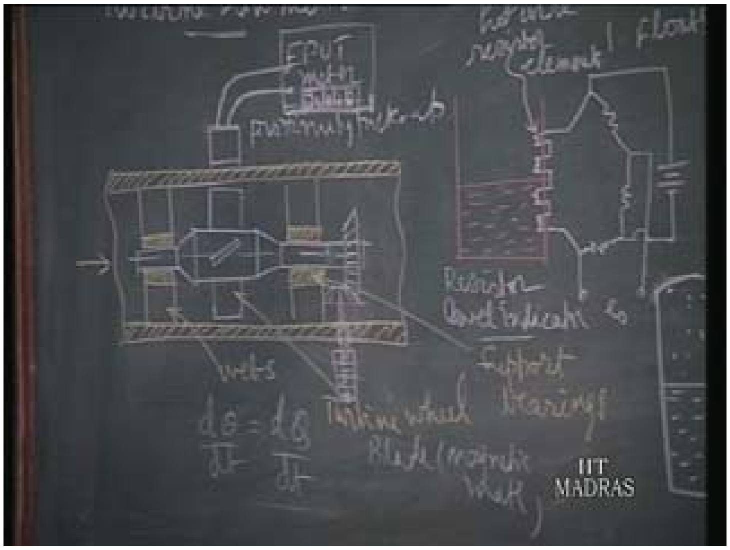


Next we go to Rotameter. For small flow rates and all rotameters are used, both liquid and gas it can be used but mainly people use it for liquid flows. It looks like a conical jar with hole, with some functions with height it will be there. The method of functioning is due to flow, the float rises when the flow is there it rises to different rise at different flow rates and where it stops that scale is written there and that scale reading you can calibrate in terms of flow rate. This is the way it is made use of. The principle of functioning is assuming that float is at some height and let w be the weight of the float and buoyancy force is equal to the volume of this float times the specific rate of the liquid that floats, that is a buoyancy force. That is weight minus buoyancy force is balanced by the delta p is the pressure drop across this float into A_f that is projected area of the float will be net force balancing. The remaining weight is taken up by the delta p times A_f that is the equation for equilibrium.

Now we find for any given float or for any liquid w is constant, b is constant, A_f is constant for any given float and for any given liquid. So when everything is constant then delta p should be constant but at same time we find the equation for flow rate, q is the flow rate through this rotameter is given by A_2. This A_2 is the annular space, these both put together is called A_2 annular space through which flow is taking place, cd is coefficient of discharge, delta p is the pressure drop across the float, rho is the mass density of the flowing medium and A_2 we have seen it annular, A_1 is the pipe this is A_1 which is the pipe inlet area. So in this if you delta p is to be constant then whenever Q varies, all other things considering A_2 by A_1 is too small we can neglect it and c two is a constant, so you find Q is proportional to A_2. Since delta p should be constant, when q varies A_2 has to vary that is the reason for different flow. It rises so that larger area is there for the flow rate, so as it rises area is increased at a linear rate. As the area increases as float rises in a linear relation, linear relation is obtained by some parabolic curve because if it is conical then you will find the area is no more proportional to the lift.

So some quadratic function say the way it should vary the profile hence you get area proportional to the lift. So you find q is proportional to lift also that is why we get some linear scale, indicating the flow rate. So that is the way rotameter is functioning. It has got a linear scale, as the flow changes, we measure the height. Depending upon the different densities of the liquid manufacture gives different shapes for the float; accordingly we have to use it that is given by the manufacturer. Before we pass onto level measurement, see one more method for the flow measurement that is called turbine flow meter.

(Refer Slide Time: 00:16:14 min)



This is domestically used in almost all houses where it is to be charged for the water conception. If it is to be charged then normally people go for such type of turbine type flow meters, its turbine flow meter. That is in the pipe line, insert 1 turbine, here it is shown. This turbine really is shown here with bearing and with webs which is radially probably 3, three webs here diametrically schematically shown here, 3 or 4 webs may be there. Between the webs it will be flowing but the bearing is continuous so it's a cylindrical piece. So that's how it is mounted so we have got the turbine wheel, turbine wheel blade made up of magnetic material. So whenever a blade comes near this proximity pickup, proximity pickup can be positioned outside the pipe carrying the liquid or water and whenever a blade comes, this proximity pickup will give one pulse. Such pulses are counted in events per EPUT meter, it is nothing but events per unit time per second or per minute or per hour you can select.

So many pulses per second actually that is proportional to flow rate, the counting rate a pulse rate is proportional to flow rate. When we want to find out the total flow in a given duration then you start the flow and at the end of the duration, what is the total reading or total pulses that represents the total flow. Total number of pulses represents the total flow and pulse rate per second or pulse per minute or per hour represents the flow rate per second, per minute and per hour respectively. That is whenever it rotates to that extent, so if d theta is angular rotation that represents small differential flow of dq. Then d theta by dt it's as same as dq by dt that is the counting rate, d theta by dt is given by the pulse rate. So this is a principle, if you don't have this proximity pickup, you can also go for purely mechanical counter also. So suppose this is a rod extended and you can just connect a set of bevel gear and bring it out with suitable sealing and let it be counted here, this is mechanical counter.

So it's a bevel gear unit connected to the axis of the turbine. The moment the rotation is brought outside by a set bevel gears and the second bevel gear axis is connected to a mechanical counter so here you can take the reading. This is what is used normally in houses you will have the mechanical counter. The person will come that is in the beginning of the month one reading and at the end of the month one reading. The difference with two readings represents so many liters or so many gallons per month. So that is how it is used for making total flow or float rate measurements. So here rotating speed if you find out, then from the counter also we can find out the flow rate. So with this we close this flow measurement.

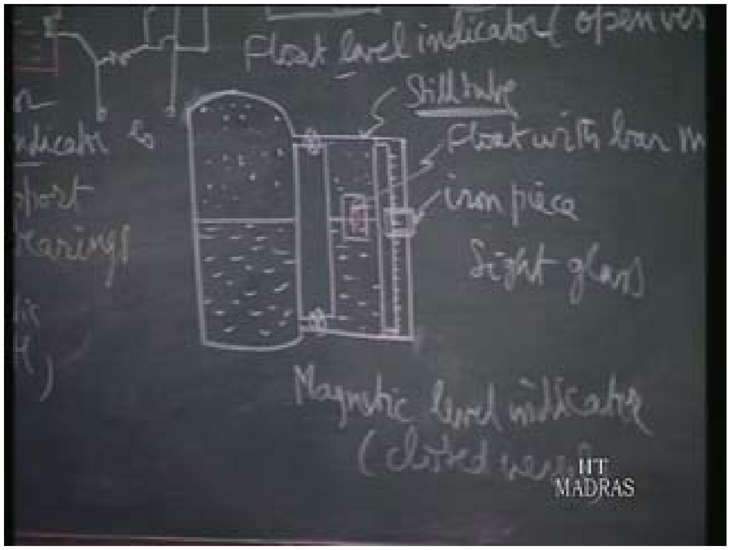
Next we pass onto the last chapter in our topic, mechanical measurement that is level measurement. First and foremost method is using floats, floats are often used to find out sense the flow level of a liquid and also we find in almost all houses we have water tank. Water in the water tank is invariably sensed by having a float there. If the level is full what will happen? This motion of the float is made use of to close the valve that we can see the linkages.

(Refer Slide Time: 00:19:39 min)

Suppose you want electrical signal or if you want just make a reading you have a scale. The float end is connected to an extension rod that rod end is moving over a scale, you can just make readings. So many meters height water is there or you can also connect it to a resistance potentiometer, convert this level into suitable electrical signal and process it and you can take it to a control room say in for process industries tank may be at some distances inside the factory. That signal is brought to control room, the operator knows at any instance what is the level in the particular tank, it's given there. So float is the convenient mechanism that is it is hollow plastic sphere.

So when it immerses when its weight is going to be very small and even small immersion is sufficient to support this weight and any further rise, it will push this float up and you might have felt if you just try to push this float up, it will sufficiently big dimension you find lot of force is there. That force is more than sufficient to actuate a valve and close the water inlet into the tank in case the tank is full that is very convenient mechanism. That is more or less in open vessel we use such type of floats.

(Refer Slide Time: 00:21:29 min)

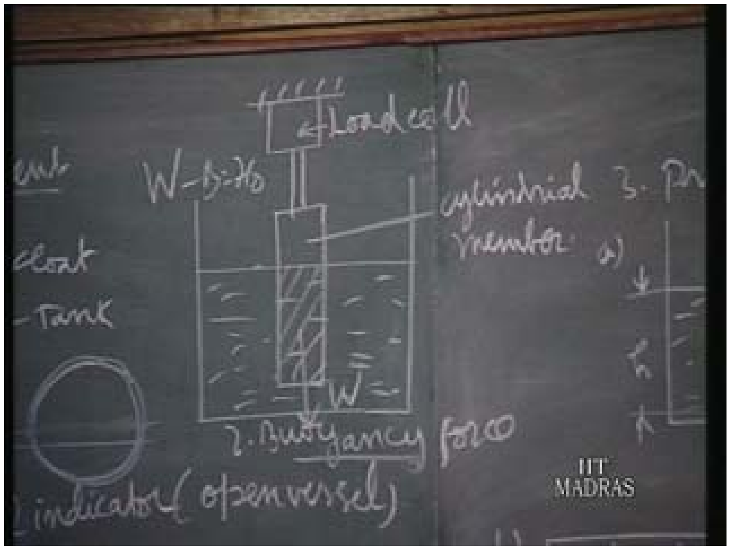


Suppose we have a closed vessel just like boiler for steam engines. For example or in power plants we have got boilers see if you don't have free surfaced atmosphere, you find immediately above the liquid level you got stream at very high pressures. So in such situation this type of float is not useful but if it is medium pressure we can go for a side glass. It's called side glass, we can connect a glass tube to the tank so that the water level can be seen from outside. It is only for low and medium pressure of this wafer, if it is of high pressure then glass may not withstand then we go for the metalic tube connected to this main tank. It's called still tube made up of metal. Then we don't see it, since it's an opaque we don't see the level then we make use of the float with a bar magnet, some bar magnet will be there as part of the float.

As the float rises, bar magnet also rise along the float and nearby we have an iron piece guided by a round piece where scale also is marked. So as the float rises the magnet will pull the iron piece also to indicate the level. So wherever the float is there the magnet piece attracts the iron piece and adjust this level. As the float rises on for and goes down, the iron piece also will go down and up along the magnet. So from outside we can see where the iron piece is there and that is a level of the liquid. So this is how in the closed vessels the level is sensed or seen from outside.

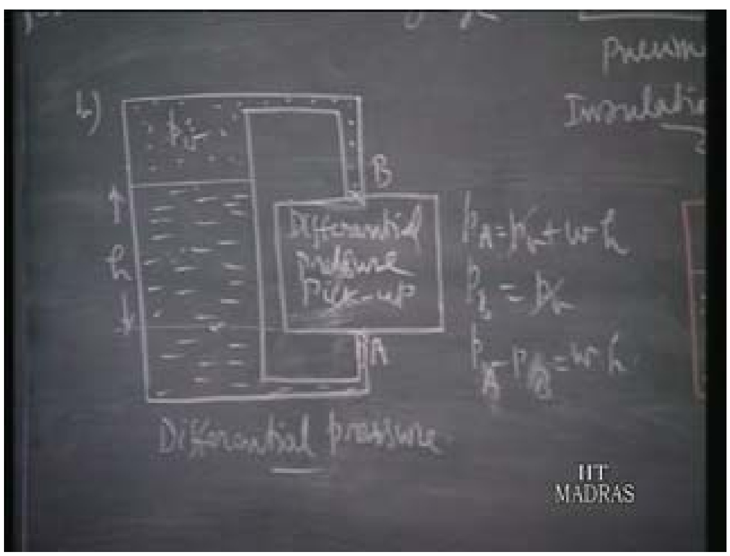
Another method is by using buoyancy force. suppose we have cylindrical member like that and if there is no liquid in this column, no liquid in the tank then you find the load cell will give the total weight of the, it can be hollow and made up of any metal and it can be also a metallic hollow cylinder. So cylinder weight will be indicated by this instrument by the load cell and that you will mark it as zero level because full force is there. As the level increases you find the immersed volume, this immersed volume times the specificity of the liquid is buoyancy force. So if w is the weight of the cylinder minus buoyancy force will be the reading here, load cell reading so x_o. This is our x_o reading, load cell reading that will be calibrated having known level, later on unknown levels can be read from the load cell.

(Refer Slide Time: 00:23:20 min)



So load cell reading can be calibrated in terms of the level here because buoyancy force is a function of level so x_o will be a functional level where w is a constant. That is how we use the buoyancy force to sense the level. Then when there is a liquid column then the pressure at the bottom is a function of the column weight, this is a well-known principle.

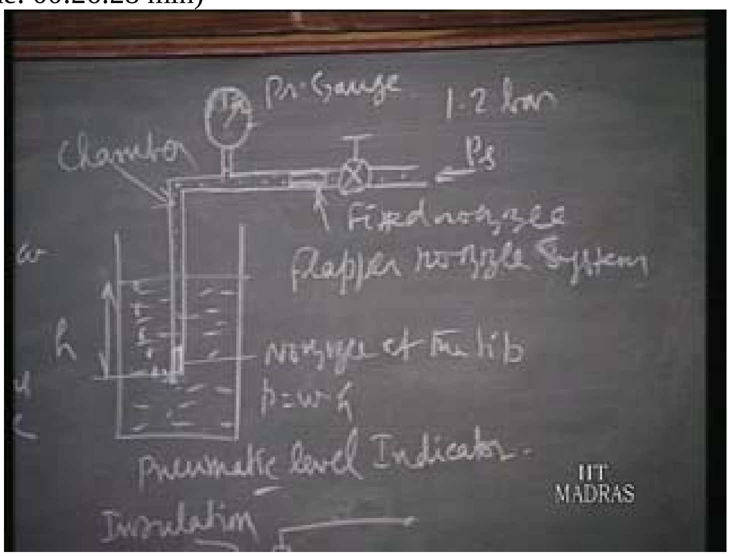
(Refer Slide Time: 00:24:35 min)



By using that we have got some designs by using pressure sense in different ways under different situations, we can also sense the level of the liquid. One is at the bottom of the vessel we connect a pressure gauge so we know pressure indicated in the pressure gauge is a function of height and this specific weight of the liquid w into h. So for a given liquid w is constant so p is proportional to h. So the reading in the pressure gauge is calibrated in terms of the height of the column, height of the liquid in the tank this is obvious method. Then second method this is again open vessel, then closed vessel we go for the differential pressure pickup, this is a differential pressure pickup.

We have the vapour of the liquid also above the liquid so the vapour pressure is taken to as one of the input pressure to the differential pressure pickup and the bottom point that is nearer to bottom it can be as small as possible that point A. So total pressure at A, at this point that is p_A liquid column plus vapour pressure so that is how p_A is equal to p_V wafer pressure plus w into h, w is the again the specific weight of the liquid here and whereas p_B at this point vapor pressure will be there. So p_B minus p_A that is the proportionate reading in the different pressure gauge, pressure pickup is equal w h. So these two cancels p_B minus p_A sorry p_A minus p_B. So p_A is larger, so p_A minus p_B will be equal to w h, these both cancels so w h where w is constant for any given liquid at given temperature. So p_B minus p_B is proportional to h. So the reading of the differential pressure pickup will be in terms of the h and later on we can use for any unknown h, the reading. This is second way of using the pressure reading. Third way is using the pneumatic principle.

(Refer Slide Time: 00:26:28 min)

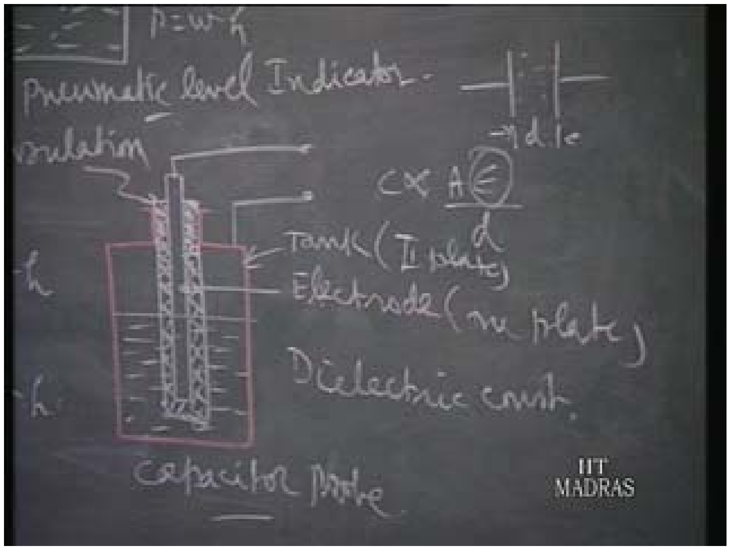


That we call it flapper nozzle system, once I explained earlier flapper nozzle system. That is what is made. Flapper nozzle system consists of two nozzles, this is one nozzle here that is we will say the nozzle at the tip and this is another nozzle, we call it fixed nozzle. As per the flapper nozzle system or principle, the pressure in between the two nozzles we call it chamber. The space between the two nozzles is called the chamber. The chamber pressure depends upon the resistance for flow at the nozzle, at the tip that is the principle and inversion or an application of flapper nozzle system. So at this point the pressure here is equal to; again if h is the height then pressure p is equal to w into h that is the pressure. If the chamber pressure is just above the liquid pressure at this tip then the gas will escape in terms of bubbles.

So until you note bubbles, adjust the supply pressure with the valve just rotate it so the higher and higher pressure will be allowed and the pressure in the chamber through the fixed nozzle, the pressure will be I mean, the gas will be entering or air, pressure air also pneumatic air we can use, say preferably 1.2 bar. For pressure gauge if you have, you can adjust it so that different pressures can be allowed and when the pressure builds to the extent of this pressure, due to this column then it will start, just at the times stop adjusting it and note down the chamber pressure in the pressure gauge and that you can calibrate in terms of the known height. Later on any unknown height can be read in this scale.

So pressure gauge will be calibrated in terms of height of the liquid above the nozzle at the tip. So these are three ways in which pressure of the liquid column can be made use of to sense the level of the liquid.

(Refer Slide Time: 00:28:50 min)



The other one is capacitor any liquid or any solid or powder material will have its own dielectric constant, its called dielectric constant. So we know capacitance is proportional to the area of the two parallel plates. This is two parallel plates, area and the dielectric constant of the material divided by d, the distance is d. We know capacitance is a function of all these things. The area and distance and all are constants. The electrode is one plate and the tank is the second plate for the capacitor. When the charge or the liquid or whatever the level, powder or whatever the liquid level is increasing then dielectric constant is varied. This is what is varied but in the two plates the dielectric medium level is changed, hence you will find dielectric constant for that capacitor made up of this electrode and tank will change and this will form one capacitor in a simple circuit, electrical circuit and proportionately you can get a signal output from the circuit.

So as the level changes, epsilon changes, capacitance changes then voltage output corresponding in the electric circuit will change and from that we can get a signal proportional to the level. So to insulate these two plates we have got this insulation, this is one plate this is another plate and in between two insulation we have got insulator. In case the liquid or the metal powder is a conducting material then extend this insulation for the full length of the electrode. If it is nonconductive one it's sufficient if you insulate only at the top where the electrode and the tank are insulated but if the material, the liquid or the gas or liquid or the metallic powder whichever is showed there is conducting then extend this insulation throughout the electrode. Then you will have again the variation as per the level the dielectric constant will vary and you will get the signal. That is the capacitor principle for the level measurement of the charge inside the tank. The last method is shown here that is by using hot wire resistor elements.

(Refer Slide Time: 00:31:29 min)

This is mainly used in the cryogenic fuel. Suppose in a rocket I mean at the time of manufacturing of the rocket itself you will have the tank to store the liquid fuel and in filling the liquid fuel in the tank, we should be noting at different stages of the filling of the liquid fuel what is the level that is in the tank. To note that level of the liquid fuel in such tanks in rockets, people normally go for this hot wire resistance element. There at the wall of the tank you find the resistance elements at different heights. This is one element then you will have some gap and another element like that. So it can be as small as possible, every 1 mm you can embed such resistances and resistance will be open to the liquid and it will be inside the valve, element alone will be exposed to the liquid.

So as the liquid level increases for example at this level, two resistances are immersed in the liquid and especially when it is cryogenic situations you find, the moment any element is immersed, previously we will say it is switched on. The whole resistance embedded will form one of the arms of the Forearm Bridge or Wheatstone bridge. So before filling up we find the current is flowing through all the elements, due to current flow it will attain certain temperature. So as soon as any element is immersed then heat transfer coefficient of that element will drastically increase and thereby lot of heat will be given to this liquid cryogenic liquid and that element resistance will come down and that means previously if we have balanced it with any liquid and the moment one element is immersed immediately the balance is affected to that extent and will have an output voltage.

Similarly number of elements when are immersed then it will be multiplied, so many times it will multiplied. Approximately if you assume linear relation then the output voltage is proportion to the number of elements immersed. So you can calibrate that reading in terms of the level of the filling up of the liquid fuel that level you can always get in terms of the output voltage or imbalance voltage of the bridge. So this is a bridge, this is one of the arms so if you call it r_1, r_2, r_3, r_4 and against two terminals you have a power supply. From the other two terminals you take the output, this is a typical four arm bridge circuit. So the hot wire resistance are immersed, these are the few methods used for level measurement though there are many other methods these are conventional four methods. So with this I come to the close of the whole subject mechanical measurements. Thank you.