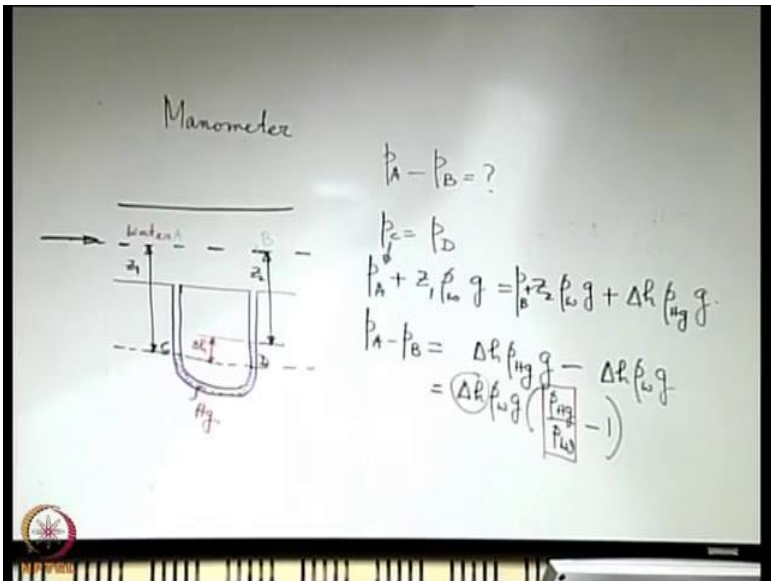
Introduction to Fluid Mechanics
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 15
Manometers

We continue with our discussions on fluid statics and what we will first do today is we will see some other mechanisms by which you can measure the pressure of a fluid. In the last class we saw the example of barometer.

(Refer Slide Time: 00:36)



Today we will first see the example of a manometer. Since this concept is well known to you we will briefly recapitulate it through an example. Let us say that there is a pipe and there is some fluid which is entering the pipe, there are two different sections say marked by A and B, and we are interested to find out what is the difference in pressure across this two. To do that what we will do, we will be considering a u tube connected across these sections.

This U tube will be the so called nanometer and it will try to measure the pressure difference between these two. To see how it how it actually does, let us say that these device contains some other fluid of course, there is a fluid which is passing through the pipe say that fluid is a water. Now the fluid which is the part of these u tube manometer it is something different, because it is the difference in density of these two fluids which will dictate the principle of operation of these device. Let us say that that fluid is mercury as an example, mercury is a very common fluid for manometers and we just take that as a specific example. Now when the fluid is flowing from A to B, which side you expect to be a higher pressure A or B? You expect a to b a higher pressure we will see later on that it is not always true that fluid will flow from higher pressure to lower pressure, it will definitely flow from higher energy to lower energy and the here other components of energy being un altered as an example like the kinetic energy and potential energy therefore, the pressure deferential is the soul driving parameter for the fluid flow to take place.

If A has a pressure greater than B, and if we have some fluid here which is not water, but some other fluids say mercury, on which side you expect it to be more depressed on A side or on B side? So, wherever the pressure is more it will depress it more. So, let us make the sketch accordingly and let us say this is mercury, and let the difference in the level in the two sides or the two limns of the manometer with delta h; what is our objective our objective is to find out what is the difference in pressure between A and B. So, we want P A minus P B that to be evaluated. To do that we will just consider some reference dimensions let us say that this is a Z 1 let us say this is Z 2, the difference between these two of course, is delta h.

What fundamental principle we will use here, we will use the fundamental principle that in the absence of any other body force when the fluid is at rest within this manometer, the pressure in a connected system is same along the horizontal line does not change. So, if you mark this point say C and D, you must have the pressure at C and pressure at D as same.

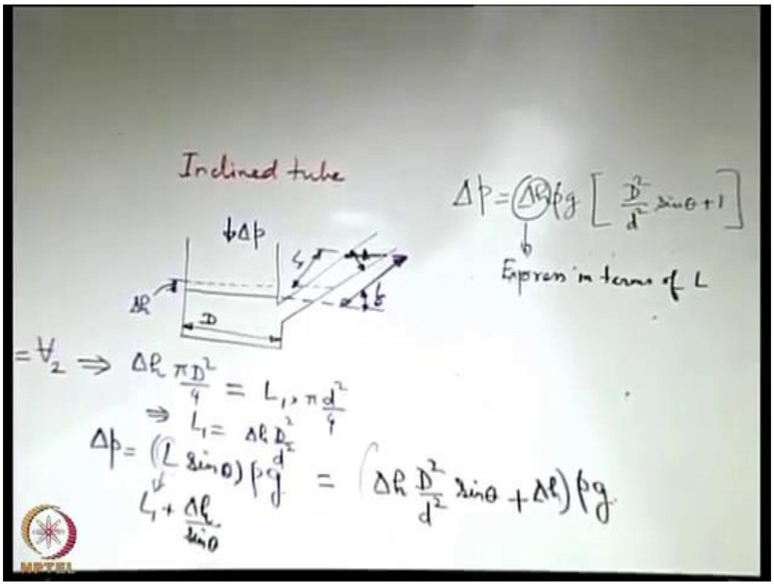
So, how can you write the pressure at C in terms of pressure at A? It is equal to pressure at a plus Z 1 into the density of water because this is filled up with water except for this rate dots the remaining is water. So, these into rho water into Z that is the pressure at C. What is the pressure at D; it is because of a combination of some column of water and some column of mercury, what is the column of water? So, first pressure at B plus Z 2 rho water Z plus delta h rho of mercury into g. From here it follows that P A minus P B is equal to you can write this as delta h rho mercury g minus it will be the rho water g taken as common into Z 1 minus Z 2. Z 1 minus Z 2 is delta h as you can see from the figure. So, it will be delta h rho water g. So, it is delta h rho water g to take as common it is also written in this form. So, you can clearly see that by measuring what is delta h, this you can experimentally measure the difference in the height of the two limns you can clearly find out what is the difference in pressure between two points. What is the factor that is dictating your result is the relative density of one fluid over the other and of course, not only that what is the density of the original fluid that is also important?

So, this is in a very simple way what is the working principle of a manometer; you may have manometers in series connected from one point to the other point, and if you want to find out the pressure difference between two points, what you may do is you may start with a point and traverse along the manometer; when you are traversing along the manometer along the same horizontal level, if you have the same connected system you may consider the pressures to be equal.

So, you may neglect whatever is there below that and that is how you may go from one point to the other calculate the pressure difference go on calculating the pressure difference like coming down and going up like a snake ladder game. So, you come down somewhere find out what is the increasing the pressure, again go up find out what is the decreasing the pressure so on. Along whatever fluid you are traversing you have to consider the density of that corresponding fluid for calculating the pressure differences. You can clearly see that this devices although we say that these are pressure measuring devices, but that is a very loosed way of looking into these because these actually measure pressure differences not really absolute pressures.

So, whenever you have a fluid you expect that the there may be different pressures at different points, and these mechanism is only trying to find out pressure at one point relative to the other not in a very absolute sense. The other important remark is if you see that the resolution of these device strongly depends on what is this delta h, because if this is very small there can be a lot of reading error and that will magnify the error in the description of or error in the determination of what is P A minus P B. So, if this is quite large or magnified it may be easier for us to read with greater accuracy; to do that sometimes people use inclined tube manometers.

(Refer Slide Time: 10:20)



To understand the working principle, we will again take an example. In a inclined tube example it need not always be a u tube, it is basically having a measuring tube it may be a collection of measuring tubes may be u tube, but the access of the tube is inclined with a vertical it is not vertical. So, let us say that you have a tank like this and you have a tube connected to it in this way.

Initially everything was a expose to atmosphere, and let us say that these red colored dotted line represent the initial height both in a inclined limn as well as in a tank. Let us say that capital D is the diameter of the tank and small d is the diameter of the tube, assume both of circular cross section.

Now let us say that you apply a pressure difference here, that is you apply a higher pressure from the top if you do that this level will be depressed it will come to a new location let us say it comes to this location; when it comes to this location; obviously, there is a drop in high and where this extra liquid will go it will climb up the inclined. So, it will comes a to some height like this, and you therefore, now have a net difference in the level as say L. So, L is the new level difference earlier there was no level difference, but because of the application of a pressure differential say delta P the fluid in the big tank has gone down, the same volume has gone up along the inclined tube and the level difference now is L. This is inclined difference and that is what you can (Refer

Time: 12:40) if you graduate with lines on or markers on this inclined tube, you can read the length very easily just like as scale.

Let us say that you have the angle of inclination as theta with a horizontal. Now one important principle that may guide you that what should be the corresponding rise; if you have length up to this much say L 1, then you can clearly relate L 1 with say the distance by which the level has gone down in the big tank, let us say that that is delta h. Since a big tank this may be small since this is the smaller cross section the change will be large. So, we can say from the conservation of volume that delta h into pi capital D square by 4 is equal to what L 1 into pi small d square by 4. So, this is from the consideration that the volume at state one is same as the volume at state two; that is what is the principle that is guiding with very simple expression, from here you can find out what is L 1. So, that is delta h into capital D square by small d square.

Now, what is the difference in pressure now between the two levels? It is that difference delta P, because if one end is expose to atmosphere then the and the other end is subjected to a pressure of say difference of delta P then that should give rise to the difference in level. So, delta P will be what delta P will be L sin theta into rho into g; you can replace L with what L 1 plus delta h divided by sin theta, and L 1 you can write in terms of delta h. So, this you can write as delta h into capital D square divided by small d square into sin theta, plus delta h rho g. You can take certain term as common say delta h rho g it will come to even of course, replace delta h with L 1 again, because at the end it is not delta h that even measuring its L 1 or L that you are measuring.

So, you can write it express in terms of say L. So, either way I mean mathematically you can express either in terms of delta h or in terms of L, but when you come to the final expression it is more convenient if you express in terms of L because that is what you can experimentally read more clearly, and that is the whole objective of keeping it inclined. So, when you keep it inclined you can see that the for the same vertical height you can get more inclined distance, and pressure differential is dictated not by the inclined distance, but the vertical height. So, for the same vertical height you will have the same pressure difference, but with more inclination you can have more inclined length, and that is how you may have a greater length for greater readability or for better readability for the pressure difference measurement.

If you have say the same system, but with a vertical tube say with water as a fluid, then that will be equivalent to some h water into rho water into g. So, the L divided by h water is an indicator of the sensitivity of this device; that h water for a vertical tube may be very small, but big for a inclined tube the corresponding L which shows the same pressure difference may be quite large. So, it adds to the sensitivity of the device. So, L divided by that equivalent h water is also an indicator of the sensitivity of the device.

Now, it is not just the manometer that is commonly used for measuring pressure differences, if the pressure differences are not very large sometimes they are in expensive means of measuring pressure differences and one such example is a pressure gauge. So, pressure gauge it is an indicator of pressure at a point relative to some other reference pressure, very often that reference pressure is the atmospheric pressure and therefore, it implicit implicitly many times reads the gauge pressure, we have earlier defined that the gauge pressure is the pressure relative to atmospheric pressure at that location. So, we see an example with a demonstration to see a pressure gauge.

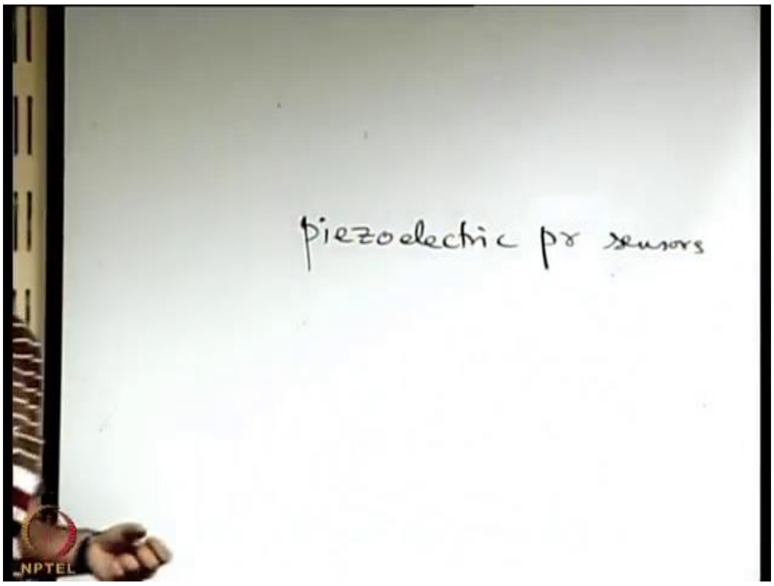
(Refer Slide Time: 19:49)

The example that we will be seeing here it is known as a Borden gauge. So, if you look at this one we will see the example once more, but if you see that it has a tube and the tube is connected to a mechanical arrangement, and one end of the tube is fixed and the tube is of say elliptical cross section it is a deformable tube; when fluid enters the tube then what happens when fluid enters the tube the tube gets deformed, and the section of the tube tends to get more circular as compare to the elliptical one.

So, what is happening is there is a fluid that is entering the tube one end of the tube is fixed the other end of the tube is moving or movable, as the fluid enters the tube there is a deformation in the tube and that deformation is being read by a dial indicator. So, the deflection of the indicator in the dial gauge it gives an indicator of the deformation of the tube, and the deformation of the tube has taken place because of application of a pressure differential. Earlier it was zero deformation or a base state deformation now it application of a pressure difference there is a change in deformation from that.

So, if this is calibrated then one may calibrate the deformation as a function of the applied pressure difference, it is just like calibrating a spring because of a application of a force. So, it is just like spring mass type of arrangement. So, this name of this device is a Borden gauge. So, that is an interesting or a simple way of measuring pressure. The more advance ways of measuring pressure are not these once, the more advance ways are by utilizing principles of certain things known as transducers. So, what the transducers do they convert may be one form of signals it is a mechanical form of a signal into an electrical form of signal. So, there are certain piezoelectric pressure sensors.

(Refer Slide Time: 22:14)



So, what do these do say piezoelectric pressure sensors; these are made up of materials which when subjected to a pressure difference converts that into an electrical voltage signal. So, that electrical voltage signal is read by a convenient mechanism, and that is how you may have a digital output which does not directly show the pressure difference, but it shows the corresponding electrical voltage that is developed, and if the pressure difference is calibrated with that voltage, then it is possible to very accurately describe that what is the pressure difference that actuated that voltage one; obviously, needs to calibrate these type of device, but once it is calibrated it may be very very accurate.

So, it is based on the transformation of signal in one forms it is a mechanical form into a signal in another form like the electrical form. In a summary what we may say that we have discussed very brief about different pressure measuring devices starting from simple barometer to manometer, pressure gauges and pressure sensors in piezoelectric form. With these pressure sensitive devices what we may experimentally find out is what is the value of pressure at a point may be relative to some reference.