Robotics
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Lecture – 32
Sensors (Contd.)

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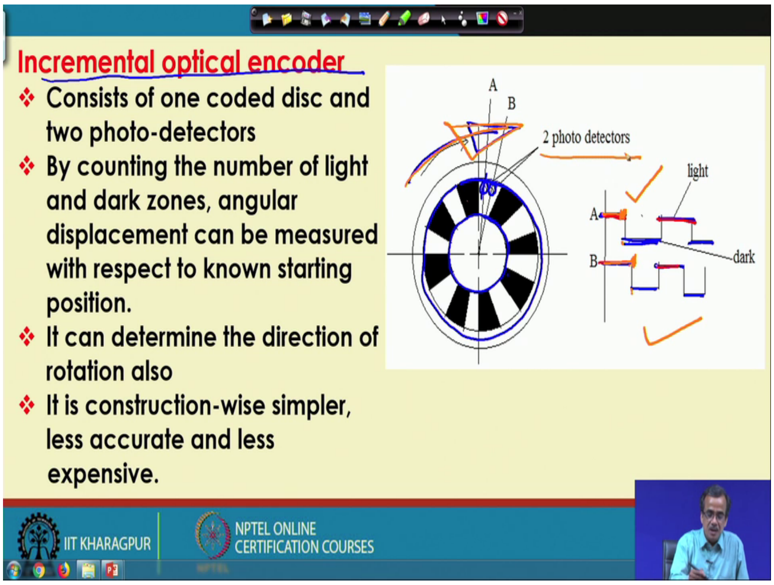

Now, we have already discussed the working principle of one absolute optical encoder. Now, this absolute optical encoder which I have already discussed is actually very precise, but the problem is actually the number of photo-detector should be equal to the number of concentric rings. So, if I use stain concentric rings, so I will have to use actually 10 photo-detectors which are very costly, and that is why actually absolute optical encoder are very costly. And in place of absolute optical encoder, we use incremental optical encoder.

Now, here in incremental optical encoder, we use only 2 photo-detectors and there is a only one coded disc. So, we do not use a large number of coded disc here, and we do not use a large number of photo-detectors here. Now, let us try to understand the working principle of this particular absolute incremental optical encoder.

Now, this incremental optical encoder as I told, we have got only one coded disc. So, this is actually the shaft whose rotation I am just going to measure. So, and here we mount only one coded disc. So, this is nothing but the coded disc here; so, this is the coded disc.

And here on this particular coded disc, we have got the black zone and the white zone, black zone and white zone, black zone and white zone. So, the black zone and white zone are placed here.

Now, if there is black zone, then there will be no light is going to pass; and through this particular white zone, the light is going to pass ok. Now, here actually what happens, here the principle is slightly different, different in the sense like your, here we have got only 2 photo-detectors and these 2 photo-detectors are kept fixed; so, their positions are kept fixed.

Now, what I doing is, so here we put one photo-detector that is A and another is B, and their positions are kept fixed. And this particular the shaft is rotating. The moment it rotates supposing that this particular incremental optical encoder, which is mounted on the shaft, so this is rotating in the clockwise sense ok. So, if it rotates in the clockwise sense, then photo-detector A will enter the black zone first; and after that photo-detector B is going to enter the black zone.

Now, if you see the plot, so this is the plot this indicates the black zone, and this is actually the light zone I am sorry; so this is the light zone, and this is actually the dark zone. So, this is the light zone and this is the dark zone. Similarly, your this is the light zone; and this is the dark zone; the light zone and this is the dark zone ok.

Now, let me just use another color. So, for this light zone I am using the red. So, this is the light zone, this is the light zone and this is the light zone ok. Now, here actually what happens your the moment so it is rotating the clockwise sense, so this black portion, this A is going to face the black portion first ok; and then B is going to face. So, here actually what happen this source, now this is the light zone; that means, A will be light zone for small duration compared to B; and B will be in light zone for more amount of time.

Now, here you can see for this particular A, so it is a light zone only up to this; whereas B is a light zone up to this slightly more than that that means your A has entered the black zone first. So, this is the starting of the black zone, this is the starting of the black zone. So, A has entered the black zone first. And after that B has entered the black zone ok. So, once again let me repeat. So, A will be in light zone only up to this and B will be in light zone up to this that means A will enter the black zone first, and B will enter the black zone after sometime ok.

So, this type of actually the signal you will be getting or corresponding to the photo-detector A and photo-detector B. And now, if I see so this particular signal, so if we see this particular signal, and if we count the number of light zone, and the number of black spot, for example the light zone, light zone and the black zone.

Similarly, here also, I am just going to count the number of light zone and number of dark zone. So, by counting the number of light zone and dark zone, in fact, we can find out, how much is the angular displacement ok. So, the angular displacement can be determined by counting the number of the dark zone, and this particular your the light zone.

Now, actually the next thing is, so it approximately we can find out how much is the angular displacement of this particular your the incremental optical encoder, or the shaft whose rotation I am going to measure. Now, here another information we are going to get, that is your it can indicate the direction of rotation. For example, if you see this particular your signal once again, for example, here A enters the dark zone first, B enters the dark zone after sometime that means, your so this is rotating in the clockwise sense. Now, the reverse will be the situation, if it is rotating in the anticlockwise sense. So, you will be getting the different type of signals here ok.

So, let me once again repeat. A will enter the dark zone first, and B will enter the dark zone after sometime. It indicates that this particular shaft is rotating in the clockwise sense ok. So, this is the way actually it can find out, how much is the angular displacement, and what is the direction of movement of that particular the shaft. And as I told that here, we use only one coded wheel; here there is a only one coded well and only 2 photo-detectors, so it is less costly. And of course, it will be less accurate compared to your this absolute optical encoder. But, as it is less costly, so it is very frequently used as feedback device in robot; and this is used very frequently as a position sensor. Now, this is actually the working principle of your incremental optical encoder.

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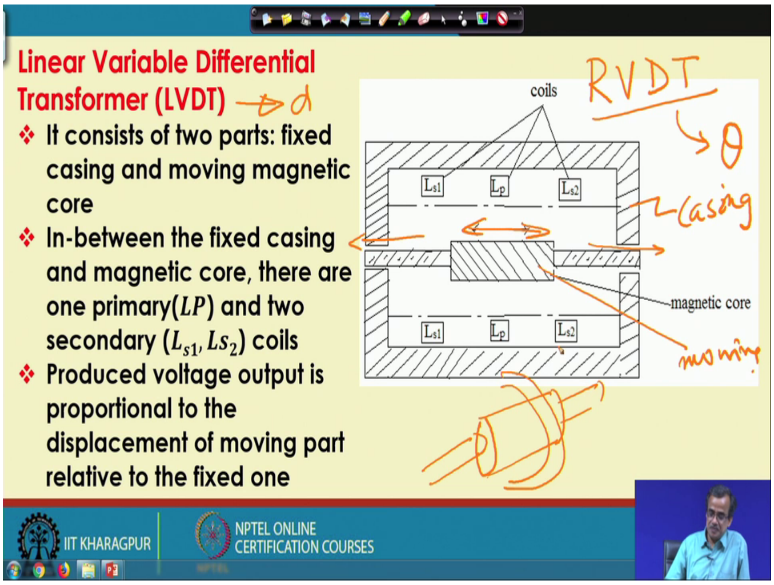

Now, I am just going to discuss the working principle of another very popular optical very popular position sensor that is known as your that is known as LVDT that is a Linear Variable Differential Transformer. Now, this LVDT stands for linear variable differential transformer, and this is used to measure the linear displacement that is d ok. Now, similarly we have got RVDT that is called Rotary Variable Differential Transformer. And this particular RVDT that is rotary variable differential transformer is used to measure the angular displacement that is nothing but theta ok.

Now, let us try to understand the working principle of this particular your this LVDT that is linear variable differential transformer. Now, construction wise, it is very simple, we have got one fixed casing. So, this is nothing but the fixed casing. And we have got one moving magnetic core, so this is actually the moving part that is the magnetic core. Now, this particular magnetic core, it can slight along this two direction that means, it can slight towards this or it can slight towards this ok. And we have got the fixed casing here.

Now, in between the fixed casing and the moving magnetic core, so here we put one the primary coil that is L P, and two pairs of secondary coil that is L s 1 and L s 2 ok. Like if we just draw, so here we have got so surrounding this we have got actually the primary coil. Now, if I just draw one very rough sketch sort of thing, for example, say this is the magnetic core say, if this is the magnetic core now here surrounding this actually we have got this primary coil; so we have got this particular primary coil, and here we have got two such secondary coils ok. Now, let us try to understand the working principle of this, and how can it measure the displacement that is your the linear displacement with the help of the fixed casing. Let us try to understand the working principle.

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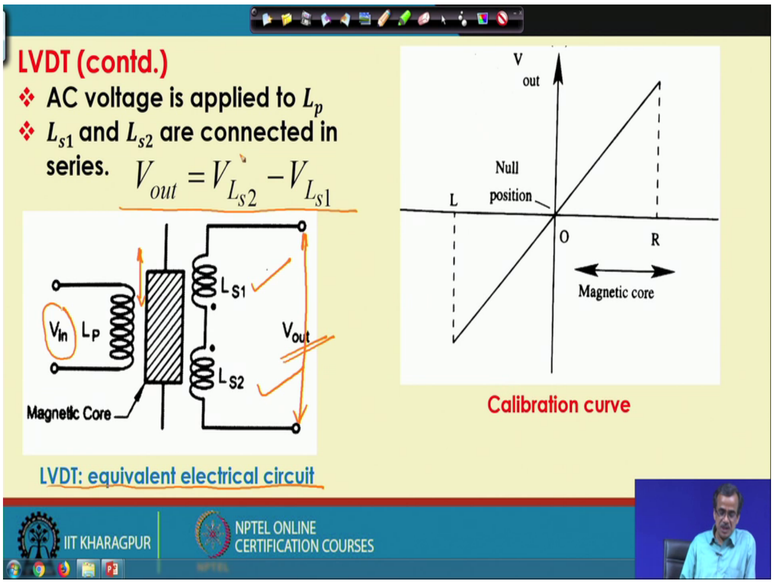

Now, to understand the working principle, actually what we do is we try to see our its equivalent electrical circuit first ok. Now, this is nothing but the equivalent electrical circuit. So, this is actually the equivalent electrical circuit. So, this equivalent electrical circuit corresponding to that LVDT, this is the magnetic core. Now, here in this particular sketch, the magnetic core can move up and down ok. And here, we have got the primary coil. And we put the input voltage that is V in through the primary coil. And we have got the secondary coil, the first secondary coil and the second secondary coil. And here, in between these two points, we try to measure how much is the output voltage that is V out.

Now, let us see how can you measure so this particular displacement or the movement by measuring your output the voltage. Now, this V out is actually nothing but V L s 2 minus V L s 1. Let me explain, what is this V L s 1 and V L s 2.

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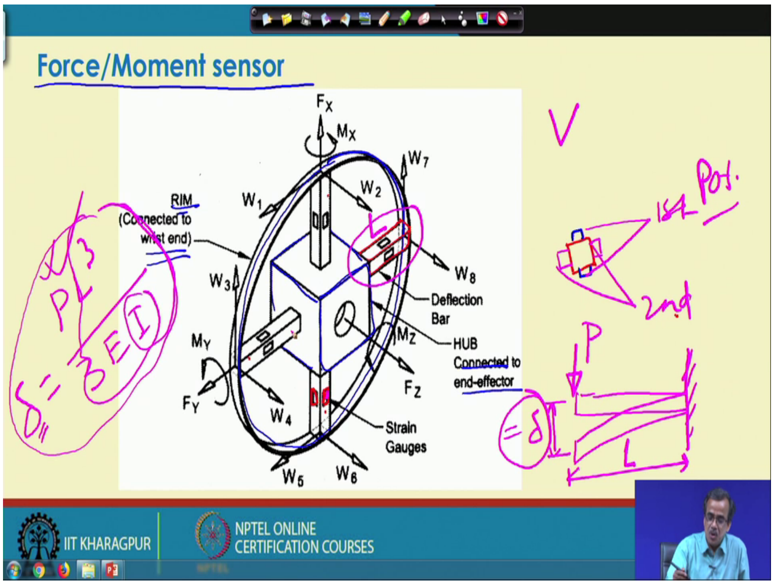

Now, to explain this actually what we do is let us go back to the let us go back to the previous picture first.

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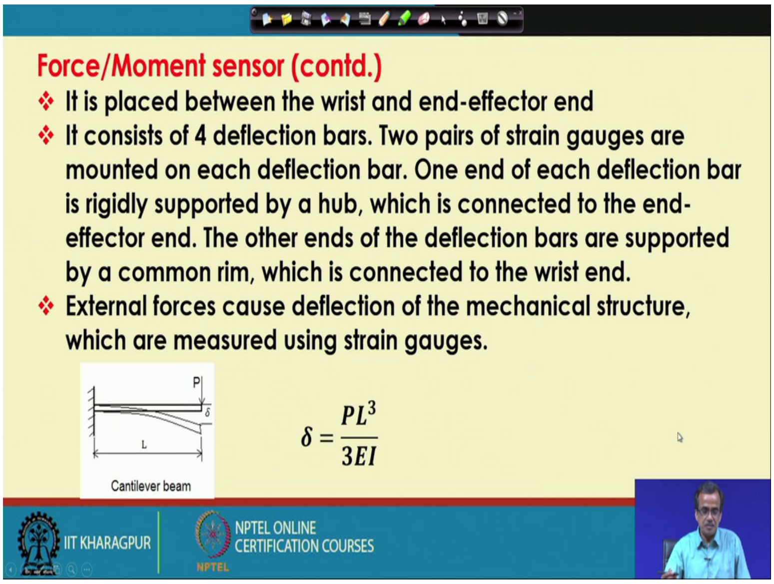

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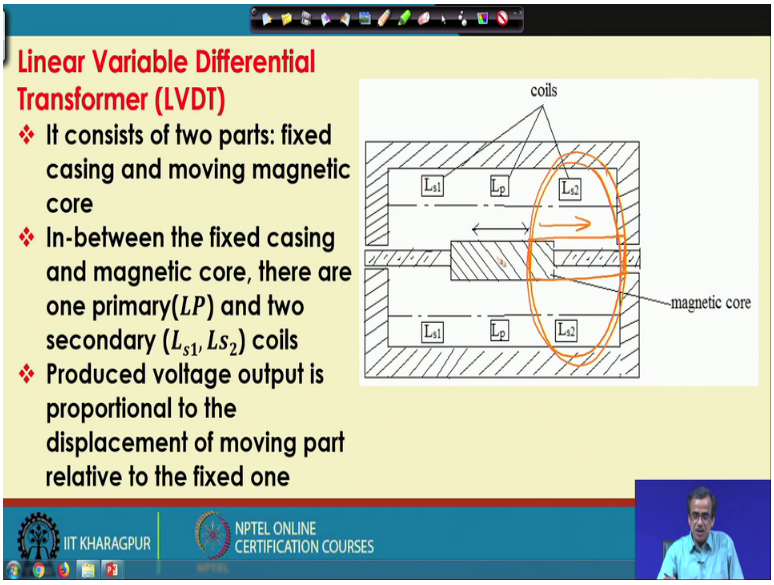

Now, if you see the previous picture, so here supposing that so this particular the magnetic core, so this is sliding towards my right. So, the magnetic core is here ok. Now, if it the magnetic core is here, so it will be closer to the L s 2 compared to your L s 1.

So, coupling between L s 2 and the magnetic core will be stronger compared to the coupling between your the permanent magnet, the magnetic core and L s 1. So, here the magnetic strength will be more the linking will be stronger. And due to this stronger linking, actually what will happen here is the induced voltage in L s 2 will be more compared to that in L s 1. So, due to this stronger influence of this particular the magnetic core, the induced voltage in L s 2 will be more compared that of L s 1.

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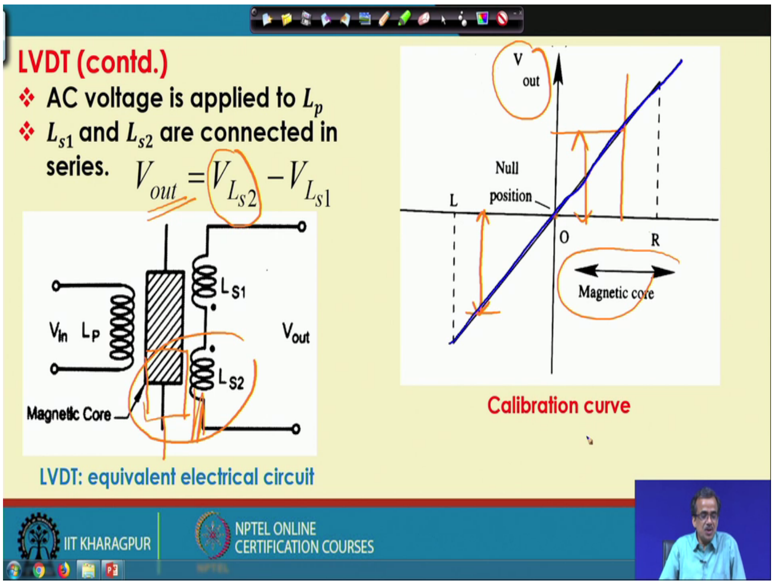

And, now let us see what happens here. That means your if I just draw it the same situation, it is more towards L s L s 2 that means my magnetic core is somewhat here ok. That means, this particular coupling is stronger ok, compare to this coupling. That means your L s 2 the induced voltage in L s 2 that is V L s 2 will be more compare to the V L V L s 1, and I will be getting a positive V output ok.

So, I will be getting a positive output voltage, if it is moving towards, if this particular thing is moving towards that towards downwards ok. And reverse is the situation, if it is moving towards the upwards. So, in that case the V L s 1 will be more compare to V L s 2, and V out will become equal to some negative value ok. Now, here this show actually the calibration curve. So, this corresponds to the null position ok. Now, this is R indicates as if it is it was moving towards the right, so that that means this R indicates this particular position ok and corresponding to this R, so I will be getting some positive V out. So, I will be getting some positive V out.

And if it is sliding towards L s 1, so I will be getting the negative V out, that means I am here ok. So, I will be getting some negative V out here. So, this particular plot like output voltage versus your the position of the magnetic core with respect to the fixed casing ok. So, this is actually your the calibration curve. And once this particular calibration curve is pre- known or pre-determined, now by measuring this particular V out, so what you can do is so, we can find out like what is the position of this particular magnetic core or what is the displacement of the magnetic core with respect to the fixed casing. So, we can measure, how much is the linear displacement of the magnetic core with respect to the fixed casing.

So, this is the way actually this particular LVDT works. And as I told this is used just to measure the linear displacement. And for measuring the angular displacement like we will have to go for RVDT that is Rotary Variable Differential Transformer. Now, this particular LVDT is used in robots. It is used very frequently in different machine tools. For example, lathe, milling machine, drilling machine this type of LVDT are generally very frequently used. So, this is the working principle of your this LVDT.

Now, we are going to discuss the working principle of another the sensor that is called the force or the movement sensor. Now, the purpose of this force or the movement sensor is to determine, how much will be the force or the movement acting at the robotic joint. Let me take a very simple example.

Supposing that this is my wrist joint; now if I consider say this is the serial manipulator, so this is my wrist joint. And with the help of this wrist joint, so this particle end-effector is connected. Now, I am just drawing something or I am a writing with the help of this marker ok. The moment I am just going to do some manipulation task with the help of this finger, so this particular joint is subjected to some amount of moment, some amount of torque ok.

Now, if I want to measure this particular moment and torque at this wrist joint, so how to measure this particular the moment or the force. To measure this moment or the force, we put this type of the force or the moment sensor. Now, what I do here is your so on the wrist end, so this is the wrist end. So, we wrist end we put this particular your the rim portion. So, this is actually the rim portion, which we put at the wrist end, so this is connected to the your wrist end. And here, we have got one the square block sort of thing or cube sort of thing, cuboid sort of thing ok, so this is called the hub. And this hub is connected to the end-effector or this particular finger with the help of which I am doing that particular the manipulation while writing ok.

So, once again let me repeat the hub is connected to the end-effector, and this particular the rim this particular circular, the rim this is connected to the wrist end. And what is our aim, our aim is to determine what should be this particular the joint the moment or the joint torque or the force, so that we are going to find out. Now, let us see how to determine that. Now, let me first explain the contraction details of this particular your this force sensor. Now, construction wise actually as I told this is connected to the wrist end; and hub is connected to the your the end-effector.

Now, here in between the rim and the hub, we have got some sort of the deflection bar. So, here we have got one deflection bar. Similarly, I have got another deflection bar here; another deflection bar here; another deflection bar here. Now, if I see this deflection bar, these are actually the bar having some sort of square cross section, and made of elastic material ok.

So, for example, say elastic material in the sense, for example, we can use some set of steel, steel will be working within the elastic zone by elastic material, I wanted to mean that it a steel, but it is working within the elastic zone. It has not reach the plastic zone ok. So, this is actually made of steel in fact and it is having this type of square cross section.

And if you see on the deflection bar, you have got some strain gauges. So, here we are putting some strain gauges. In fact, on each deflection bar we put two pair sub strain gauges. For example, say here we put say one pair here, so this const constitutes one pair of the strain gauge, and there could be another pair of strain gauge; another pair of strain gauge could be something like this, so this is actually the strain gauge, this is this particular stain gauge.

So, we have got one pair, so this is one pair of strain gauge; this is the second pair of strain gauge. So, this is the first pair and this is the second pair of strain gauges ok. So, on each of this particular deflection bar, we have got two pairs of strain gauges, and I have got four such deflection bar, so I have got 8 pairs of strain gauges ok.

And with the help of this strain gauges, in fact we are just going to measure, how much is the deflection of this particular deflection bar, and if I know the deflection, so from there let us try to find out, whether I can find out how much is the load acting at the deflection bar.

Now, let us see how to determine this, now to determine this with the help of, that means the moment, so this particular end-effector is doing some sort of manipulation job ok.

For example, it is handling some weights, it is doing some sort of peak and place type of operation and something like this, so what will happen is each of this particular deflection bar will be subjected to some amount of force ok. How to determine that, now if I concentrate on a particular deflection bar, it is almost similar to the situation as if, so I have got one beam sort of thing. So, this type of beam I have ok. And for this particular beam, so this is the fixed end, and here as if some load concentrated load is acting, and this type of cantilever beam we can assume.

So, here on this particular cantilever beam, there will be some deflection something like this; and if there is some deflection, due to the load, so this deflection can be measure; so this delta deflection can be measured ok. Now, let us see how to measure, so this particular the delta deflection with the help of strain gauges. The strain gauges are mounted here ok. And with this particular strain gauge, actually we count some potentiometer circuit, which I have already discussed with the help of potentiometer, what do you do? We measure the output voltage, and by measuring the output voltage, we can measure how much is your the deflection.

So, we use potentiometer, for example I can use some set of say, the linear potentiometer to find out, how much is the deflection? And this particular potentiometer, the output of the potentiometer, that is nothing but the voltage I can measure with the help of one voltmeter or multimeter.

Let me repeat, for example say we have got the deflection bar. On each deflection bar, we put two pairs of strain gauges. Now, each pair of strain gauge is connected to the potentiometer circuit. And on the output side of the potentiometer, we can measure. Actually, the output voltage and that particular output voltage is proportional to the deflection or the displacement.

And that particular deflection is nothing but this particular delta. And, if I know this particular delta, and this is a cantilever beam, and supposing that I know, the length of this particular the beam or the length of this particular your the deflection bar is L. I know the cross section I know the material properties, so very easily I can write down. So, this particular delta is nothing but P L cube divide by your 3 E I this is the standard formula.

Now, this is valid if and only if, so this particular bar is working within its elastic limit. Now here, so this delta is known, E is the Young's modulus. So, modulus of elasticity that you know for the material, I is the moment of inertia, I know the cross section of this particular deflection beam, I know the dimension ok. So, I can find out the moment of inertia. L is the length of the this deflection bar. So, all the things are known except this particular P, so P can be determine.

So, I can find out. So, how much is the load coming at this particular point to make that particular deflection possible. So, I can find out, what should be the load act each of this particular or deflection bar. And those particular loads are nothing but the raw readings for these particular your the strain gauges.

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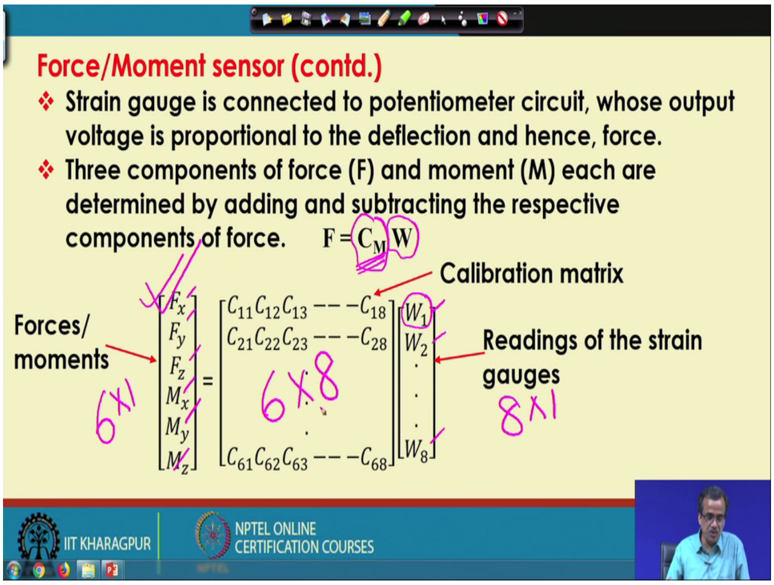

And those raw readings are nothing but is your are nothing but, your this thing the W values, so these are nothing but the raw readings which we are getting ok. Now, this particular raw readings so this W 1, W 2 up to W 8, because we have got 8 number of 8 pairs of strain gauges; so, each pair is going to supply W values like W 1, W 2 up to W 8. And our aim is to determine F x, F y, F z; moment about x, moment about y, and moment about z.

Now, so this particular W values, we can calculate, we can determine with the help of experimentally you can find out, with the help of strain gauge and potentiometer circuit. And our aim is to determine, so this particular F, F x, F y, F z; M x, M y, M z but in between there will be some calibration matrix, which is nothing but so this particular the C M. So, F is nothing but C M multiplied by W, and this particular C M is nothing but the calibration matrix.

Now, here in the matrix form, so I have shown the calibration matrix, how to determine. I am just going to discuss, now let us see the dimension of this particular matrix, here there are 6 such values, so it is 6 cross 1 matrix. And, here we have got 8 such numerical values W values, so it is 8 cross 1 matrix. Now, to make this particular multiplication possible, so this particular matrix has to be 6 cross 8 ok. So, this particular calibration matrix C M matrix is nothing but 6 cross 8 matrix.

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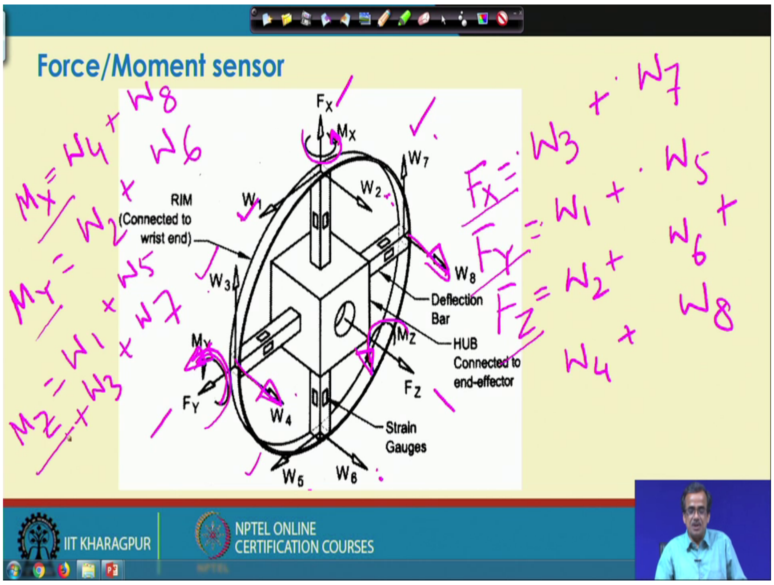

Now, how to determine that, so that I am going to discuss now, if I just concentrate on the previous thing, for example say so this particular thing if I concentrate, and our aim is to determine your F x, this is the x direction, so our aim is to determine F x; this is the Y direction, F Y and F z, then moment about X; then comes your moment about Y; and moment about Z; I will have to find out. And these are all raw readings of the strain gauges that is W 1, W 2 then comes your W 3, W 4 then 5, 6 then comes your 7, 8, 7, 8. So, these are all raw readings of the strain gauges, and I have already discussed how to get this particular the raw readings.

Now, with the help of those raw readings actually how to determine, so this particular F x. F x is the force along the X direction. Now, here W 1 and W 2 are at 90 degree with F x, so along F x there will have no contribution, no component. Similarly, W 5 and W 6 will have no component along X direction. But, W 3 and W 7 will have some contribution towards X. So, there is a possibility here W 3 will come, and W 7 will come, and of course there will be some calibration terms, which I am going to discuss after sometime ok, there will be some calibration terms here.

Next come is your F Y F Y that is in this particular direction. So, 3 and 4 will have no contribution; 7 and 8 will have no contribution; but 1 and your 5 will have some contribution, so I am writing W 1 plus W 5, and here I am just going to write something, after sometime ok, so this is actually your F Y. Then F Z if I want to find out, so this is the F Z direction, so this W 2 and 6 will have some contribution; so W 2 plus something into W 6 plus, so W 2 W 6 then comes your W 4 and W 8, so W 4 plus W 8 will have some contribution then comes your moment about X.

Now, let us try to understand this is the X direction, so this W 1 W 2, 5 and 6 will have no contribution towards M X ok. Now, let us see whether 4 and 8 will have some contribution towards M X or not. Now, W 4 is acting in this particular direction, it is acting in this particular direction ok, so definitely so these two will have some contribution towards M X.

So, W 4 and 8 so W 4 and W 8 will have some contribution. Then comes your moment about Y, so this is the Y direction this is the moment about Y. So, let us see the moment about Y, the 2 and 6 the W 2 and W 6 will have some contribution towards moment about Y. So, W 2 and W 6 will have some contribution then comes your moment about Z.

Now, this moment about Z, M Z so this is the Z direction. So, this 1 and 5 1, and 5 will have some contribution, then comes your so next is 1 and 5 will have some contribution. And next is your next is your 3 and 7, 3 and 7 will have some contribution, so 3 and 7 will have some contribution, because, this is your Z direction. So, 3, 7 will have some contributions towards M Z ok. So, this is the way actually we can find out F X, F Y, F Z; M X, M Y, M Z.

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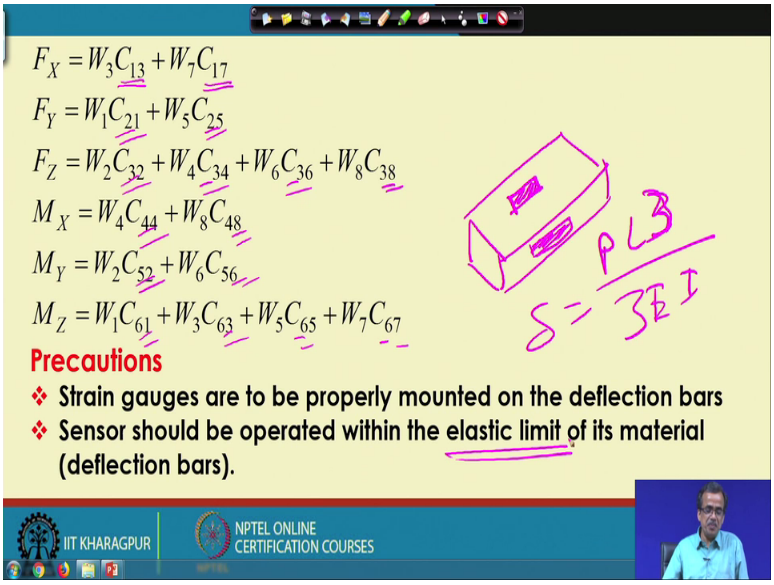

Of course, I have not put the calibration terms. The calibration terms actually I am just going to show it here. If you see, the calibration terms have been written here. Whatever I discuss that F X depends on W 3 and W 7 multiplied by this calibration matrix, so W 3 multiplied by calibration matrix C 1 3 plus W 7 multiplied by C 1 7.

Similarly, for F Y, so these are the calibration matrix; F Z these are the calibration matrix; M X these are the calibration matrix; M Y depends on your 2 M 6 these are the calibration matrix; and M Z depends on these calibration the terms ok. So, we can find out how much is the force acting its three component what is the moment? There is moment about X; moment about y; and moment about Z.

Now, here if you want to use this type of force or the moment sensor, some precautions are to be taken. For example, strain gauges are to be properly mounted on the deflection bar. So, on the deflection bar, in fact we are going to mount the strain gauges, and we will have to mount very properly, otherwise we may not get the proper reading ok, the strain gauge are to be correctly mounted here ok. There should not be any such gap sort of thing, properly mounted ok, so this is one precaution.

Another is your the depletion bar, will work within its elastic limit. Otherwise that particular formula will not be able to use for the deflection that is delta equals to P L cube P L cube by 3 E I, so that particular formula will not be able to use, unless it is working within that particular the elastic limit. So, these are the precautions to be taken.

Thank you.