Industrial Automation and Control
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Lecture - 6
Motion Sensing

Welcome to this lesson on motion sensing in the codes on industrial automation and control.

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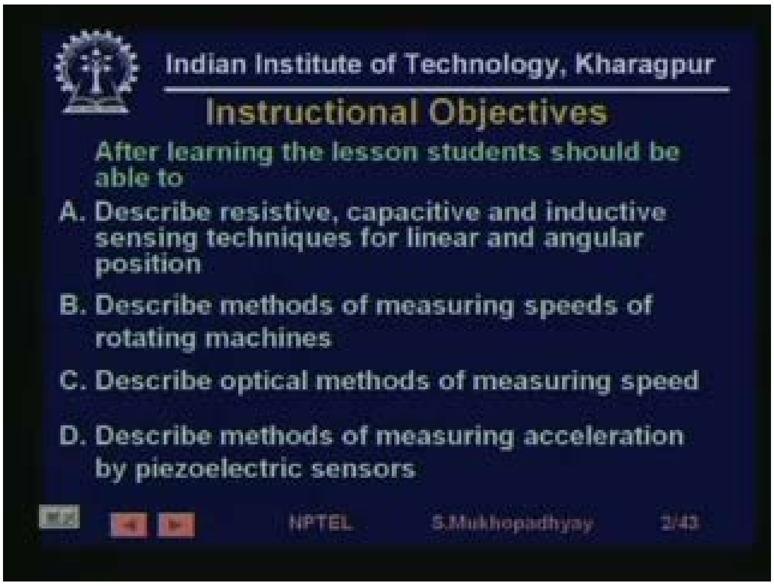

So, today our instructional objectives are that, we will motion means position velocity acceleration. So, today we will and there are various types of motion sensing instruments, but we will only look at those which are of relatively more importance in the context of industrial automation. There are other application areas like aerospace where some of the other kinds of sensors are very important. There are also motion sensors, but we will not look at them person.

So, the first objective is that there are some basic techniques by which we will see that how changes in position can be converted to, changes in resistance, changes in capacitance or change in inductance. Sometimes, you know changes in mutual inductance. So, and then once we so that is the first step where we are converting this mechanical motion into an electrical parameter change. After that we can employee standard signal conditioning circuitry for which are there for, you know sensing these changes.

So, we will learn about the signal conditioning circuitry at another in in another lesson. So, right now we will show how predominantly we will show that how these how the motion actually translates into changes of resistance capacitance or inductance. So, that is the second, one of the major applications is measuring speeds of rotating machines because rotating machines are a very important class of actuators in the industry and they have to be controlled.

So, for the purpose of controlling it is very important that we measure their not only their position, but also because position measurement is basically angular position measurement. So, we not only measure their position, but we also measure their speed. So, we will see look at some of the methods of measuring speeds of rotating machines. We will also look at some optical methods of measuring speed. Optical methods are very good in some respects and not so good in some others, but they are there are distinct class of methods. So, we will have a look at brief look at that. We will also look at measurement of acceleration, which is typically done in the industrial context by piezoelectric sensors.

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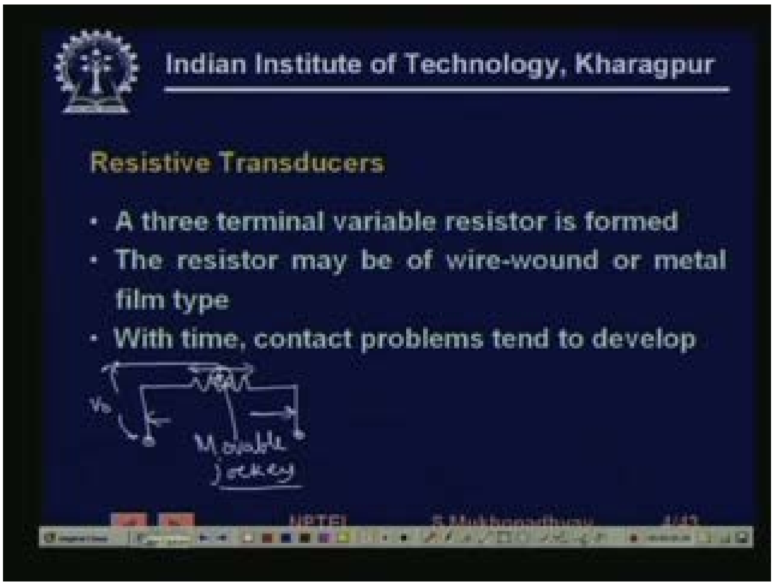

So, having said that let us we will first look at position sensing. So, let us look at resistive transducers first. Resistive transducer, the basic principle of sensing position using resistance transducers is that uses a three terminal resistor. So, what you have. So, what you have is let us let us look at this. So, what you have is you have a three terminal resistance. So, there are two fixed terminals and there is one variable terminal. This terminal this position can move. So, movable position sometimes we call it a jockey.

Now, so obviously, as this moves, it can move either in a linear fashion or in an angular fashion. As it will move naturally the resistance between these two terminals will change. So, if you. So, it can work either as a resistance or it can work as a voltage divider. In which case the if you supply voltage across the fix voltage then the voltage across these two terminals this is V out will change as you move the position.

So, basically this principle is what is used for resistive transducers. Now, naturally since there is a since there is a point which has to constantly move on this resistance. This resistance can be either a wire wound type where on some former thin wires are many turns of a thin wire are wound. So, that if you move, if you have a small displacement you will have a small resistance change. So, you have you generally have a good resolution or you can sometimes have a resistance film on which movable contact will move.

In any case there is going to be a contact and this contact is continuously going to move. So, contacts problems tends to develop there is problem of contact potential. There may be problems of contact loss. So, this is one of the biggest problems although this transducer is actually very cheap, but this is one of the biggest problems of this transducer.

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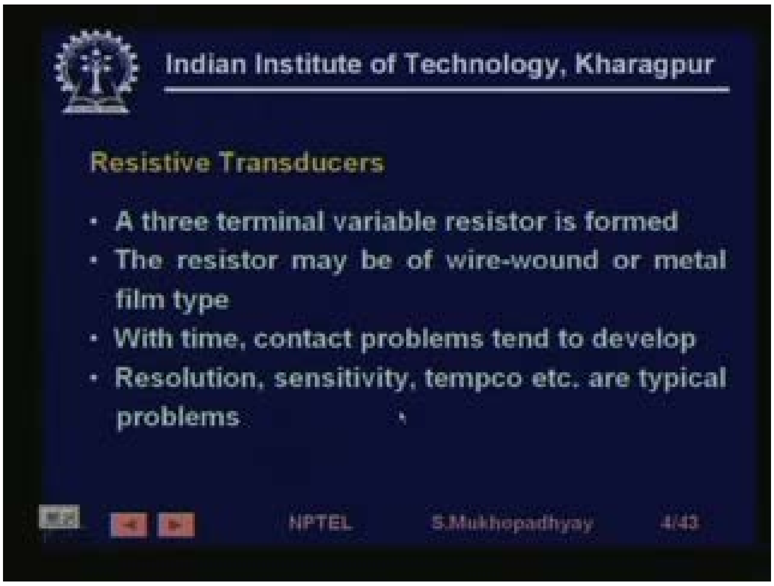

So, you have for example, you have resolution sensitivity temp co problems. So, if you have the sensitivity may actually depend on how much current you are sensing through this resistances that, if you send too much current temperature of the wire will rise. So, the resistance change will now be effected by what is known as self fitting error. So, these transducer although they are cheap they are often affected by such problems.

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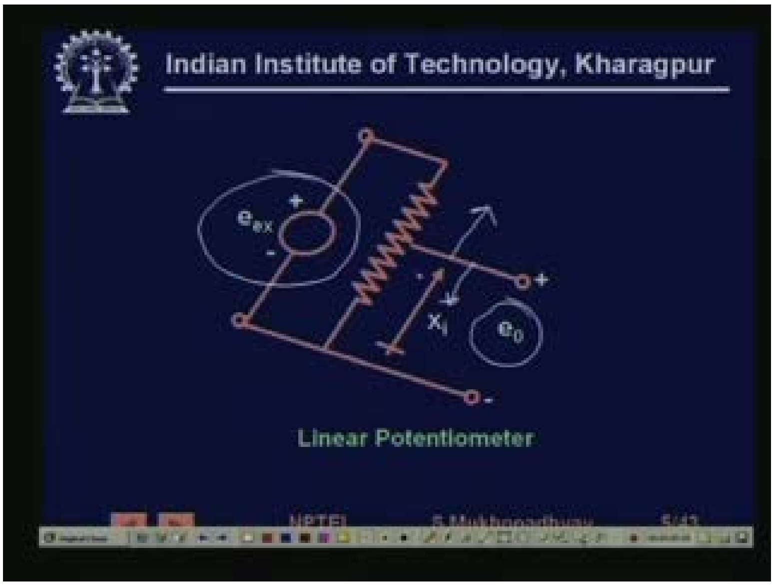

This is a typical configuration for the linear motion case. So, as you can see that this is the excitation, exciting voltage it can be DC or it can be AC also. This is the output voltage. So, as it moves towards this the voltage increases then as it moves towards this point the voltage decreases.

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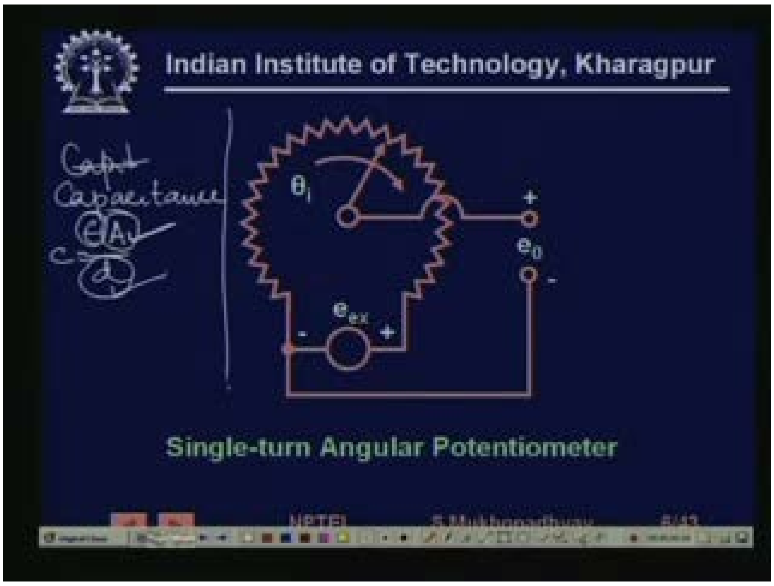

Similarly, you can also have you can also use a similar configuration for you know angular current sensing angular motion sensing. So, for example, this is the case where you have a single turn angular potentiometer. So, nothing one only thing is that now the movable jockey rather than moving in a linear fashion is going to move in an angular fashion and then the resistance coil is also wound in an angular fashion. That is the only change as such circuit wire there is no change. So, this is mainly about resistive transducers.

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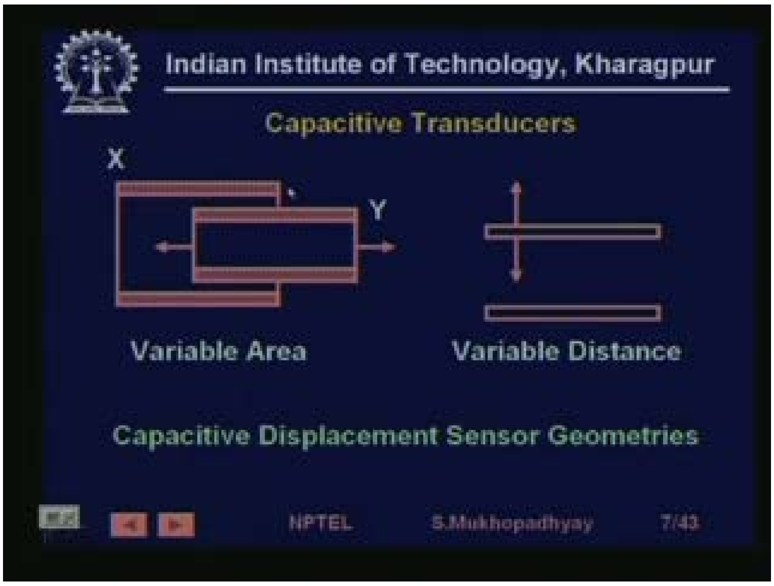

Now, we come to capacitive transducers. So, in capacitive transducers due to the motion there is going to be a capacitance change right. So, we know that typically if you take a if you take the case, if you take the simplest case of a parallel plate capacitor. For example let me explain this. So, I do not know why this is changing. So, we can write here itself. So, the capacitance is given by epsilon A by d for a parallel plate capacitor.

So, change in capacitance can occur either due to the change in the area or due to a change in the plate separation or also due to a change in the dielectric medium right. So, these principles all three principles actually can be used for making capacitive sensors. In the case of motion sensing typically change in area I mean geometrical configurations are used where due to the motion either the area changes or the displacement changes.

Now, you have to note that, if there is a change in area, then the change in capacitance is actually linear with respect to change in area while it is not linear with respect to the change in d. So, this must be remembered because as we explain that we generally look forward to a linear characteristic in sensors basically, because of ease of use. So, now we come to the capacitive transducer. So, you see this is this is one particular configuration.

So, here what is happening is that you have two cylinders. So, which are where one is fixed and the other keeps moving. So, you can well understand that the area basically the capacitance plate which is going to form is on the intersecting part of the area. So, as it moves. So, this area is going to vary right. So, this is a typical variable area geometry while if you have two plates and then one plate for example, suppose one plate is fixed and then the other plate is moveable and it keeps moving like this then there is a constant d variation.

There is a capacitance variation with respect to d only noting that the variation is not linear. It is approximately linear when this change in d is small. So, therefore, this geometry of a variable distance can be used for you know small displacement sensing. I mean keeping this sensor as linear.

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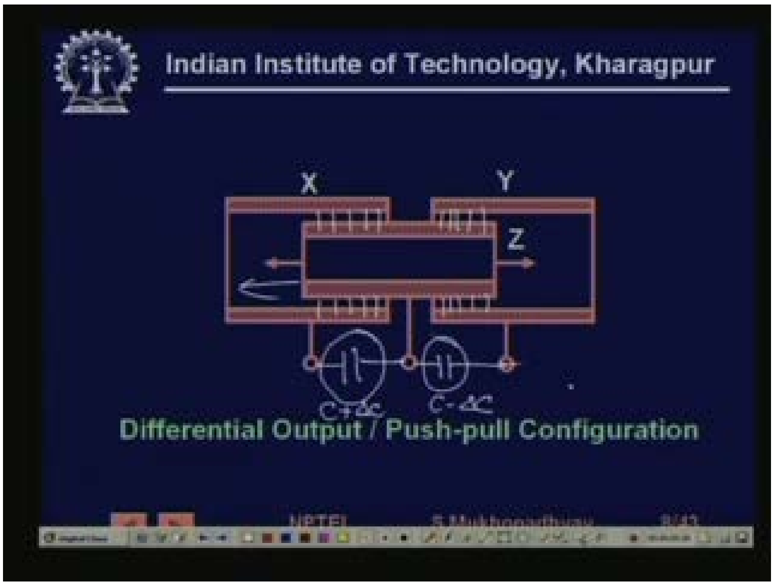

This is the case where you have a push-pull configuration. You known sometimes we find that you know push-pull configuration can actually cancel some non-linearities. So, not only that they will also they will also enhance the sensitivity. So, here what is being done is that there are two capacitances which are formed. So, you know this forms one of the capacitances which is formed between these two terminals and this is forming another capacitance which is forming between these two terminals.

As this is moving here the, if it moves to left then the area is increasing. So, this capacitance is increasing and by an equal amount this capacitance is decreasing because the area increase of this is exactly equal to the area decrease of this. So, you can say that it is if it is C plus delta c then this is going to be C minus delta c. So, such a configuration is called a differential output or push-pull configuration because of obvious symmetries you can either push it or pull it.

As we will shall see in our signal conditioning lessons that there are certain benefits if you have push pull configurations in terms of non-linearity as well as in terms of sensitivity. Also you know some times I mean tolerance with respect to other kinds of inputs like interfering inputs like temperature etcetera, So, for these reasons sometimes the push-pull configuration is preferred and this is a push-pull configuration for capacitive you know motion sensing.

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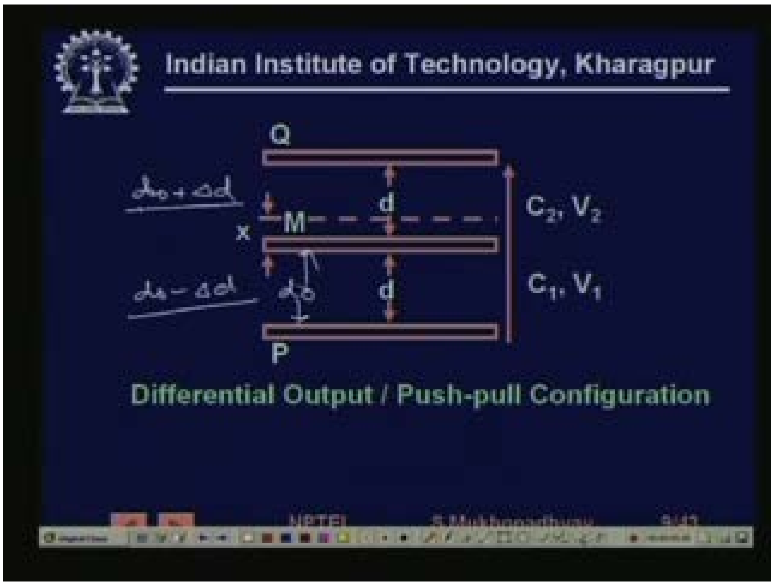

So, similarly this shows a push-pull configuration for the variable plate separation case. So, here there are actually this is these are the two fixed plates and there is in the middle there is one variable plate which keeps moving. So, you see that you can understand that at any time if the middle plate separation can be called d 0, then for any position of this plate one side will be d 0 plus delta d and another side will be d 0 minus delta d.

If this delta d is small we shall find approximately that the change in capacitance can also be considered to be proportional to this delta d which is the motion. So, these are the basic sensors which are used for capacitive sensing. The next part is basically signal conditioning. So, since we are going to learn, you know this capacitive sensing arises in in various context. So, but their signal conditionings are mostly uniformly.

So, we shall see in our signal conditioning lectures that how such changes in resistance inductance or capacitance can we transduce to a change in voltage or current. So, that is why we are not talking about it now, but we will talk it talk about it in an uniform manner in our signal conditioning lesson. Now, we come to a very you know well known sensor which is called the linear variable differential transformer or the well known LVDT.

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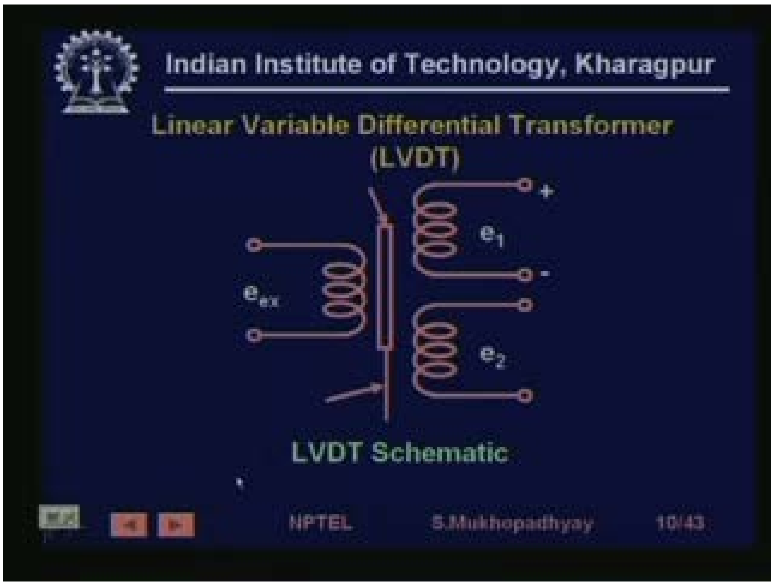

Now, this is very much used for accurate position sensing and the basic principle it is called a transformer and then a transformer is basically a set of coupled coils. So, there is a variation mutual inductance in this case. So, what happens is that actually there are there is one primary coil and there are two secondary coils with which both of which are actually coupled to this primary. Now, this degree of coupling is actually what changes with the motion.

So, this degree of coupling depends on the, obviously, depends on the reluctance of the magnetic path. So, therefore, if the reluctance of the magnetic path can be varied then more flux can be the of the total flux produced by the primary some more parts can be linked with the secondary, with one of the secondary's and less will be linked to another secondary.

Therefore, we are going to get therefore, our induced EMFs. So, a pulsating flux induces an EMF. So, the induced EMF will change in the two coils, and then as we shall see that if we connect these coils in what is known as series of position and we can get a sent we can get a signal which is proportional to the motion.

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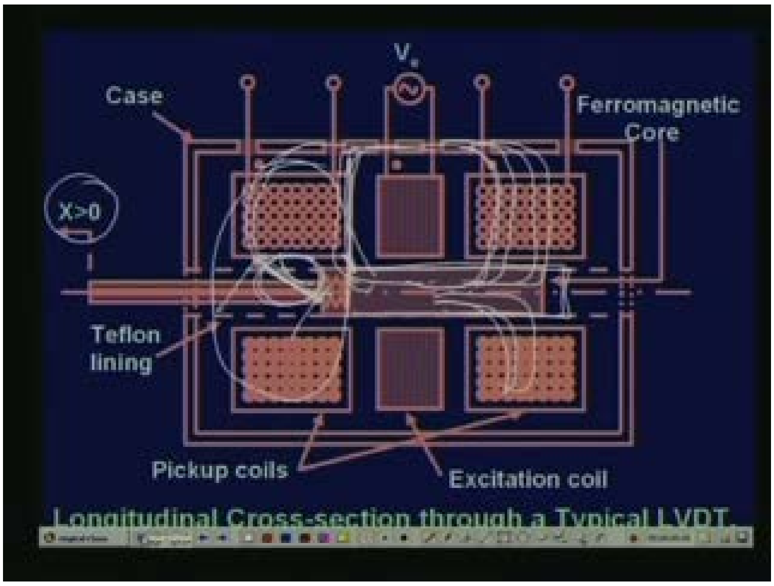

So, this is the case where you this shows the constructions. So, you see this is the primary coil this is the primary coil and these two are the secondary. So, the flux actually passes like this. So, you can see that if the core this is the core which is actually connected to the motion. So, if the core is placed let say here, then this flux will actually linked many of much of these coils. Many of these coils, while the similarly there will be branches here, but when it will return.

Since these parts are non-magnetic and therefore, if it has to return through this see here it is magnetic. So, therefore, the overall reluctance of the path is actually limited to this air gaps, but if it has to come through this path then it has to go through this much of air gap. So, therefore, fluxes actually will not prefer to pass through such path, but will pass through such path and therefore, they will not they will not be linking the second coil

So, as you can see that if the core shifts to the right then the number of turns of one secondary more number of turns get linked, while less number of turns get linked in the other. So, this is the basic principle of sensing. So, they are an induced EMFs are going to be different. So, this is the principle on which.

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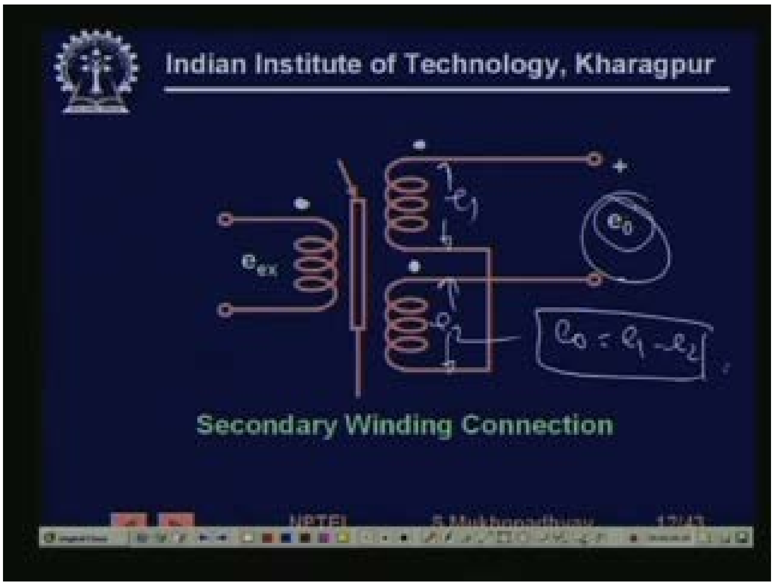

Now, if now we are going to connect these secondary into series of position actually you know if you we have not shown, but there is. So, if you want to connect them at series of position then there is a concept of dot. So, two of the either you connect the two dots short the two dots together or you take the outputs from the two dots and we short them together. Then it will be in series of position. Position means that you will this e 0 will actually if you have an EMF e 1 here and if you have an EMF e 2, here then e 0 will be e 1 minus e 2. So, e 0 equal to e 1 minus e 2, this is called series of position.

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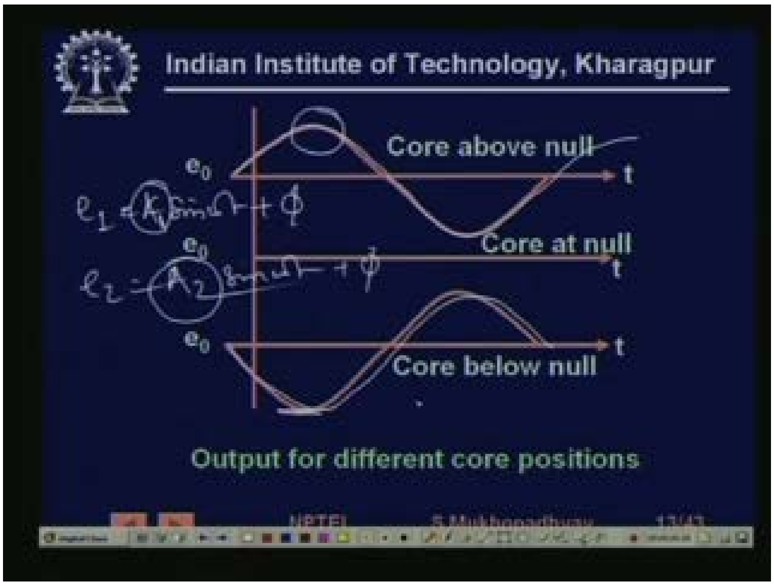

So, we connect them in series of position. So, what happens is that obviously, as you can understand that, if the core is above null, null is a middle point. So, it is above null. So, it is. So, one of the let us say e 1 which is equal to let us say A sin omega t plus, there will be some they can be from phase shift also. So, if this is A sin omega t then because it is linking more number of turns therefore, A 1 will be larger and e 2 will be also another sinusoidal EMF which may be of A 2 sin omega t plus phi. So, but this A 2 magnitude is going to be less than A 1. So, therefore, when you do e 0 minus A 1 you are going to get you are going to get one sin wave.

If the core is below null then you are going to give another sin wave. In both cases you are you are getting sin wave because your excitation is actually sinusoidal, but you can see that if this sin wave is can be called positive this sin wave is called negative or there is phase shift. So, now, but. So, this is exactly what happens. So, you have the output for different core positions.

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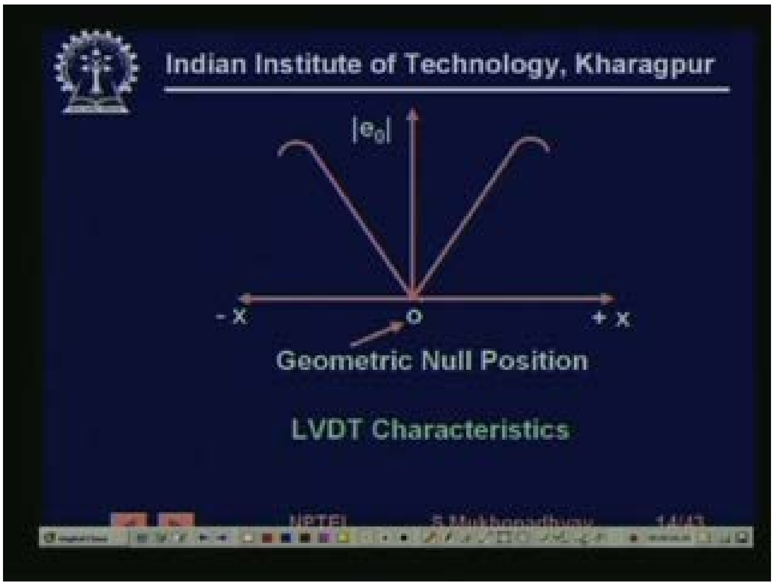

So, if you see now this output amplitude will also change. So, if you just look at the amplitude then the LVDT characteristics looks like this that is as it moves from the null position then the amplitude of e 0 increases, and in this case also it increases, but there is a phase shift. So, now you can see that if you just see the amplitude you cannot differentiate between a plus x displacement and a minus x displacement.

So, the sense is lost just from the amplitude therefore, we have to when we want to therefore, we have to extract the phase information if you want to know which side it is moving that is the algebraic sign of the displacement.

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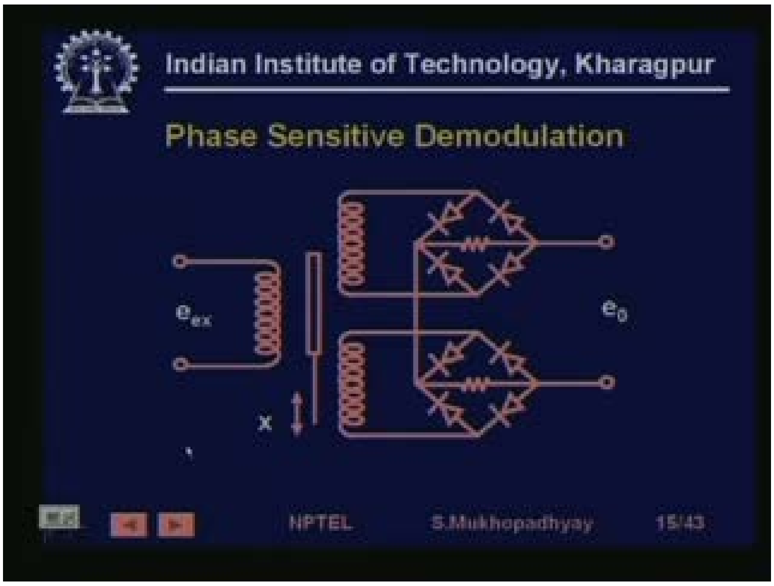

That is exactly what is done by what is known as phase sensitive demodulation. So, we will talk about phase sensitive demodulation this is just one of the circuits of phase sensitive demodulation where you use rectifiers. You can use various kinds of circuitry for phase sensitivity demodulation, which is also used in various which is also a communication technique. So, we will not talk much about it. We will rather talk about it in our in our signal conditioning course in a signal conditioning lesson.

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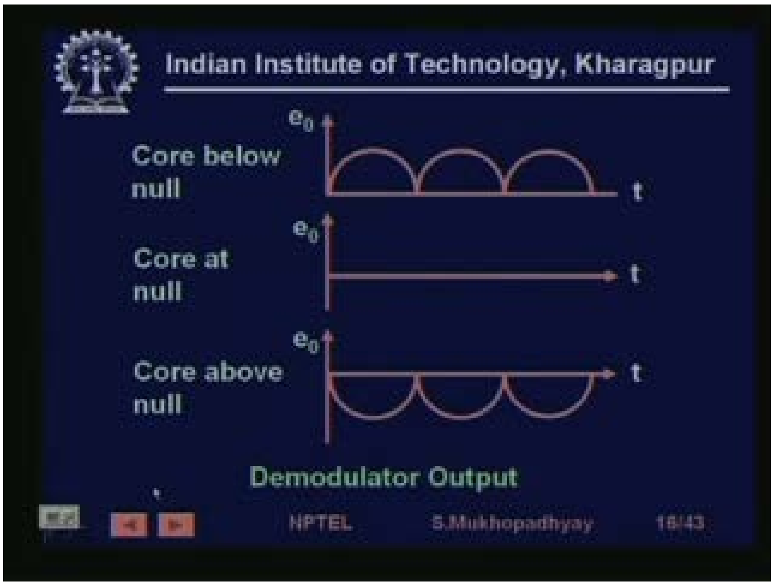

So, only we want to say that now using phase sensitivity demodulation what we can do is again we have. So, what we can do is that, is you see now if the core is below null then you get a rectified wave. If the core is above null then you get a rectified wave, but which is negative. So, therefore, now if you just simply low pass filtered this wave then you will get a DC. So, now if the core moves below null you get a positive DC and if the core moves above null then you get a negative DC. So, directly from the sign of the DC you can also see the sign of the motion.

So, this what phase sensitive demodulation achieves. It gives you a finally, from the various phase shifted AC waves which are actually produced by the LVDT itself it will extract out it will extract out the motion. So, if the motion in the positive direction then it will give you a DC signal which is in a positive direction and if you and if it is negative then it will give you negative.

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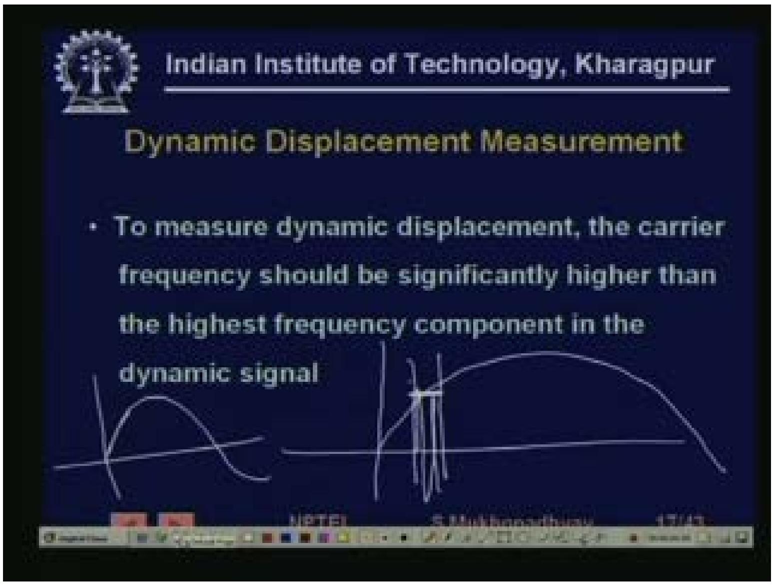

So, this is now we can actually extend this concept little bit. So, for example, suppose the motion of the core is a slow sinusoid. Like this typically what happens is that the excitation is given at an electrical frequencies, something like you know I mean hundred hertz two hundred hertz typically four hundred hertz. So, you see the AC is actually a four hundred hertz. So, it is very fast moving every second it is changing sign for hundred times.

On the other hands this this motion is generally low much lower frequency two hertz three hertz five hertz ten hertz like. So, actually what is going to happen is that. So, you see this is the motion. So, between at any point if you take a small time interval, then if you assume that it is actually remaining constant that is an approximation. Then during this time you are going to get an AC right you are going to get an AC. So, actually let us look at this. So, actually the... I have to change the pen.

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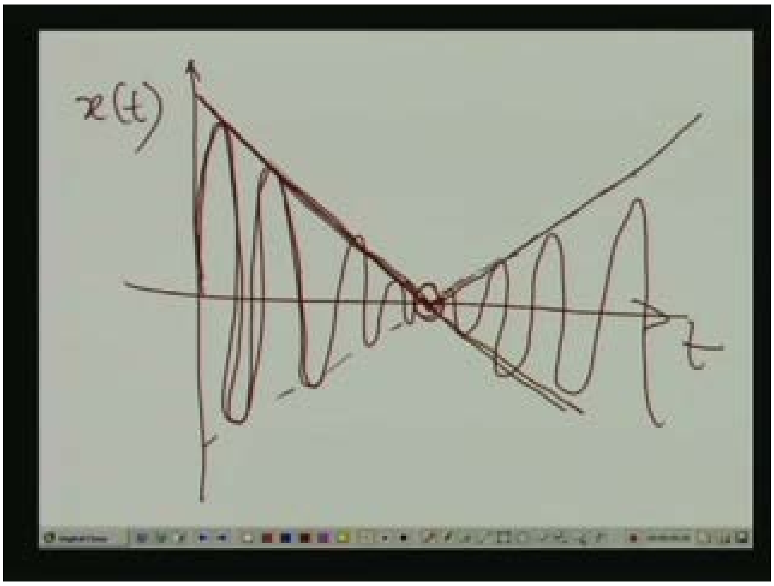

So, actually if you have this is very important to understand that if you have a motion let us say like this. So, this is the time axis t and this is x t. So, you have. So, x x t is going from positive to negative, then what will be the LVDT output. So, the LVDT output will actually be sinusoidal. So, it is going to be like this. Actually there are many more cycles than this I cannot draw that. So, therefore, I am showing it like this. When this will go negative then actually this will change phase.

Now, the thing is that, this change phase occurs at nearly 0 magnitude therefore, it cannot be seen. Therefore, if you just see what you are going to see actually on the, if you connect a c r o a cathode oscilloscope to the LVDT terminal is this. So, obviously you cannot make out whether x is positive or negative. So, dynamic if you if you now feed it to a phase sensitive demodulator then the phase sensitive demodulator will actually extract out this wave and show whether the motion is like this or whether the motion is like this right.

So, only thing is that for the phase sensitive demodulator to work well, what is necessary is that the frequency of the sinusoid is much higher than the rate at with these change right. So, then demodulation becomes easy. So, to measure dynamic displacement the carrier frequency should be significantly higher than the highest frequency component in the dynamic signal.

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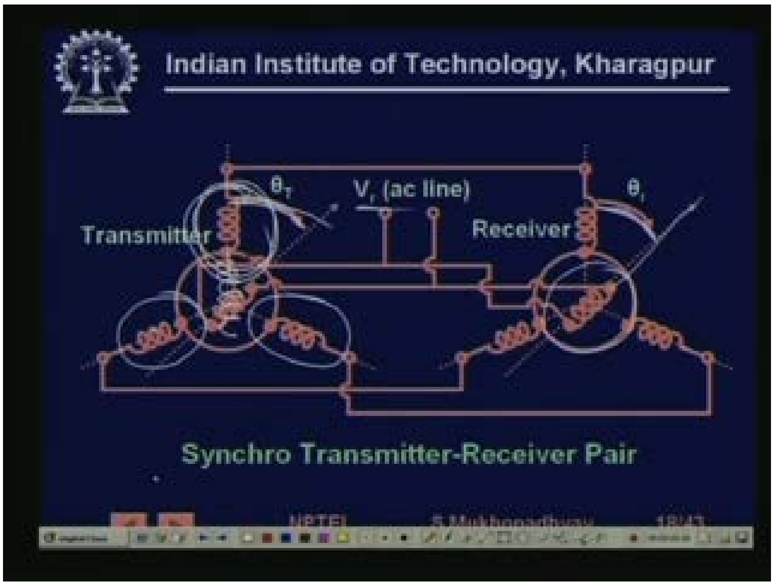

So, now we come to. This is another this is actually not a this is actually a system where by a position command can be transform, transferred to a distance using some using a pair of machines called you known synchro transmitter receiver pair. This is also sometimes used in control of course, now a days these methods are becoming somewhat dated and for transferring motion signals for control other methods are employed.

So, we can look at that later, but to understand this actually what happens is that you have a motor on which you have three coils. You are going to excite these three coils you are going to excite these three coils by single phase AC. There is a problem. So, we are going to excite this coil by a single phase AC and you are going to remember that these two are actually at some distance apart.

So, what happens is that, if you rotate the rotor on the transmitter and what will happen is that the voltages induced on these coils are going to be of different magnitude. So, may be when the coil is in this position this voltage, the voltage induced here is going to be maximum and the voltage is induced here are going to be less and so on. So, now these voltages are actually transmitted by cables to another machine which is getting supply from the same AC line.

So, it can be shown that if this is applied in the so called stator of the machine and if the same AC line is giving supply to the rotor then this rotor will actually move to the same angular position as this. So, actually if you move the rotor of one machine the rotor of the other machine will actually move by an equivalent amount. So, by this you can transmit actually a motion command right. So, this is what happens is in a synchro transmitter receiver pair. This is not actually sensing, but I mean the, but this is one way of transferring a motion command which is also used in control systems.

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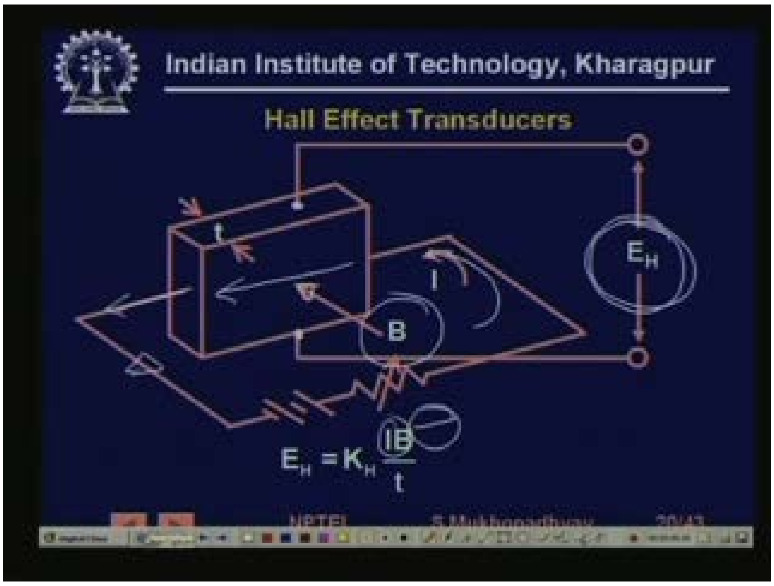

Now, we come to Hall Effect Transducers. These transducers are used quite a lot in especially in a machine, I mean motor applications, where you know there are as we will see later when we study drives that for some motors for their drive, for example, there is a class of motors called a brushless DC motors. So, for their drives you need to know what is the rotor positions. So, as the rotor is at least at some points of time at certain discrete points of time, you need to detect that the that the rotor has come to that position this is this is necessary.

So, this is typically achieved using Hall effect transducers and the basic Hall effect transducers are also widely used for measuring current which is also used in also used in drive application where you need to do current control, but in this case to in today's lesson we actually talking about motion control. So, therefore, we are going to look at that in that context. So, what happens in a Hall effect sensor is that this is a piece of semiconductor through which you can see that some current is being circulated. So, this current I is actually flowing through the semiconductor.

So, current is flowing let us say along one axis. Now, on a perpendicular axis, there is a flux there is a magnetic field applied, which is causing a flux density of B. So, the magnetic field intensity is, in this case the flux density which is actually going through the semiconductor is B. It turns out that if you actually send a current in one direction and you send a flux density you send you apply a magnetic field in the in a perpendicular direction, then along the third direction some potential difference will be developed this is known as the Hall effect.

So, therefore, along the third direction if you connect two terminals, then there you will get a voltage across these terminals. This voltage magnitude will be proportional to the product of the flux density and the current right. So, turns out. So, and this is very convenient. So, now, typically in the case of motion applications we pass a certain amount of current through it and then and then we detect position.

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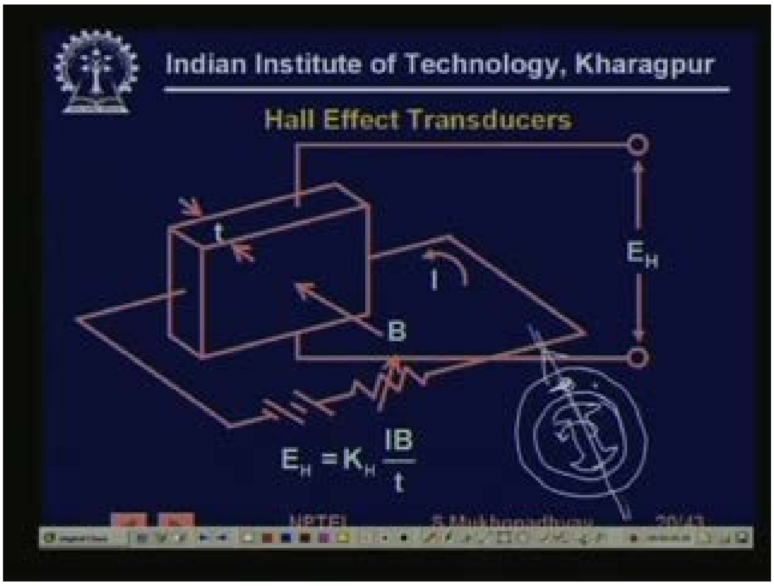

For example in the case of the motor what happens is that. For example, suppose you put a Halls and this is the stator and there is a rotor. Suppose there is a rotor just I am drawing an obstruction suppose there is a rotor which is creating a magnetic field. So, it creates a magnetic field along this axis this rotor is rotating. So, this is rotating. So, whenever this rotor comes to this position where the magnetic field where the Hall effect sensor is placed, immediately the Hall effect sensor will actually sense that magnetic field.

There is already current passing through it. So, the moment this rotor will pass through that position, this position actually very small. So, it will just pass through that position during that time for a brief time there will be flux passing through the Hall effect sensor and then for a brief period of time it will give a voltage pulse

So, this is very much used wildly used in industrial motor drives for actually sensing the rotor position. So, whenever you get the voltage pulse you know that this rotor has actually passed through a particular angular position right. So, this is the way the Hall effect sensor senses position.

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Similarly, it. So, now there are actually Hall effect sensors are used because of various reasons main reason. One of the main reasons is that is it is very reliable, there is no contact required and just from a it is a actually noncontact environment and then there is no moving part in the sensor. So, it is a. So, if you just embed it once in the stator then it is going to work.

So, this is one of the reasons and it is very small. Only thing is that it had the level of signals which actually comes from the sensor is low. So, you need to amplify the signal. So, you know some times often you get Hall effect sensors with some integrated electronics we. So, to amplify…

So, now we come to what is, these are you know this is a glimpse of typical position sensing mechanism there are others. For example, there is a just like the Hall effect sensor there is also a method of position sensing called a magnetic pick up, where you actually put a search coil. You make an arrangement that that as something is rotating the field passing through that coil will actually change.

So, if the field passing through that coil suddenly gets linked with the coil, then you will get a pulse again right. So, such pulses can also be used for position detection, but we will, so but similar coils are actually also used for velocity sensing. So, we will look at velocity sensing in in that context.

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So, now we come to velocity sensing.

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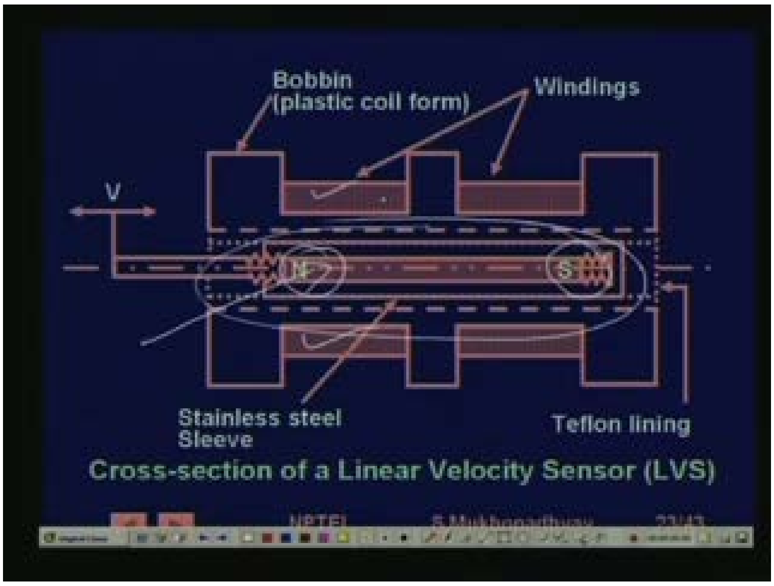

So, this is what I was saying that this is a linear velocity sensor yes. So, again it is actually much like the LVDT except for the fact that, now there are two coils. So, you now again these as this will move this is the linear velocity sensor actually this is an inductive sensor. So, these inductances of these coils will actually change because of the motion of the core.

So, you can and this is a push-pull configuration. So, therefore the inductance. So, you can have a you can construct as we have as I was telling that, you can if have push-pull configurations then you can construct a linear sensors. So, that is why this is a linear velocity sensor in the sense that the if you. There are there are actually various ways in which you can do it.

For example, if this is permanent magnet. So, in this case what is shown is a permanent magnet. So, if you show it is as a permanent magnet then as this magnet will move, then the EMF induced EMF will be induced in these two coils and depending on the motion of the coils these EMF amplitudes will actually change. So, this is the case where the velocity and you know as we know that the EMF induced will be directly proportional to the velocity of the magnet, because it is proportional d phi by d right. So, it this principle which is used in... So, basically this is an electromagnetic induction principle which is used for sensing velocity.

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Typically somewhat similar principle is used in the probably the most common sensor for sensing motor speed which is the permanent magnet DC tachogenerator. So, it is nothing but a DC generator where again where here the case is slightly different in the in the previous case the coils were fixed and the magnet was moving. In this case it is the magnets which are the fixed on the on the stator of these and it is the coils on the armature which are actually moving. So, as they move they create they give you a DC voltage as we now that the magnitude of the voltage is going to be directly proportional to the speed because the flux is constant. So, therefore, we have this. So, this is a very common instrument which is used. You can also similarly you can also use rather than using DC tachogenerators which have the you know DC motors sometimes have some problems.

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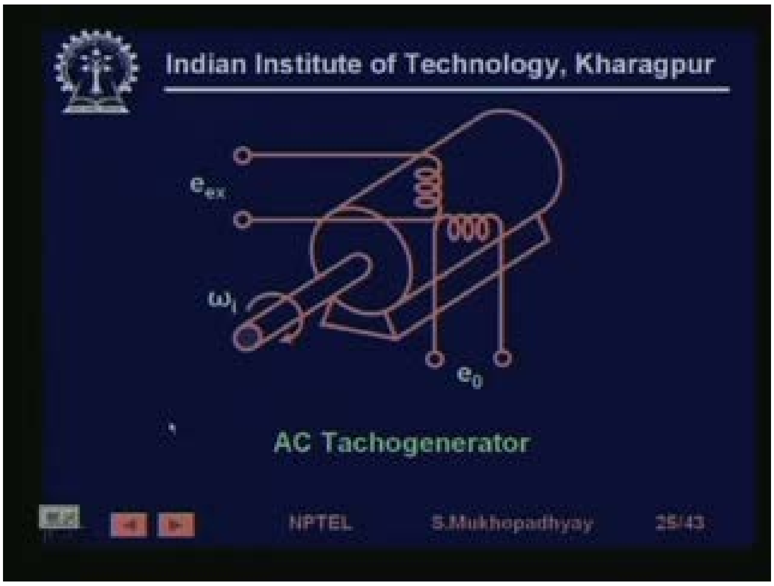

You can also have an AC tachogenerator where you can give a where you can give a supply n excitation and if you rotate the armature, then you will get some AC voltage out of it. So, it is a basically an AC generator right. So, basic principle is the same that you have to rotate you have to basically change the magnetic field linkage with a coil. So, you create some excitation either from permanent magnet or from some voltage source which can be AC or DC. Then you see that as you change these excitations. So, the flux link with the coil will change and there will be an induced EMF.

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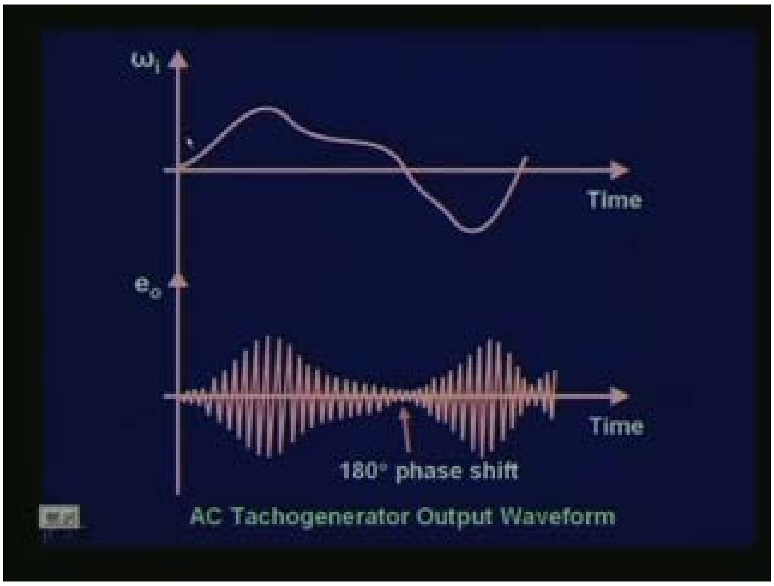

So, you see that if you have a DC tachogenerator or if then or if the speed changes like this, then you from AC tachogenerator you have what is known as the modulated wave form. So, again you have an AC, but the amplitude of the, this is exactly like the LVDT. Only thing is that in the LVDT the EMF was looking exactly like this, but it was proportional to the position, it was the proportional to the motion of the core. Here it is proportional to the speed of the shaft. So, that is the only difference.

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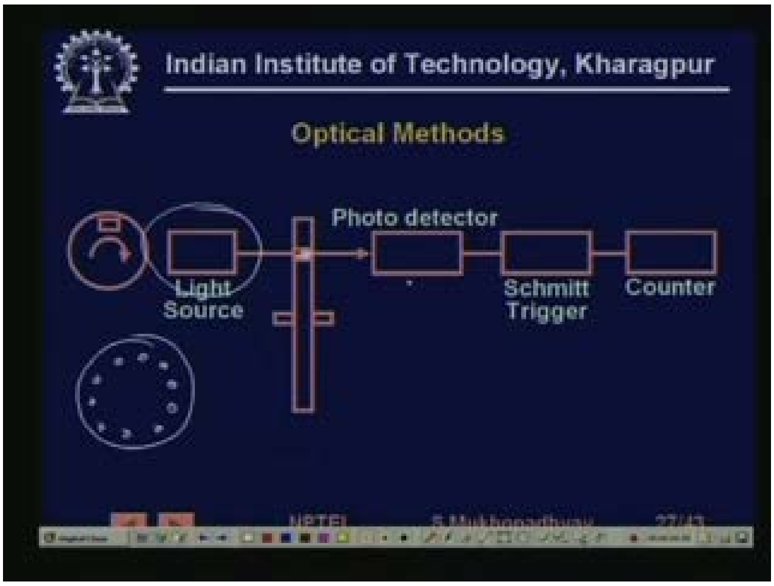

Similarly, so these are all you know inductive methods by the way there are we might also mention that in many cases suppose you have a basic sensor, which senses position.

So, if this the if the signal is not very noisy then you can always differentiate the signal to get to get velocity, but generally this is avoided because if you differentiate with noise you will get very huge amount of noise amplification, but it can turn out, but you can have various signal processing schemes. Similarly, if you have a basic velocity sensor then by integrating that that velocity also you can generate position, provided you can you know initialize the sensor with the initial position.

So, such things are also possible. So, in this case you know this is also a very simple speed measurement situation which is often you know I mean implemented by students in a very low cost. So, this is one of the way is that, here the motor is rotating motor suppose the motor is rotating and on the motor actually you have a disc. So, you have a you have a disc, let us imagine this to be a disc. So, the disc is rotating right.

Now, on the disc you actually put holes. So, you can imagine that this is the disc and here this is the hole. So, you can have a series of holes on the periphery of the disc. So, if you look from the front there are several holes and at one position you have a light source right. It has to be a you can make an you can have an LED or you can have. So, now on the other side of it you have, you can have a photo detector. So, either a photo transistor or a photo diode.

So, the basic principle is that on these devices if some light falls on these devices then they start conducting right. So, what happens is that it is. So, as the disc will rotate. So, therefore, whenever these this hole will actually pass through the light source light will pass through the hole and then fall on the photo device. At that point of time the photo device will start conducting. So, every time these there is a light pulse falls on the photo device you are going to get an electric pulse.

Now, this electrical pulse can be actually processed by various electronic circuits something like Schmitt triggers counters a simple circuits. Then you can actually count the speed, count how many pulses you are getting per second. So, from there you can easily reduce what is the revolution of, I mean how many revolutions per minute is the rotational speed of the motor. This is a very simple scheme of simple optical method. Many variance of these methods are used.

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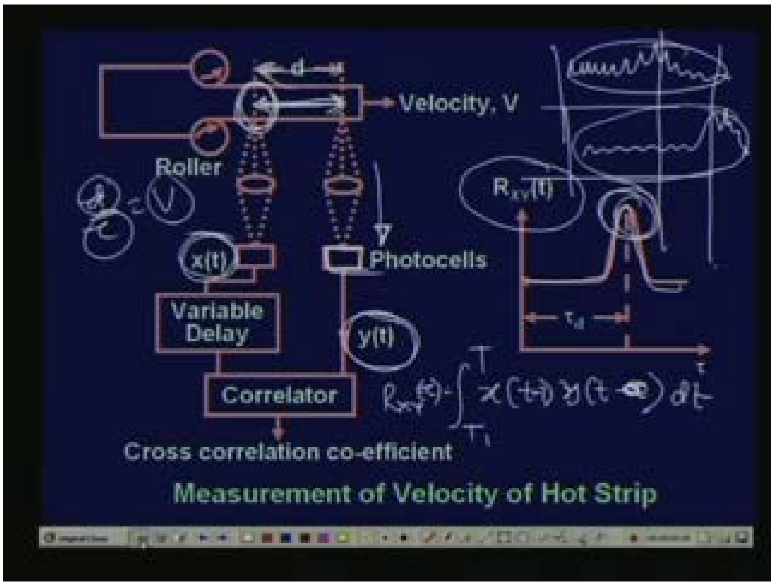

Here is a slightly complicated scheme where we use the concept of correlation. So, you know this is the case where we are trying to measure the velocity of a hot strip. You know it turns out that when you are in a rolling mill, where you are you know trying to feed a thick bar of steel through two heavy rolls. When it is passing through the roll gap it is actually getting thinner. So, you are reducing the dimension by rolling. This is a very important mill which is there in almost all steel plants.

So, in hot rolling this bar which is getting rolled is actually red hot right. So, you can imagine it is very high temperature and therefore, as we know that you know we need to sense the speed from a distance. We cannot we should not go too close it. So, therefore, for example, magnetic sensors may not work at very high temperature.

So, what we are going to do is that we are going to, now you might think that if the rod is hot then it itself emits light. So, when we were talking about optical method it is not that we are going to always talk about light in the so called visible frequency, visible frequency range. Sometimes, we apply you know lasers or I mean light in different frequency ranges different wavelength light.

So, and we can also have detectors which are actually sensitive to certain narrow wavelength bands. So, if the hot strip is not radiating in that band then we do not have any interference from the radiation of the hot strip. So, this must be remembered. So, having said that let us look at the fact. So, now, you see what we are doing is we are actually. So, we are we are taking we are actually taking the signal from two channels one is x t another is. So, another is y.

So, even if our signal. So, we have now we have suppose imagine that we are actually receiving radiation from one channel. Now, this radiation will actually depend this radiation pattern will be probably varying like this. Now, so the radiations sensed by these two signals are going to be may be going to be delayed. Actually the basic premise is that the radiation pattern from a particular part of the of the strip is going to be is always shape may slightly change and the signal is going to be erratic, but it will over a over a small distance is going to preserve its shape.

Therefore, we are going to have as it travels when we take signal through the second set of when we take the signal through the second set of sensors. So, I mean what is going to be happen is that the correlation, I mean this the signals received here are actually going to be a going to be a time shifted version of the signals in this channel. So, the basic premise of this measurement is that the signals y t are actually noisy versions of x t, but time shifted.

Now, how much time shifted that we do not know that actually depends on the speed. Since, this distance d is fixed. So, therefore, by how much time shifted they will be that will depend on the speed of the strip. So, now we are going to determine precisely that. So, what we do is for that. So, if we have two time shifted signals roughly time shifted they are going to be they may be slightly different. Then there is a technique of correlation. So, if we compute let us say t 1 to t 2 x t to x t y t minus tau d tau d t.

So, we time shift x and so x we are we are measuring. Suppose, we time shift in this case as it shown that x is time shifted. So, we time shift x and. So, in this case we let us say we time shift x and we keep y t. So, with time shift x and then we multiply it with y and then integrate. So obviously, if the maximum it can be shown that this correlation function this actually a function of tau R x y tau.

This will achieve its peak when this. So, we gradually vary tau and then start plotting this function. So, wherever this function reaches the peak that is actually the tau which is required, that is the time required for this strip to travel these distance d. So, basically tau d by tau is the velocity and since d is fixed. So, by computing tau we can get V.

This is called a cross correlation method of measure measuring a measuring velocity. It is also used in flow measurement in the case in what is known as cross correlation flow meters. So, we are moving fast and we are giving you glimpses of various kinds of measurements. So, one of the advantage what is the advantage of this is that if you use you know powerful light sources and if you use powerful sensors and then you can do actually do the measurement from a distance. You know temperature does not affect these measurements too much.

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Now, we come to. So, we have seen some methods of velocity sensing. Now, we come to acceleration sensing.

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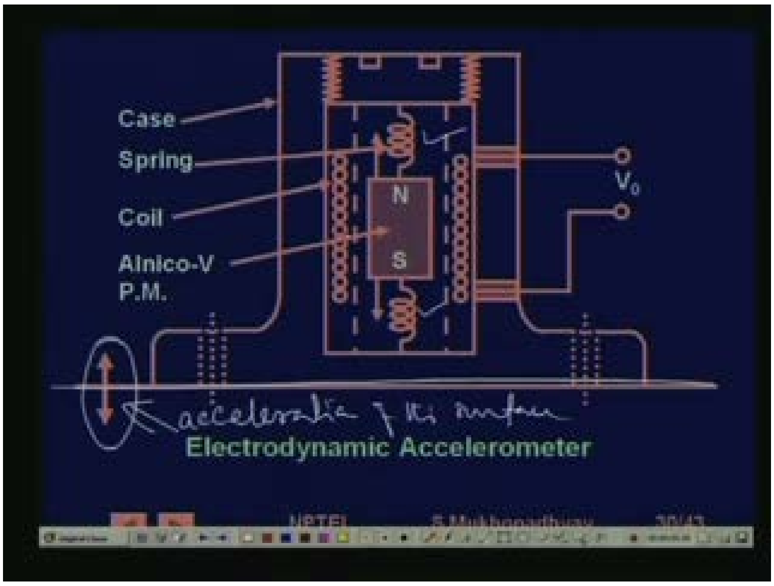

Acceleration sensing, is not very much used in the industry not or not too much when compared to that velocity and velocity and position sensing are much used. This is a typical configuration of an accelerometer, which is so. So, therefore, in fact, you know acceleration sensing is mainly used in the industry in the context of vibration sensing, which is sensor, which is widely used especially for maintenance and fault diagnostic purposes in all kinds of machines.

So, piezoelectric sensors are basically in a way they can be called acceleration sensors.

So, that is the biggest class of acceleration sensors which are used, but just for a general principle, you know this is an electrodynamic accelerometer in the sense that you have a in such mechanical electromechanical or rather electrodynamic accelerometers you have a mechanical part and you have an electrical part.

So, the mechanical part is generally a mass spring damper system right. So, you have you see you have here you have a permanent magnet and you have these two springs. Additionally damping is created sometimes by putting in oil because that will give you viscous friction that will give you damping. There is this coil right. So, it turns out that as this. So, if you give now, this accelerometer is actually put in the surface. You are interested in actually measuring the measuring the acceleration of this surface.

So, as you can understand that if, this is actually sort of floating in may be oil using these two springs. So, you can understand that if you this is actually sitting on this surface and if this surface is actually accelerating then this magnet, then this mass which is sometimes called a proof mass is also going to vibrate. So, you are going to get a signal which is. So, now, that will that will induce EMF right. Now, it can be shown that this EMF induced can in in especially in certain frequency ranges this equipment can be so designed that, this EMF is going to be proportional to this acceleration right.

So, this is one basic technique of you know. So, in many accelerometers you will find that there is this concept of this mass spring damper system, which is connected to either a position to resistance sensor like a potentiometer or it can be connected to other kinds of you now position to. For example, in this case velocity to voltage sensor.

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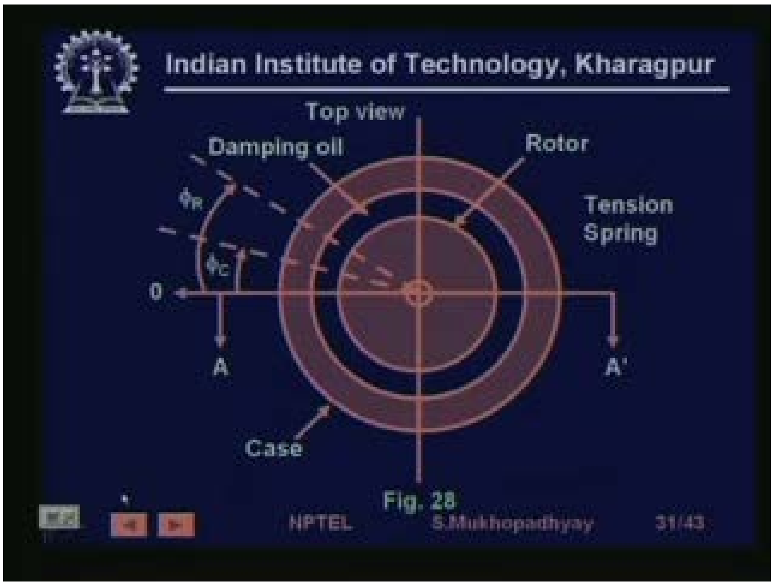

So, this is actually a rotational version of the same where previously the proof mass are rotating like this, now it will be moving inside. So, you have some tension springs. So, again oh I am sorry. So, again you have you have some springs. No make this change. So, anyway. So, again we have this rotor which has some movement of inertia which is the rotational equivalent of mass. We have damping oil, which gives you friction. Similarly, we have some and the torsional springs actually these are torsional springs. So, you again have effectively have a mass spring damper system, but now in rotational terms. So, you can have both. We will skip this slide.

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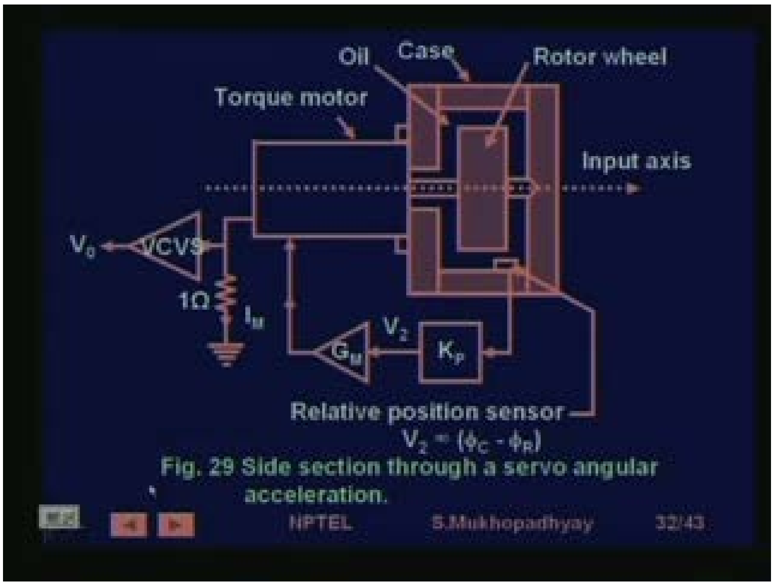

This is what is known as a close look measurement method. We will actually skip this slide.

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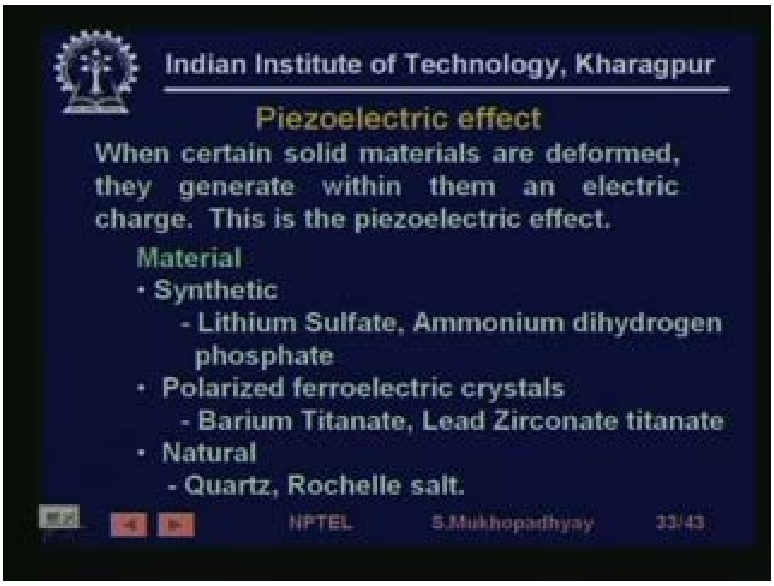

Now, we come to the piezoelectric sensor which is the main sensor used for acceleration sensing. It turns out that certain solid materials, if they are deformed due to force then they actually across their dimensions they actually generate potentials. They actually generate charges and then they generate potentials. So, this is called the piezoelectric effect. These typical materials are you know there are synthetic materials, there are some what are known as polarized ferroelectric crystals and there are some natural materials like quartz. So, if you… So, as we will see in the next figure what happens is that.

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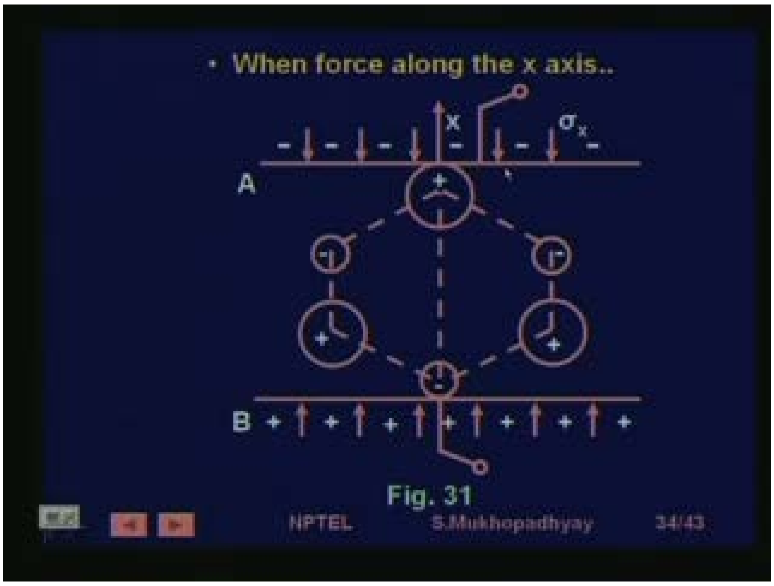

If you suppose you have the crystal cut in this shape and we are shown we are showing only one dimension. So, there is basically a crystallization structure. So, when you if you put force on it then that crystallization structure becomes deformed. So, when it becomes deformed it actually generates an electric field inside and that leads to you know accumulation of charge on the two sides. Obviously, that will give you some voltage difference because the electric potentials becomes different at the two ends. So, it is this voltage difference that is to be sensed or the charge which is to be sensed, right.

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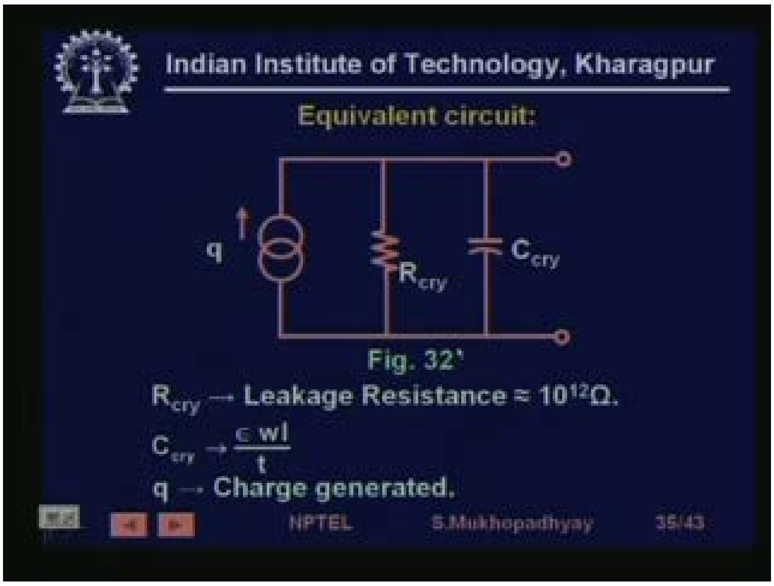

So, if you see the equivalent circuit, then this device can be seen as a can be sometimes seen as a charge generator and why this is happening. So, the model is that, it can be seen as a charge generator in parallel with a resistance cry means crystal. So, in parallel with the resistance and the capacitance of the sensor. This is a leakage resistance that sensor which is generally very high ten to the power twelve ohms and C the capacitance is again this is essentially like a parallel plate capacitance. So, it is given by you know epsilon a by t, a is width into length. So, therefore, epsilon w l by t.

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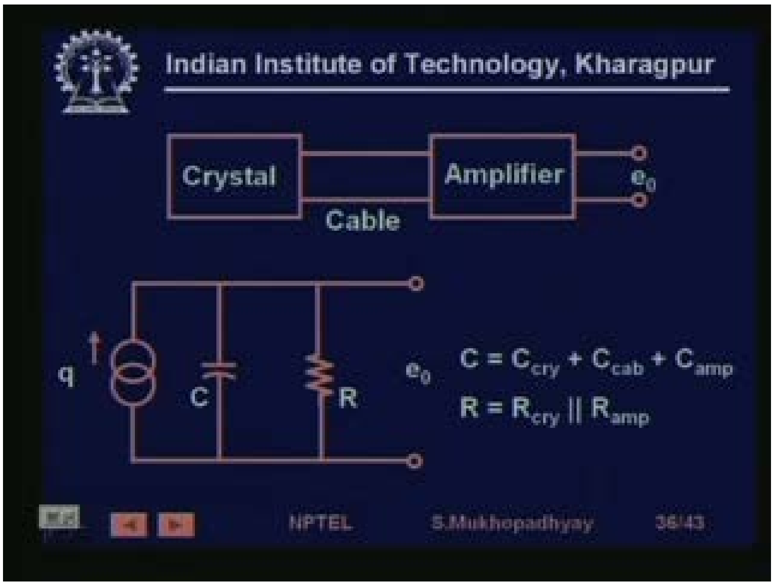

Now, this crystal it will now generate a charge and a voltage or a voltage and just to be sensed. So, it has to amplified obviously, to some voltage which is measurable. So, this crystal is to be connected by a cable. So, now it turns out that that the movement you connect this cable. This cable also has some capacitance. So, because of this capacitance the circuit equivalent circuit previously which was C crystal and then R crystal. Now, this C and R will change because the cable.

If you have a long cable then you have a distributed capacitance to ground. So, now, this capacitance will actually come in parallel with the crystal capacitance. Similarly, this amplifier resistance will also come in parallel with the crystal resistance.

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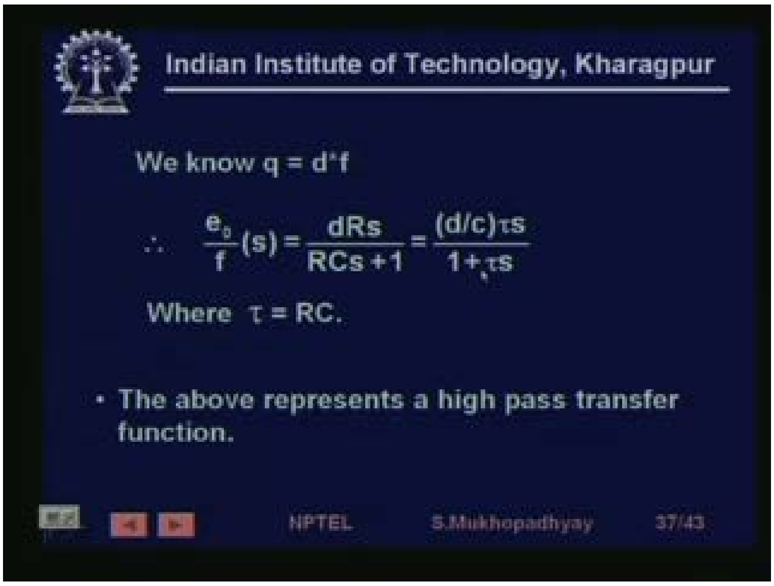

So, what will happen is that, you can it turns out it turns out that the, if you are talking of a force and if you say that the charge generated is actually proportional to the force applied on the crystal. Then dynamically it you can see that, the EMF generated by the force. Force is like acceleration you know if some mass is actually accelerating then the then the force applied on the crystal will actually be proportional to the acceleration.

So, therefore, you can see that the amplitude of the output voltage not only that the see that, this is the time constant of this transfer function depends on RC, but it is sensitivity also depends on C right. So, if the C changes. So, if you now connect a higher length cable then the sensitivity which is going to change which is a very you know very undesirable situation. So, therefore, this is the first point.

The second point is that this is a high pass transfer function. Therefore, DC forces constant forces, if you apply a constant force there is not going to be any EMF. So, therefore, these kinds of sensors are not used for measuring constant forces, that is why they are used for measuring vibration where you have high frequency oscillations.

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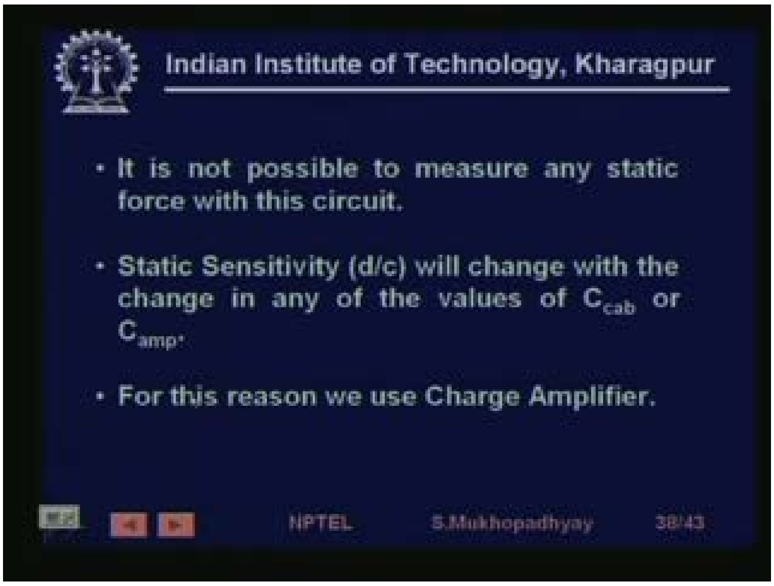

So, it is not possible to measure static force with the circuit and static sensitivity will change as I said. So, we often use a circuit which is known as a charge amplifier.

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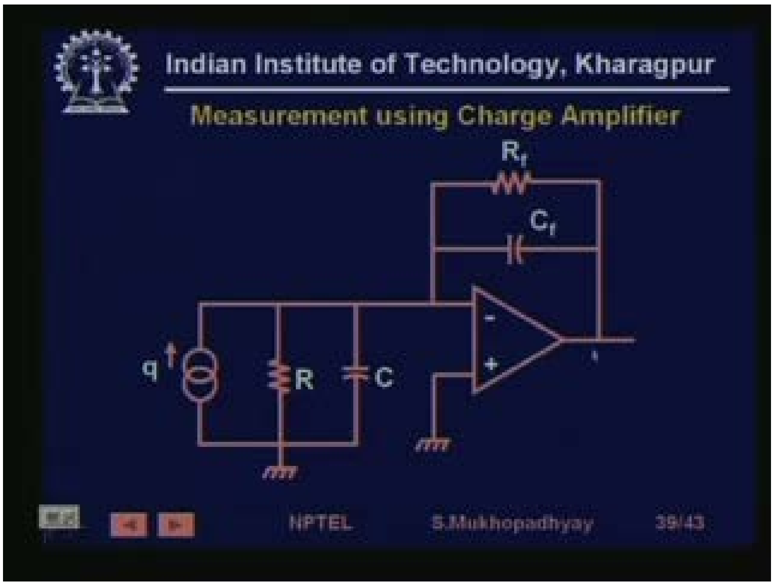

So, it can be shown that, in this circuit because of the fact that this potential is actually at 0 because of the virtual ground property of the operational amplifier, it can be shown that the this circuit behavior is actually independent of this capacitance. So, the static sensitivity you have, you can actually variation static sensitivity can be avoided. So, that is why charge amplifiers are widely used with piezoelectric crystals.

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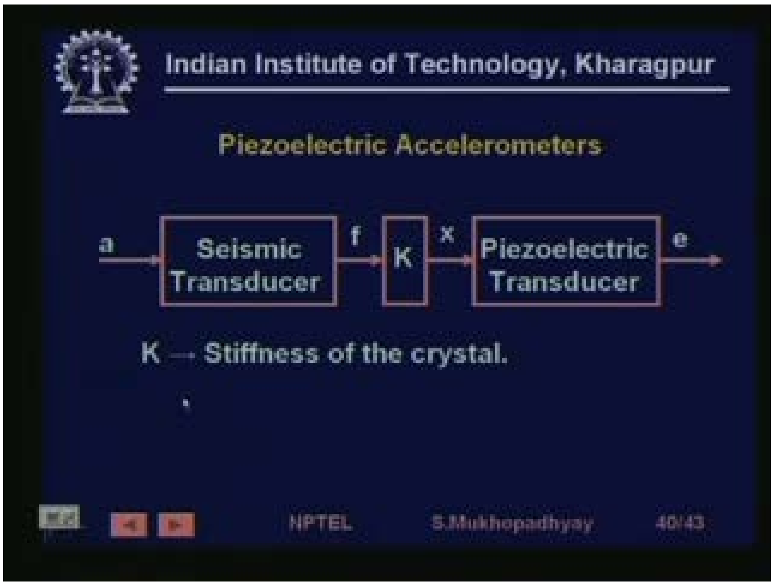

So, basically we have if you have the in piezoelectric crystals we have the acceleration which is sensed by a seismic transducers. So, the seismic transducer mass actually apply the force f on the crystal. So, with this creates a displacement depending on the spring constant and that creates an EMF. So, that this EMF is now to be processed by a suitable circuit like a charge amplifier.

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So, this is what we have briefly covered some we have basically taken a glimpse through some methods of position and velocity measurement, which are used in the industry. So, let us look at the summary. So, we are looked at position sensing and we have seen in inductive resistive and capacitive ways of position sensing. We have seen velocity sensing, we have looked at electromagnetic methods of velocity sensing, we have looked at optical methods of velocity sensing. We and we have seen acceleration sensing where we had basically looked at piezoelectric and also one electro dynamic method. So, this has been a quick view through motion sensing.

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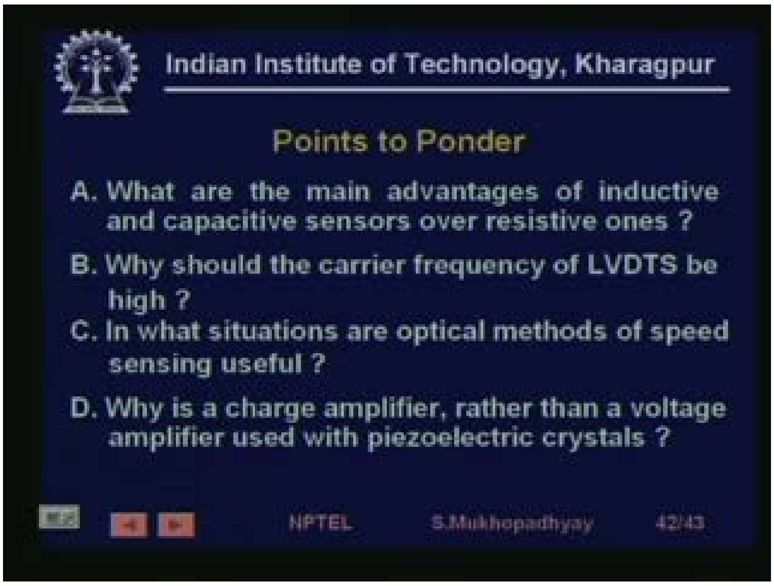

Coming to points to ponder. What are the main advantages of inductive and capacitive sensor over resistive ones. So, you can understand that it is very clear. Why should the carrier frequency of a LVDT is be high. So, you can again, you can try to figure out that what happens if the carrier frequency is low. In what situations are optical methods of speed sensing useful. This is also an interesting question. Finally, why we you must use a charge amplifier rather than a voltage amplifier with a piezoelectric crystal. You can you can try to look for these answers, and then I think you will learn slightly deeper.

So, thank you very much. We end here today.