Industrial Instrumentation
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Lecture - 6
Torque Measurement

Good afternoon! This is lesson 6 of Industrial Instrumentation. In this lesson, we will cover the torque measurements. As you know, the torque is very important parameter. Even though it is not exactly the process parameter, but it is also a parameter which is, these are paramount important for the, most of the, most of the mechanical measuring systems, where there, wherever there is a shaft, rotating shaft, so there is a need to measure the torque, I mean developed in that, in the, in the, in the shaft, because it is necessary to know that, know the optimal force up to which that shaft can withstand. So, it is necessary to measure the torque in the system, so torque in the shaft. So, for that reason, we have to measure the torque in the shaft.

So, there are various techniques of measuring the torque. Now, we will discuss in brief two measure, two techniques and we will discuss the details one of the most modern technique and its signal conditioning circuitry, which are actually used in the, I mean in the industry.

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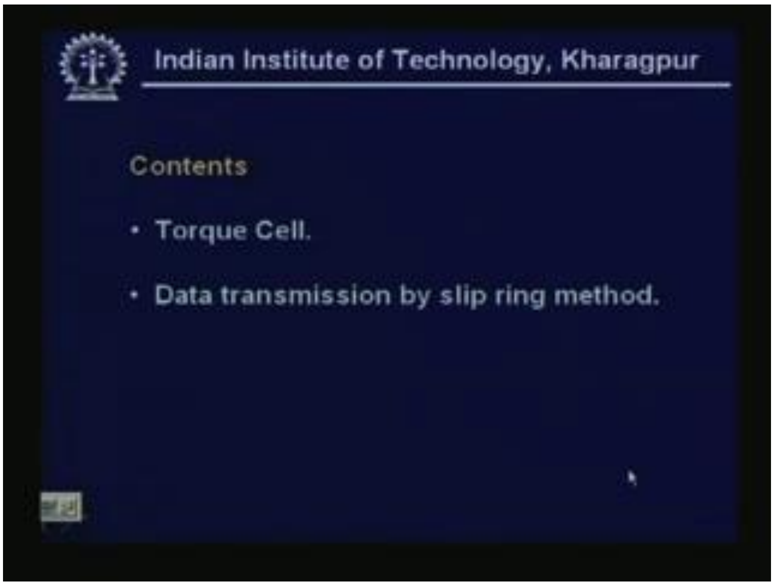

Its contents - the torque cell, data transmission by slip ring method. Torque cell means it will cover all the three different cells and when the question of data transmission comes, it is basically the third type of torque cells which we will discuss, which is based on the strain gauges. So, it is concerned with the third type of torque cell or torque measurement techniques and wireless data transmission. There is, one is the slip ring method, then there is wireless data transmission. This we will discuss in details.

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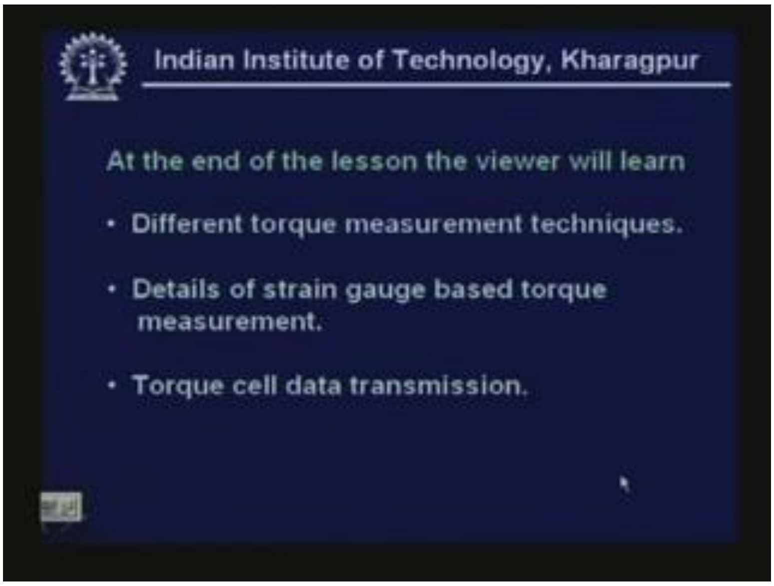

At the end of the lesson, the viewer will learn the different toque measurement techniques, details of strain gauge based torque measurement, torque cell data transmission.

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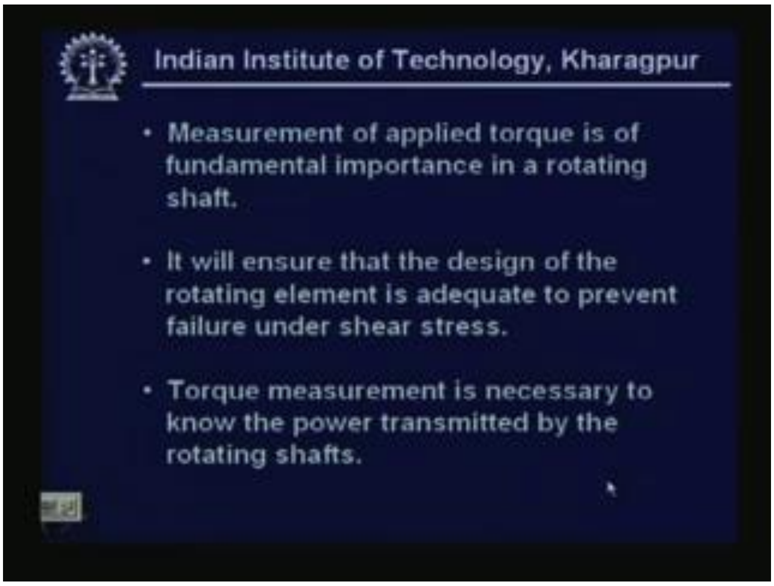

Now you see, the measurement as I asked you, I mean told you earlier, the measurement of applied torque is of fundamental importance in a rotating shaft. It will ensure that the design of the rotating element is adequate to prevent failure under shear stress, because you see it is a rotating shaft, so always there will be some shear stress will be developed. So, we must know that how much is of, what is the optimum, I mean shear stress which the shaft will withstand and before, I mean failure. So, for that reasons we have to measure the torque.

Now, torque measurement is necessary to know the power transmitted by the rotating shafts also. These are, I mean need of the torque measurement.

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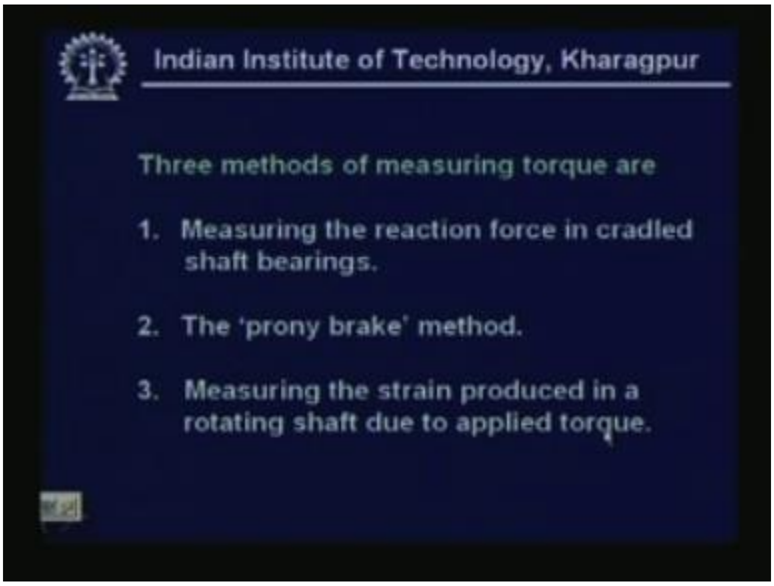

There are three methods of measuring torque and these are measuring the reaction force in cradled shaft bearings. This is one of the methods or I should say the prony brake method. Then we have, sorry, these are the, this is basically cradled shaft bearing and the second is the prony brake method and third is the measurement, measuring the strain produced in a rotating shaft due to applied torque. This is basically based on the strain gauges. This, the third one, we will discuss in details.
This one we will discuss, this one, third one we will discuss in details.

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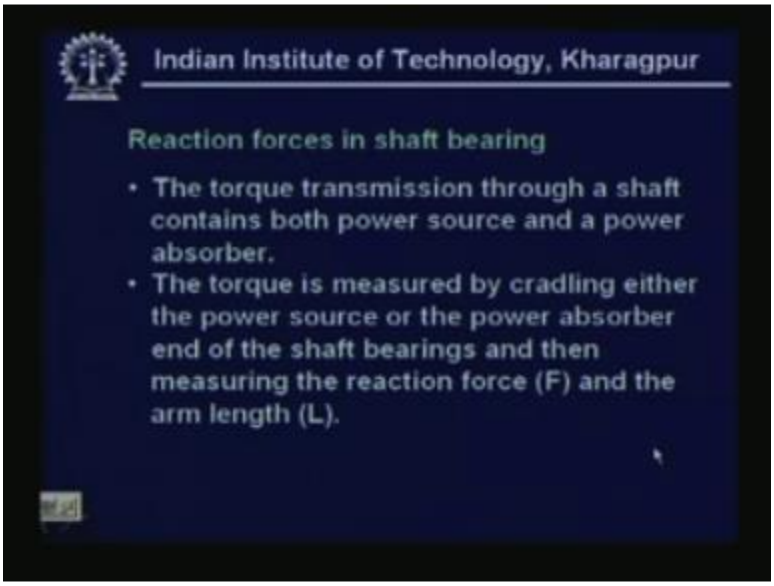

Now, reaction force in shaft bearing, you see the torque transmission through a shaft contains both power source and a power absorber. There must be a power source, it must be some motor through which the power is coming and it is transmitted to some other, suppose somewhere in the some lath machines or some other devices, so that is the power absorber. Now, the torque is measured by cradling either the power source or the power absorber end of the shaft bearings and then measuring the reaction force F and the arm length L.

Now, the torque will be given by F into L. So, you must know F and we have already, L is fixed, so we will know the L, measure the L, we will measure F and this will give you the torque.

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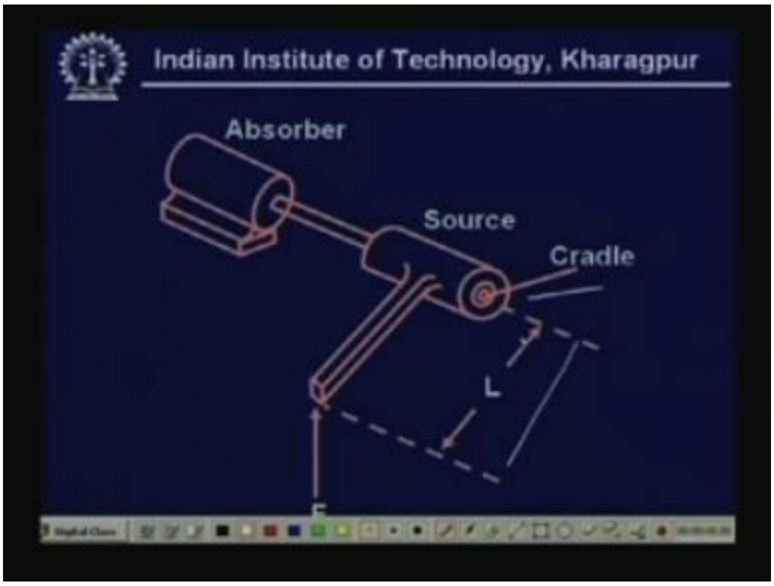

Now, this is, you see this is our, this is our cradled system. You see, here we have a absorber and we have a source and we have a cradle. You see, here this length is L. So, if you know L and if I know the force F, this is the Force F, so I can measure the torque. This is one of the oldest methods of measuring the torque, right?

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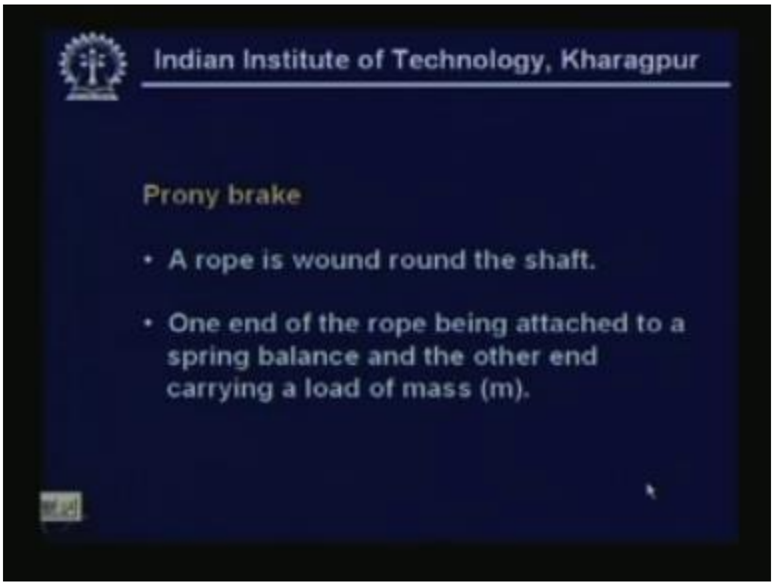

Now, prony brake method is basically, a rope is wound round the shaft and one end of the rope being attached to a spring balance and the other end carrying a load of mass m, right?

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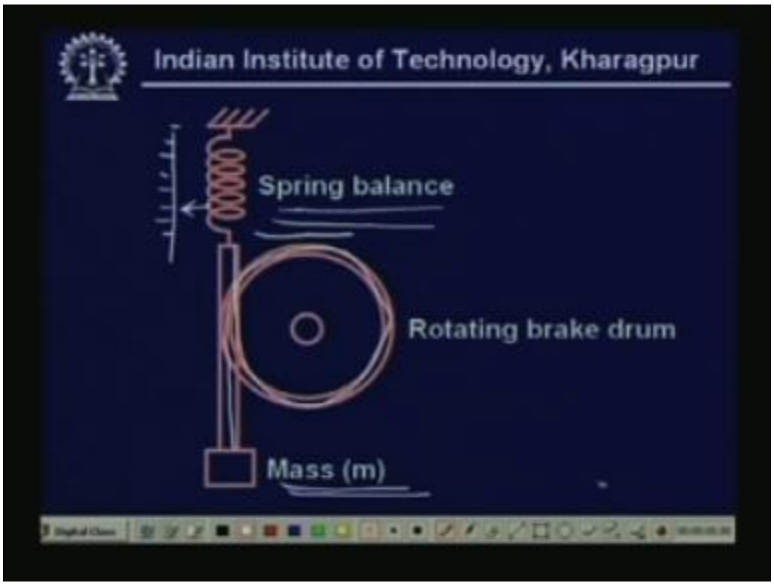

So, it looks like this. You see that we have a spring balance here and sorry, we have a spring balance and then, it is rotating. Actually the, this should be little thinner, so it should be the very … like this one. It is wound like this and it is coming like this. So, it is little bigger and mass m is installed in one end and the spring balance is installed in the other ……. This spring balance is graduated, so it is moving on a scale like this one; has a conventional spring balance system, right?

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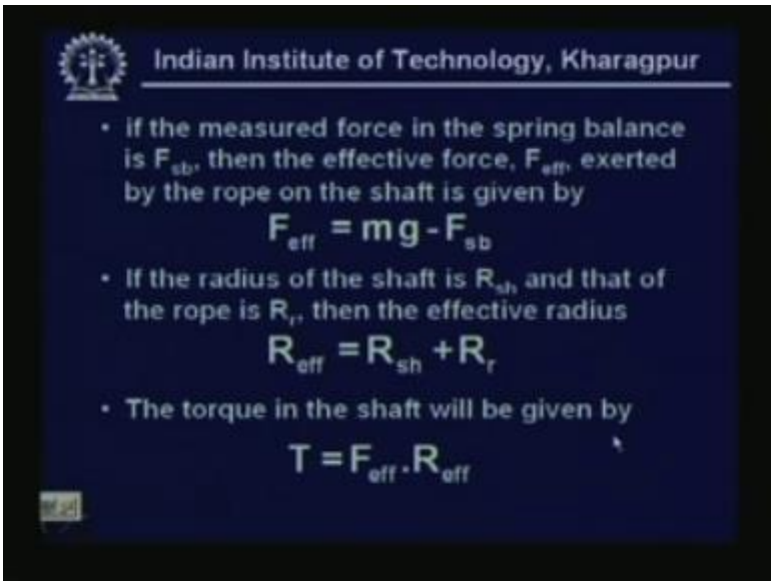

Now, if the measured force in the spring balance if F sb, then the effective force F eff exerted by the rope on the shaft is given by F eff that means F subscript eff equal to mg minus F sb, where F sb is the measured force, right? If the radius of the shaft is R sh and that of the rope is R r, R subscript small r, then the effective radius is R effective equal to R shaft plus R r, radius of the, radius of the shaft and radius of the rope. So, if it is there, then I can write, the torque in the shaft will be given by T equal to F eff into R eff. Obviously, it is in Newton meter, right?

Now, one of the most convenient, because you see, in all the previous cases of, both the cases prony brake and the cradled systems, so we do not have the, the output is not electrical. It is a mechanical output. It is very difficult to, I mean convert that type of mechanical signal in the electrical domain and in all, you know, in the instrumentation system we always prefer the electrical signal, because it can be transmitted easily. It can be converted to the current domain, it can be transmitted over a long distance, it can be digitized; all those advantage is there in the electrical system. So, always we prefer the electrical system, where in instrumentation system where the output is electrical.

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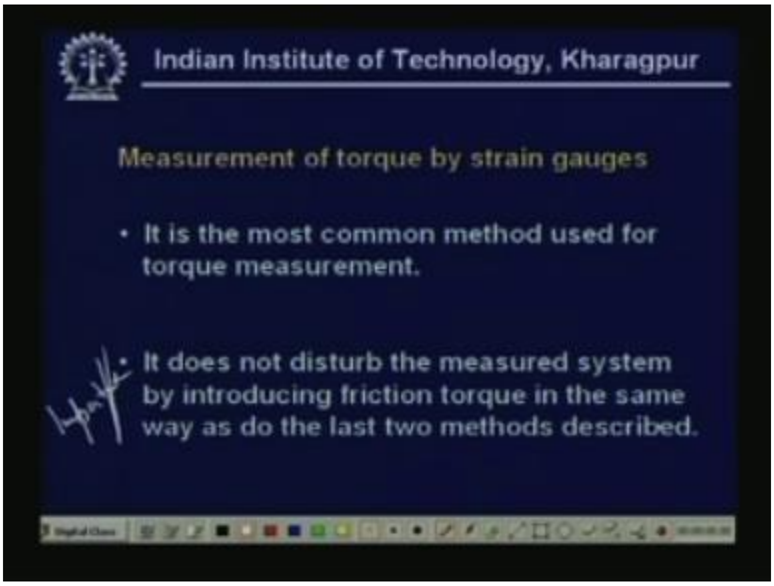

In this case, in the measurement of torque by the strain gauges, you see basically the four strain gauges are used, right? 4, I will show the diagram just now. Four strain gauges are used, because if the, if the torque is rotating, so there is some amount of shear stress on the torque. So, we will measure that shear stress and find the torque, right and then we will put the strain gauges. There are four strain gauges, as you know, the four strain gauges is always necessary to make the temperature compensation as well as the large bridge output. So, it will be, I mean we will, it is converted to the electrical domain.

So, this will be connected to a Wheatstone bridge and we will get the unbalanced voltage. That unbalanced voltage will give, will be calibrated in terms of torque. So, basically whenever we are talking of the sensitivity and all these things, so please note that we are considering the, this torque cell as well as the assembly, entire Wheatstone bridge assembly. So, it is the torque cell Wheatstone bridge assembly we are talking about, not the torque cell only or the Wheatstone bridge alone, clear?

Now, it is most common method used for torque measurement. As I told you, this is a very common method. It is widely accepted method of torque measurement and it does not disturb, this is the most important thing, this, I mean this third point is most important, I think this point is very important; it does not disturb the measured system by introducing the friction torque in the same way as do the last two methods described. Because you see in the last two methods, basically we are …., we are not getting the actual torque truly. If you look at, because we are introducing certain amount of torque, because we are introducing certain amount of frictions, so the, so it will introduce certain amount of torque. So, we are not getting exactly the value of the torque in that above measurement systems, right?

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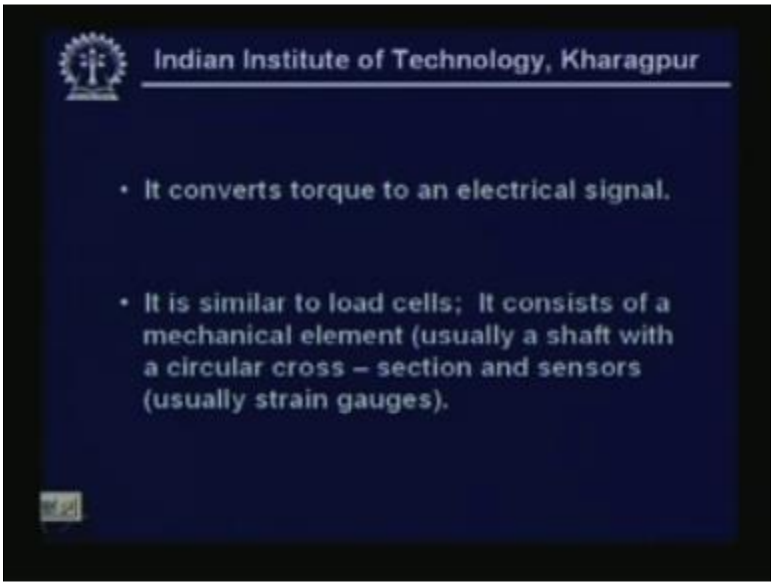

It converts to an electrical signal; it converts the torque to an electrical signal. It is similar to the load cells. We are, we have studied the load cells, load cells it consists of a mechanical element. Usually we have seen the load cells of the link, unit link column type load cell. We have seen the beam type load cells. In all these different cells we will find that that we are using strain gauges. It is similar thing; on the wall of the shaft the strain gauges are to be installed. It is similar to the load cells. It consists of a mechanical element, usually a shaft with a circular cross section and sensors, usually strain gauges.

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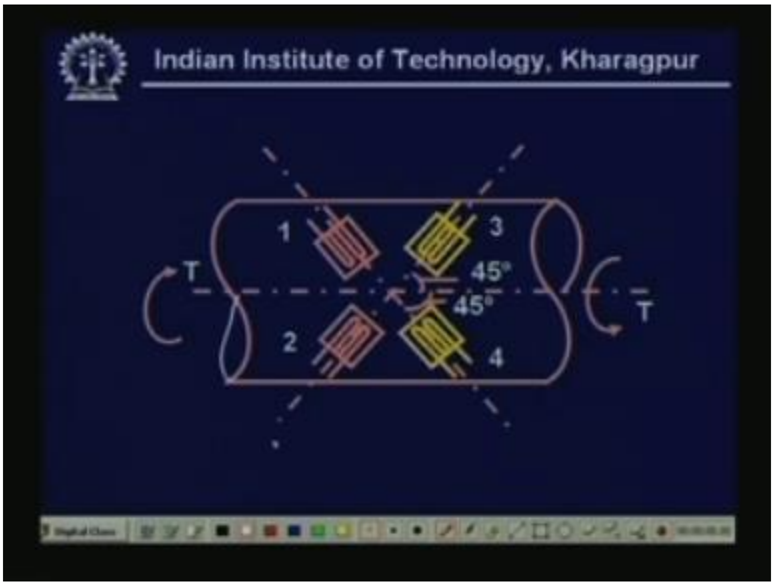

You see, this is our typical strain gauge, this is our typical, I mean measurement systems. It is actually a shaft. We have taken a section of the shaft, so this should actually go like this one, a section on the shaft and the four strain gauges are installed on a 45 degree helix, right? Actually, if I say, it will look like this.

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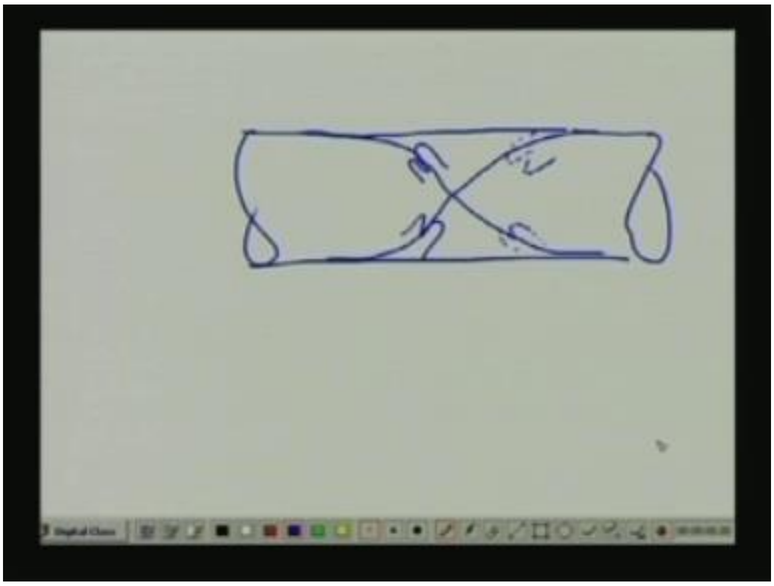

If I take a blank page, you see here actually this, if I take the shaft like this one, these strain gauges are installed on a 45 degree helix. It will look like this one, right? So, the four strain gauges here, these strain gauges you cannot see from this side. It is in the other side of the shaft, so we cannot see this. So, that is the reason I have …. dotted. So, this will give you the four strain gauges. Let us look at that.

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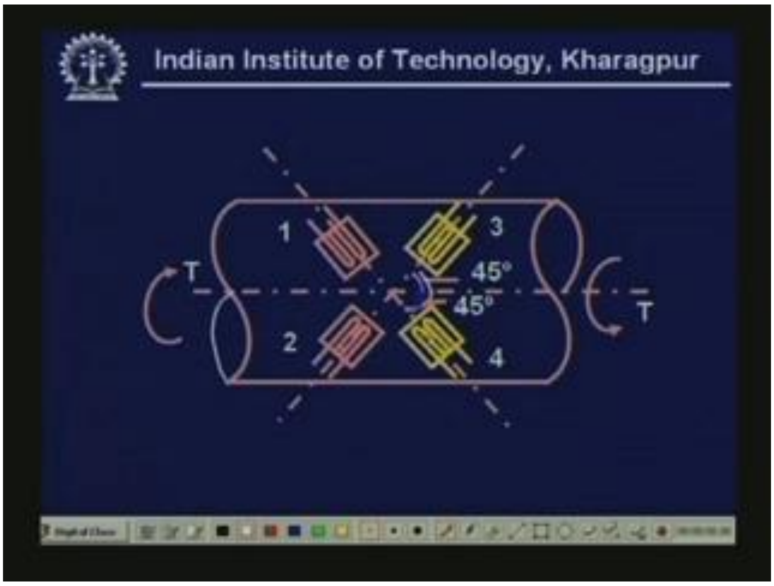

Yes, you see here that this is our, you see that this strain gauges 3 and 4 you cannot see. This is the 45 degree helix and you see here this is the 45 degree, this is the 45 degree angle. It is coming up. This is 45 degree. This is also 45 degree, 45 degree helix. This is 45 degree, this is also 45 degree and these 3 and 4, you cannot see from this side, right? It is on the other side of the, that is the reason we have drawn it different with different colour, right and so, I should draw here, fine, strain gauges 1 and 2 and 3 and 4, right?

Now, let us look at, so this is the, installation of the gauge is very important, because it will, if it is, I mean not in the helix, we can write, cannot write the, actually the equations of this output voltage for the torque cell.

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The four strain gauges are mounted on two perpendicular 45 degree helixes, as I told you and the strain gauges 1 and 3 are mounted on the right hand helix and these are under elongation. Please note these strain gauges 1 and 3 are mounted on a right hand helix. These are under elongation. Strain gauges 2 and 4 are mounted on the left hand helix and these are under compression. So, we have seen also in the previous cases, when the two strain gauges are under elongation and two strain gauges are under compression, we can put a …. in such a way that the, our b output will be, will be quite large. If it is not four types it can be quite large, because all the strain gauges are active.

You see that I can measure in all the previous cases also. In that lesson we have seen that we can use the single strain gauges, but we are using multiple strain gauges to maximize the output voltage, right. So, strain gauges 2 and 4 are mounted on the left hand helix and these are the compressions and the strain gauges 1 and 3 are mounted on the right hand helix and these are under elongation.

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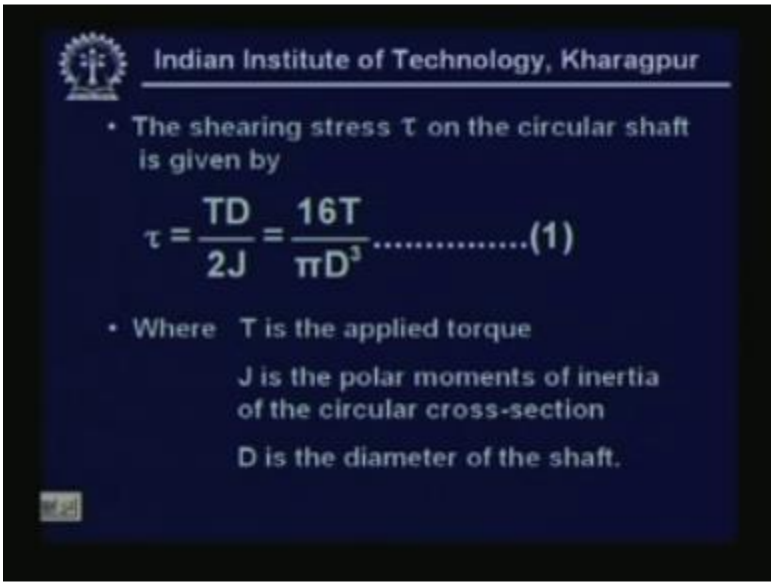

The shearing stress tau on the circular shaft is given by tau equal to TD by 2J, which is equal to 16T by pi D cube. This is equation number 1, where T is the applied torque, J is the polar moments of inertia of the circular cross-section and D is the diameter of the shaft, right? If you put all these things, I can get the shear stress and we assume that the, all the normal stresses are zero in these cases.

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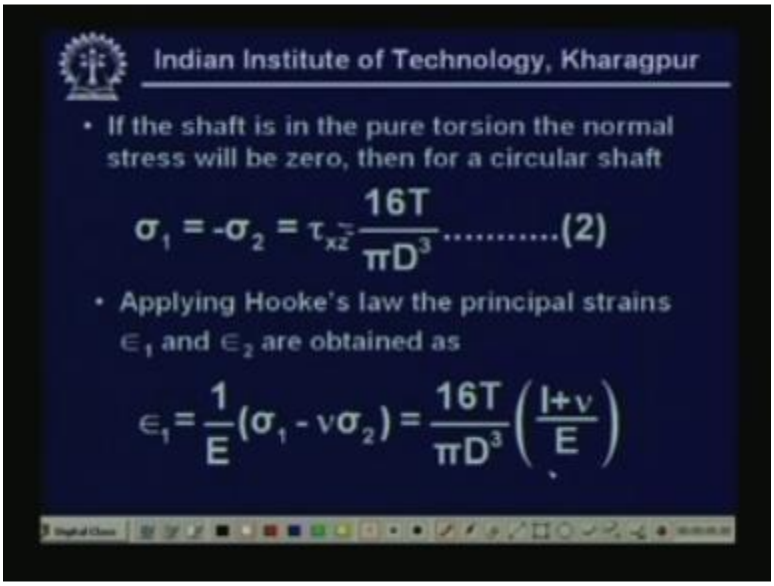

If the shaft is in the pure torsion, the normal stresses will be zero. Then, for a circular shaft we can write sigma 1 and sigma 2, sigma 1 minus sigma 2 equal to tau xz. I think this will be equal to, sorry, this will be, this is will be equal to, so applying Hook' s law, the principal strains epsilon 1 and epsilon 2 are obtained as epsilon 1 equal to 1 by E sigma 1 minus nu sigma 2 16T pi D cube 1 plus nu into E, right?

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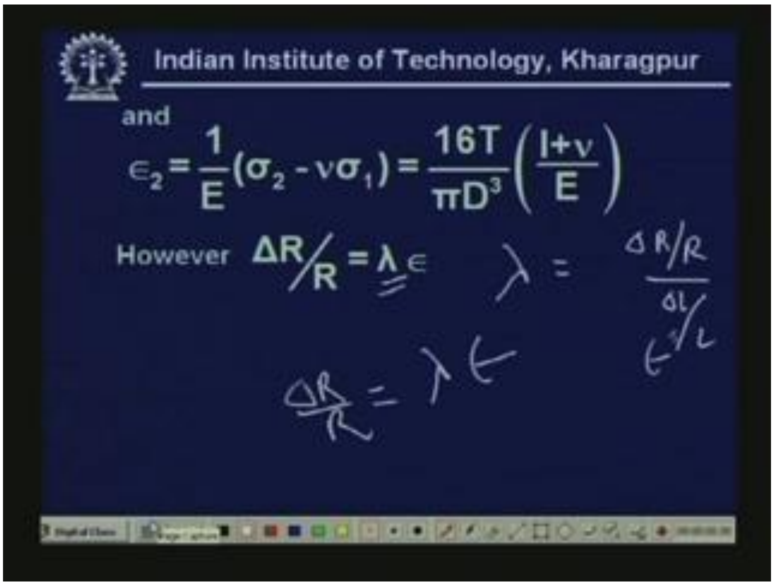

Epsilon 2 equal to 1 by E sigma 2 minus nu sigma 1 equal to 16T by pi D cube 1 plus nu divided by E. However, delta R by R, I mean R equal to lambda. This is actually, delta R by R is the change of resistance. So, as you know the definition, from the definitions of the gauge factor, because as you know this is the gauge factor. Gauge factor is actually defined as delta R by R by delta L by L; we have seen this thing, right, so which will give you, so this is epsilon. This is equal to epsilon. So, I can write that delta R by R equal to lambda into epsilon, is not it?

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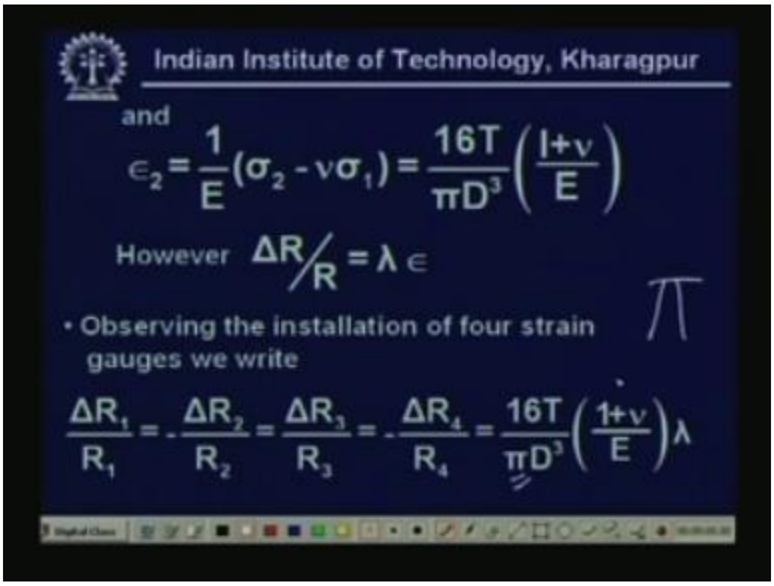

So, observing the installation of the four strain gauges, if you, we look at the installation, because we have seen that the delta, I mean strain gauges 1 and 3 will be under elongation. So, it will, sense the positive strain and strain gauges 2 and 4 under compression, so it will, I mean sense the negative strain. So, what will happen? You will find that the delta R 2 by R 2 will be negative with respect to delta R 1 by R 1. So, we have written the equation, delta R 1 by R 1 equal to minus delta R 2 by R 2 equal to plus delta R 3 by R 3 equal to minus delta R 4 by R 4 equal to 16T pi D cube multiplied by whole 1 plus nu by E minus into lambda. This is pi, please note and it is not in math mode, so actually it is the pi like this one.

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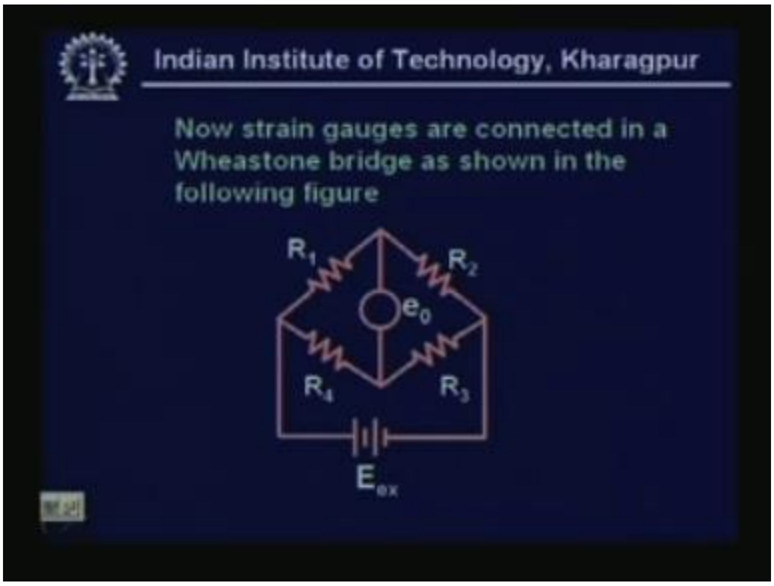

Now, the strain gauges are connected in a Wheatstone bridge, as shown in the following figure with all the strain gauges. You see, this is a strain gauge. We have, you see, this is, that I mean connecting the strain gauges in the Wheatstone bridge is very important. So, that suppose if the very common question regarding the case of link type load cell that, if we, what will happen if you, if you connect, if you interchange between R 2 and R 3?

So, it will to be a problem, because in that case what will happen? You see, in that case, R 1 and R 3 both will increase and R, R if I interchange, I am talking about if I interchange R 2 and R 3 what will happen? You will see that in that case both R 1 and R 3 will be under elongation, R 2 and R 1, R 2 and 4 will be under compression, right? So, the unbalanced voltage will not be there, so this will create problem. So, for that reasons we have connected like this.

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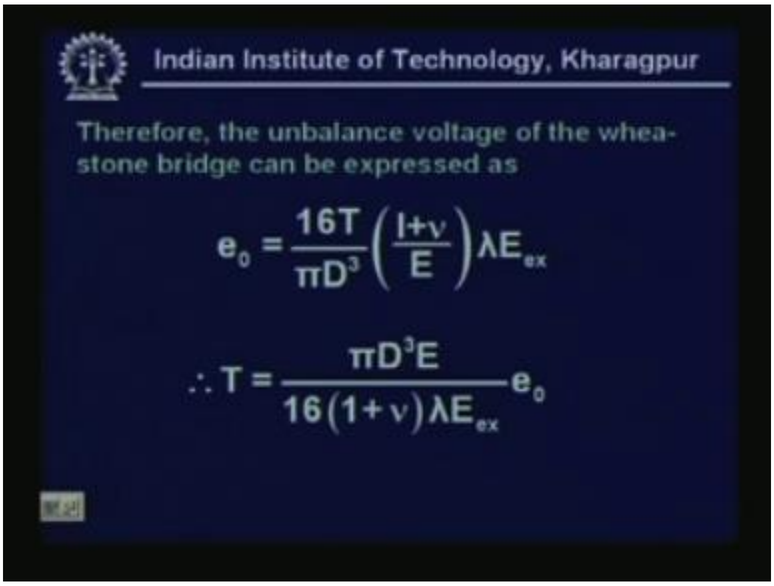

Therefore, the unbalanced voltage of the Wheatstone bridge can be expressed as you see here; e naught equal to 16 T by pi D cube into 1 plus mu divided by E lambda E into E ex. So, what are the relations? You see, the relations are important, I am sorry.

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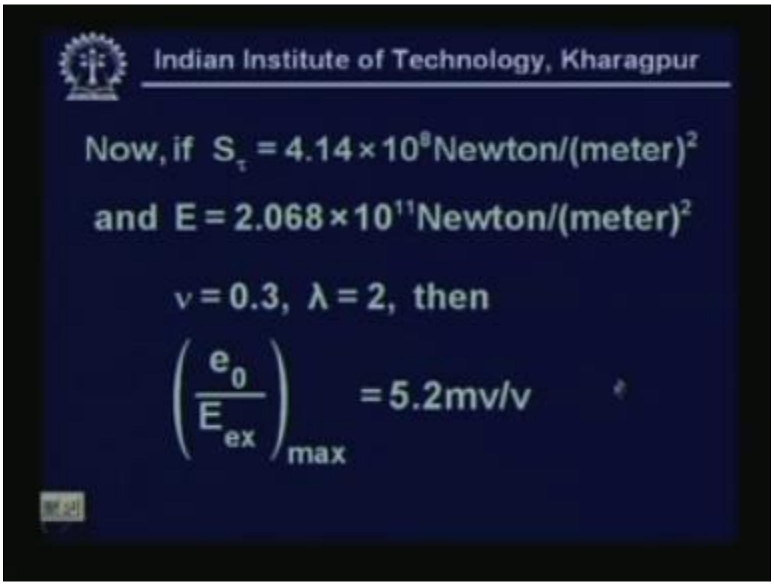

This is the sensitivity of the torque cell. So, if I go and S equal to e naught by T equal to 16 1 plus mu lambda E ex, you see, if you look at, these are, these, this excitation voltage of the Wheatstone bridge, this young's modulus of the elasticity, D is the diameter of the, diameter of the shaft, mu is the Poisson's ratio of the ( ) of the shaft and lambda is a gauge factor of the strain gauges, whatever the strain, I mean gauge factor we will use and so, you see that these are sensitivity that means for unit change of torque, How much the output voltage I will get in the Wheatstone bridge? These are sensitivity of the torque cell and the Wheatstone bridge combination.

Now, obviously what we will see? You see that, (( )) you will, you can increase the sensitive by increasing the excitation voltage, by increasing the lambda. That means increasing the, choosing the type of strain gauges which is, which are the higher level. As you know, the lambda varies little bit, when varies from 2 to 4, usually, from the, for the metal wire gauges; whether it is does not matter and if suppose, if you take advance it will be lambda equal to 2. If you take (( )), it will be equal to 3 by 5 and if you take (( )) and all these things, you, you will get the lambda equal to four point something, 4.1 or something.

So, it is not, does not vary much, until unless if we use the semiconductor strain. Semiconductor strain is not suitable for this type of operation, because large vibrations and all those things are there. So, I can increase. So, lambda do not have much choice. So, either 2 or 4 and in the excitation voltage, as I told you earlier also, we cannot increase the excitation voltage, because it will increase the dissipation in the individual strain gauges. So, now all the strain gauges has some limitation that means how much power you dissipate.

It is, ultimately it is a resistance. So, obviously the how much power it can dissipate, you must be calculate, right? So, depending on that you can optimize the value of the excitation voltage in the Wheatstone bridge. Obviously, if I can reduce the D, obviously the and E the young’s modulus velocity, your sensitivity it will be decreased, but reducing D and reducing E obviously we will decrease the range of the torque cell, right.

Now, see the sensitivity of the range of the torque cell will be given by pi D cube. This is the T max, the maximum value of the torque pi D cube by S tau by 16, right? So, if you reduce, you see here, if you reduce D, obviously what will happen that the value of the, value of the maximum torque also will be reduced. If you reduce E, at the same time S tau also will increased. So, obviously T max also will reduced. So, we have to make the compromise between the sensitivity and the range of the torque cell, right.

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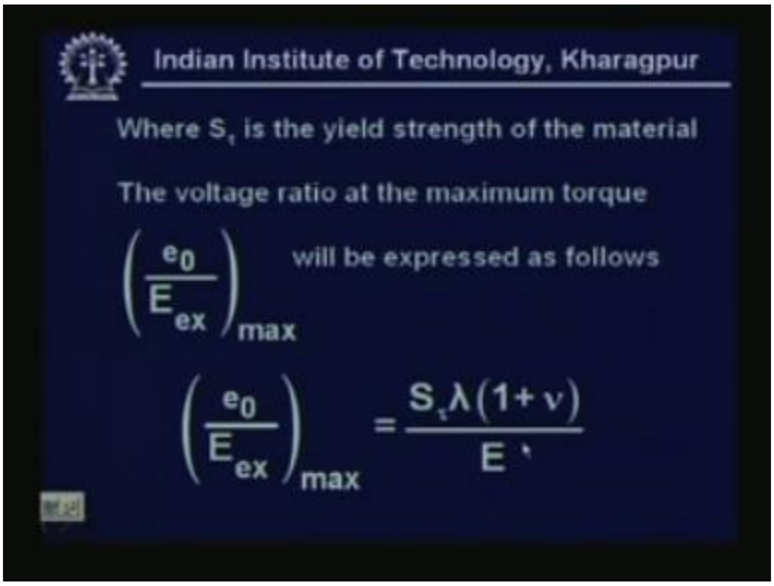

Now, where S tau, which was in the previous equation, it is the yield strength of the material, right? The voltage ratio at the maximum torque can be given by e naught upon E subscript ex maximum, will be expressed as follows is e naught by E ex max equal to S tau lambda 1 plus nu upon E, right? S tau is the yield strength, lambda is the, your gauge factor 1 plus nu. Nu usually varies, it, it is around .3 and E is the young's modulus of velocity, right?

So, it will give you the maximum voltage for a particular value of the excitation, what can be the maximum voltage output for the particular value of the excitation, right? So, we will show one example by which you will know that how much will be there? Suppose for 10 volt power supply, how much will be the value of e naught, maximum value of e naught, right? So, here as we can see that if increase the, if I increase, decrease the, decrease the E or decrease the S tau, so obviously what will happen? The maximum voltage also will decrease.

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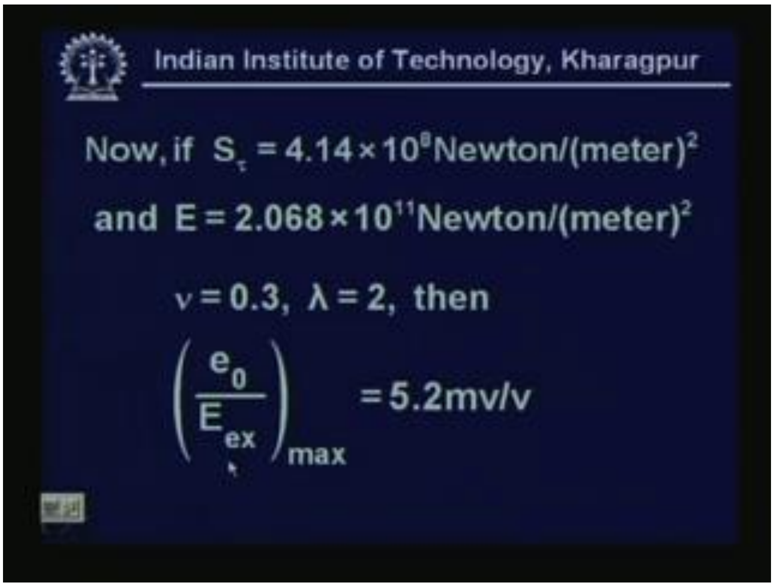

Now, we have taken an example. If S tau is equal to 4.14 into 10 to the power 8 Newton per meter square, Young's modulus velocity, it is 2.068 into 10 to the power 11 Newton per meter square, where nu is .3, is a Poisson's ratio and lambda equal to 2, then e naught equal to E ex, I can write maximum, equal to 5.2 millivolt per volt, right? So, it will give you the 5.2 millivolt per volt. So, you can say that if I have a 10 volt power supply, so if I have a 10 volt power supply, so I will get a 52 millivolt maximum output from the, from the load cell.

Now, data transmission is most important. It is not very important in the case of the other cell like your link type load cell or the load cell I am talking about the link type load cell or the beam type cell, because these are stationary, whereas in this case, you see, all the strain gauges, the power supply, especially strain gauges is to be rotated at the same speed, because these strain gauges is to be cemented on the shaft and it is rotating at the same speed as the, as the shaft of the, shaft of the machine. So, it is very much necessary to give the power supply, because if whenever we are using any Wheatstone bridge, we have to give the power excitation voltage to the bridge as well as you have to take out the unbalanced voltage from the bridge. Whether you are using an unbalanced, it is, does not matter, so we have to take out the unbalanced voltage from the bridge. So, there are two methods - one is the slip ring method.

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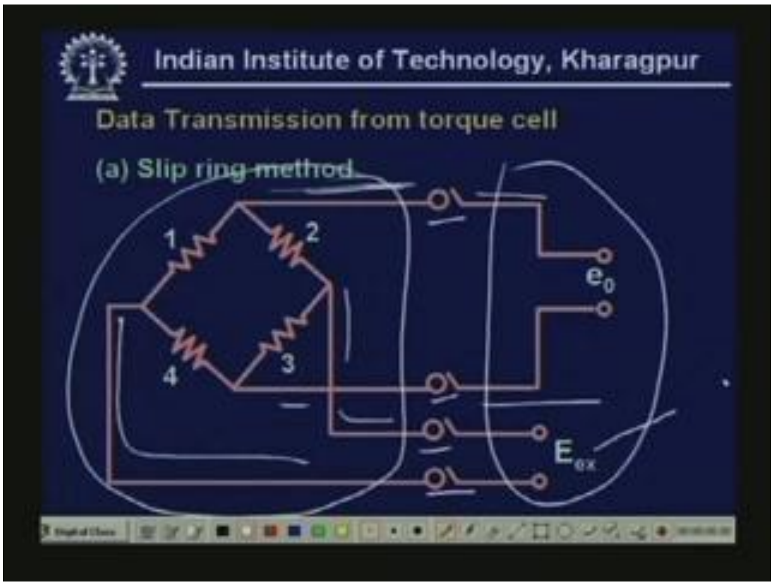

Slip ring method is very common and other is the, other is the wireless telemetry system. Now, slip ring method is convenient, because people work on the slip ring for quite a long time and the telemetry method is rather new in that sense, right? Now, you see here that this is basically a slip ring method of the torque measurements. We have the same three strains. These are all installed on the torque cell. Please note these are all 1, 2, 3, 4 are all installed on the strain gauges on the, on the torque cells; with the usual cement and all these things you must install the gauges and we have the slip rings.

These are the basically slip rings; you can see this is, are the slip rings; four slip rings are there. So, through this I am giving the excitation voltage. So, this slip ring excitation voltage is there and through other slip rings, through this, ….. the slip rings. Because this part is rotating and this part is supposed to be stationary, this part should be stationary and this part should be in rotating, right? Because it is on the shaft itself, so through slip rings we have to take out.

Now, there is a typical problem in the slip rings, because you see the contact resistance varies and as I told, you cannot increase E ex, because that will control the dissipations in the, in the sensor itself. So, we have to limit the value of E ex. So, when the contact resistance varies what will happen? The current will also vary, so which will lead to the noises in the system. This is one problem with the cases of the slip rings. We have to use some special materials and we have to use some special, I mean some optimum forces we have to apply, so that the, there is no variation of the, no more variations of the pressure or because, because ultimately it is a brush and springs, so that you know variations in the pressure, so all these things you have to look at, only then you will get the value of the e naught which is noise free, right?

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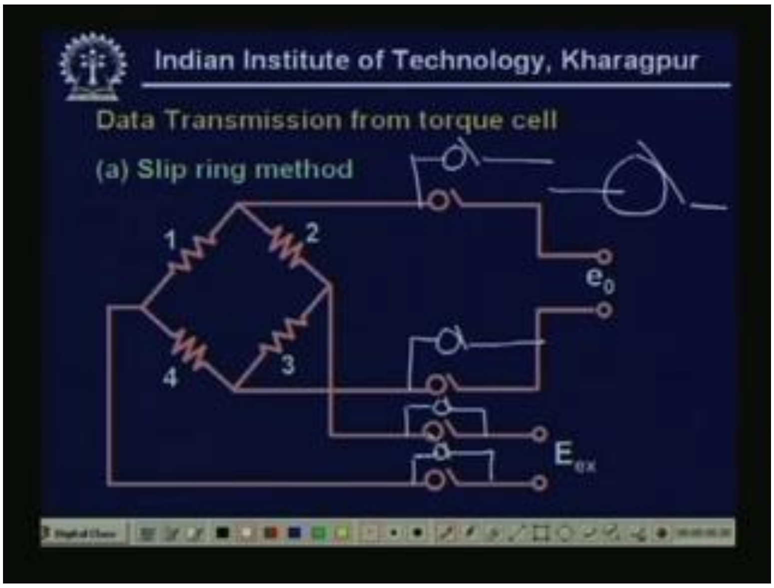

So, this basically, you can use another slip ring also like this one; so you can use another one. So, this should be in contact actually, it should be like this one, like this one, please note, right? So, this will go like this one, so I can have all the four, I mean I can have all. So, it is the current in, in each ring, right? If the current is large, so we can, usually in the DC machines and all these things, we give the power like this, so same principle is used, see, because we have the same technology we know, so based on that we have developed these type of systems, right?

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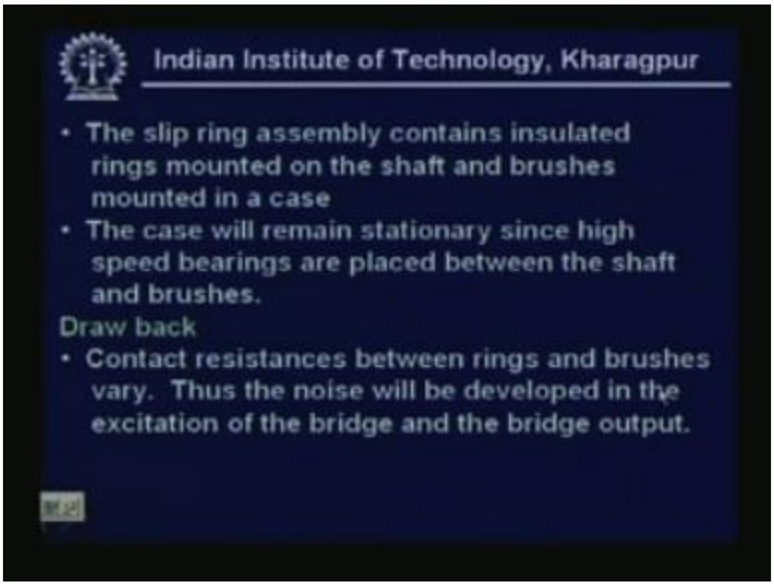

Now, the slip ring assembly contains insulated rings. Now, the details of the slip rings method - the slip ring assembly contains insulated rings mounted on the shaft and the brushes mounted in a case. The case will remain stationary, since high speed bearings are placed between the shaft and brushes, right? The drawback, as I told you earlier, the contact resistances between the rings and brushes vary. Thus the noise will be developed in the excitation of the bridge and the bridge output, because the, both the, you see, whenever taking, I am sorry that is we are talking not only about the bridge output, even your excitation voltage will also contain noise, right? There will be, further noise will be added when you are taking out the unbalanced voltage. That noise will be already present in the unbalanced voltage.

Noise present means whatever the noise entering the, even though you are supplying, giving the supply from battery, so those slip rings will introduce some noise which is going to the, as excitation to the bridge and when you are taking out the unbalanced voltage from the bridge also you will get the, I mean noise; it will be added rather.

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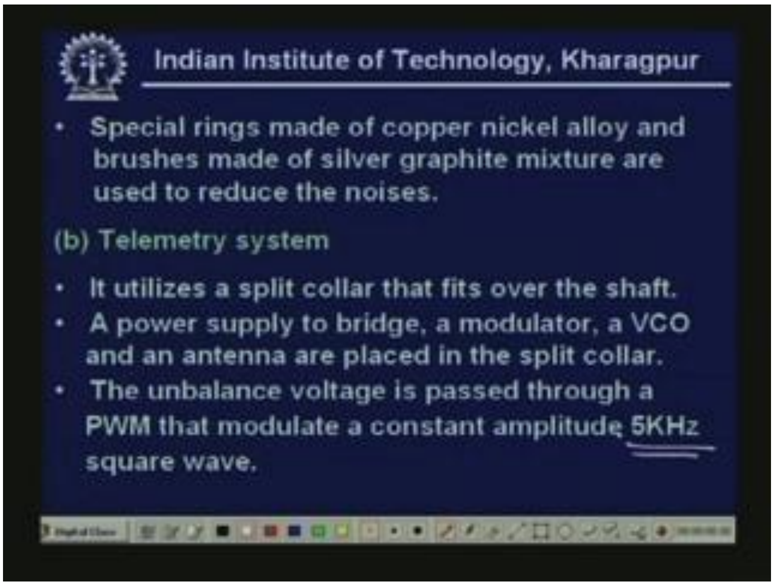

You know special rings made of the copper nickel alloy and brushes made of silver graphite mixture are used to reduce the noises, right? So, there are different special types of, I mean slip rings we have to use, so that the, made of silver graphite and mixtures which is used to reduce the noises. Now, next is coming to the telemetry systems are that systems, which is or a wireless telemetry system, because there is no wire. To avoid all these, I mean because you see that whenever these types of things are there, slip rings has another problem which we have not discussed.

It is prone to very wear and tear after long rotation, after rotation for few days. When the shaft is rotating continuously in the plant, so what will happen that there will be wear and tear. All the brushes will be, will be, I mean there is a wear and tear in the process, so you cannot avoid that. But instead, if I use a telemetry systems or wireless systems, which is totally contactless, so that type of things will improve the, the life of the entire measurement systems. So, I will discuss now the telemetry systems.

Telemetry obviously means the wireless telemetry. It utilizes a split collar that fits over the shaft, right? There is a split collar, which fits over the shaft and a power supply to bridge, a modulator, a VCO; VCO means voltage control oscillator and an antenna are placed in the split collar. So, what are they placed? It is the power supply to the bridge, a modulator, a VCO, an antenna are placed on the split collar. The unbalanced voltage is passed through a PWM pulse width modulator that modulates a constant amplitude 5 kilohertz square wave. You see, this is 5 kilohertz square wave.

Now, what is this? Actually you see that unbalanced voltage is coming. Let us look at some of the, you see, what will happen? So, there are different modulation techniques, as you know that we have, I mean pulse width modulation, we have binary phase shift modulation, so this is one of the modulation techniques.

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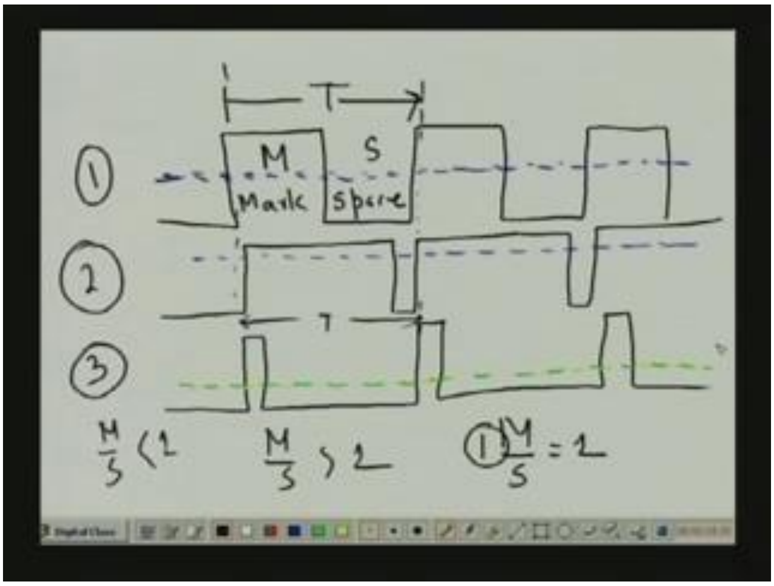

Suppose I have the signal here, sorry, is not it? This is a wave and we can have another wave of, like this, yes or we can have another wave, right? Is not it? You see, here in all the three cases the average value will not remain the same. In this case, the average value will come down here, somewhere here. If I take a different pen, so average value will come down, yes, average value will come down here, you see here. In this case average value will come down here and in this case, average value will come down here, isn't it?

I do not know, it might be not very much visible, so I can take some other pen. You see, the average value is changing in all the three cases, is not it? However, you see this is the time period of your signal. If I take this is the time period of your signal T, you see the T remains constant, right? So, what is varying then? If you can carefully note, in communication system we call it mark. In a wave this is called mark and this is called space, right? This mark to space ratio is getting changed, right?

If mark to space ratio is 1, we call it 50% duty cycle clock, right? If the mark ratio is not 1, so we call it something else, not the 50% duty cycle. M is mark and this is space, right? Now, here you will see that mark to space ratio is 1. Now, in the case, this is the case 1. In case 2, we made M by S greater than 1 that is the average is going up, right? In case 3, you look at very carefully; M by S is less than 1. In all the cases you see, I am sorry, this cannot be the, your, fine, right? So, actually time period will come and it will come down here. Sorry, this should go away. How it will go? I am sorry, so it will come like this.

Now, see one thing very important that here, I mean you will see there. Let me choose the pen again; here that mark to space ratio is varying. If the mark to space ratio varies, then what will happen? Obviously, you will find that the, that the average value of your signal also will vary. This signal, this average value of the signal we feed to a VCO. Now VCO, as you know is a voltage control oscillator. It is nothing but, the input is a DC voltage and the output will be the, output will be the frequency and which are varying frequency. So, depending on the, your input voltage your output frequency will vary. This is typically the VCO, voltage control oscillator. It has always a free running frequency, right? Usually it is very quite high. So, we make a free running frequency. Suppose 10.7 megahertz or something like that, right and along with that we can, we can do that thing, right?

So, this is actually, so if I choose this one, so it will go like this one, right? This is our time period; this is actually the time period. You see the time period is not varying in all the cases. You see, if I take this one, so time period is not varying, right? So this is again time period and this is the time period here, right, isn't it? But the mark to space ratio is getting …, that is actually the PWM, pulse width modulators. I am modulating the width of the pulse by which my signal will be, because you see, the DC signals which I am getting that is a very low value, so we cannot transmit it; I mean the DC signals cannot be transmitted, it is to be converted to the AC signal. That is the reason we are making it pulse width modulated.

Once we got the pulse width modulations, we now again we give it to the, again we are taking some DC signal here. Then, we are giving it to the, some the voltage control oscillator, right? So, it utilizes the split collars and which I was discussing and the amplitude of unbalanced voltage is passed through a PWM that modulate a constant amplitude 5 kilohertz square wave. So the basic square wave is 5 kilohertz. That means what is that?

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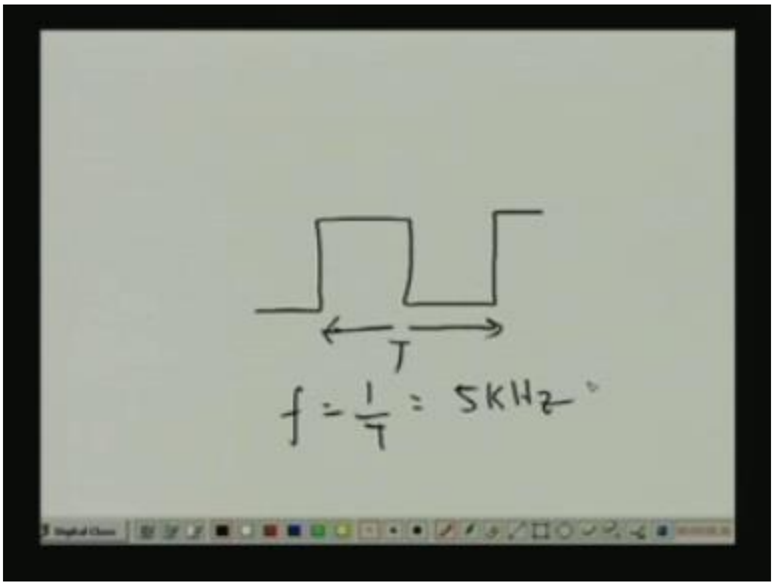

That means what we are discussing that means if I take a, so this signal, so this is T. So, f is equal to 1 by T equal to 5 kilohertz, right?

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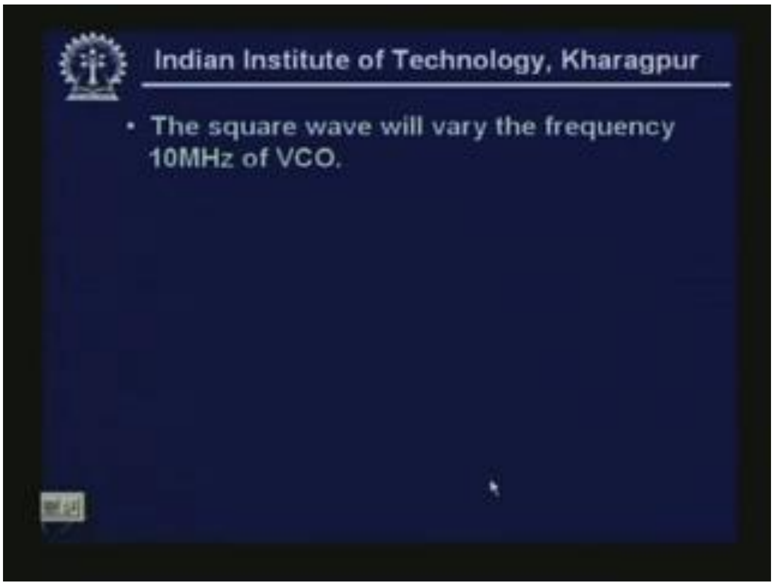

Now, if I go back, now square wave will vary the frequency of 10 megahertz of the VCO, right? In the square wave, actually we cannot ….. smoothen it. We will convert it into DC, I mean then it will convert, like what will happen?

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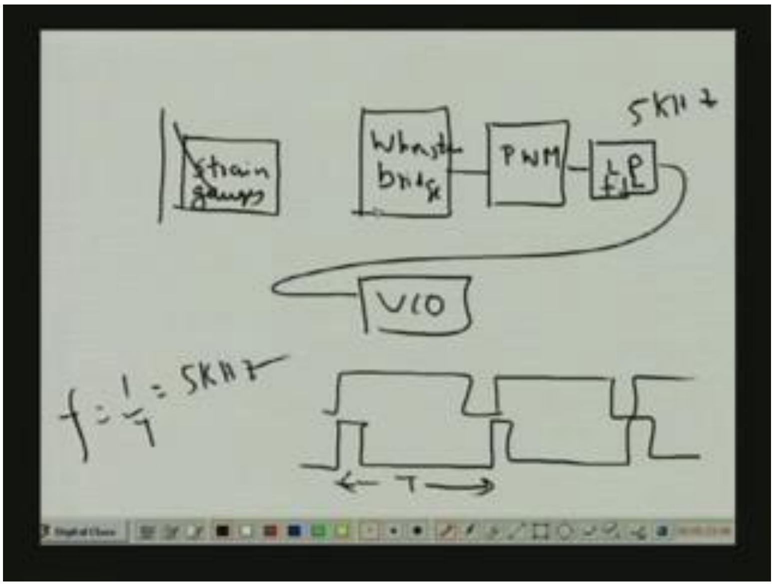

You will see here that actually if I look at, so we have the unbalanced voltage which is coming from the strain gauge or I should say it is a Wheatstone bridge. So, it looks like this that is I have a Wheatstone bridge. Then, it is coming to the, this is the DC voltage. This is the DC voltage; it is coming to a PWM. Then, we are coming to a low pass filter, because you see, this I mean signal, I mean which is coming from the PWM depending on the, this is to be converted, passed through a low pass filter to average it or the signal can be like this, like any thing. Then, it is coming to a VCO.

Now, here this, the frequency which you are, we are modulating, it is 5 kilohertz. What is 5 kilohertz? That means this frequency, that means if I say in time periods, so T or f equal to 1 by T equal 5 kilohertz, whereas VCO frequency is quite high. It is around 10 megahertz or something like that, right, so that this will control over this one that means some DC voltage will come down here, which is given to the output. So, the output voltage of the VCO will be proportional to the DC voltage we will give and this DC voltage again will depend on the unbalanced voltage of the Wheatstone bridge, clear?

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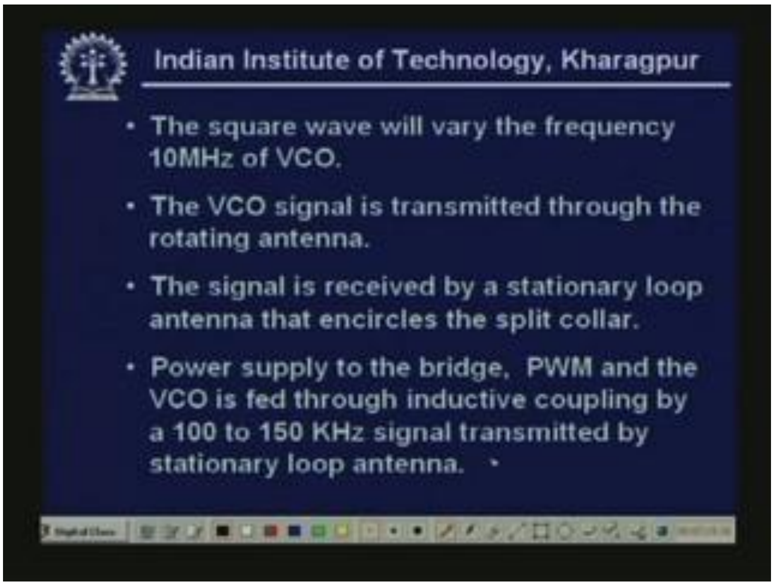

Now, this square wave will vary the frequency 10 megahertz of the VCO. The VCO signal is transmitted through the rotating antenna. Everything is rotating, I mean VCO signal is transmitted through the rotating antenna and the signal is received by a stationary loop antenna that encircles the spit collar. It is a collar like this one. See, if you look at, it is, it is very difficult, so we have a shaft and it, it is split like this one. So, it will be put like this one. Split, we can split it, so there is another antenna here on the outside and it is stationary. Inside, it is rotating. There is another antenna in the rotating shaft also, right?

Now the, how the, how I will give the power supply to the bridge? Next, that is;
So, signal is received by stationary loop antenna that encircles the split collar. So, there are two antennas. One is rotating antenna, which is installed in the shaft itself and that antenna is rotating as the same speed as the shaft. So, antenna, your Wheatstone bridge, power supply, everything is rotating and stationary loop antenna, the signal received by the stationary loop antenna. Interestingly, you will see that the same stationary loop antenna can be given for both the excitation, given to the bridge as well as taking out the unbalanced voltage. Obviously, the frequency will be different, so there is no question of overlapping.

We can, at the receiving end we can have the band pass filter. The power supply to the bridge you see here, the power supply to the bridge, PWM pulse width modulator and the VCO, because we are assuming that the low pass filter is incorporated within the pulse width modulator and the VCO is fed through inductive coupling by a 100 to 150 kilohertz signal transmitted by the stationary loop antenna. There is no battery we are providing as such, because Wheatstone bridge needs some excitation, isn't it, so that entire, all those, I mean chip excitation, all everything, we are giving through a stationary loop antenna, which has a frequency of 100 and 150 kilohertz and the other frequency, the VCO frequency it is quite high. It is 10 megahertz.

So, if you are at the receiving end on the, if you have two different band pass filters of the appropriate bandwidth, we can easily separate these two signals or you have, at the receiving end if you have a low pass filter, obviously this signal will go out that means the excitation signal will go out. We will receive only the signal, which is coming out of the, coming out of the bridge which is very high frequency around, it is, it, we have a 10, 10 megahertz is the frequency. So, around 10 megahertz, because when it depending on that you see it is, what will happen?

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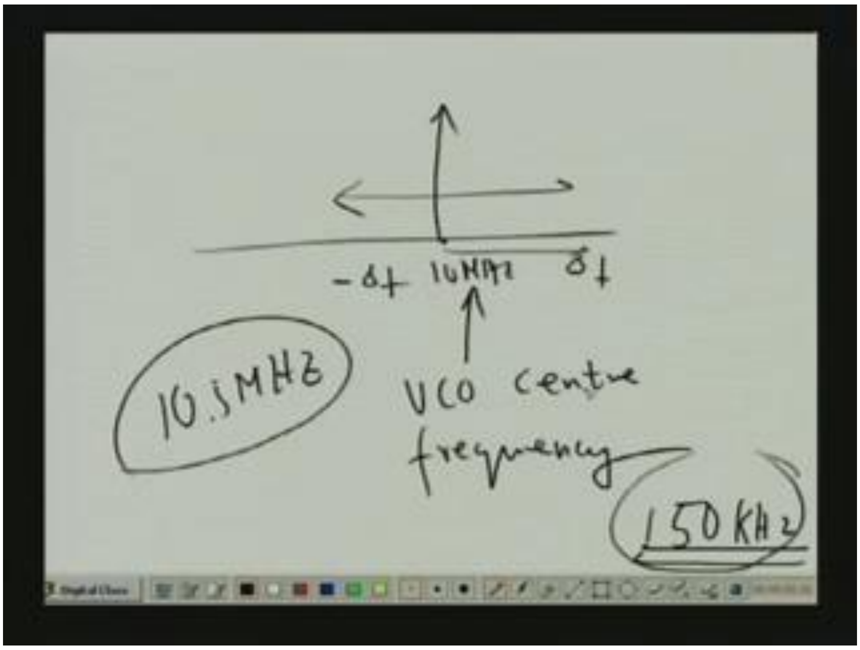

You see here that I have a 10 megahertz signal. So, over this there is a overlapping, so I will get a signal range like this. So, this is 10 megahertz. So, this is minus delta f, this is plus delta f, I will get, so over this, depending on the unbalanced voltage of the Wheatstone bridge I will get. This is the centre frequency of our VCO. This is the VCO centre frequency, right? So, this is 10 megahertz signal, so over this I am getting shift, right?

So, on both side you will get signal of, depending on the, whatever the and this, how much the shift will be, because since it depends on the DC voltage, the input to the VCO DC voltage, how much is the shift, it will also depend on the mark to space ratio of the PWM and the mark to the space ratio of the PWM will depend on the unbalanced voltage of the, your Wheatstone bridge. So, the frequency shift around 10 megahertz of the VCO will depend ultimately on the, on the, on the signal which is coming from the unbalanced voltage, right? ,

Now, interestingly, you see the, usually how much this is? Suppose this is 10.5 megahertz, your unbalanced voltage, a frequency of the VCO corresponds to unbalanced voltage and what is the frequency of the …which is given to the stationary loop antenna? Suppose 150 kilohertz, so these two frequencies are totally different. We can easily filter out ….These two frequency, we can filter out by a low pass filter.

If I, if I, if I use the high pass filter, obviously through this frequency we will get and this frequency will be chopped out, clear? Because, our information about the unbalanced voltage, because this unbalanced voltage or the shift of the frequency from the VCO, from the VCO centre frequency will be calibrated in terms of torque, please note that.

So, this frequency will be calibrated. This is, the shift of the frequency will be calibrated in terms of torque. Ultimately, if the larger torque, the frequency shift will be large; if the smaller torque, frequency shift will be small around 10 megahertz, right? So, this frequency change is to be calibrated in terms of the torque and if I get this signal by a high pass filter, simply if I can reduce the, if I can chop off this 150 kilohertz signal, so I will get 10.5 megahertz around that thing, fine, no problem. So, I will get that signal. I will calibrate the, my meter according to the torque, right?

So, this is all about the power supply, all these things and this almost we came to the end of this, I mean lesson before we are going to the some exercises, I will give you the exercise and I will give you the solution also. But please note I will give the answer, but not the solution as such, so you should compute of yourself. This is nothing but, plugging in your all the expressions and you will get the answer. It is just nothing great deal, but to know that what is the typical range and all these things, just to bring the flavor of the or what is the torque measurements, what is the typical range and all these things. You see here, let me take a blank page. The problem is like this.

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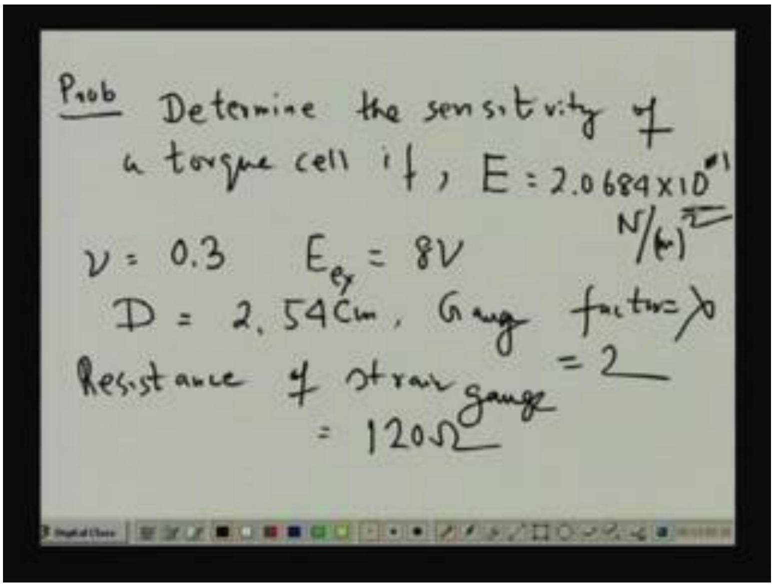

Problem 1, determine the sensitivity of a torque cell if modulus of elasticity of the link material, E which is modulus of elasticity of the link material is 2.0684 into 10 to the power 11, 10 to the power 11 Newton, say Newton per meter square. Then, Poisson's ratio nu of the link material is .3, excitation voltage that means E ex is equal to 8 volt, diameter of the shaft D is equal to 2.54 centimeter, right? The gauge factor of the strain gauge, lambda is equal to 2; it is the advance strain gauge, obviously and the resistance of the gauge, resistance, all are active gauge; resistance of strain gauge is equal to 120 ohm. So, it is nothing, I mean to, just you plug in all these formula, so it is 10 to the power 11. Please note, 2.0684 into 10 to the power 11, right? So, you plug-in all these value, you will get the sensitivity, because we have already given the expression for the sensitivity in our class, right? So, answer you will get. I will give you the answer.

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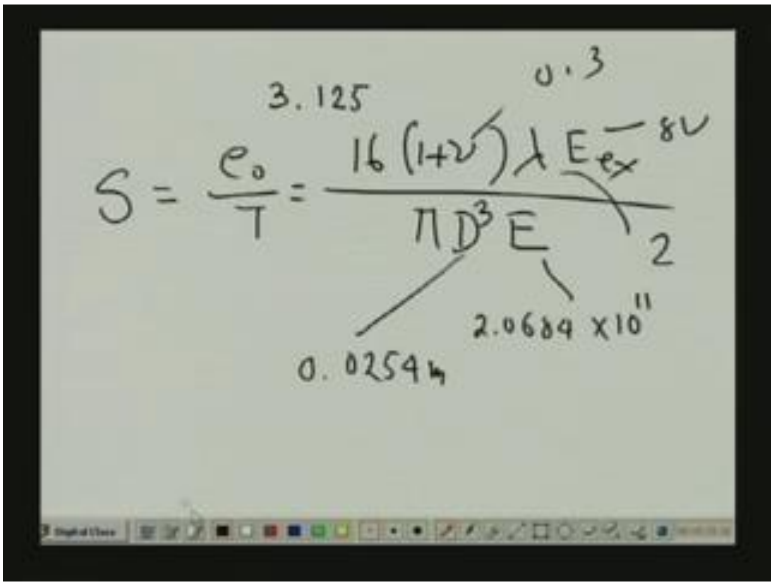

Answer you will get is, three point, just plug in all these values, 125. In which equations you have to plug in? Because what I ask you? I ask you to find the sensitivity. So, if I look at, so if I, the sensitivity expressions you see, our sensitivity expression will look like this. S is equal to e naught by T equal to 16 1 plus nu lambda E ex pi D cube E. All data's are given, is not it? So, what, in what sense? You see here, E is given, E is 2.0684 into 10 to the power 11, E ex is 8 volt, this is 8 volt. This is 2.0684 into 10 to the power 11. D is given. D is given; although it is given in centimeter, it has to be converted into meter. So, it will be 0.0254 meter. Then, Poisson's ratio is .3, lambda is 2.

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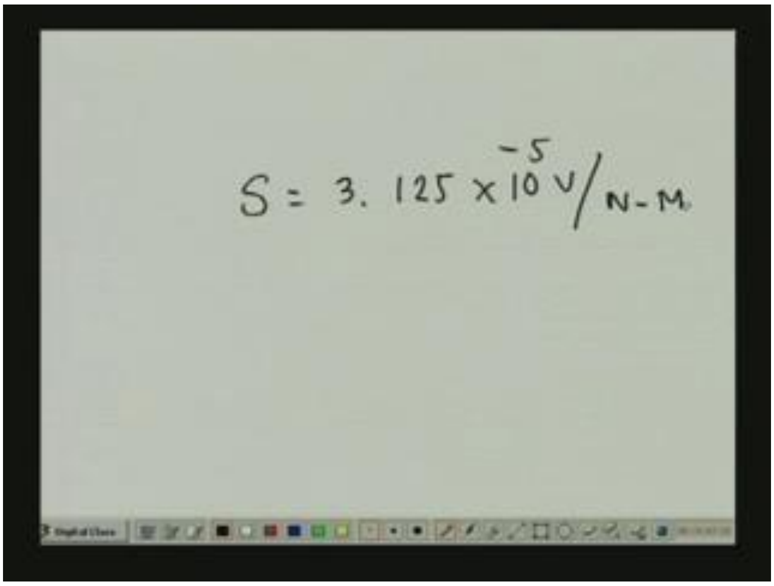

So, if you calculate, so actually the value of S will come up as, S will come up as S equal to 3.125 into 10 to the power minus 5 volt per Newton meter, right? Voltage by, voltage by torque, so obviously it will, it will come like this. Now, interestingly the second part is telling the, let me write the second part.

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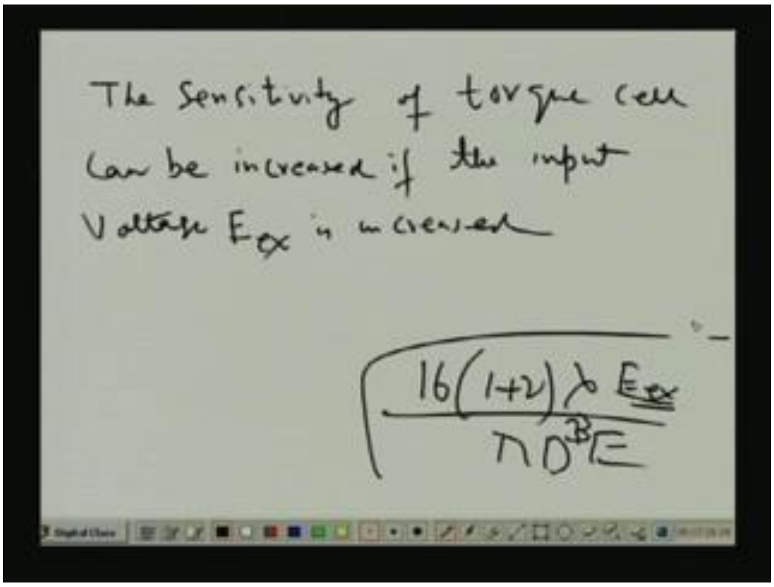

The sensitivity of torque cell can be increased if the input voltage or excitation is increased, right? That you have seen, is not it? You have seen that if you increase the exaltation voltage our sensitivity also increased, because in sensitivity expressions, we have seen that it is in the numerator, is not it? All the sensitivity information, we have seen the sensitivity expressions it is in the numerator, is not it, because sensitivity if you look at, it is this 16 1 plus nu lambda E ex upon pi D cube E, is not it? So, if I increase E ex obviously my sensitivity will all increase, right? Voltage E ex is increased, so that is given as it is.

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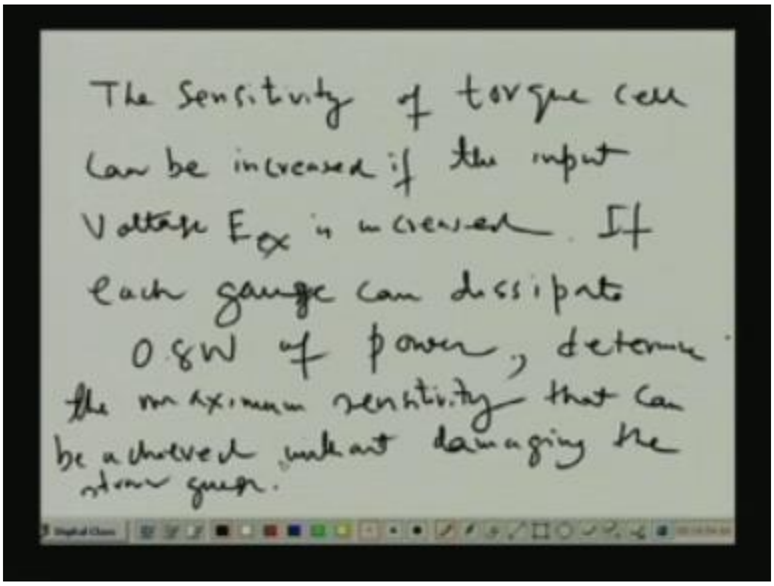

So, that means if I take this one, so it is increased. If each gauge, each gauge can dissipate, each gauge means each strain gauge, it dissipates .8 watt of power, power, determine the maximum sensitivity that can be achieved, that can be achieved without damaging the strain gauge? You see, know I always the strain gauge has some limitation that means how much power it can withstand? So, that is already given..8 watt of power it can pass. So, accordingly you have to, must calculate the current.

Once you get the current you know the voltage. So, once you get the voltage you can calculate the, I mean sensitivity, right?

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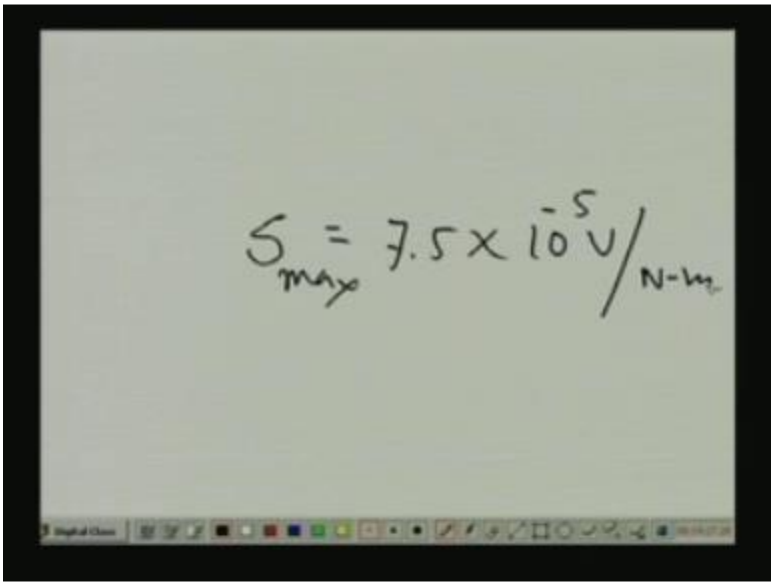

So, the sensitivity here in this case will be S equal to, S max will be given by 7.5 into 10 to the power minus 5 volt per Newton meter, right? So, with this, I come to the end of this lesson that is of torque cell.

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Welcome to the lesson 7 of Industrial Instrumentation. In this lesson, basically we will discuss the thermistor. As you know, thermistor is a temperature sensitive device, I mean if you increase the temperature, its resistance decreases and by using this property, mainly it is used as the temperature sensor, but it has many other applications in electronic circuits that we will discuss one by one.

Now, contents of this lesson.

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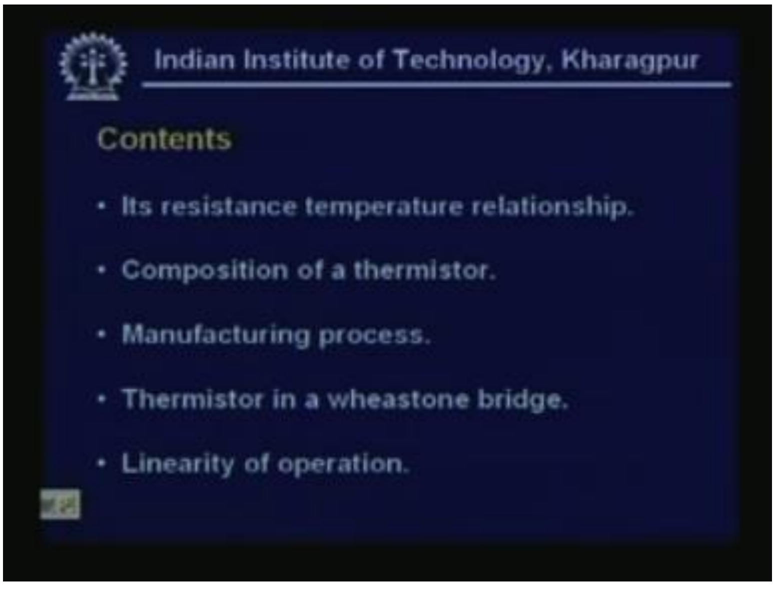

Its resistance temperature relationship or characteristics, composition of a thermistor; because it is a semiconductor material, so you have to look at what are the compositions and how it is made? Manufacturing process, how actually a thermistor is made and thermistor in a Wheatstone bridge. This is very important. We will show that Wheatstone bridge is used to take an unbalanced voltage which is calibrated in terms of temperature and its linearity of operation.

We will also see the thermistor in a potentiometer circuit. Either you can use it in a Wheatstone bridge or in a potentiometer circuit, we will see both. We will analyze both and what is the linearity of operation? Thermistor is very non linear sensor, we will look at all these things.

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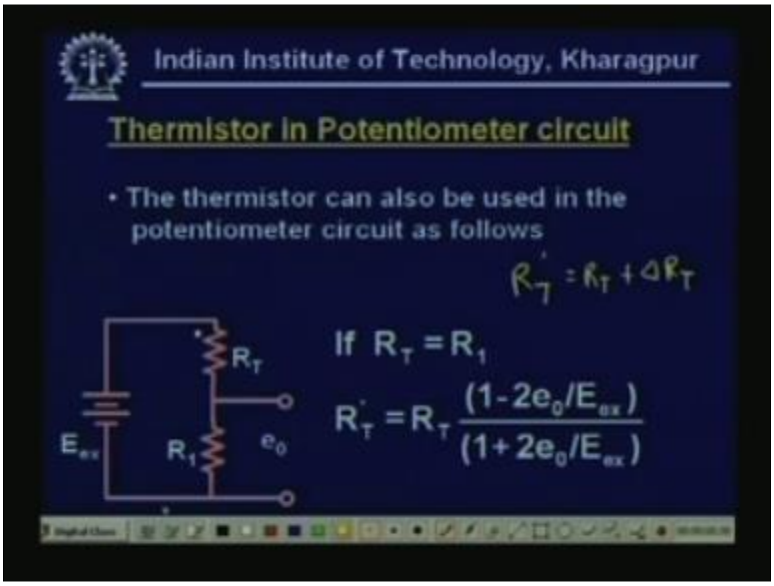

Thermistor also can be used in a potentiometer circuit, right? We will see there are various potentiometer circuits, used in the potentiometer circuit as follows. You see, this is the, one of the thermistor which is used in the potentiometer circuit, right? You see here that this, this should be the sign. So, this is the thermistor R T and R 1. In this case, if R T equal to R 1, so R T dash will be equal to R T that means changed resistance, where R T dash, as I told you earlier, will be equal to R T plus delta R T. R T dash equal to R T 1 minus 2 e naught by E ex, excitation upon 1 plus 2 e naught by E ex.

Now, interestingly the one common question arises. What will happen if I flip it? That means if I put R T here and R 1 here that means the circuit, if the circuit looks like this, then what will happen?

This ends the lesson 7 of Industrial Instrumentation.