Principles of Mechanical Measurements
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Lecture No. # 16

For measuring reciprocating velocity we have seen last time a seismic mass mounted over a spring and damper used as velocity for the purpose of measuring reciprocating velocity. Now this is another version, this modified seismic velocity pickup. Here the conventional mass is replaced by the coil because in the earlier setup we had the mass here and spring. This is damper and to measure the relative velocity of the mass we had separately the moving coil, moving magnet pickup like that.

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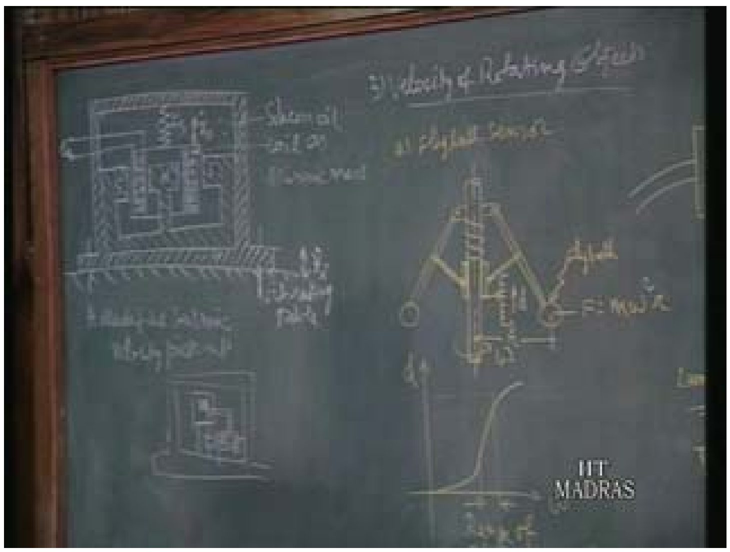

Now the moving coil weight itself is taken as mass here for this instrumentation so that is the only difference. So this was our earlier instrumentation. Now this mass and the coil mass or this is our permanent magnet and this permanent magnet is here as it is and the coil mass is taken as the seismic mass here. Seismic mass is the coil itself and for spring you have got the whole mass is suspended from your spring and for damping purpose this whole volume is filled up with oil preferably silicon oil which doesn't decompose in course of time.

So damping is from the filled oil, for the spring you have got this is k_s, for the mass the coil itself. So the same vibrating body the whole instrument is fixed to the vibrating body, bottom is the vibrating body a table or whatever it is, whose velocity we are interested to measure. So bolt it and as it vibrates more than the natural frequency of this mass spring system say twice more than that then you will find the relative motion of the mass with reference to the frame that is now the permanent magnet itself forms part of the frame fixed to that, so any relative motion we have got a voltage output. So this voltage output will represent when the frequency is much more than the natural frequency the input velocity itself that's what you have learnt yesterday.

So this is one modified version of the earlier type of seismic pickup where we have separately a mass but the mass and coil are combined together in this setup. So it is cheaper in the sense and simple in construction. So this completes our measurement of reciprocating velocity. We are seeing three types of velocities one is continuous motion, second reciprocating motion and third one is velocity of rotating objects. This is simple to measure hence we find large number of methods are available for measuring rotating speeds rpm or rotation per second, rotation per hour all these things are available in plenty. We will see few of them.

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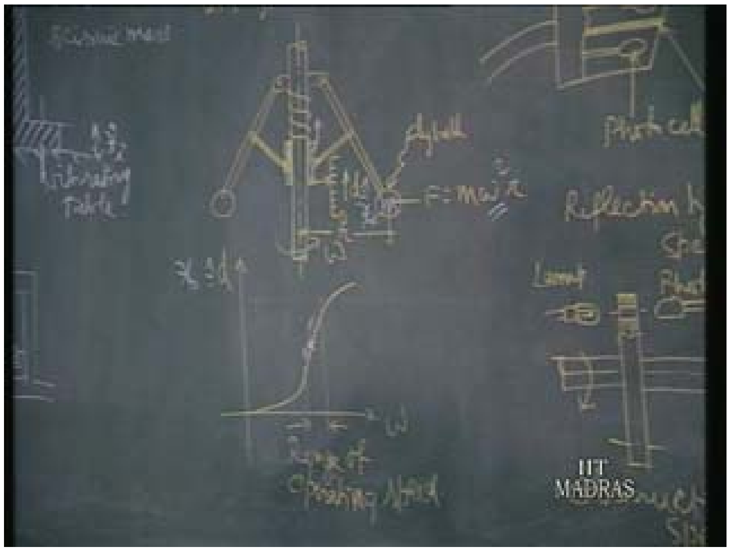

The first one is the fly ball sensor; it is used since long time especially in power plants. The turbine speed is control by having this fly ball mechanism. This fly ball sensor it senses the speed of the turbine shaft and gives signal for the control of the speed. So you find this fly ball mechanism that is if m is the mass of the fly ball then centrifugal force equal to m omega squared r proportional to omega squared, omega being rotating speed. So this force is transmitted to this collar, this is the collar which is mounted free on the rotating shaft. Rotating shaft rotates at omega so the part of the force through the linkage the centrifugal force is transmitted to this collar. So the collar try to raise and in the process it is compressing a spring so proportional to the force it gets compressed and that distance is this is our output signal x_o.

So now if you plot the x_o versus omega you have got some nonlinear characteristics that is because of the quadratic equation comes into the picture but the operating speed of the turbine will be somewhere in the middle of this linear portion of the curve. So the speed will be varying along this then immediately if speed falls down then the governor, it will be sensed when speed falls this comes closer and then some linkage will be actuated and I mean turbine speed steps will be taken to increase the turbine speed. That is for power plants operation this is widely used. Still in some other tachometers fly ball mechanism are still used old type this is one of the conventional methods. Now we have got the modern methods of measuring the shaft rotation but there in the rotating shaft itself we have connected suitably the fly balls. This is the shaft where you have connected but now we find in the rotating shaft we fixed one reflecting tape this is supplied by the manufacturer. So you just cut a small piece and fix it and it will have its own adhesive.

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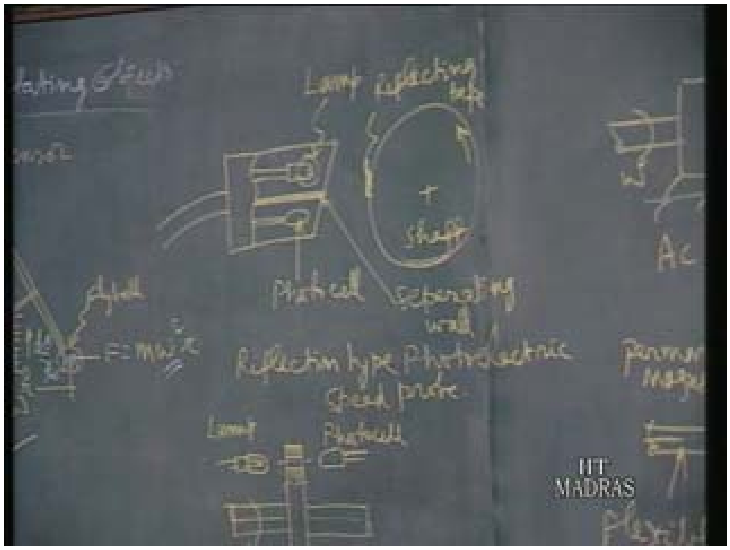

You can just paste it on the shaft and this is based upon the photoelectric speed probe but even before that we have learnt this proximity pickup. We already learnt proximity pickup, suppose to the rotating shaft a gear is fixed. This is a gear so a gear is fixed and near about the rim of the rotating gear we can fix a proximity pickup, this is a proximity pickup. Whenever a tooth comes in front of the proximity pickup one pulse is given, suppose there are 10 teeth then 10 pulses will be given and this is connected to a universal electronic counter where it can be counted per second. So per second so many pulses will be there that divided by the ten will give the rpm per second. You can select a different base one second or 10 seconds whatever it is. Suppose if you have selected once again whatever be the pulse it will be counted and that if you divide by 10 that will give you the rotating speed per second that is the inductance principle.

The principle here is inductance principles; the inductance varies whenever a tooth comes. So when you don't have any gear anything like that then what you can do, you can substitute gear by a screw. Now the shaft is there we can substitute it by a screw head just by a screw head and now put your proximity pickup near the screw. Whenever the screw head comes in front of proximity pickup one pulse will be made. In all these methods we are measuring the pulse that's why we can call it pulse counting method of speed measurement. There we are measuring, when the reluctance, this is actually reluctance variations under inductance principles when the reluctances varies we have got one pulse and in another method we can have light source instead of the inductance principle you can have light source. In this probe tip we have got light source then it contains two chambers at the top chamber now we have the lamp and the bottom one we have got the photocell and in the rotating shaft we fix a tape like reflecting tape and the light falls on the tape and it gets reflected.

Whenever the tape comes in front of the probe tip you get one pulse. This photocell will be forming part of an electronic circuit so one pulse electric voltage pulse will be produced. In case you have a disk already in or let us look in another way of measuring this using lamp and photocell is fix a disk to the rotating shaft like this with the number of holes say 4 or 6 holes.

Whenever a hole comes in front of this say this measuring station lamp is there this side, other side photocell when the hole comes light passes through the hole and it falls on the photocell and photocell will be forming a part of electronic circuit and one pulse will be produced. So whenever a hole comes it will be producing one pulse. In such measurements say either in the proximity pickup using proximity pickup inductance principle or reluctance variation or in the reflecting type photocell or this is we call it obstruction type photoelectric speed probe here. All these things are part of pulse counting method of speed measurement, the error in all these methods, error is plus or minus one pulse and how do you say plus or minus one pulse for that we just see here as an example, say consider the disk where the hole is there as measuring station when the hole comes the one pulse is produced.

Suppose the shaft starts rotating at this station A and it starts rotating in the direction, it comes and stops at station B just before the measuring station then it has completed almost one rotation but since at no time this was in front of the measuring station no pulse is produced. So you find theoretically it is rotated for one rotation but no measurement actually measured is zero so error is 1 minus zero plus error, this a plus 1 error, plus one pulse is error and in another way suppose the hole started just in front and stopped immediately after it passes through the measuring station. So it is registered as one, measured as one pulse or one rotation because only one hole means one rotation, one pulse represents one rotation and really if the size is small it may rotate at very few degrees only. So in limit it may be zero so zero measured is minus one, actual rotation zero so it is minus error so plus or minus here one rotation is the error.

Similarly if you have 4 holes so one fourth of the rotation will be the error. So as the number of holes increases error comes down, this is the advantage of having more number of holes. So that is the pulse counting method and next is we have DC and AC tachometer that is in a DC generator the voltage developed is proportional to the rotor speed. So the voltage output of the DC generator is calibrated in terms of rotation that is in terms of rpm. So it is then called a tachogenerator, that is simple.

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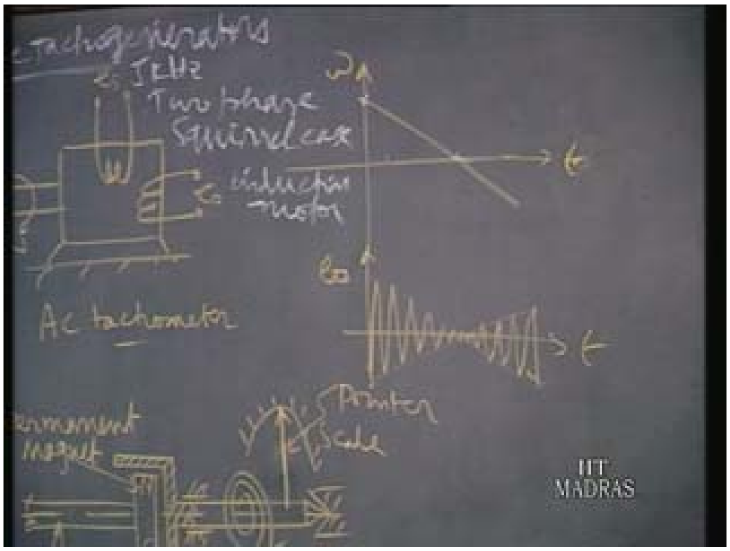

The ordinary DC generator is used to measure the rpm of the rotor; the voltage output we know is proportional to rpm of the rotor. So the voltage is calibrated in terms of rpm. Now in the AC tachogenerator what is done is, it is induction two phase squirrel cage induction motor that can be used for measuring speed. What is done is there are 2 coils at electrically 90 degrees and separate them out and in one of the coils you give the supply voltage say at particular frequency say 5 kilohertz for example and in the other winding you will get the output proportional to speed as per this diagram. Suppose omega varies starts at a high omega and falls to zero and rotates in the negative direction then in that case the e_o output from the other one will be modulated wave like this. So again if you have only one direction rotation we can simply use an AC voltmeter to give the magnitude of the rotation or rotating speed or if it is rotating in both the direction then you will get the direction by using a phase sensitive demodulator and low pass filter what we have learnt earlier.

So that is the AC tachogenerator, if it rotates on both directions anticlockwise and clockwise then the voltage output should be given to phase sensitive demodulator and so on that is AC tachogenerator. The last method is the eddy current tachometer which is used in all vehicles mostly used in vehicles say a scooter or lorries and all places they are using this principle and it gives the speed of vehicle, the driver can note at any instant while he drives what is the speed of the vehicle or bus. There what is done is from one of the four wheels through a flexible shaft the rotation is taken to a permanent magnet.

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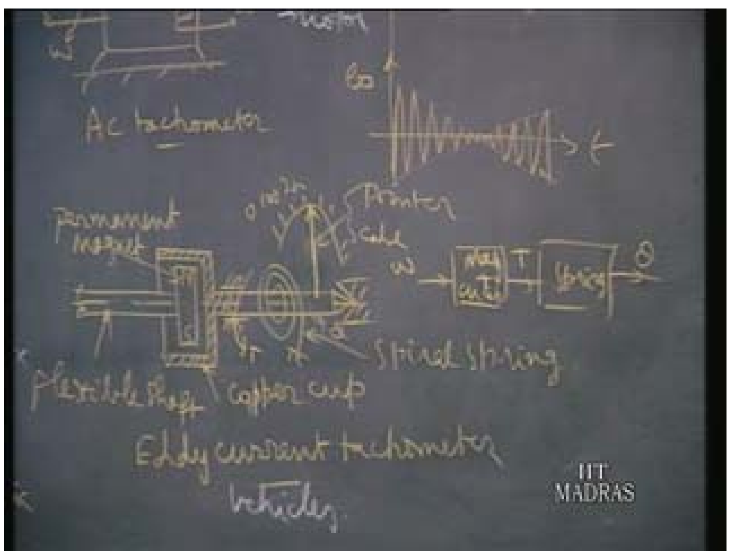

Permanent magnet is situated within a copper cup this is a copper cup actually you have to join this, it’s not open, this rim. It’s open but you will see the rim as per the drawings principle. So when it rotates the magnetic lines are cutting the copper cup so copper cup is a good container so electrical lines are there, so eddy currents are there and due to eddy current we have the magnetic lines that magnetic lines interact with the rotating magnetic lines we have got a torque. So torque is produced in the copper cup, this torque is absorbed by the spiral spring while it turns that is what we have the signal flow diagram is we have omega as the input signal that is given to the magnet plus the copper cup and then you have the torque. Torque is produce from omega, this torque is taken by the spiral spring and gives rise to an angular rotation theta, so theta will be the rotation in the shaft.

The shaft will be forming a part of the cup and when it rotates a pointer is attached to the shaft of this cup and we find the scale is just perpendicular to the board. So when the pointer rotates it moves over the scale which is calibrated in terms of earlier known speed, you can write 0, 100, 200 like that rpm and later on unknown speed you can just use it. So this is the principle of eddy current tachometer often used. Now since it is rpm if you multiply with the circumference of the tire then it will be kilometer per hour, you can use kilometer per hour that's how it is a calibrated.

Next we will see the acceleration measurement. So far we have seen displacement measurement, velocity measurement and now the last acceleration measurement. All these three forms part of motion measurement. So dv by dt is acceleration or d squared x by dt is acceleration and here also we are using the absolute seismic pickup for accelerations.

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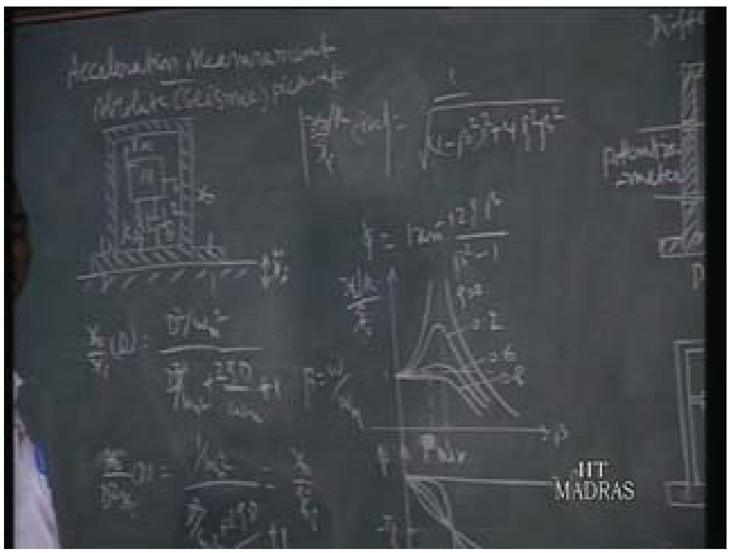

So we put the instrument, all seismic pickup as per the displacement as for the velocity, here also the whole instrument is put on the body whose acceleration we are measuring. So it is absolute measurement, so the same instrument what we have seen earlier mass, spring, K_s and damper it contains and it is fixed to the vibrating body, by bolted to vibrating body the same acceleration now we are measuring by x_o here that theory is obtained like this. We already derived x_0 by x_i difference in terms differential operator from the Newton's law we derived earlier for the displacement measurement, same equation I have written here.

Now bringing d square this side x_o by d squared x_i that is nothing but x_o by x_i two dot and calling K as 1 by omega_n squared then you will get as x_o by x_i two dot K and substituting d by i omega and finding out the magnitude for the frequency response you get this equation for the magnitude ratio x_o by k by x_i two dot and the phase difference will be pi is equal to tan minus 1 of 2 psi beta by beta square minus one where beta we know already omega by omega_n the frequency ratio. Now you find the right hand side of the these two equations is the same as what we have derived for the second order systems, frequency response of second order systems under dynamic response of say instruments we have learnt already.

So the same curves are plotted here x_o by K by x_i two dot and this is beta that is frequency ratio and same curve when omega, the resonant condition beta is equal to one resonant conditions, psi is equal to zero is infinity and for other values it attains peak value here. Now we know beta maximum for this bandwidth this is called the bandwidth, it is starting from beta is equal to zero to beta maximum that is say for 5% deviation this one is the ideal condition. So as beta increases it deviates so maximum deviations 5% error or 2% error accordingly we get beta maximum. So zero to beta maximum will be the error. So whatever the error you know we have to put it here, suppose 2% error means so psi is equal to 0.8 and 2% error means 0.98 you have to put and find out what is the beta value for a given psi is 0.8. We can find the beta value that is beta maximum that is how for any given error 2% error means the magnitude ratio will be 0.98.

Suppose psi is equal to 0.2 and error is 2% means for 0.2 the error is positive side so you have to put 1.02 here and then solve this equation. So for putting the magnitude ratio you should be careful by noting down the value of psi and accordingly take it. If the psi is less than say 0.7 you should put positive side or higher values it is negative. Its smaller values are negative so it should be less than one for smaller psi more than one you have to put error is positive, measured is more than the theoretical one. So that's how the bandwidth is fixed but now we find beta maximum suppose beta maximum is equal to say a given example may be beta maximum 0.8. That is omega maximum by omega_n is equal to 0.8 so omega maximum is equal to 0.8 times omega_n zero to omega where this is the bandwidth we want to have more bandwidth so omega_n should be more.

For having more omega_n, what is omega_n? Omega_n is equal to root of K_s by M this is what we have learnt earlier. So for having large omega_n we should have large spring constant so it is a hard spring. So for measuring the velocity and displacement by using seismic pickup we should have a shaft spring but for the acceleration measurement, instrument is same but this spring what we have to select should be a hard spring. That is the main difference in design of seismic pickup for displacement, velocity and acceleration. For acceleration purpose we should select a harder spring, for displacement and velocity measurement you should a have a soft spring. So this should be hard and mass to have a large omega_n mass should be small there that also possible. We can have smaller mass it will not give rise to any loading effect so generally the harder spring is selected.

So that is the bandwidth and phase difference we know as within the bandwidth for psi is equal to 0.6 or 0.8 more or linear. So this is what we can accept so this is the basic principle with which the acceleration measurement is made but making in this fashion it is little bit combustion. So you have got simplified versions of the accelerometer that actual construction actually available in the market accelerometers. They have this one of the constructions here that is first we are seeing the potentiometer type accelerometer just a mass suspended at both sides by springs and instead of having damper the volume is filled with silicon oil for damping purpose and the relative motion of the mass is measured by a potentiometer circuit. Here we have omega_n or f_n the natural frequency is around 100 hertz because there is some resistance for the wiper to move over the resistance it's part of the potentiometer circuit. So the relative motion is measured by potentiometer as an output voltage as you have learnt earlier how the potentiometer works. Instead of potentiometer we can also use LVDT so this point we give it to the core and the cylindrical constructions will be fixed to the casing and you can take the output. So this is LVDT either potentiometer or LVDT we can use to measure the relative motion of the mass with reference to the frame of the instrument.

If you use LVDT resistance for motion is small then the omega$_n$ goes up to 300 hertz, higher omega$_n$ means we have got higher band width that is the advantage. So another type is the cantilever type and here the x_i two dot is measuring direction is this one, here also it is this one x_i two dot measurement direction always in the instrument accelerometer they write the measurement direction. So for this type suppose it moves this way due to inertia it tries to an earlier, so it bends inertia force due to inertia force when it is accelerated it bends. When it bends then you will find a stress and strain are produced near about the fixed end of the cantilever and that strain is converted into an electrical signal by using strain gauges.

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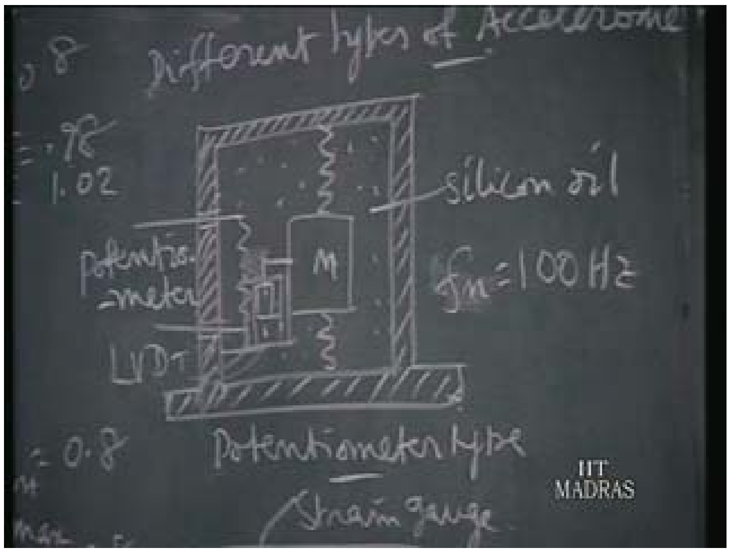

So Strain Gauge Bridge and all it will built, you can use carrier frequency amplifier which we have learnt already. Two strain gauges will be forming two adjacent terms of the bridge network and the whole instrumentation is same, carrier frequency of about oscillator, excitation, the modulated wave, amplified then demodulated and low pass filter and then the signal comes out. All those things we have learnt I am not repeating those things. So that a final reading will be calibrated in terms of accelerations. How it is calibrated? Suppose when we want to calibrate, suppose this is basic instrument put it on the table and then you will find g will be acting, g is the acceleration due to gravity.

So due to the g the mass is converted in terms of weight so this weight acts over this spring and deforms a distance and the distance is measured by the relative displacement pickup and the reading of the instrument, we write it as plus g and then now tilt the instrument just 90 degree you tilt it, now when it is fixed like this the g acts along the axis of the spring. This is the axis of the spring, the helical spring when it acts like this then it is plus g that is spring is being compressed.

Now tilt 90 degree then this spring will come in this direction and no force will be acting along the axis of the helical spring. So we will find a zero reading so it's zero, now tilt another 90 degree so it will fix upside down, this will be top and this will be bottom. That means the g will be acting opposite direction and we will have minus g that is how three readings are obtained in an accelerometer. You can check any accelerometer by mounting in these three ways.

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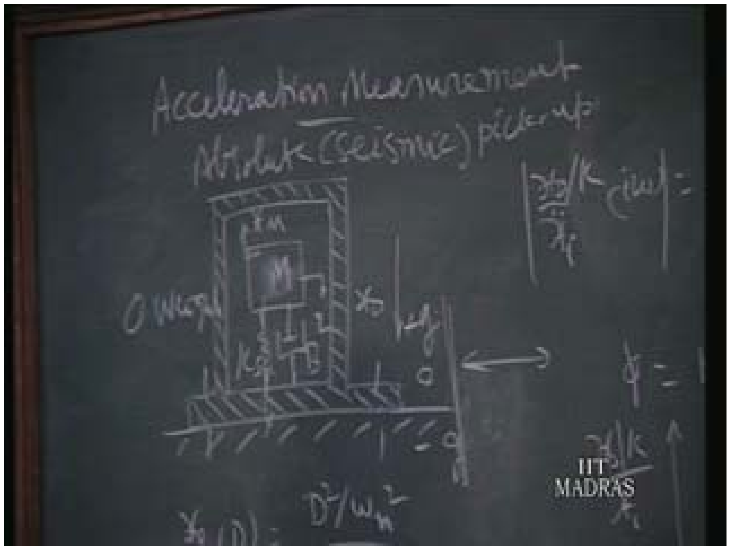

First as per the direction g along the measurement direction that you will have plus g and then tilt 90 degree zero, another 90 degree upside down that means minus g. So you can measure on both sides I mean plus g and minus g in both directions. So this calibration is mainly meant for horizontal motion when the motion takes place horizontal perpendicular to the g direction the calibration is valid. It is because when the motion is vertical, you have to be careful. In case it falls freely down what will happen. What is the weight of the mass, weight of any freely falling body has got zero weight. So when it is falling freely, acceleration is g but what is shown is zero. So for vertically downward motions what are the instruments shows you have to add 1 g, that you have to be careful.

If the motion is against g then you have to subtract 1 g so for vertical motion you have to be careful otherwise whatever we calibrated by using g that is valid for horizontal motion. When it is stationary it will be shown g, that is no motion it is g for vertical motions when we go up then it’s already one is there that we have to subtract. That’s why for falling down body we have to add 1 g and for moving up you have to subtract 1 g from the reading. Otherwise the calibration is valid for horizontal motion. So that is calibration that is how all these instrument are calibrated.

Now that is cantilever type, here we have got 300 hertz omega_n as we have, if you have LVDT whatever the same. Instead of LVDT we have strain gauge measurement. Now this type of construction is suitable for micro manufacturing, this type of construction is valid. We have got the mechatronic components the so called silicon accelerometer. So the whole accelerometer may be within few mm square it can be accommodated that is called micro manufacturing.

That is of type lithography or and all these photo etching principles are made use of. From silicon crystal itself the whole mass and the lever everything is made and the strain gauge also will be made up of silicon and that is amenable for the micro manufacturing, this construction rather than the other type. That is the specialty of this cantilever type manufacturing and another type is reluctance principle is made use of.

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So reluctance type of accelerometer. That is the resistance for the flow of magnetic lines that is made use of. Now the magnetic lines are created by the excitation winding, probably this can vary from 5 kilohertz to 20 kilohertz depending upon the frequency of the… Now this is the direction of motion for this x_i two dot, this mass is here and it is supported by the four leave springs, these are the four springs.

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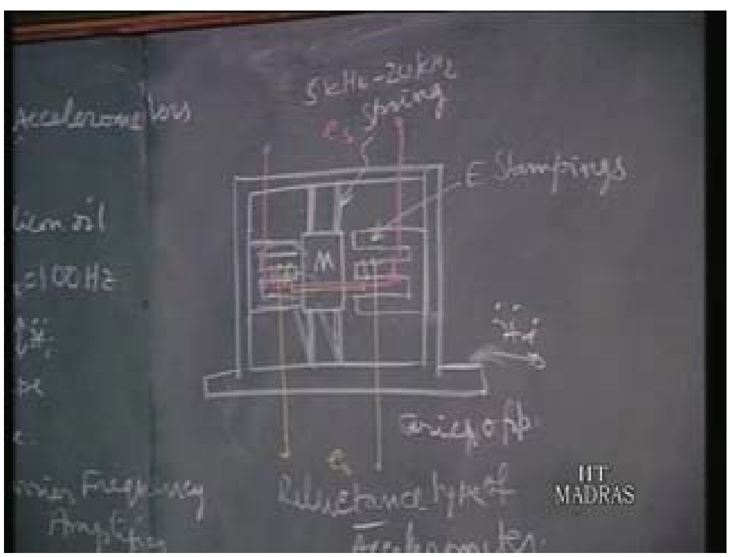

Suppose the acceleration in this direction then the mass tries to occupy the earlier position due to inertia force, so it will deform like this. The springs will be deforming like this that means the gap between the e stamping at the left hand side and the mass will reduce, this side gap will increase. So correspondingly you will find here we have got more number of lines created so magnetic path will be taking, this is iron, this also is made up of irons and e stamping is made up of iron.

So we will find in this number of magnetic lines will increase and to the same extent number of magnetic lines in this e stamping will reduce. So the two secondary coils are in series opposition so the voltage developed here and subtracted from the voltage developed here, net voltage comes here and this voltage is a modulated one. It will have the frequency same as around supply frequency and the amplitude of this signal will be proportional to the deflection here. So the deflection is proportional to our inertial force, inertial force is proportional to our acceleration hence we find e_o is proportional to the acceleration but it is a modulated signal, since acceleration take place in both the ways. This modulate signal you have to give it to phase sensitive demodulator and the low pass filter.

If you want you can use amplifier also and then low pass carrier I mean demodulator phase sensitive demodulator and then filter all those circuits will be there that I have not shown, we understand. That is something like LVDT also we are making measurement, afterwards the signal processing is known. So that is the reluctance type of accelerometer, the inductance principle is made use of.

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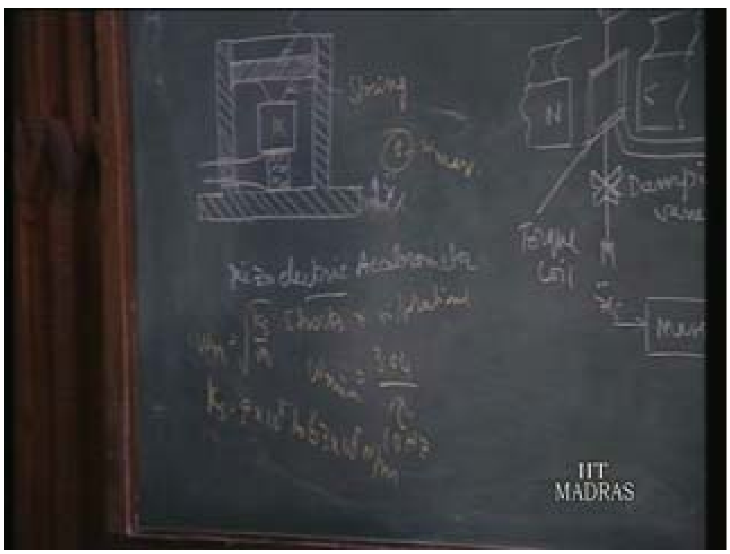

The next type of accelerometer is piezoelectric accelerometer which is very widely used in measuring shaft and vibrations because it has got very high undamped natural frequency. So it is widely used type of accelerometer where you find say mass is there. Now the relative measurement of mass we are using earlier types potentiometer LVDT and so on. The reluctance principle here we are using the piezoelectric crystals that is say for example quartz crystal is made use of to measure the displacement. We have learnt as one of the methods is using a quartz crystal that is what is used here for measuring the relative motion of the mass with reference to the frame of the seismic pickup.

There is one problem if we want to measure the acceleration in both the directions, the crystal can take only one direction stress, it can be only compress it cannot take any tensile load. To overcome that difficulty what is done is the crystal is always kept under compression by having a spring, this is a spring lee spring suitably bent and by tightening the nut, we can have different compression in the crystal.

Suppose motion is upwards then the compression is will increase and motion is downwards acceleration downwards, compression will reduce that's all. The crystal will never go into tensile strain that is advantage of initial compression. Initially compress it later on you can use for both directions, in one direction compression is increased, in another direction compression will reduce. So to facilitate that we have got this special set up with the spring and nut so it is initially assembled under compression. So now when it is subjected to any acceleration it produces a charge, the crystal and that is taken out and connected to a charge amplifier, the output can be read there. There is another draw another difficulty in this accelerometer. We know accelerometer it has got bandwidth from zero to some omega maximum that we know in all the other types of accelerometers what we have learnt earlier, potentiometer and cantilever type and all but here in piezoelectric accelerometer this static measurement is not possible. It is because we know the piezoelectric crystal for displacement measurement can be only for dynamic measurements.

That is omega minimum is equal to the same as the single capacitor principle 3.04 over tau this is what we have learnt already for a single capacitor displacement transducer. The tau is the time constant of that capacitor circuit or piezoelectric, we know it is metallic coating and from there it is taken. So in between we have got this insulating material so it's a typical capacitor. So same thing holds good so omega minimum should be is equal to 3.04 over tau, tau is the electronic circuit for this piezoelectric crystal that time constant tau. So it is sometimes omega minimum may be 10 hertz below 10 hertz you cannot use this instrument that is why it is used in measuring shocks. What is shock? Shock contains continuously varying accelerations, so varying acceleration up to this frequency that is minimum frequency it can measure below than that we cannot use this one and what is the higher range.

Here mostly you will find for the omega$_n$ the natural frequency of this is equal to root of K_s by M. That is generally the equation, now the M is the mass of the seismic mass but K_s the spring constant of the crystal is normally very high. It is of the order of 9 into that K_s, K_s for the piezoelectric crystal is 9 into 10 to the power of 8 to it varies 63 into 10 to the power of 8 Newton per meter. Such a high value it has got, so omega natural frequency is also very high. So it is of the order of 5 kilohertz this is a bandwidth. So it will be omega$_n$ will be still may be of this order but another problem what you have get is the psi is more or less zero. When it is psi zero in the earlier case you remember x_o by k divided by x_i two dot for psi is equal to zero, this is beta for this is one so psi is equal to zero it is going like this (Refer Slide Time: 39:50). This psi is equal to zero curve, so range is for 1% or 2% it immediately goes up, range is beta maximum, this should be a small value.

So you have to substitute in that equation this is x_o by k divided by x_i two dot is equal to one over root of one minus beta square whole square plus 4 psi square beta square, in that suppose you can permit an error of say 5% then you have to give 1.05, 5% because psi is equal to zero so this is zero then from this you will get a beta maximum for psi is equal to 0.5 you have got approximately 0.2. Beta maximum is 0.2, 5% error when psi is equal to zero beta maximum comes around 0.2 because this also 0.04 5% error only for a capacitor circuit or piezoelectric crystal. So for 5% 0.02 that means into omega$_n$ so the beta maximum may be 0.2 so that is equal to the omega maximum is equal to 0.2 into omega$_n$. Natural frequency is a high value and it gives rise a bandwidth with which we get a bandwidth of 10 hertz to 5 kilohertz. So it may be around say 25 it may be omega$_n$ may be 25 kilohertz so then it gives rises to 5 kilohertz, omega$_n$ is large will be 25 kilohertz. So even though we have got beta maximum B is of very small value 0.2 but still you have got measurements range of bandwidth very large it is because that omega$_n$ is very large.

So we can go up to 5 kilohertz whereas in the earlier cases omega$_n$ itself is of the order of 300 and 0.8 times equal to 240. So 240 hertz will be maximum hence they cannot be used for measurement of shock where acceleration is varying at very high frequencies, you cannot use it. So in such instances you have to go only for this piezoelectric accelerometer.

Next type is servo accelerometer so all these instruments up to here they are open loop systems, their accuracy is say plus or minus 1% of the full scale whereas if you want to have 0.1% accuracy or uncertainty then you should go for necessarily closed loop instruments and this servo accelerometer is one such closed loop accelerometer. Here the one type basic construction it is being sketched here so coil is there in between permanent magnet that is actually it's a torque coil it is called and that is mounted on 2 pivot bearings with its axis. To the axis we have got this mass which is attached to a lever connected to the axis of the coil and at the other end we had a plate which is moving in between two inductive pickups.

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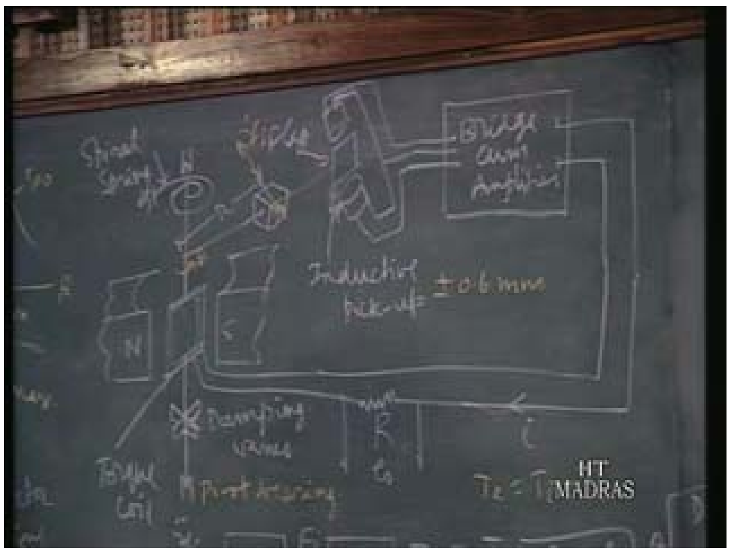

We know inductive pickups we can measure motion up to plus or minus 0.6 mm or plus or minus 1 mm. Actually they will be very close but I have drawn like this just for explanation purpose and to the whole axis we have connected spiral spring and the output of the displacement pickup this is a displacement pickup, inductive pickup given to the bridge network and then the current comes through a constant resistor, the voltage drop is taken as output signal and when i goes through the coil then this coil is put in between permanent magnet a torque is produced. So this is the construction, how it functions we can see in this signal flow diagram, the signal flow diagram of the servo accelerometer say when x_i is there when that is x_i is in this direction perpendicular to this of arm x_i two dot.

Suppose the x_i is towards stress then the inertial force will be there, trying to keep it in earlier position inertia force. So you have a torque, this inertia force is acting at a distance r from the axis of the coil then you will find a torque is produced. The inertial force due to this acceleration, inertial force is felt by the mass and that force is acting at a distance r gives rise to a torque T_i and this supported system. The coil and assembly is supported at the two pivots, this is pivot bearing bottom and top we have got pivot bearing so it can rotate about this axis.

So a torque is applied and there is another torque coming from the current flow that is called T_b when this torque is larger than this feedback torque then you will find that is the difference between the two torques is converted into an angular rotation theta by the spring. That is how the it is called T_e is equal to T_i minus T_b so difference between this torque is taken up and that is converted into the angular rotation theta and theta times this length of this lever gives a displacement in front of this two inductive pickups and when it moves then we we know how inductive pickups are functioning and it is amplified, it is a carrier frequency amplifier again. So the bridge output, the amplifier gives a current output of i. So then this i goes through the coil then a torque is produced in opposite direction trying to bring back the mass to its original position. So how much current required to bring it back, it is a measure of the torque acting on this that again of inertia mass, inertia force that again in terms of the accelerations.

So proportional to acceleration the current is maintained here so that this is always brought back or near about the original positions. Required current, it is a signal that current flowing through a constant resistor gives rise to a voltage drop e_o. So now e_o is our output signal x_o that is e_o is our output signal so input signal is x_i two dot and output signal is e_o. So it is a closed loop system, all advantages of the closed loop system is there. In open loop system if the temperature rise the spring constants will come down then it will show higher reading but to bring back also we require a smaller current that's why the error is eliminated in any closed loop systems. Hence closed loop systems are higher or generally more accurate than the open loop systems up to 0.1 or even less than that we can obtain depending upon the elements you have selected.