Principles of Mechanical Measurements

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Lecture No. # 19

We have seen until now the mechanical devices for measuring force or weight. They are normally meant for smaller range few kilogram or for example compound lever mechanism. That is our platform balance probably it may be 1 or 2 or 3 tons. Suppose hundreds of tons if we want to measure, naturally people go for hydraulic or pneumatic load cells.

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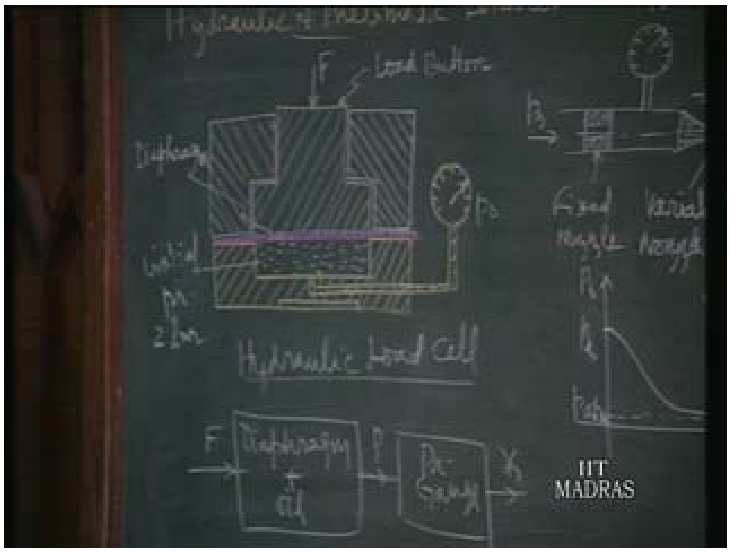

Hydraulic is for still higher range, medium range is pneumatic load cells. How a hydraulic load cell and pneumatic load cells are functioning, we are going to see one or two principles. First the hydraulic load cell, there is a diaphragm. The load button sits on the diaphragm and below the diaphragm we have got incompressible liquid and which is connected to a pressure gauge and we have got the chamber, suitable chamber at the bottom. So that when the force F acts on the load button the liquid below the diaphragm gets compressed because of the deformation of the diaphragm. So for a particular force a pressure is developed in the liquid and that is being read by a pressure gauge, probably it may be a bourdon type pressure gauge and that pressure reading is calibrated interms of hundreds of newton's or few tons in terms of tons. The working principle we can see the signal flow block diagram, diaphragm plus oil converts this force into pressure. This pressure is read in the pressure gauge and we have got the output signal as in the form of motion of a pointer over the scale so that is our x_o.

So how to ensure the moment you apply a force it is converted into pressure, for that is achieved by having an initial pressure. We have got initial pressure of say 1 or 2 bar. It's of the order of 0.2 bar I mean 2 bar pressure, two times atmospheres or 0.2 newton per millimeter square. A two bar pressure is built in that is our initial pressure. So the pressure gauge may read two bar or some pressure that is written as input signals with zero force that will be zero force. Further increase can be only from the applied force. So that is a compact unit made up of hydraulic elements.

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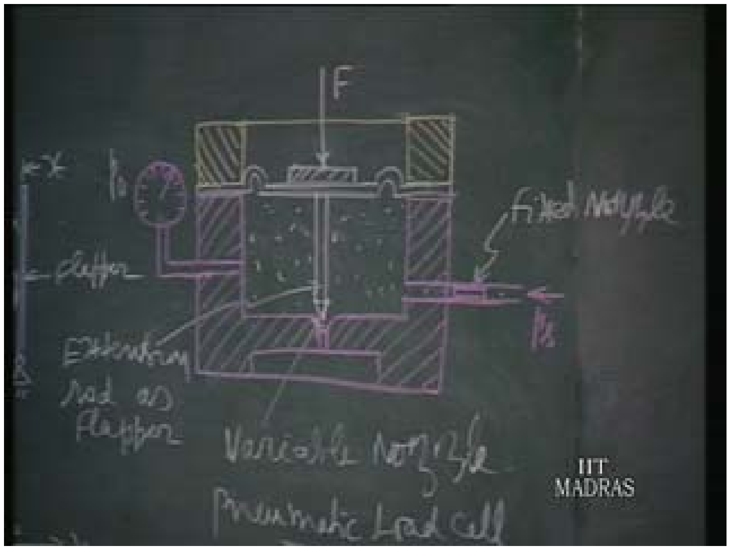

Next we should see the pneumatic load cell. In the pneumatic load cell we have the principle nozzle I mean flapper nozzle principle that is this constitutes a flapper nozzle principle is made use of in the pneumatic load cell. It is because the compressed air can be compressed, it is a compressible medium whereas liquid is incompressible. So this is simple setup whereas with pneumatic air or any gas since the fluid is compressible we are using the flapper nozzle principle. So this is the flapper nozzle principle it is written there.

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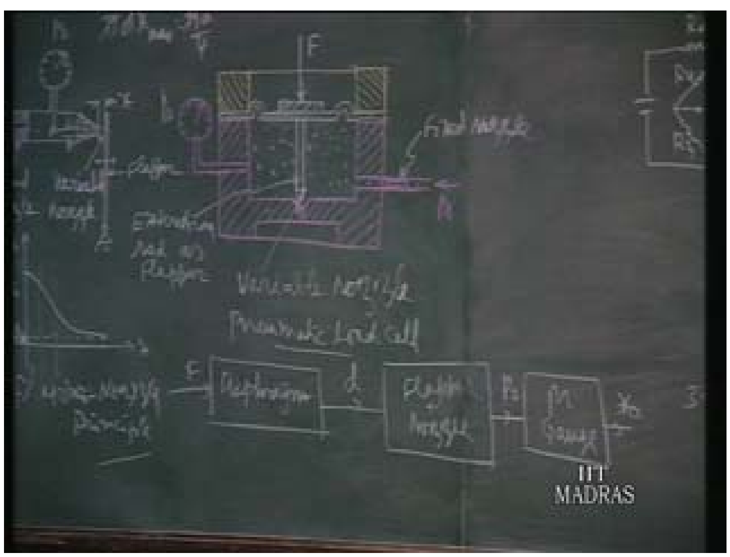

So that is we explain before we go to that load cell say here we have a fixed nozzle and variable nozzle in the form of an imaginary cylinder, this nozzle being extended in this gap that is the variable nozzle and in between these two fixed nozzles we have the pressure gauge that is the chamber pressure is measured by a pressure gauge.

Now the distance between the end nozzle and the flapper, this is the flapper which can rotate or move, varying the distance in front of that tipped nozzle and the chamber pressure in between these two fixed nozzle we have got supply pressure. It is of the order of 1.2 bar, this is usual pressure for the flapper nozzle system, a gas or compressed air at 1.2 bar is the supply for this whole instrumentation. So as x varies the P_o varies as per this curve, when x is equal to zero P_o is P_s. That is when the flapper fully closes then this pressure becomes the supply pressure, for any other distance x then it varies, more or less you have got some range as linear range in this instrumentation. Anyhow this is principle, by giving a displacement x we covert that displacement into a pressure by the flapper nozzle principle. That is what is being made use of in this pneumatic load cell, we have got fixed nozzle similar to that fixed nozzles and variable nozzle between the extension rod and the bottom valve we have this variable area. Now what is this variable area pi d, if d is the diameter of this tipped nozzle, pi dx is the imaginary cylinder from the tip of the nozzle to the flapper that is pi dx is area and that x will have effect on this pressure P_o until this cylindrical area becomes equal to the cross sectional area of this whole. That is the maximum that you call if it is x maximum that is equal to pi d square over 4.

Until this cylinder surface area equal to this cross sectional area of the nozzle, you will have the effect of x on P_o. Later on you will not have, that is both the area is equal. Now you find pi d they cancels out then you will find x maximum is equal to d by 4 that is the maximum distance one can have. So such a distance is given to this extension rod by the diaphragm, when the diaphragm is acted upon by a force F. So the force F, see the block diagram or signal flow diagram, force given to the diaphragm then diaphragm gets deformed. This deformation is carried to this nozzle to this opening by this extension rod. So the amount of opening is varied when the diaphragm deforms that is our variable area analogous to variable nozzle. So this distance is converted because this is fixed nozzle, this is a variable nozzle in between these two nozzle we call it chamber here.

So chamber pressure now that is chamber pressure is a function of the amount of opening here. So the amount of opening is given which is nothing but our displacement in the extension rod. So that is proportional to that extension rod, so d is converted into P_o by this flapper nozzle system. This P_o is read by a pressure gauge and we have got the signal here.
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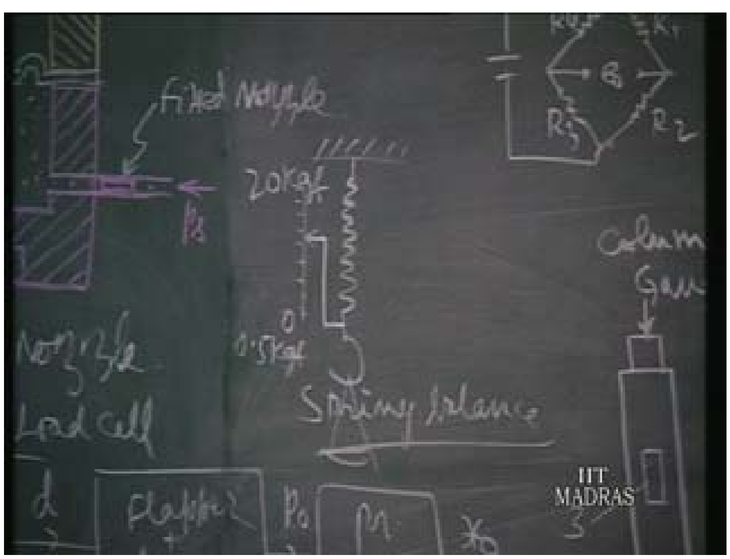

So this pressure gauge reading will be calibrated in terms of force we have applied. So known force we can give and calibrate it by having dead weights or something like that. Later on the machine member will act on this and then unknown force can be read from this pressure gauge which is calibrated in terms of tons or newton's, whatever it is. So these are the two principles under the hydraulic pneumatic principles. Next we are going to see elastic elements. How elastic elements are made use of in force measurement? A typical elastic element is an ordinary spring, helical spring. This is helical spring, we call we call it spring balance domestically used, I mean normally used there. So there you will have the hook and here you hang your weight whatever weight you want to measure and from the other end a pointer is taken, this will be moving over a scale.

Only scale we see, all the things are covered by a cylinder or a cover. This pointer mechanism analog will be inside. So you see the outside of the pointer moves over these scales. So normally we may have up to zero to 20 kilogram force is normal range domestic spring balance and with a least count of 0.5 kilograms. We can read point up to 0.5 kilogram force, this is a very convenient to measure the household articles. So this is the first foremost elastic element that is a spring itself is made use of in the form of spring balance and other is elastic element is the foremost and often used is the column type strain gauge load cell.

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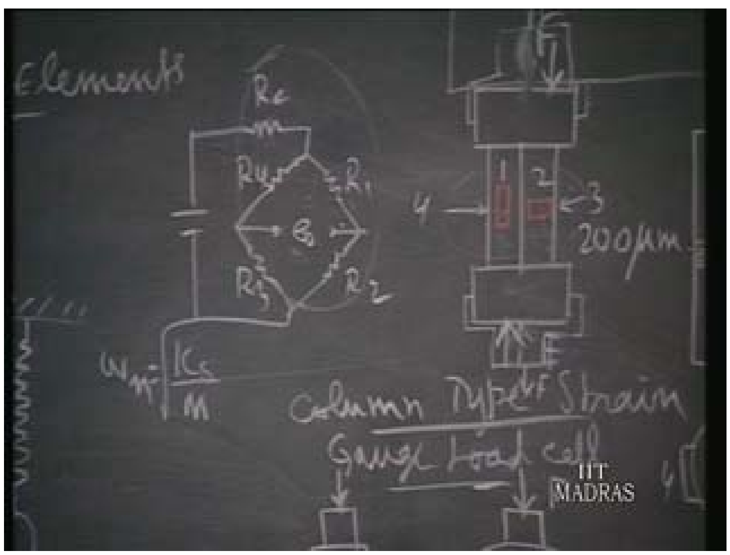

This is very often made use of and it has got fairly high capacity so up to few tons we can measure. The main advantage of all this instrumentation is this spring balance is purely mechanical instrument because only static, no dynamic measurements can be made but in case of this column type strain gauge load cell we are converting the mechanical signal force into an electrical signal. So you can use it for both static as well as dynamic measurement, force can be varying and still you can measure it. As you find this is a typically a second order instruments we have got a particular I mean spring constants that is the force per unit deflections. So spring is there and air is the surrounding medium damping medium and the mass here will be the force transmitting element. Suppose this is being transmitted by a machine member that must also we have to consider in finding out the natural frequency of the whole instrumentations.

So the mass of the transducer alone is not sufficient, the force transmitting member that weight also you have to add to this machine, to this instrumentation of this column. So it is a typical second order instrument here what you are doing is we take a length for suppose this we are using for a compressive force. When you want to use it for tensile, you have two cups or whatever it is with the screw threads you can make suitable fittings and then apply a tensile force. So same instrumentation we can use it for tensile for same column also. Here we want to stick strain gauges so if it is sufficient to large diameter, surface area we need not make the flat surface, we cannot make a square surface inside, just on the cylindrical surface itself you can place a strain gauges. So this may be 1, the 2 is at perpendicular directions, this is 2, 3 are just diametrically behind this. So this is our 3, this is our strain gauge 1 and this is 2 because in transverse directions it is pasted 2 and 4. So 1, 2, 3, 4 these are the, that is if the column is having, if the cylinder has a sufficiently large surface then we can paste the strain gauges on surface itself but if it is a smaller diameter then the curvature may not allow us.

The small curvature may not allow us to paste this strain gauge rigidly. So in that case we make a square cross sections or flat surface we machine it and then paste the strain gauges for better bonding. So after fixing the strain gauges on the column then it becomes part of the column and this column material you have to carefully select. You should reduce the hysteresis effect of the spring material. So some alloy steel or spring steel with some additions will make a large elastic limit as well as less hysteresis. This is what is important for long time usage or long life. The calibration should not change. So once if we know for a column type we cannot paste all the strain gauges along the axis, this we have learnt already under bridge network, the sensitivity of bridge network. So two strain gauges along the axial direction that is the strain gauge loop will be along the axis. Then the other strain gauges it 90 degree perpendicular to the axial, two in axial directions two strain gauges in transverse directions that will make 2 into 1 plus nu where that is the total sensitivity of this instrumentation where nu is the Poisson’s ratio.

We learnt that time Poisson’s ratio where s is the sensitivity of a quarter bridge. So with such instrumentation we will have the twice the, suppose if it is 0.3 then you will find 1.3 so 2.6 times the sensitivity of a quarter bridge that will be total sensitivity. Higher sensitivity means we can have larger signal output e_o. So now the four stain gauges are connected in the bridge network R_1, R_2, R_3, R_4. R_1 and R_3 are axial strain and R_2 and R_4 takes transverse strain, Poisson's strain so is called Poisson’s configuration, we have learnt already earlier so it should be like this. If all of them in the axial direction, the output will be zero so to avoid it we put to two in Poisson's and two in transverse directions and so. Now this instrumentation we find it is insensitive for the temperature variations because it’s a full bridge, all the 4 strain gauges are under the same temperature conditions. So we find temperature compensation is already there. There is no need for any dummy gauge. Because all temperature brings same effect in all the strain gauges, any same effect and all the strain gauges will give rise to zero output which we know already.

So temperature is taken care of regarding the coefficient of linear expansion that aspect of it but temperature will affect the Young’s modulus of this column material. That is when temperature is higher then Young’s modulus will come down that is for a given force we may have larger deformations, when Young’s modulus comes down then that is to be accounted for that is done by having a resistance in series with the excitations to the bridge. How this will be compensated for this change in Young’s modulus? Suppose temperature is increased then Young’s modulus comes down then large strain is there so larger output voltage will be there in the bridge network.

So this we want to reduce it, that is done by having R_c in series this is also in the same atmospheric conditions, same temperature. So when temperature increases R_c will increase when R_c increases voltage drop here will increase so net voltage coming to the bridge will be reducing. We know the sensitivity of a bridge is proportional to the excitation voltage when excitation voltage comes down then the voltage output reduce. If you so select the value of R_c this reduction is equal to the increase due to the reduction in the Young's modulus. So you will find more or less that net may be very small, if they are not equal it may be very small so error may be within tolerable limit. So that is for temperature compensation for change in Young's modulus we put a resistance in series and you will find one more advantage of this instrumentation is this will be sensitive only for this axial loading.

Suppose there is a bending movement due to some eccentric loading, suppose it is here and you apply like it so we find a small couple or movement is there. In such situation what will happen, suppose the 1 will be tilted in this way so 1 will be in tension and 3 is opposite face, 3 will be in compression. Now 1 and 3 they are subjected to opposite strains and that means they should be put in adjacent terms for maximum sensitivity but you find they are put in opposite arms. So opposite strain in opposite arms gets nullified as per the rule of the bridge. So even if there is bending, there is no output due to the bending strain. Similarly if this way excitation is there and 2 will be in tension and 4 will be in compression and 2 and 4 on opposite arms and opposite strains gives rise to zero output voltage. So we will find this instrumentation is insensitive for both bending load and temperature effects.

So that is advantage but one should be careful when we design this column, column height should be sufficiently short so that under this compressive load it doesn't buckle that is one thing. Secondly the place where we are going to fix the strain gauges should be sufficiently weak to produce sufficient strain in the member. If we fix the strain gauges on the existing member which has been designed for strength then you will find the strain produced will be very small of 0.1 or 0.2 micro strain which will not give rise to any output voltage. So when we want to fix the strain gauges in existing member then at that place you have to weaken it so that there is sufficient strain but you should not weaken in a way it goes to plastic region but still the loading range should be just above the elastic region. So it will produce at least a 200 micro strain that is what we expect at least 200 micro strain should be there for the maximum loading. If it is 0.1 or 0.2 microns then it will not produce any effect.

So you find for this load cell where we want to fix the strain gauges there should be sufficient strain to that extend we have to weaken that place and then only fix the strain gauges, this is what is important. So here you find in the column type, the spring constant since it is a solid member it is fairly large and deformation will be very small, to have some more sensitivity but advantage is since K_s is large and $omega_n$ which is root of K_s by M will be larger $omega_n$. So it will have naturally larger bandwidth but the problem here is since it is a column it may have the smaller deflections or sensitivity may be small. To increase sensitivity what we can do is; see one disadvantage is when we reduce the cross section then it becomes too narrower or you may have very small area for the strain gauges. To avoid the problem what people do, we can have a hollow constructions, at the place where we want to fix the strain gauges have the hallow construction small valve thickness. So inside it will be hollow so that we find it is weak at same time sufficient area is there for fixing the strain gauges. So all these measures we can observe so that sufficient sensitivity comes but another better design is going for the proving ring transducer. Here we have much more sensitivity than this but problem here is K_s spring constant is reduced and bandwidth is reduced.

So this always the case instrumentation when you want to increase one characteristic value and some other characteristics gets affected that's why you have to come to compromise. Anyhow this is the proving ring load cell or transducer is widely used in places, industries and laboratories.

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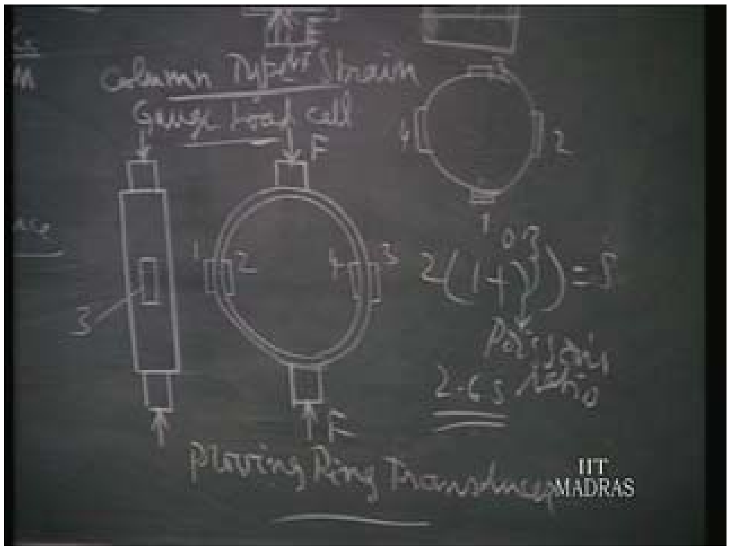

It is made up of just you have a ring and the inside and outside surface and in the surfaces we place the four strain gauges as it is shown here and this is end view of it. So you find when the load is applied F, the ring is compressed. So this compressive load converted into bending strains at the surfaces, 1 and 3 will be subjected to tensile strain 2 and 4 will be subjected to compressive strain. Then the same bridge holds good 1 and 3 in compressive, 2 and 4 in tensile, 1 and 3 tensile, 2 and 4 in compressions. So bridge we can use again you can have this compensation for elastic modulus change due to the temperature. So the same circuit we can use it for this one also.

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Advantage is here more sensitivity but the load capacity is reduced so probably 1 or 2 ton. Here you may go up to say for 50 or 100 tons we can go for column type, here it is a small it will be reduced. The disadvantage of the set up is if you unknowingly load more then these points may go into plastic deformations. It may not come back to original because we might have exceeded the elastic limit that is danger; to avoid this we have some other design. That is a load cell with overload production; see here the special construction with a gap s so in one circle we have got 2 circles with the central gap. So when you put the load here F and this is a fixed surface when it is compressed and when the gap is reduced to zero any further loading will go to the floor or the ground directly, it will not stress or strain the elastic member.

So until it becomes zero you have got strain here, it will be within the elastic limit. So you will find beyond elastic limit, the force will go not through this element but directly to the floor through this bulging. So that is the overload protection here. So if you want to have still higher sensitivity and say for smaller load range, the natural its a few gram onwards we can measure by having the cantilever type of load cell. Say it is written is cantilever transducer but cantilever load cells, this we have made use of for explaining many principles, bridge network principles we are using this example very often. So you find at the top surfaces are two strain gauges 1 and 3, same bridge network whatever we have learnt earlier same thing holds good.

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So this is 1, 2 this is 3, 4 that is 1 and 3 will be in say for this type of loading its tensile strain 2 and 4 will be in compressive strain and for I mean 2 polarities we have got. So all the four will give rise to 4 times sensitivity of a quarter bridge. So this is a full bridge and temperature compensation is there and for counting for the Young's modulus change due to temperature we connected R_c see it's a circuit we can have it. So this is for smaller load range we can go for this cantilever type. By having the different thickness and different length we can have different load ranges in this, it's very versatile useful a principle. Then next one is using diaphragm and using LVDT diaphragm type of load cell.

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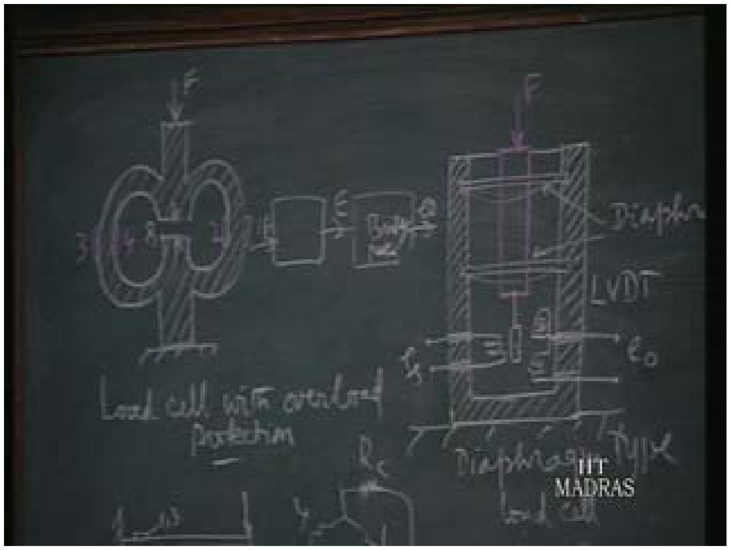

So two diaphragms are there and at the middle of the diaphragm one rod is connected and at the end of the rod we give the force which we want to measure. It is supported in the say it can be supported on the floor, now give the load and the diaphragms deforms like this. So this deformation is maximum at the middle so the rod comes down at the bottom end of the rod we connected the core of an LVDT or of self inductance pickup, here it is LVDT. So this is your supply voltage, two secondary connected in oppositions so the output voltage e_o is a modulated voltage, a modulated signal modulated modulation between e_s and the magnitude of the displacement of the core and further we process it as we have learnt earlier in LVDT by giving amplifying or without amplification give into phase sensitivity demodulator and low pass filter and finally we get a displacement. This displacement there, that displacement is written in terms of Newton or kilogram force. That is how the displacement reading is calibrated in terms of force unit.

So here we have two transducer one to transduce the force into deformation and this deformation back to voltage that voltage is written in terms of Newton, so 2 transducers in essence. That is the case in almost all the type of the elastic members with strain gauges; we use a one member elastic member to transduce the force into strain that is the block diagram.
That is the force converted into strain either in the cantilever or in the proving ring or in the load cell, we use that primary this is a primary transducer load member. So this has to be properly designed so that sufficient stress and strain is there and then later on we give this to a bridge network that is our bridge network and from there we get an output voltage. This is the instrumentation; this output voltage is further amplified or read according to the situations. So two transducers more or less we will find 2 transducers are there epsilon to e_0, either the LVDT or strain gauge anything we can use.

The one problem in the cantilever type of transducer is suppose this is load button this is a place where you are supposed to apply the load or force. If it is little bit changed say it is little bit changed then you will find for the same force, little bit earlier in this cantilever we have the less strain here. Then the instrument will show a less reading, smaller reading the force may be 10 or 100 Newton but the instrument will show only about 90 Newton it is because it is shifted from its original place by due to some error or something like that little bit earlier.

So to that extent the instrumentation gives rise to that is it is very sensitive to the proper placing of the load on the instrumentation in the load cell. That problem is solved once you go for the shear type of load cell.

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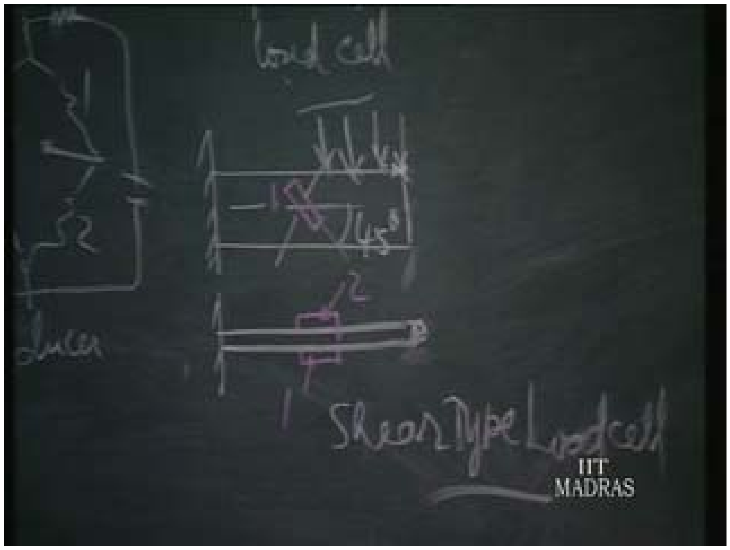

Here we can apply it here or here, nothing will happen it will give the same reading. It is non-sensitive for the location of the load, more or less this is the loading point say about the loading point if you vary it is not affecting the instrumentation where it is in cantilever type it is very sensitive for this small error in applying the load. How it is non-sensitive? It is because this instrumentation based on shear type, we know the bending movement diagram for this cantilever is, it goes like this. From tip is zero bending movement and at the bottom is of the near about fixed end, we got the maximum bending movement, it varies linearly. Whereas shear force diagram for the same cantilever shear force diagram is rectangle, from this point up to the fixed point shear force remains same.

It is same as applied load that means shear force doesn’t change with distance of the application of the load so that is the property what is made use of it. Load is supplied area and we know shear force is same throughout so we can select any place but here we have to be careful because from shear force we have to go for the maximum stress or strain that is principle strain, the compressive or tensile strain that is at 45 degrees to these axis of this one. So if the one then the other one at the back side you can put of 90 degree to this orientations. So that will be in dotted line I am drawing so it will be like that. So if one is in tension, due to shearing in this axis, so compressive tensile will be available at 40 degrees to this one which we have learnt in machine design.

So 1 will be in tension and 2 will be in compression then you connect so in the same bridge 1 is in tension this is tension and the other 2 is in compression. So adjacent arms you connect and if we want 4, 3 also we can have 1 and 3 in the same way, you can have another parallel and you can have 4 strain gauges also. This will be 3 behind at 90 degree to that it will be 4. So that full of full bridge, if 1 and 2 alone half bridge we have got which we are making use of.

So that problem of loading exact place or if we make I mean if this is an instrumentation which is not sensitive for the loading point. So it is nowadays very often used, shear type load is often used and next what we are going to see is three dimensional load cell. Suppose you have force F acts in some random direction like this.

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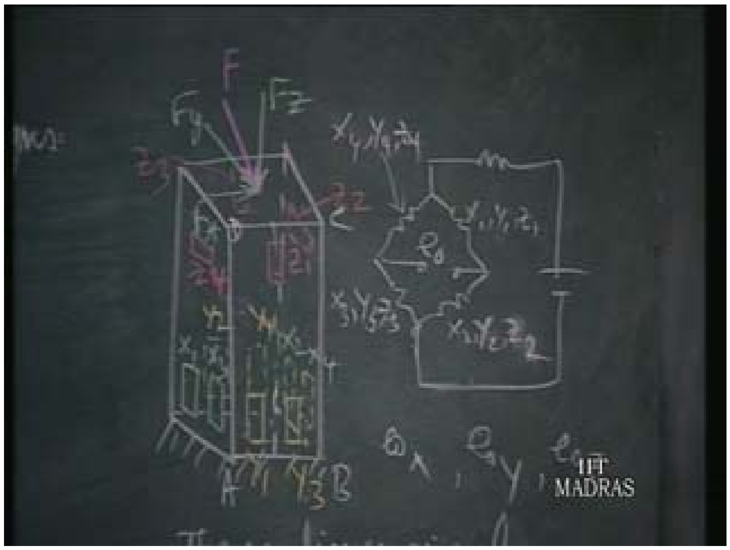

This is a random directions which a component which is F_x, F_y and F_z along the three coordinate axis. This is a three dimensional one so it is not vertical or horizontal or x direction, y direction so some random directions. So for that we use a column like this, this column should be little bit sturdy or a strong column because due to this application if it bends it gives rise to lot of error. So the amount of deformations should be limited, to that extent we should have a strong beam fixed at the bottom end. Now the F_x and F_y they will bend the beam having a cantilever, having a fixed end at this bottom. The beam will function as a cantilever for F_x and F_y, for F_z it is again a column.

We know instrumentation for bending; for bending top surface 1 and 3 tension, bottom surface 2 and 4 compression. Similarly if we consider F_x when it is this way, this layer will be under tension the other layer will be that is the bottom layer will be under compression. So X_1 and X_3 are in tension and Y_2 and Y_4 are in compression I mean X_2 and X_4 are compression.
So I have drawn one bridge network and I am supposed to draw 3 bridge networks, one for X another for Y separately but nomenclature will be more or less same that's why I indicated here but we should have 3 independent bridges. One for X instrumentation in X direction and another one for Y instrumentation and another one for Z instrumentation, three bridges we should build for each component force and this is e_o, you will have e_{ox} from the x bridge, e_{oy} for the Y bridge and e_{oz} for the Z bridge. So three different bridges, they are added finally in algebraic fashion and final output voltage will be proportional to F. So algebraic addition of these three independent voltages from three bridges will be proportionate to the final three dimensional force F but we should be careful, the instrumentation for X direction F_x should not be influenced by Y direction force or the instrumentation, the strain gauges meant for F measuring F_y should not be affected by the F_x. That is possible only when you fix the strain gauges about the neutral axis, symmetrical distance from the neutral axis.

For example you consider this face ABCD; this is the phase and neutral axis more or less at the middle. So we find Y_1 and Y_3 will be at equidistance from the neutral axis. In that case we will find the instrumentation for Y will not be affected by the other two forces. For example you can see Y_1, Y_3 and F_x is this direction. So we find this is above the neutral axis Y_1 will be in tension, Y_3 will be in compression, Y_1 Y_3 should be in adjacent arms for F_x but Y_1, Y_3 are in opposite arms, so it gets canceled out. Similarly you can analyze in all the strain gauges, Z_1 is at the middle and you will find top side will be in tension and bottom side from the neutral axis compression within the strain gauge itself it gets canceled out. So instrumentation for one direction force will not be influenced by the other direction provided the strain gauges are fixed symmetrical about the neutral axis on each face. So for F_x and F_y we have got 4 strain gauges similarly for F_z, F_z is column type. So you cannot have all the four axial directions. So here we have the four times sensitivity for F_y and F_x as the quarter bridge whereas for F_z we have the 2.6 times sensitivity of the quarter bridge because it is the axial force.

So two in axial direction two strain gauges, other two strain gauges should be transverse in Poisson's configuration. So sensitivity for Z will be little small, it does not matter we are going to add these forces and then later on we are going to calibrate. So this is the way all the three components and finally we add the output of individual bridges and get the signal proportional, algebraic addition and get the signal proportional to F.

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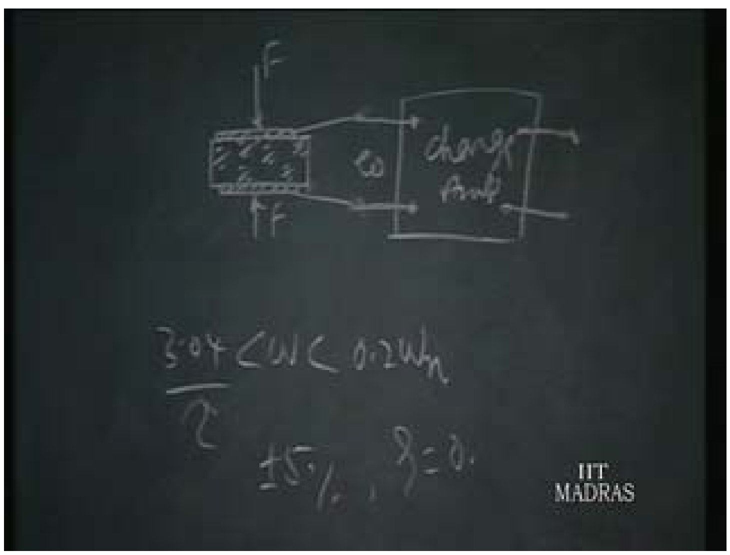

Next we see the piezoelectric force transducer. We know the piezoelectric crystals and they respond to dynamic loads. So we can have this piezoelectric crystal apply the load either I mean given displacement signal or we can give force signal also. Displacement signal alone we cannot give without a force because the crystal will not deform, it has got very high spring constant. So we now use it for measuring force, supply the force then it deforms that deformation is producing a charge and that charge we take into a charge amplifier this can be taken to a charge amplifier and the voltage output can be read with the help of a voltmeter.
So instead of displacement we can use it for force also, known force to calibrate the readings and later on allow the unknown force to act and then from the calibrated curve we can find the force.

As we know this crystal can be used only for a dynamic load that omega being between say 3.04 over tau and 0.2 times omega_n. That is for plus or minus 5% error and also when size equal to zero that is crystal works more or less air damping; air damping can be assumed zero. So we will find under these conditions the bandwidth for this instrumentation is 0.4, tau is the time constant of the electrical circuit, it is 3.04 over tau that is it functions like a simple capacitor transducer because this is a metallic plate at the bottom and at the top. So this is a dielectric medium insulating material so it is typical capacitor circuit, we already learnt 5% error, omega should be larger than this value 3.04 over tau and considering second order system we have found out, it should be less than 0.2 omega_n for 5% error psi being zero, these all we have arrived already. So this is the working range for this piezoelectric transducer. Otherwise it is a very good dynamic measuring instrument, a force measuring instrument.

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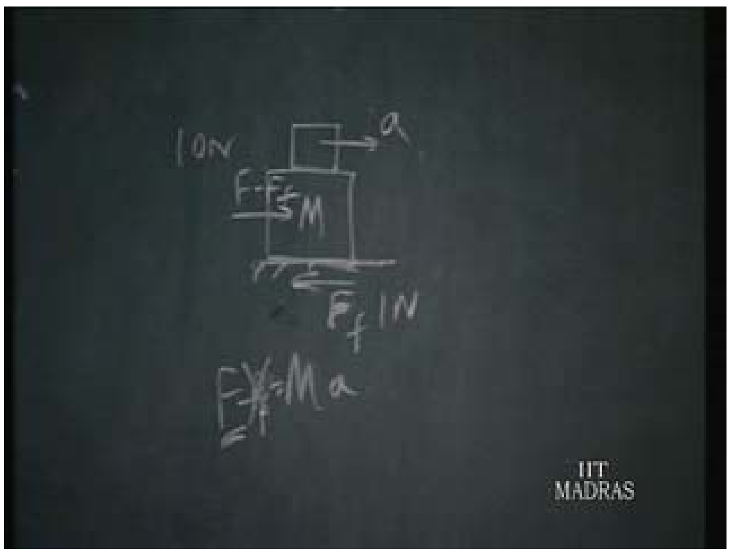

Next method is force by acceleration measurement. That is a member is there, this is a machine member and we want to find out what is the force acting on this member. So we can connect a load cell and find the force but many instances it may not be possible to connect to bring a load cell here. So people what they do, they put an accelerometer here. They will measure the acceleration a and now we know force F is equal to, if M is the mass so mass into acceleration. So measuring the acceleration and knowing the mass of the body of machine member on which the force is acting, we can find out the force. It is indirect way of measuring. So by measuring the acceleration we measure actually a force but what is the drawback in this. It will measure only the resultant force, suppose there is friction force. It is moving over a surface suppose that a friction force F_f, the net force is F minus F_f. Now instead of F, F minus F_f.

F minus F_f will be equal to equal to Ma that means you should know the friction force. If you do not know the friction force you will be assuming that to be force so that will be error. so you are measuring a smaller force but you will be calibrating as a bigger force. Suppose you have 10 newton and here 1 newton then only 9 newton alone accelerate this mass. So accordingly this acceleration will be smaller and that will be writing it as 10 newton because you do not know the friction force so that is the error component.

So that means the acceleration will be proportional to the net force or resultant force and you cannot find out the different forces constituting the resultant force. So this instrumentation we can use it only when the resultant force is one or if there is another force that force amount should be known to avoid the error in the measurements. Drawback is if acceleration is a result of the resultant force that is the point what you have to measure. The next what we are going to measure is closed loop instrument, it's called electromagnetic balance that is the electromagnetic balance what I have written here electromagnetic balance.

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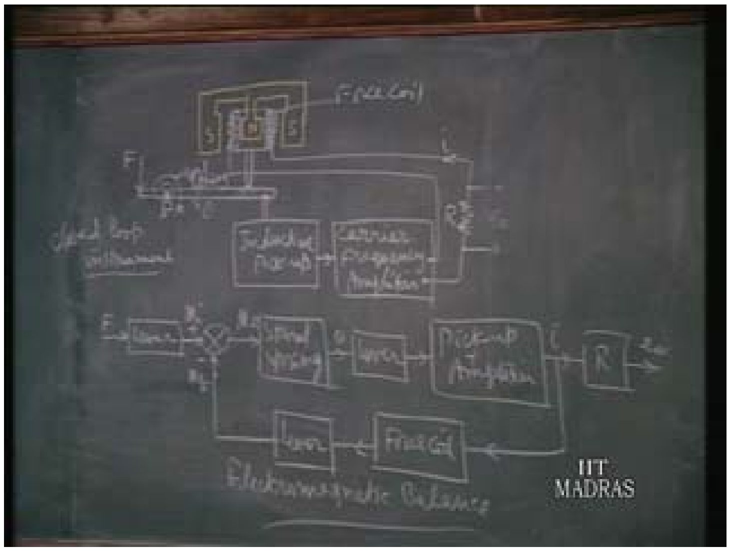

This is a closed loop instrument. So far what we have seen all these instrumentation, earlier version whatever we have seen they are all in open loop instrumentation but now it is closed loop instrumentation that general advantage whatever it is there in closed loop instrument, it is here for this instrument also. That means they have got higher accuracy say 0.1% accuracy we can get, whereas in open loop we can get 1 or 2% accuracy alone we can get. So it is functional like this, this is one of the versions there are many versions one of the versions of such instrument is we have got a lever at the end of which we apply a force F and the other end we have got this inductive pickups and this is a force coil and we can call it a force coil, this is force coil are arranged.

The functioning is like this we can explain with a help of the signal flow diagram also, we apply a force F and at the end of a lever this is a lever so a moment is there that moment say m_i this is m_b. There will be some force on the force coil that is acting at a distance so there will be some m_b, the resultant of these two movements is m_e, m_e acts over this coil spring. So that moment is converted into angular rotation theta. This theta at a distance of another distance we have got a pickup at some other distance. So theta times the distance will be displacement at this tip that is this is the tip, displacement inductive pickups for measuring displacement. So that much displacement will be sensed by this pickup and it is given to carrier frequency amplifier, the current will be flowing here i due to this current. This current is taken to the force coil; the force coil gives rise to a force bringing the lever back to its original positions. So amount of current required to bring it back it’s a measure of the force. A force is larger it will tilt more and it has to brought back a higher current will be going.

So the amount of force required in the coil to bring the lever back is a measure and proportional to that force, you have got current flow in this system. So you find a current flowing through that constant resistor R gives rise to a voltage drop e_o so that is why it is taken here. So i following flowing through R gives rise to e_o this output signal and this i is taken to force coil to give rise the feedback movement. So now e_o read here with a help of voltmeter can be calibrated in terms of force here. So that is how the closed loop instrument is functioning. Any error, any temperature rise and all will not affect this instrumentation accuracy because if a coil spring constant is changed due to temperature, the same coil resistance that same spring constant is valid for the feedback also. So that softening of the spring will not because softened spring will require only a less force here in the coil also, so you find it gets stabilized this error source gets nullified. So that is how it is having a larger accuracy. We will close it with this one.