Principles of Mechanical Measurements

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Lecture No. # 15

Apart from the transducers using resistance, inductance, capacitance we have some more transducers for measurement of displacement.

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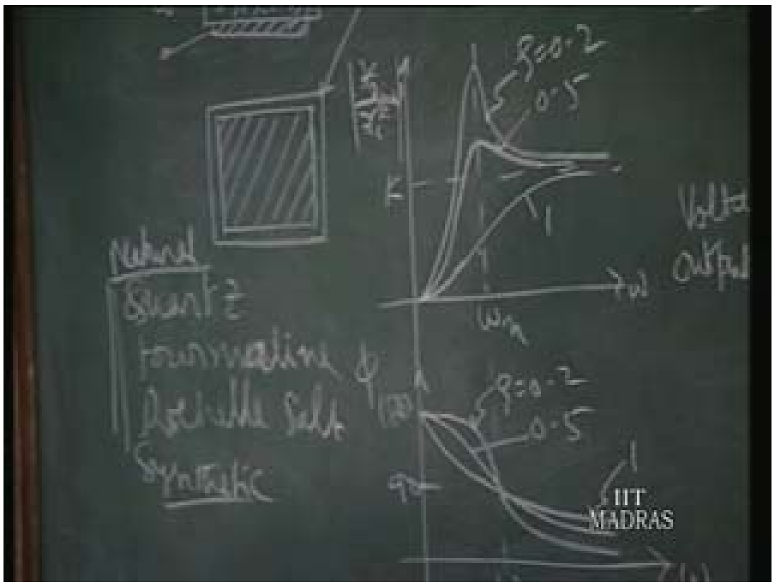

I am bringing under that three different transducers piezoelectric transducer and fiber optic displacement transducer and seismic absolute displacement transducers. Among various things these three are widely used and now regarding piezoelectric transducers we know that there are natural crystals, when we give vibrations they produce charge or when we give displacement to the crystal it produces a charge or voltage. Similarly if we give that is reversible action if you give a voltage, an AC voltage to the same frequency it vibrates. So this is the property what is made use of in the piezoelectric transducers we have crystals like quartz, tourmaline, Rochelle salt. These are the three natural crystals which exhibit this piezoelectric, it's called piezoelectric property and we have synthetic crystal also. These are natural crystals and synthetic crystals also are available which produces the same effect and some of them is lithium sulphate, ammonium dihydrogen phosphate and so on, some more crystals also available.

Among these three crystals the quartz is very often used, it is because it has got moderate vibrations and cheap and available also, whereas tourmaline we get very small vibrations but very strong and the Rochelle salt, it has got a very large amplitude of vibrations but very weak this is very weak and the tourmaline is strong but use very small amplitude of vibrations. So quartz is moderate vibrations and cheap and it's available hence you find wherever we go for piezoelectric crystals we select conveniently quartz crystal unless otherwise there is a demand for the other one.

For example the natural frequency of the crystal depends upon the thickness. Suppose this t is the thickness, the natural frequency say omega$_n$ is equal to K by t were K is a factor decided by the cut of the crystals. For example quartz crystal you have got, it's a hexagonal prism so it is somewhat like this hexagonal pyramidal structures so this is the axis of the crystal and now in making a slab the transducer is made in terms of slab. You can cut slab either here or in any directions it's called say it is a y cut. This is x cut and xy cut like that they make slabs and with reference to geometric axis or optical axis they cut a different slabs and depending upon the cut its characteristics also varies. Suppose say if it is an x cut then it will respond to the compression say here displacement we are giving it may respond to that.

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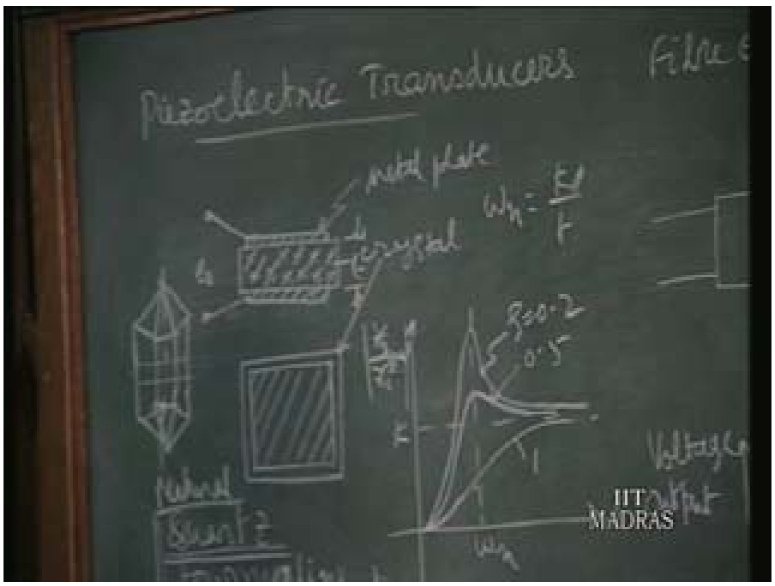

So if it is a y cut probably it will respond to shear only, the compression will not give any signal. So like that depending upon the cut the crystal behaves and when we give AC signal for this, now the transducer is made like this. The top surface and bottom surface are metallic coated and we can give our supply and you find at the natural frequency of the crystal then the whole circuit will draw the maximum current. So whatever the frequency at which the maximum current flows through the circuit at same time vibrating this, that is the natural frequency of the crystal. Now the natural frequency is again given by K depending upon the type of cut, it is a constant given by the manufacturer divided by the thickness. So when we want a higher natural frequency so up to 10 megahertz you can go for the quartz crystal. If you want more than 10 megahertz natural frequency then the thickness becomes too small for a very high natural frequency thickness becomes too small then under vibrating conditions this quartz crystal fails.

In order to avoid this is done is tourmaline since it is a strongest among the available crystals that is selected for higher than 10 megahertz natural frequency tourmaline is selected though it gives rise to smaller amplitude of vibrations. But the crystal is cut like this and with metallic coating on two surfaces we can take away the charge developed in the crystal. Our displacement signal is given by compressing, this is d to the extent it compress then you will get the output voltage that is your displacement is transduced into a voltage that is what we want to achieve here.

You find how this behaves this, now we have got metallic plate and in between crystal which is a non-conducting material it's a good dielectric material. So essentially it constitutes two parallel plates with a dielectric medium that means it is a parallel plate capacitor. So it behaves like a parallel plate capacitor whose property we have found yesterday. In a simple circuit with one capacitor in series with a resistance then across the resistance we take the output, that output we find it is there only for the dynamic signal. For static displacement this charge will be zero as per the pervious class, this single capacitor responds only for a dynamic signal. So the displacement what we give should be of changing magnitude that is it should have certain frequency as per our derivation yesterday, the minimum frequency should be 3.04 over tau where tau is the time constant of the circuit and beyond that frequency alone you will get the charge here that is the limitations. Otherwise this is crystal also is made use of for transducing displacement into a voltage. Now the next one but what we want to see is fiber optic displacement transducer.

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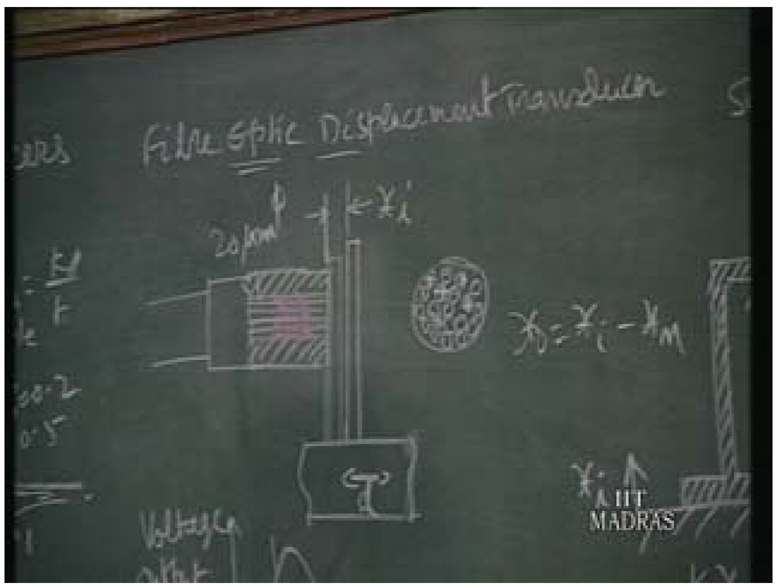

It has got some special advantage in the sense here we don't carry any voltages, only the light is taken through fiber optic, each fiber is of the order of 20 micrometer diameter and you will have hundreds of fibers in a bundle. This is a cable through a cable it will be taken to an instrument where there is a photo detector and the associative instrumentation, where you will have the reading amount of light reflected will be taken and shown as the reading there. Suppose we want to measure a displacement d of a machine number, you attach a flag like this and then this is a probe tip, it is fixed there. So with reference to the probe tip, this plate will be moving to and fro this is a fixed surface against this. What is happening? Half of the number of, now it will be if you see in the end view this bundle you will find the glass fibers glass fibers will be arranged in this fashion and you will find half of them will be bringing light towards the target and half of them will be carrying the reflected light. Suppose when we say the x_i zero or the displacement zero that means it is budding against the probe tip, suppose it is budding no gap is there x_i is zero. In that situation the incoming light is not I mean is not reflected anymore.

So when there is no reflection the pickup fibers will not take up any light and that means the photo detector inside the instrument will not receive any light then you will find the voltage output of the instrument is zero. When x_i is zero voltage output is zero. Now as this moves away from this point the light carrying fibers we find the light beam travels in so to say with a conical fashion and you will find depending upon the distance the area, this is the area of reflection. The area of reflection depends upon the distance from this tip end, the more distance means bigger area because the light will be dispersing like this. So depending upon the area reflected light also increases so as x_i increases from zero, you find reflected light is increased and hence the pickup fiber picks more light and that goes to the photo detector, more light comes more voltage will be produced but that is only up to a particular distance. Later on what will happen the other light lost to the atmosphere becomes more and more, you will find the voltage output of the instrument starts dropping down.

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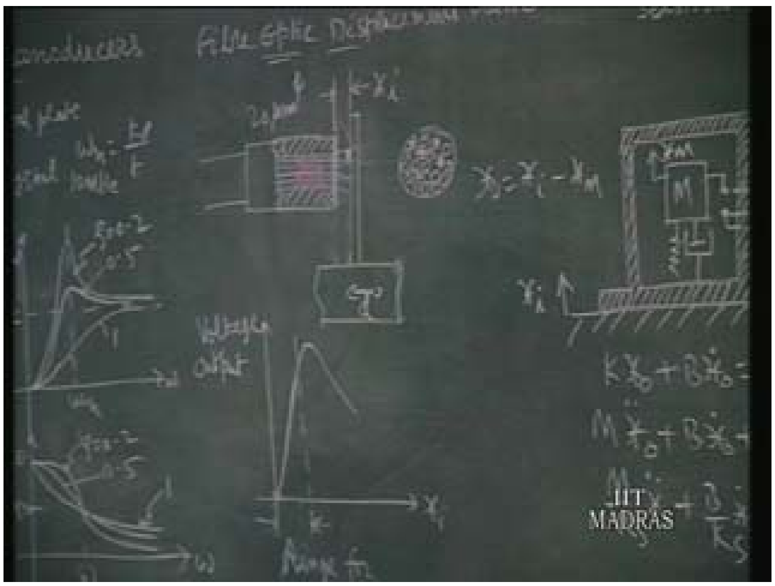

So you find for a particular distance you can measure that is how this is a linear range in which the instrument can be made use of, say from zero to 1 mm or zero to 4 mm, up to 4 mm such fiber optic displacement transducer is available. The main advantage is even if we have the power line nearby 50 hertz; it will not induce any error. That was the case in earlier instrumentation wherever we have a wire carrying signal, in that wire the nearby power line also induces voltage that will be superimposed over the signal so it becomes noise. Such a noise cannot present in such type of instrumentations, it is free from such a magnetic disturbances. Since it is light rays passing through they are not affected that is the main advantage.

Second advantage is it’s a non-contact type of transducer so the measuring instrument doesn’t touch the moving member. Hence you find no loading effect in such an instrumentation. That is a main advantage of fiber optic displacement transducer; many American firms are making this type of transducers. Lastly we are going to see under this topic displaced measurement, seismic absolute displacement pickup.

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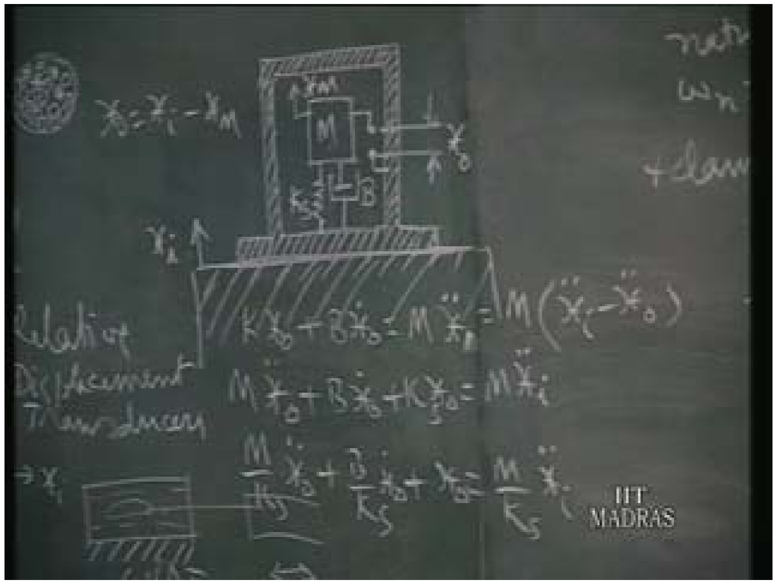

Now it is unique in the sense so far what you have learnt, all the transducers they are called relative displacement transducers. That is if you consider an LVDT, LVDT is a tubular construction there we have your core and now you find the core is given to the machine member whichever is moving to and fro at the cylindrical portion fixed to the ground to the frame, it will not move. So relative to this that is one of the two members of this transducer fixed to the frame the other member is connected to the moving one. So it's a relative to one member, the other member is core that motion is measured by this transducer that is our LVDT or in any other transducers in self-inductance pick up also the coils are fixed and the flag is moving. Flag and the coils constituting transducer, one part is fixed other part is moving but here the main difference is the whole instrument is fixed to the body. This is the body suppose this may be the body which is moving, this may be a table moving up and down.

So this is the instrument, as this seismic is something to do with mass. So this is the whole instrument is mounted over the moving body in contrast to making a part of it fixed, part of it moving that is not there that is why it is called absolute displacement. Since the whole instrument is fixed on the whole vibrating or moving body. What is a construction? As per the name seismic we have a mass and the mass is supported by a spring with a spring constant K_s and a damper with a damping coefficient B, damping coefficient is Newton per unit velocity that is Newton per meter per second. So here it is spring constant that Newton per millimeter or Newton per meter this is kilogram and it is the one end of the spring is fixed to the mass, other end to the frame of the instrument and the cylindrical portion to the frame and the pistol portion to the mass and this is the frame of the instrument.

Now you find the whole instrument is fixed to the moving body whose displacement we are interested to measure. Now the theory of function is like this, this is a construction. Theory of functioning is, suppose the body is moving up, this is the direction in which. So for any displacement x_i there should be an acceleration also for the motion and the mass also getting accelerated.

Whatever the motion we give this also gets accelerated, to accelerate any mass we require a force for this mass M that force can come to the mass only through the spring and the damper. Now when the vibrating body moves through a distance of x_i, the mass moves through a distance of xM, x capital M and there may be difference between x and xM that is what is known as x_o output motion of the mass. So the difference between these two x_i minus xM that is appearing as a relative displacement between the mass and the frame of the instrument that is x_o so the x_o is equal to x_i minus xM. Now the relative motion between the mass and the frame that is the compression part or elongation in the spring, so spring constant times the x_o will be the force flowing through the spring.

Similarly corresponding to x_o we have x_o dot velocity so x_o dot times B because B is Newton per unit velocity. Now velocity is x_o dot so B into x_o dot so these are the two forces transmitted to the mass. So K into x_o plus B into x_o dot is the force accelerating the mass M that is M into xM two dot xM is the motion of the mass so this is the basic equation using Newton's law of motion. Now xM we know xM is equal to x_i minus x_o so write M into x_i to dot minus x_o two dot, arranging all x_o terms to one side M x_o two dot plus B x_o dot plus K_s x_o is equal M x_i two dot and dividing whole thing by K_s the coefficient of x_o we have got this equation and now substituting the undamped natural frequency.

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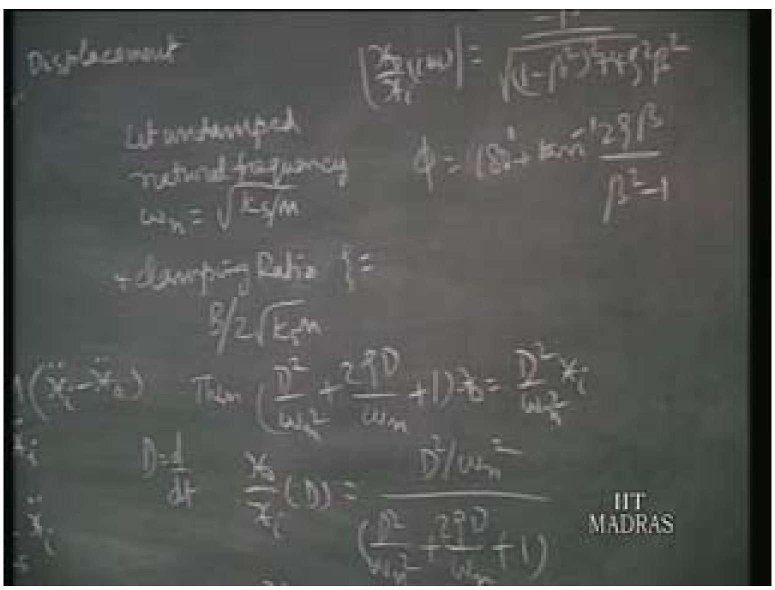

Undamped natural frequency omega$_n$ is equal to root of K_s by M where K_s is the spring constant and M is the mass of the body and damping ratio now it's not damping coefficient it is damping coefficient is d damping ratio. Let damping ratio be psi is equal to B by two into root of K_s into M, these are two constants and D is the differential operator we know already, D is equal to d by dt. Then substituting these terms in this equation we arrive at this equation D squared by omega$_n$ squared plus 2 psi D omega$_n$ plus 1 into x_o is equal to D squared by omega$_n$ squared into x_i. Now arranging these terms x_o by x_i in terms differential operator D you receive this equation D squared omega$_n$ squared and so on.

Now to find the frequency response of this setup substitute D by i omega, D is equal to i omega that is our standard method of finding frequency response. So by i omega putting it, so minus i omega square whole square is equal to minus one so you have got this equation. Now the magnitude of this, this is a complex number so magnitude of this equation is equal to minus beta square minus you can forget also because it is a magnitude, a root of 1 minus beta square whole square plus 4 psi square into beta squared and the phase difference phi is equal to this minus term will give rise to 180 degree plus tan minus 1 of 2 psi beta by beta square minus 1, these are two equations arrived from these differential equations.

Now how the magnitude ratio varies? How the phase difference varies? Plot this for different values of psi now here beta is equal to omega by $omega_n$ that is frequency ratio, frequency of vibration of the body of the table to the natural frequency of the instrument root of K_s ,they are made up of a spring constant and the mass. So that is of frequency ratio beta is equal to omega by $omega_n$. Now plotting those two equations magnitude ratio and phase difference you are getting these two curves, these two curves. You can also plot versus beta also the ratio then it becomes one. Now we find this will be one, beta is the ratio so that is resonant condition omega by $omega_n$ is equal to one so this one here. Now you will find when psi is equal to zero or psi is equal to 0.2 we have got; anyhow from that equation one can find when beta is zero you find the whole thing is zero, the magnitude ratio is zero.

So you find when beta is zero, omega is zero that is static displacement. If you give any static displacement stop there. You don't get any output x_o will be zero for any static input of x_i. That is what we understand that is when beta is equal to zero means you don't get any output from here and the ideal condition is we get a x_o as x_i that is as one that is around one you will have only from this beta, this is your beta minimum for measurable range, from should be around one. So you find initially zero but later on as the beta increases, it increases and when psi is small value you have got some oscillations, some peak value and then against stabilizes towards one. One is the ideal condition for a beta minimum or for larger value of beta only we have got the measurement that means the instrument can function only when the measurement can be made only when beta is greater or equal to beta minimum.

Now beta minimum may be say here if it is one, beta minimum may be 2.5 that means omega minimum is equal to 2.5 times $omega_n$. Beta is omega by $omega_n$ so omega minimum is equal to 2.5 times $omega_n$ that is natural frequency 2.5 time natural frequency of systems then only the measurement range starts. What is the physical explanation? That is omega is the vibrations at which the input signal is vibrating or moving and when I say at only very high frequencies only we can measure the input displacement. That means when the frequency is too high what happens the mass becomes more or less static. It is not able to follow the motions; it is because frequency is very high it is not able to move. so it becomes more or less static say xM becomes static that means xM is zero, it is unable to follow the vibrations it is more or less become static in space. When xM is equal to zero then we find x_o is equal to x_i at that time we find whatever it is x_o it becomes x_i that is the physical explanation for this functioning of seismic pickup for displacement measurement. So now $omega_{min}$ is we have found $omega_{min}$ is 2.5 n so $omega_{min}$ we want to have say 2.5 times $omega_n$.

If we want to have a smaller value for $omega_{min}$ because we would like to measure from lower frequency onwards then $omega_n$ should be minimum it should be a smaller value. What is $omega_n$? We know $omega_n$ is made up of root of K_s by M we want this smaller valve so that we can get a smaller $omega_{min}$ then either M is large, either you make the mass of the body inside instrument large or you make a soft spring, both the methods will lead to a smaller $omega_n$. So to make $omega_n$ either go for soft spring or large mass. What is the disadvantage of having a large mass here? This may give rise to loading effect but the amplitude of vibration may be dampened. So this is not preferable hence go for a softer spring. By having a softer spring you have a smaller $omega_n$ by having smaller $omega_n$ you have got smaller value for $omega_{min}$ so that you can use this instrumentation at lower frequency of vibration itself. This brings to the close the different transducers used for displacement measurement. At the end let us see a worked out problem.

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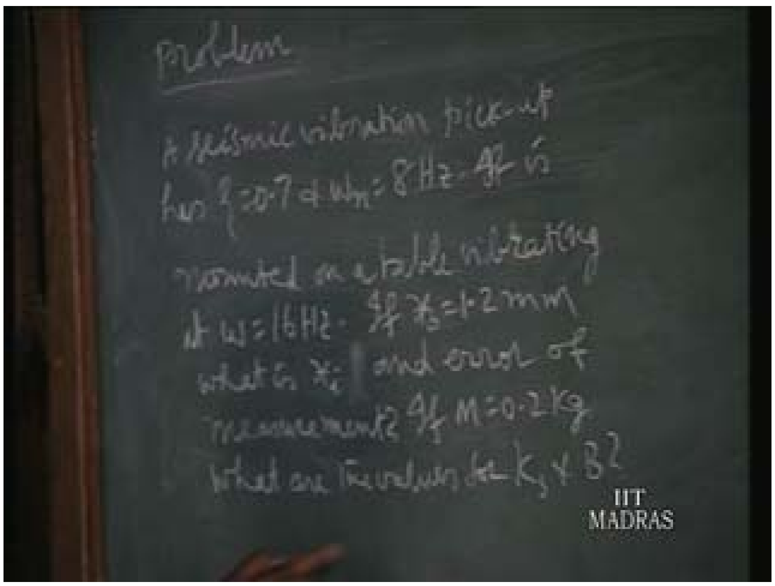

So it is like this, a seismic vibration pickup has damping ratio 0.7 and the undamped natural frequency as 8 hertz. It is mounted on a table vibrating at a frequency of 16 hertz. If the measured displacement x_o is 1.2 mm what is the amplitude of vibration of the table that is x_i and the error of measurement. What is the error of measurement? That is one part of the problem, second part is if the mass of the seismic instrument is 0.2 kilogram what are the values for the spring constant and the damping coefficient? So naturally the approach for this is what is the ratio of displacement measurement x_i and x_o that is our ratio of the displacements that's magnitude ratio for the differential equation. That is equal to beta square root of 1 minus beta squared whole squared plus 4 psi squared beta square that is the magnitude ratio of the displacements of x_o to x_i.

Now here beta is given as 2, the omega by $omega_n$; omega is 16, $omega_n$ is 8 so beta is equal to 2 and psi is given as 0.7. So substitute for beta and psi then you will get this value here as 0.975. So now x_o is given, x_o is 1.2 by x_i is equal to 0.975 giving rise to x_i is equal to 1.231 millimeter that is 1.2 millimeter x_o, so x_i the amplitude of vibration of table happens to be 1.213.

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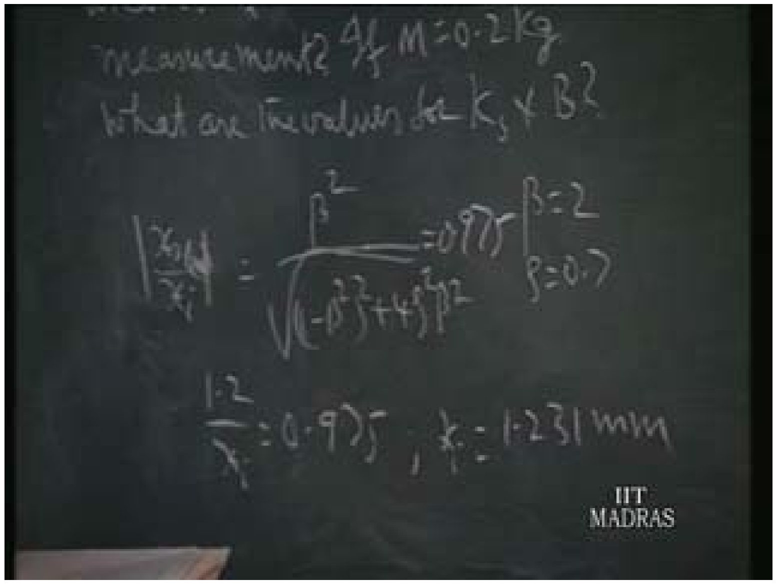

Now then what is the error of measurement? Definition of error is measured value minus theoretically value by theoretically value. So error is equal to measured value is 1.2 mm, theoretical value is 1.231 by theoretically value 1.231 into 100 percentage of error so this comes about minus 2.52 % so this is the error of measurement.

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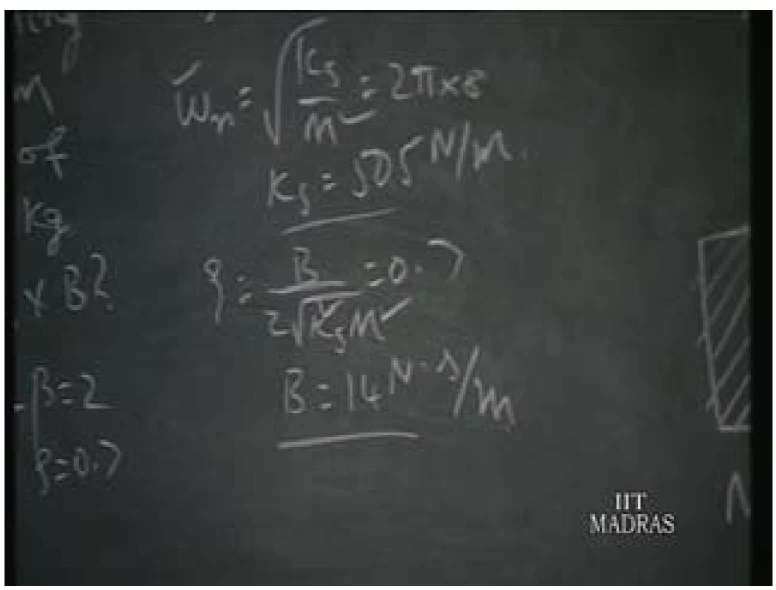

So we see within allowable limit we are able to measure, by having this seismic absolute displacement measurement provided the vibration frequency is much larger than the natural frequency. Here it is 2 so it is giving within that error zone. So plus or minus 3 is acceptable so -2.52 since vibrating frequency is large then x_o becomes more or less same as x_i.

That’s what we have demonstrated which we saw previously. Physically we saw that it should happen like that so it’s a demonstration. Now the mass of the body within the instrument is given as 0.2 kilogram whatever the other things, we can easily find out by using the equation omega$_n$ is equal to root of K_s by M. Now M is given, omega$_n$ is 8 hertz, 8 hertz is equal to 2 phi into 8 radians per second so M is given so K_s you are getting it simply in the equation you substitute, so K_s becomes 505 Newton per meter and now we know the damping ratio psi is equal to B by 2 into root of K_s into M. Now psi is given as 0.7, K_s we already found out, M we know already 0.2, so B is equal to 14 Newton per meter per second, 14 Newton per unit velocity meter per second so second comes up, so these are the value. So that is how we demonstrate the principle of function of absolute seismic displacement pickup that is only worth concept we demonstrated.

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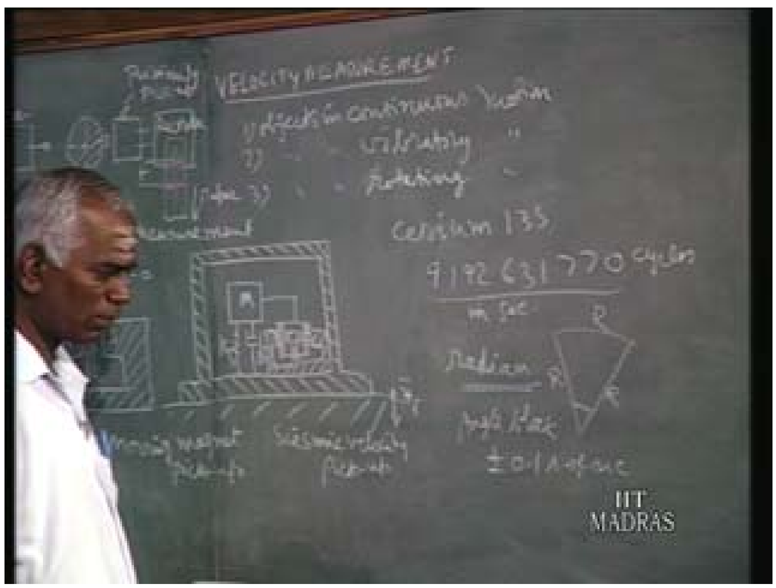

Now we move on to the next topic, we have completed the displacement measurement. Next we go to velocity measurement now velocity we know there are two quantities involved, one is length another is time because velocity is meter per second. For meter we know and for making any measurements we need a standard without standard we cannot assign a number to the parameter. So for displacement that unit is based on which we are going to assign number is meter. So for meter we have already unit but now the time unit meter per second so what is the principle of the unit for time. Second is the basic unit. So in terms of second we assign number for duration.

Now the latest definition for second is the so many cycles of automatic resonant frequency of cesium 133 when it resonates at its resonant atomic resonate frequency. Then so many cycles occurs in one second 192631770, so many cycles so after radiations comes in one second, say in one second so many cycles come. So that means 10 figures are there or 10 to power of 10. So that means if you can have one cycle one over 10 to power of 10 of part of your second itself can be measured. That is the beauty of this one, so one in 10 to the power of 10 parts of a second can be measured by, we have a cesium 133 and this cycle.

Anyhow the standard for the second is the second is duration in which so many cycles of atomic resonant frequency comes out of cesium 133 that is the basis for the second. Now the time is in terms of seconds we can measure, that is second is the unit. Later on I mean multiplication of second, minutes and hours are there for longer durations. So these are the units for the velocity measurements, meter we know but velocity is measured not only for a linear motion but also rotary motions, velocity that is so many rpm like that we are measuring. For that what is rotary motion? Rotary motion is angular so many angles or so many rotations. Now angle is made up of again and unit for angle is radian. Radian is not an independent quantity but it is a derived unit, a radian is one which is suspended by an arc equal in length to the radius.

This is radius and this also should be radius whatever is subtended. So you find it is all length units, radian is made up of length units but we have or angle blocks so called angle blocks available in metrology lab. So for definite angles 10 degrees, 5 degrees, 10 degrees and so on with an accuracy of plus or minus 0.1 second of arc it is available because one degree and one degree is made up of 60 minute of arc and each minute of arc is made up of 60 second of arc. So you have got up to 0.1 second of arc accuracy angle blocks are there so you can build number of angle blocks to obtain any angular rotations or any angular positions.

For any angle you can stack the angle blocks and get that angle required angle within this accuracy. So with that we have the basis for the angular motion also though it is in terms of length but we have got angle block themselves for giving the standards. So these are the standards for velocity which is made up of either length or angle and second also we have seen so the unit for the velocity measurement is there. Now the velocity measurement is done under three circumstances. The object may be in continuous motion and that time also we are supposed to measure velocity just like vehicle on roads vehicle on roads, we are interested to measure the velocity at what speed we are traveling in our scooter or car or train we are interested that velocity also is to be measured and there are also instances that is continuous motion.

First is continuous motion and second category is vibratory motion for example a piston motion inside a cylinder. This may be a hydraulic cylinder we give the pressure oil and the pressure goes out. When you supply pressure oil it moves from one end to the other end and then later on we give a supply here and this output so we switch on by using a directional valve, you can switch on the supply here or thereby making the piston move to and fro within the cylinder. That is called a reciprocating motions or vibratory motions and at the two ends the velocity is zero, here it is zero here also zero, in between it attains a maximum velocity.

So this is variation of velocity for a vibratory motion, at the two ends velocity is zero but in between it will be varying continuously. Whereas in continuous motion vehicle moves for a long durations at a constant speed or variable speeds and the third category is rotating speed. An article rotates about an axis that velocity also we are interested to measure. So these are the three circumstances in which you are asked measure velocity, continuous motion, vibratory motion and rotating motion. Now for a measurement of continuous motion we have got different principles and say one for continuous motion.

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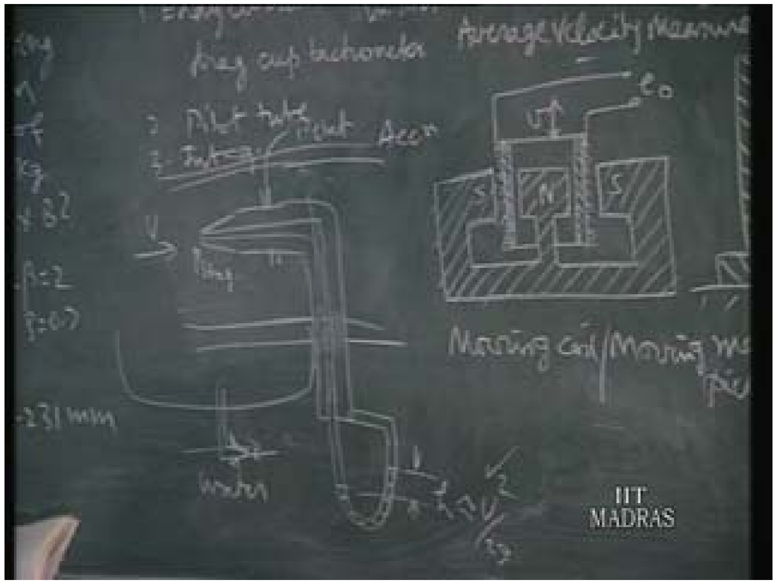

So first we have got an eddy current drag up tachometer it’s an instrument which measures essentially the rotating speed of one of the wheels of the vehicle say scooter or car it measures the rotating speed. The details you will learn little later under rotating measurement and rotating speed times the wheel circumference is the linear velocity. So it is converted in terms of kilometer per hour this is essentially a rotation measuring instruments with which it is calibrated in terms of kilometer per hour by considering the circumference of a wheel. Then second we have got the Pitot tube for the vehicles so aeroplane as well as the ships on sea also we can use Pitot tube. You know pitot tube is used in pipes to measure the velocity of fluid in a pipe line so this is a pipe line where it is fixed, this is pitot tube you take this is your p stagnant pressure and we have got the static pressure, this is p static they are connected to a manometer tube and the difference between the column in the manometer say h, this is proportional to v square, v is the velocity of the fluid.

This is the Pitot tube principle which we will learn detailed in flow measurement but the same thing is put in a ship like this; this will be projecting like this. So you find now ship is moving so to say in a pipe pitot tube is stationary, fluid is moving when we fix to a pipe the pitot tube is moving over the stationary water, this is sea water stationary water it moves. So this is reverse of this condition, instead of fluid moving here Pitot tube moves, the other one is stationary giving rise to same effect. So at the tip we will have both static pressure times velocity head and the static pressure measured a perpendicular directions and a difference between these two things as h which is here probably you can have mercury that this head is proportional to v squared over 2 g. So from there we find out the velocity that is the velocity with this the ship moves. You know this is by using pitot tube and third method is we have got the accelerometers. You can also mount an accelerometer in a ship so when it measures the acceleration of the ship, integrate that then it gives rise to the velocity. So by measuring the acceleration, integrating that acceleration you get the velocity also for the ship. This is third method integrating acceleration measurement. Fourth method is Doppler effect this is what the traffic police will use this effect to find out the velocity of any racing vehicle on a road.

Suppose on a road the maximum speed is fixed there say 30 kilometer per hour if any vehicle travels more than that speed then police staff will stop the vehicle and fine it. So for that purpose they use the Doppler Effect that means they have a source of light or sound for directing it towards the moving vehicle and the reflected light, they reflect light or sound they pick up and it is processed inside because the reflected sound or light will have the information of the velocity of the moving body. From that they find out the velocity of the vehicle and then if it is more than the permitted value then they fine the driver whatever it is. So these are the four different methods which are used nowadays to find the velocity of a continuously moving vehicle. That is in brief now we go to the next one that is objects in vibratory motions, there we have few methods.

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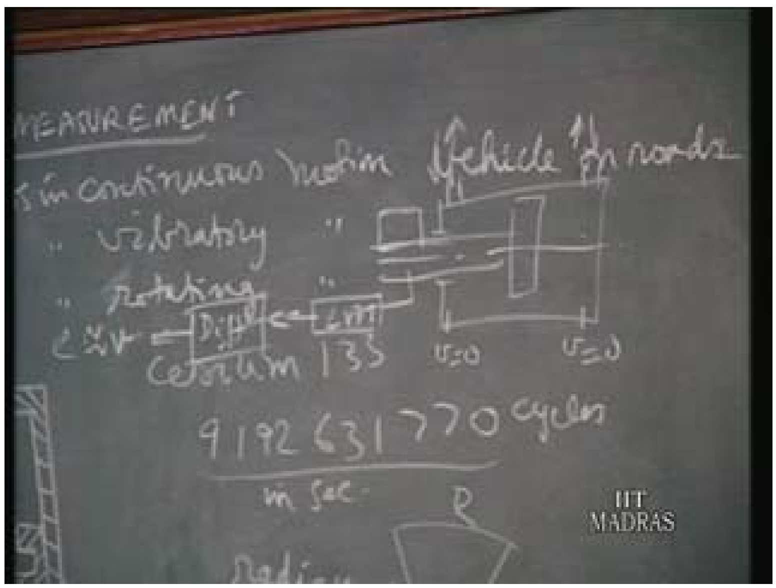

First method is suppose this body is there, the piston is moving within the cylinder and you can connect an LVDT for example this is an LVDT. To measure the displacement at any instance of the piston and then you give it to a differentiator and you get a velocity e proportional to velocity v. So by measuring the displacement by a displacement transducer and differentiating it we get the output voltage proportional to velocity. This is one method differentiation or we can also integrate by mounting an accelerometer on this moving body then integrating the acceleration we get the velocity.

So you can adopt any one of these two but the problem with a differentiation is we know from LVDT the output voltage will have some ripples, 5% ripples because that signal comes out of the low pass filter. That ripple when it is differentiated gives rise to peaks called noise in the velocity measurement whereas in integration of acceleration such noise will not be there. Hence integrating an acceleration measurement is suitable than the differentiating a displacement measurement, so that is one method. Second method is we can find the average velocity probably we are not interested from point to point what is velocity.

So we can measure for this whole travel but in two points whatever be the average velocity we can measure and for that we can go for a measurement like this and the moving body you fix it to iron strip and have in front a proximity pickup. So whenever the iron piece moves in front of the proximity pickup if you connect the proximity pickup to a recorder switch or recorder you will have two voltages because when IMP comes near the proximity pickup you have pulse impulse is produced. Voltage pulse is produced that is being recorded and the time between the two pulses is t and the distances between the two strips are d then the velocity is equal to d by t. So this is average velocity in many instances it is sufficient to find out the effect of roughness on the velocity or the supply pressure of the velocity, we can use go for an average pressure. Whenever we don't require instantaneous pressure this average pressure measurement is sufficient.

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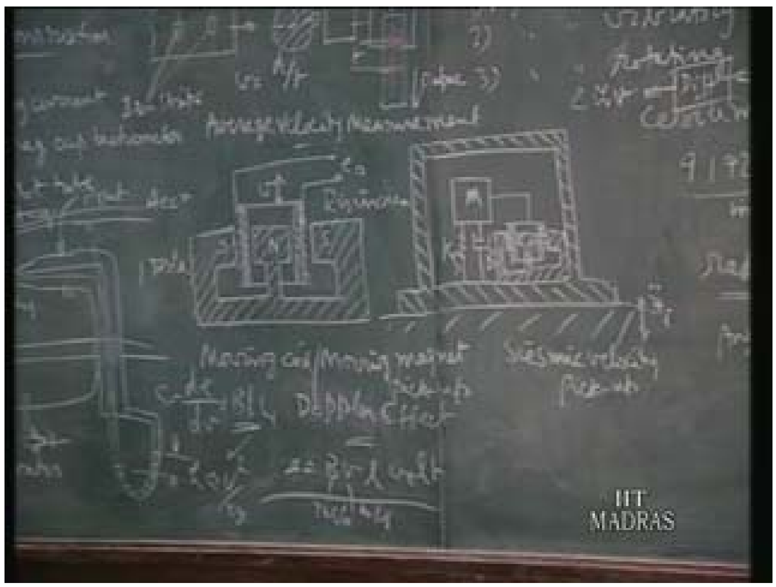

Then next method is moving coil, moving magnet pickup, it is widely used here you find voltage developed e is equal to b v l volt where b is the flux density of this permanent magnet in tesla, this is in tesla and v is the velocity of, we can have either coil may be moving. You can connect a moving member to the coil or to the magnet, anyone can be connected to the body and now the relative velocity between the coil and the magnet is important that is v that is meter per second and l is the length of the wire in meter then we find the voltage developed is volt. So by this method we can find out the velocity of the moving body. What is sensitivity of this measurement? This is output voltage, input is v so de by dv is the sensitivity that is equal to B into L that is the flux density times the length of the wire. So to increase sensitivity you can increase any one of these two things, so the flux density is developed depending upon the material you have selected for the magnet. So that you can have maximum one tesla that is available by having proper selection of the material and length should be very large. If length is very large what happens, the weight of the coil increases. Suppose you have connected the coil to the moving body then it becomes a loading effect, the velocity may be dampened. So to reduce L and having I mean we want to have smaller mass, for a given mass we want to have larger length then reduce the cross section of the wire and have a longer length.

So when you reduce a cross section the R is increased, resistance of the wire is increased because R is equal to row L by A, A is in the denominator so R is increased. So to measure the voltage you require a voltmeter of very high input resistance that is a draw back. So you cannot increase sensitivity as it is there is a limit. Otherwise this is the method what is very often used in measuring velocity in respirating bodies. Moving coil moving magnet pickup it is simple principle, voltage developed is given by flux density time's relative velocity of the coil with reference to magnet into length of the wire. So as the coil moves up and down it cuts the magnetic lines, so voltage is produced proportional to the relative velocity of the coil to magnet. So the other method is seismic velocity pickup. It is same construction as the absolute seismic displacement pickup; it is similar except we had a relative displacement we were measuring earlier. Now we have to measure the relative velocity, it is obtained by having this equation like this.

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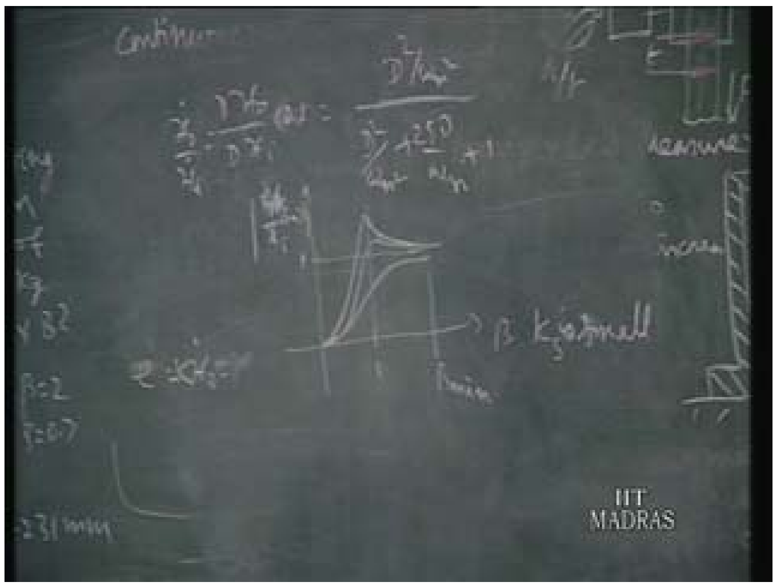

So we have already derived x_o by x_i i omega is equal to d squared over, we will say d, d squared over omega$_n$ squared by d squared over omega$_n$ squared plus 2 psi d by omega$_n$ plus one we already derived for the displacement, same thing for mass here also it will give rise to. Now for velocity add d on both sides then it becomes x_o dot to x_i dot same thing it remains same, right hand side remains the same. Now this we know the curve for this right hand side that is what we had beta as beta this is one. This is x_o dot by x_i dot i omega that is magnitude, now we know it starts somewhat like this. So suppose this is the one it comes like this. So same curve what we had seen for an absolute displace measurement that means the measurement range starts from beta minimum same considerations so only when more than beta minimum then only it can measure the input velocity in terms of output velocity so we are measuring output velocity that is the relative motion of mass with reference to frame that velocity is measured. Relative velocity of the mass with reference to frame or the instrument is measured as x_o dot. So for measuring x_o dot I have used here the moving coil stroke moving magnet pickup we have used. Here coil is connected to the mass.

So relative motion of this mass with reference to the frame because this magnet is fixed to the frame. So you can find x_o dot is given by k that is voltage output of that e is equal to K time's x_o dot. So you can substitute in terms of a x_o dot by e by K so x_o dot you can write as e over k that is again one that is we are measuring the output voltage as velocity so same considerations we should have. Here also K_s should be small so K_s is small for having beta minimum a smaller value, here frequency range should be smaller so that we can start from lower velocities. That is soft spring we go for the soft spring, instead of having a larger mass we can have a softer spring so that no loading effect at the vibrating body.

So under the same situations we can also measure the relative velocity of the body. The only difference between the displacement velocity measurements is the instrumentation for measuring the relative displacement earlier we have something like LVDT but here we should have the moving coil or moving magnet that is relative velocity should be measured that is to be interpreted in terms of the input velocity. This is the input velocity x_i dot we get in terms of x_o dot that is possible only when the beta is more than beta minim this is measurable range. So these are the various methods used for measuring the vibratory motion.