**Principles of Mechanical Measurements**
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**Lecture No. # 21**

Having seen the measurement of force, next measurement naturally is a torque. How torque is obtained? It is force acting at a distance from an axis that is a torque. Moment also similar dimension that is force times distance. So what is difference between movement and torque? Moment is given by say Newton meter, torque also given by Newton meter but the difference between these two things is that when moment is acting over a body, if the body gets twisted about an axis then the moment is called torque.

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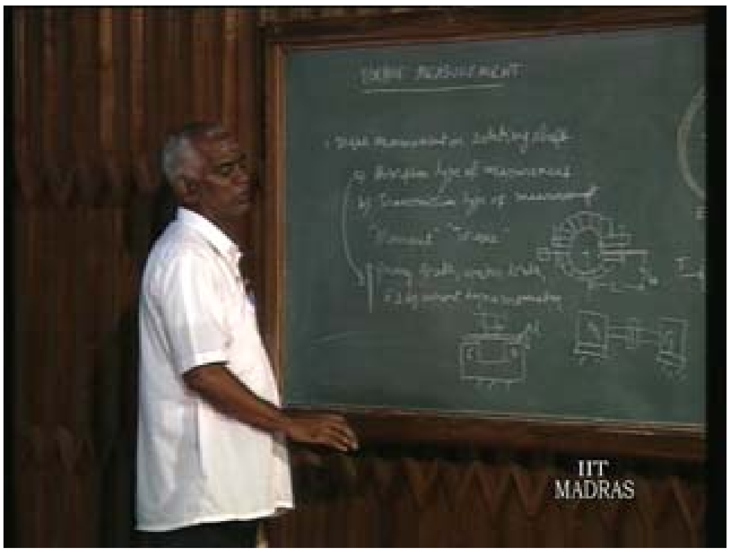


So torque is again a moment but it is under certain circumstances we call the moment as torque. The circumstance when the moment twists the whole body about an axis then moment is termed as torque. So the dimension is same as moment that is force into distance so that is now torque. Now torque is to be measured in engineering applications under two situations, sometime the shaft is stationary, one end is fixed, the other end we apply a torque. Again the shaft gets twisted about that axis of the shaft. Secondly the shaft may be continuously rotating 1000 rpm, 5000 rpm or whatever it is 10 or 20 it is continuously rotating then also we are supposed to measure the torque.

So now we will see the measurement of torque under two different situations that is when the shaft is rotating and second situation when the shaft is not rotating and for the rotating shaft we have got principally two methods. First method is called absorption type of measurement; normally you would like to have the speed torque characteristic of a driving motor or an engine. In such situations that is only engine or motor is there and you want to find out the speed torque characteristic, as speed is increased or decreased how the torque is varying. So that is a prime over, that characteristic when you want to find out then mostly you go for absorption type, we have got few options that is one prony brake.

These things are done in the under graduate level for testing of IC engines for prony brake and then water brake and eddy current dynamometer. So these are the devices normally used for absorption type of measurement. Prony brake essentially say for example is IC engines output shaft one drum is fixed and number of wooden blocks are arranged and then at the one end you will have the counter weight and the other end you can have somewhat like this. Suppose this is the drum you will have the blocks so at the end of the arm these two things are fixed and end of the arm the weight is hung and you have got a set of again blocks, these wooden blocks and here you have the counter weight.

Now the wheel is rotating in this direction and by hanging weights and noting down the distance the torque is given. So it is held by so you have to tighten it with number of screws and here also you have to tighten it. So as you increase the tightening then the grip of the wheel will be increased and the set of wooden blocks will try to rotate along with the rotating drum but that is being restrained by having a lever and hanging weight. So this moment is acting in this direction so frictional torque in the other direction. Now you will find w into L will be the torque absorbed by the set of wooden blocks and that multiplied by the rpm will give the power. So that is why some times power measuring instruments are called dynamometer because torque multiplied by speed will give the power, normally dynamometer should be used only for power measurement but some of the torque measuring devices also this is made use of. So W into L will be the torque, this absorbs the whole power developed by the engine; hence it is called absorption type of a measurement.

In transmission type no such absorption is made, the whole power is transmitted. So in this situation for example there is a motor that is coupled to a generator. This is generator and this is the motor, in such situations this is the motor fixed this is also fixed and what is the power transmitted to the generator. So the power source and this is a power sink or it may be a pump, motor to pump so both of them are there, normally we will go for transmission type of measurement. So by one of the methods we are going to learn 2, 3 methods that is transmission type of measurements. So in absorption type all the energy is absorbed by this method so when you absorb energy then this whole thing is heated and to cool it normally in the drum we pour some water during experiments in IC engines, this is one of the experiments in undergraduate level.

Otherwise you may have water brake, the viscosity of water is made use of and that is second torque measurement using water brake. Third one is eddy current type of measurements there you will have a disc rotated by the shaft, so this is rotating shaft and here you will have the permanent magnet arranged and the gap this is north pole, this is south pole. This is a fixed one, this is rotating from the motor this aluminium or copper disc also you can have. So for example aluminium disc it is rotated by changing the distance between the rotating disc and the permanent magnet, we introduce different torque on it that is when a metal rotates in the vicinity of magnetic lines eddy currents are produced and the magnetic lines interacting with the coupling with the main magnetic lines the torque is there, opposing the rotation of the disc. So here also little bit heated up it is dissipated to the atmosphere, so by changing the gap we can have different torques on it, the whole torque is absorbed and thereby measuring the gap we can measure the torque applied on it from some other calibration methods we can do it. So these are the three methods normally adapted for absorption type of measurement but many instances we are asked to find out the torque transmitted by a shaft say for example motor to generator and the first method what you are taking up is, this is purely mechanical device epicyclic train transmission dynamometer.

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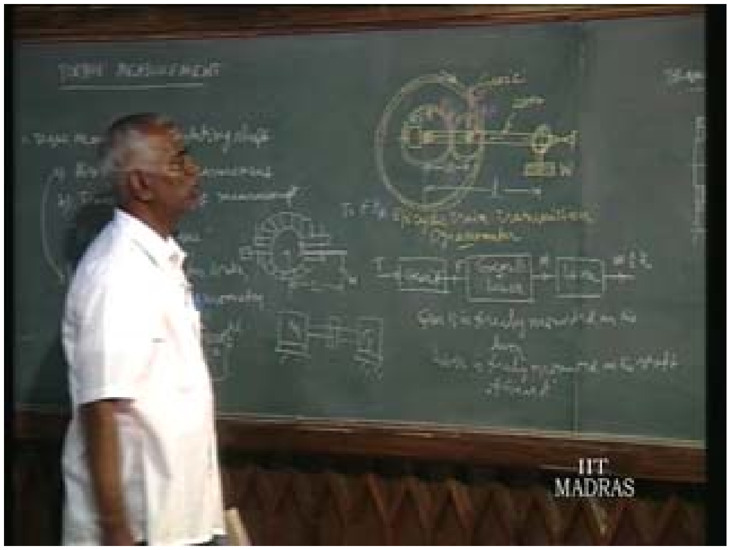


This is the device explained in Theory of Machines Bevan. When the motion is taken from motor to generator such a gear system should be incorporated in the system then this input gear A is coupled to motor and the output gear C is connected to generator, in between you should have this intermediate gear B. So this set of gears you can arrange it and when the torque is transmitted through the set of gears, the torque is measured automatically by putting different weights here against this reference mark. The principle of functioning is the torque T is acting over the gear A which is fixed to the motor or the driving source and that torque is realized as a force at the pitch line of the gear A, in such a way T is equal to F into $r_A$, $r_A$ is the radius of the gear A and B is the intermediate gear mounted freely on the lever. This is a gear B I will write it, gear B is freely mounted on the lever that is it is supported on the lever and the lever is freely mounted on the shaft of gear A. These are the construction details; the lever is mounted free on the shaft gear. When the gear A rotates, B will rotate in this direction and B is driving the load on the gear C.

So reaction of load will be in this direction, gear C is rotating in this direction. So reaction of C will be in the opposite direction so you will find 2 F are there and the reaction of these two forces will be taken about the center of the support of the gear B and so you have got 2 F is the force on the lever, since B is freely supported on the lever. So now the lever is under a moment that is 2 F into A because lever is mounted here. This is counter weight to balance the weight of it, the other side of the pivot. This is more or less, pivot of this lever mechanism and the counter will be accounting for the mass of the lever in this direction. So now 2 F into A will be the moment about the pivot of the lever and that is to be balanced by hanging weight w into l, by adding weight we can balance it so that it stands against a reference mark.

So now we find w is equal to 2 Fa divided by l and now we know F is equal to T by $r_A$. So substitute for F then you will find w is equal to 2, F is equal to T by $r_A$ into A by l. So from here torque is equal to w $r_A$ into l by 2A. So this is the torque, that is F into $r_A$. So in this except w; $r_A$, l and 2a are all known that is 2 l w into $r_A$. Except w, all the parameters are known and that means by having different weights for different torque we are measuring the torque. This is the principle of measurement by epicylic train transmission dynamometer.

That is what is shown here in the signal flow diagram, we have got torque available that is converted into a force F at the pitch line of the gear A, by using gear B and lever we convert that force into a moment equal to 2F into A that is being balanced by w into l that is moment is converted in terms of w force by having the lever. So as per this equation now different weights can be calibrated in terms of torque. So by adding different torques here then you can find the total torque transmitted by this instrument so this is one method.

Second method is reaction principle. That is when the torque is developed for example we have got say a rotor and that is mounted in stator. So this is rotor so this is stator assembly we have the bearing here. So rotor and this is the stator of an electric motor, this is shaft (Refer Slide Time: 15:20). Now when a torque is developed in a rotor, again this principle is a torque developed in the rotor; the reaction will be felt in the stator in the opposite direction. This is the principle action and reaction that is when torque T is developed in the rotor, the stator will realize the same torque but it is in oppose direction.

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It is similar to when we use a gun when the bullet moves forward, the reaction is felt on our shoulder. That is the reaction is backwards when the bullet moves forwards. Similarly here also when the torque is developed in the rotor, the stator realizes an opposite torque of equal magnitude but what they are doing actually the stator we fix it to the ground. When you fix it to the ground, the reaction of the stator is taken by the ground, we normally find we use a strong bolt they are called foundation bolt and at the end it will have some branched or split construction.

So that the foundation bolt rigidly cemented to the ground and it is able to withstand the torque. The higher the capacity of the motor and stronger will be the foundation bolt, it is because the reaction torque should be absorbed otherwise the stator will start rotating. So now here the reaction torque is to be accounted for by fixing strongly but now what we do when we want to use the reaction torque itself to measure the torque developed in the rotor then we don’t fix the stator. That is the logical approach so that is here now it is a motor whose developed torque we want to measure.

Torque T is developed that torque we want to measure, so naturally we don't fix this stator to the ground, mount it on trunnion bearings, a one pair of ball bearings. Ball bearings is of very precision and a very small coefficient of friction. Such a bearing you can select and use them as a ball bearing that is now instead of fixing to the ground and the stator is supported through a ball bearing and then fixed to the ground. So now it is not fixed to the ground it is through the ball bearing it is fixed to the ground. When the rotor develops some torque, the stator will try to rotate in the opposite direction

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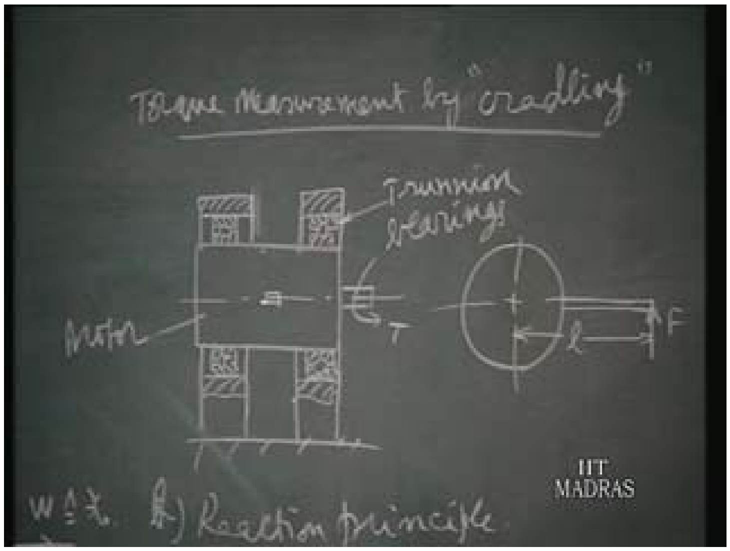


Since it is mounted on the ball bearings it is free to rotate but what we are doing is we support that and see here we have connected a lever from the stator body and it is supported at the end by having a proper support and we can measure the force F. To measure the force F we can use any one of the transducers or the load cell what we have learnt under force measurement. So when the reaction torque is there that torque is realized as a force at a lever arm so the torque is equal to F into l, by measuring the force at a distance of lever that is what is shown here. The lever comes in front and support it at the end and measuring the force you know the torque, according to the relation because l is fixed so according to this relation we can measure the torque by measuring the force, so this is one method.

The second method that is in case of small motors say small motor of say few watts say 10 watts capacity such as small motor weight will be few grams say 150 grams. In such cases the reaction measurement can be used comfortably to find the torque developed in the motor. That is now the whole motor is held in a holder; two screws are there, fixing the two screws to the stator of the motor this is held hang so from a stand. This is a holder connecting the motor stator to the torque transducer here; it transduces the torque in terms of voltage. How it functions? One principle is we can explain it here that is a torque transducer how the torque is converted in terms of voltage.

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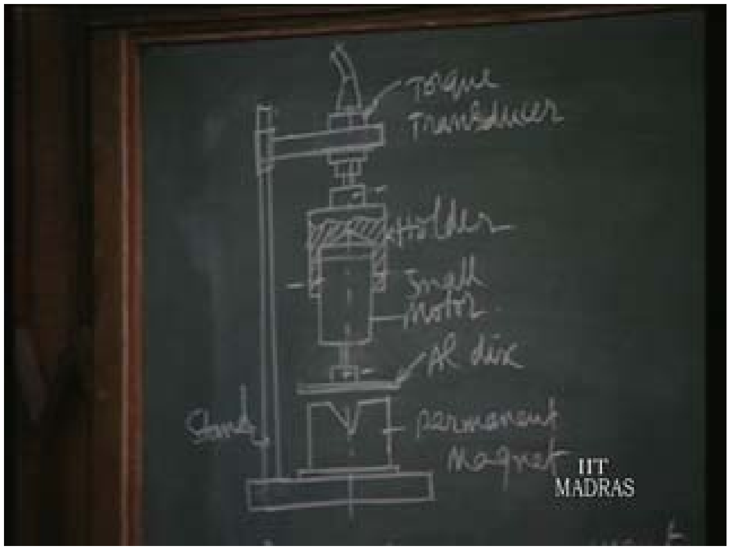


For that we can use the microsyn, microsyn we have learnt already in displacement measurement and there it can measure plus or minus say 15 degrees rotations in which it can convert into proportionate voltage where we have a rotor material distributed against 4 poles and each pole will be carrying excitation winding and also secondary winding. That principle we have learnt already so microsyn changes the rotation of plus or minus 15 degrees into a plus or minus 5 degrees or plus or minus 2.5 volts so angular rotation to the voltage is obtained by microsyn. Now the torque is applied now here it is a part of the transducer, you will have two cylinders; it is one cylinder that is fixed cylinder and then a movable cylinder connected by so called cross leaf springs. That is we learnt one of the pivot that is spring pivots that is in earlier bearings where the error source to reduce the friction or to reduce the play in bearings, we have learnt a cross leaf bearings it is one of the earlier lectures.

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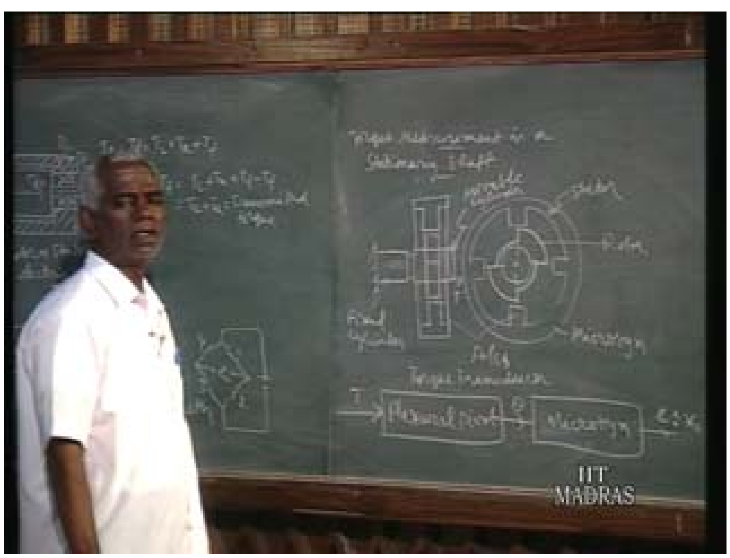

So these two cylinders are connected by 2 cross leaf springs, middle spring being the twice the width of the two end springs. Springs are just flat spring steel material so now if you can hold one cylinder and rotate the other cylinder proportionately and that rotation is proportional to the torque. So if you apply more torque it will also rotate more, with reference to other cylinder you can hold any one cylinder. So one of the cylinders is fixed and the other cylinder the torque is applied. Now the torque is converted into angular rotation by this cross leaf springs. So now this cylinder assembling, fixed cylinder and which is fixed by means of three springs inside convert the torque into theta that is what is shown here flexural pivot with the cylinders, pivot is since it is so with the cylinder is there. That assembly is converting torque to theta and theta to e or voltage is obtained by having this microsyn mounted to the movable cylinder where we apply the torque. So when torque is supplied we get the voltage output. Such a transducer is made use of here that we call it torque transducer.

So the reaction torque is there on the motor, when the motor is under the torque then naturally it is transduced by the torque transducer into voltage which will be connected to an instrument, that is the wire carrying the signal to the instrument. Now the different torques is developed in the rotating disc, disc is fixed by a screw to the shaft of this motor. So by adjusting this gap we apply different torque on the system that is what we learnt earlier, eddy current dynamometer, this is eddy current dynamometer by having different height of this plate we can change the gap and then torque is varied accordingly the torque is realized by the instrument and if you measure the rpm by having another pickup, we can plot the torque speed characteristics of the motor.

So here essentially we are measuring the torque by having reaction principle, the rotor is developed, in the rotor the torque is developed. The reaction is taken by the, reaction a torque available in the motor stator that is being transduced taken by the transducer and given voltage. Now when we are measuring the torque at the stator, does it include the friction torque because we know the rotor is mounted on the stator by two ball bearings like this. It is shown here. This is the rotor and this is the stator, the stator is or the rotor is mounted inside the rotor by having two ball bearings so when we measure the torque at the stator, does it include the friction torque which is being dissipated as heat that is the question.

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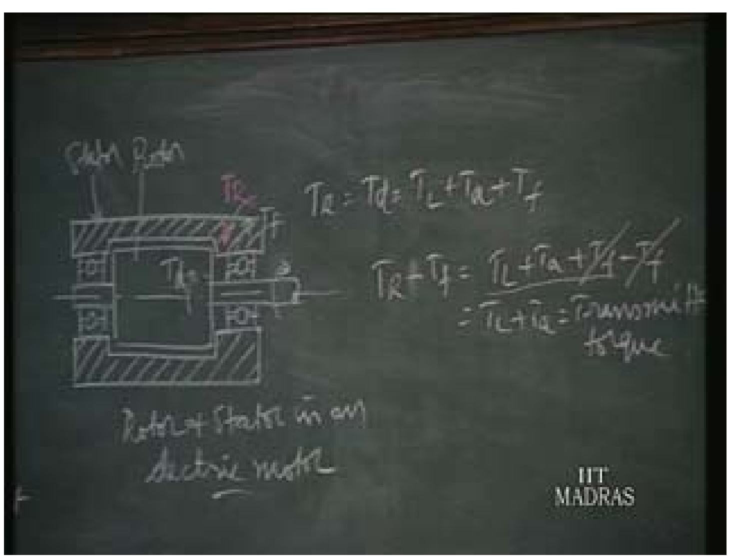

This is the rotor and this is the stator, the stator is or the rotor is mounted inside the rotor by having two ball bearings so when we measure the torque at the stator, does it include the friction torque which is being dissipated as heat that is the question. It is not the case we measure only the transmitter torque, what is transmitted from the shaft that alone is measured at the stator not the internal friction that is analyzed by the following analysis. Suppose $T_d$ is at this rotation direction so $T_d$ is the torque developed in the rotor then we know as a reaction, the reaction torque $T_R$ is developed in the stator in the opposite direction that we know. Now what is developed torque? Developed torque made up of load torque here we have got load torque acting and also acceleration of the whole mass and the load mass also should be accelerated. So load torque plus acceleration torque plus friction this is also friction is there in the overcoming friction between the boll and raise. So we find the $T_d$ the torque developed is equal to $T_L$ plus $T_a$ plus $T_f$ that is equal to $T_R$, $T_R$ is the equal amount whatever developed in the rotor equal amount is developed on the stator immediately that is the reaction.

Now what is the effect of friction? Friction is acting on the stator in such a way that is friction is coming through the ball bearings to the stator, in such a way this is stationary member normally. It is being dragged to rotate in the rotation of the rotor. So the stator will be under the friction torque trying to rotate in this direction so friction torque is in this direction. Now what is the net, $T_R$ is in this direction, $T_f$ is in this rotating direction. So what is $T_R$ is made up of? $T_R$ is made up of all the three and $T_f$ plus $T_f$ this is minus $T_f$ minus because $T_f$ is opposite to $T_R$ minus $T_f$. Now $T_f$, $T_f$ gets cancelled and what is transmitted is $T_L$ plus $T_a$. That is what is available in the stator that is what you are measuring by having such a set up. So when we measure the stator torque, we are measuring the torque transmitted from the shaft to the load and other things. So that is what is important, internal torque is not measured by this reaction principle. So this is second method, first method is a transmission dynamometer. Second method reaction principle, third method is strain gauge or this is method c strain gauge torque meter.

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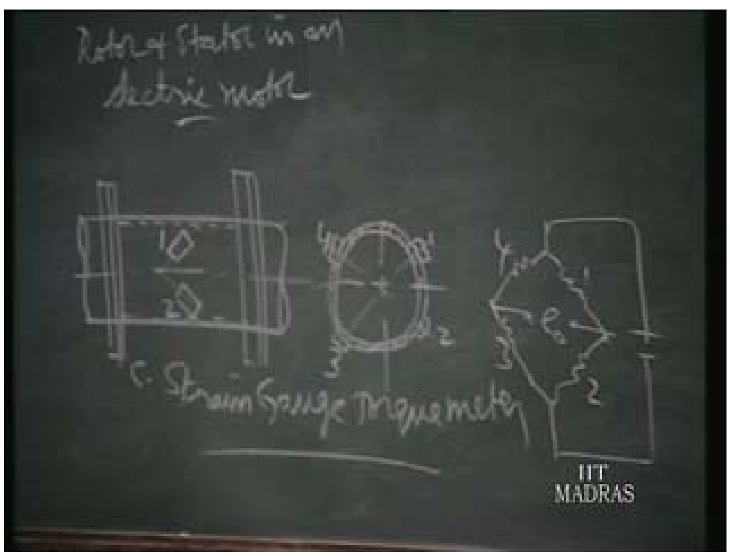

Strain gauge torque meter this is also widely used in shafts. So this is only in small motors, bigger motor you have to mount in trunnion bearings but the error in such reaction measurement there using trunnion bearing, the friction in the trunnion bearings friction torque is the error torque, error in measurements. So when you select bearing for the trunnion bearing it should be having very low coefficient of friction. Such bearings we should take and it is possible to keep the errors within the limits. Now this strain gauge torque meter this is more precise and also widely used. here what we are doing is, this is transducer this is the shaft taking the torque from the power source to power sink in between we fix these strain gauges.

As I already told in the force measurement we have to weaken the place where the strain gauges are pasted otherwise signal will not be sufficient. So for that purpose probably you can make a flange coupling in between and make a tubular member where you want to fix the strain gauge, make a tubular member, the other thing may be solid. So here we are fixing the strain gauges in a tubular member so that we have sufficient signal for the instrumentation, signal noise ratio will be sufficiently large. Now we know when there is purely a pure torsion that principal stress or strain that will be given by a sigma$_1$ or sigma$_2$ that is equal to sigma$_x$ plus sigma$_y$ by 2 plus or minus root of sigma$_x$ minus sigma$_y$ by 2 plus tau$_{xy}$.

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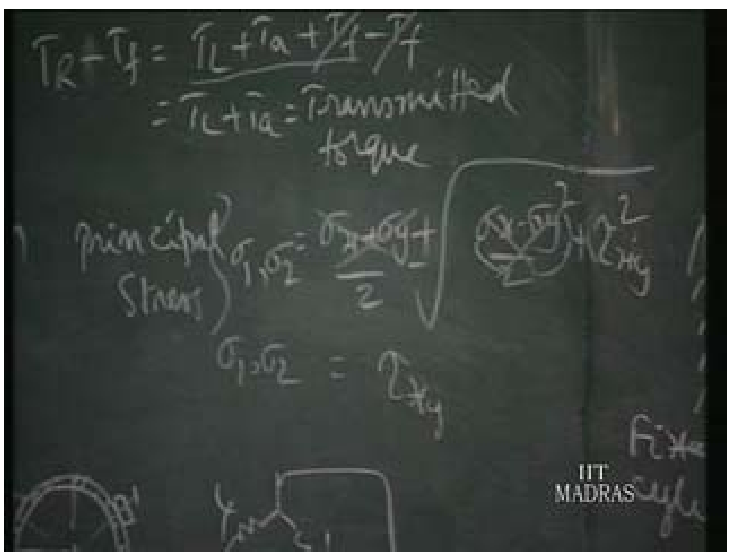


This is when any element is subjected to 2 coordinates as sigma$_x$ sigma$_y$ and also a shear stress of tau$_{xy}$ then this is tau$_{xy}$ square. When there is shear stress then principle stress will be given by this equation and in torque applications we don't have these coordinate stresses. So you find the principal sigma$_1$ sigma$_2$ is equal to tau$_{xy}$ because square root of square so that alone remains. That is principal say sigma$_1$ sigma$_2$ will be tau$_{xy}$ the principal that is same as shear stress will be appearing as the compressive or tensile stresses and also the angle at which it will be oriented is given by tan 2 phi is equal to 2 tau$_{xy}$ by sigma$_x$ minus sigma$_y$. When sigma$_x$ sigma$_y$ zero now you find tan 2 phi is equal to infinity so 2 phi is equal to 90 degree and the phi is equal to 45 degrees. So at 45 degrees to the direction of the shear stress the principle stresses sigma$_1$ and sigma$_2$ or tensile compressive stress will be available.

So this is the torque in opposite direction so torque that is twisted this way that is torque is the shears in this direction so 45 degree to that, that is how you have to fix the strain gauges. So if 1 is taking up the tensile strain then 2 will be taking up the compressive strain. Similarly opposite point that is at 45 degrees you have to fix that is how we get the direction 45 degrees. So 1 and 3 will take tensile strain and 2 and 4 will take compressive strain. So in the shaft you have to mark axial and then 45 degree you have to paste 2 strain gauges. Now you will find this both this is 90 degree, one axis to the other axis is 90 degree and that is called 90 degree rosettes are available in the market, strain gauge rosettes in one mounting, the two strain gauges at 45 degrees or with the center line it is also marked there, 45 degrees here, 45 it is fixed they are available in the market.

So purchase one such things and we marking a line in the shaft and line on the rosette also coincide, you paste it with the cement as supplied by the manufacturer then similarly in the opposite point also. The diameter opposite point is fixed in these 2 strain gauges and connect them in the bridge network as per this diagram. So 1 and 3 will be taking up the tensile strain for one particular rotation and 2 and 4 will be taking up the compressive strain. So when the torque is supplied then you will find, you get proportionate to output signal $e_o$ and that can be calibrated in terms of torque.

Now this instrumentation is sensitive only for torque and it is not sensitive for axial or bending moment that what we claim. How do you say this? Suppose this is being bent in this direction a moment is applied in this direction, so it is bent then what will happen? All layers above the neutral axis will be under tension so layers 1 and 4 are the strain gauges which will subject to tension. Now 1 and 4 in adjacent arms taking up similar strain and it will nullify, it will not give rise to any output voltage. Similarly a 2 and 3 will be under compressive strain and adjacent arms it will not give rise to any output voltage. Hence the bending moment doesn't produce any signal in the bridge network.

Similarly if it is compression suppose you oppress a compressive load, the whole shaft is compressed; will you get any error signal. No, it is because all the four when you compress the shaft like this, compressive force all the four strain gauges are equally strained and equal strain in all the four arms. We have already learnt, it will not give rise to any signal in the bridge network. So this is the loss of the bridge so you will find the instrumentation response only for the torque and bending moment as well as the compressive or tensile load on the shaft will not give rise to any error. Hence it is automatically foolproof for the other type of loading. So that is the rotating shafts torque that is transmission type can be measured in any one of these three methods. Now we go to the next torque measurement in stationary shaft.

Now it is simple say it is simple method here if you have got a shaft. It is a fixed shaft and when we apply a torque then the layer AB twists to AB dash. So if you want to measure this torque on the twisting, you can instead of fixing the shaft to the wall, you can as well fix to the transducer so that you fix to the transducer. Now the shaft is fixed to the transducer so when you apply the torque the transducer gives the signal. So that is an easy method or you can also use the strain gauge torque measurement, fixing the shaft here and put your strain gauges 45 degrees and now the wire can be little flexible wire but previously now it is rotating shaft so you require this slip ring force. These are the slip rings, 4 slip rings for the 4 corners, 2 corners for the supply and the 2 slip rings for taking output signal.

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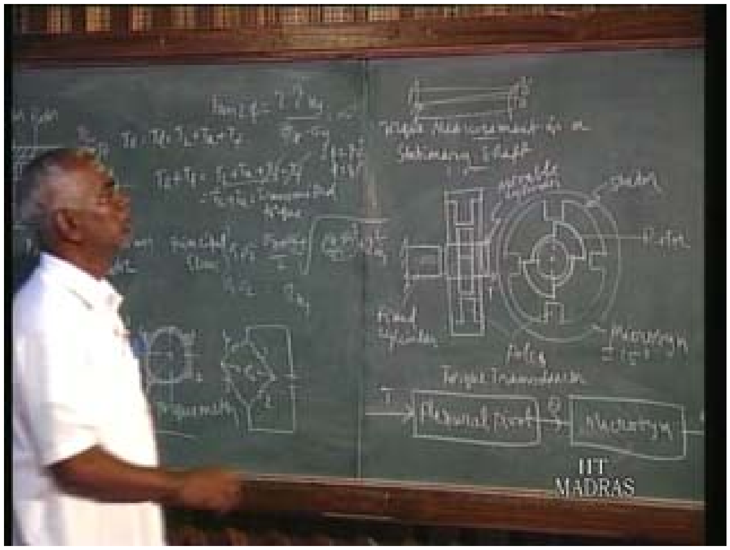


So by using slip rings we can take the signal inside and signal outside, if it is stationary shaft, such things are not required so it is easy method of measuring the fixed shaft by using the strain gauges it is easier. As we have learnt under force measurement, friction force how to measure the friction force we have learnt under force measurement. Similarly under torque measurement let us learn the friction torque measurement. How the friction torque is measured. Friction torque is the common phenomena in all bearings for example we consider the sleeve bearing, this is sleeve bearing bush or it is called sleeve within which a journal shaft or it is journalist shaft, shaft is rotated.

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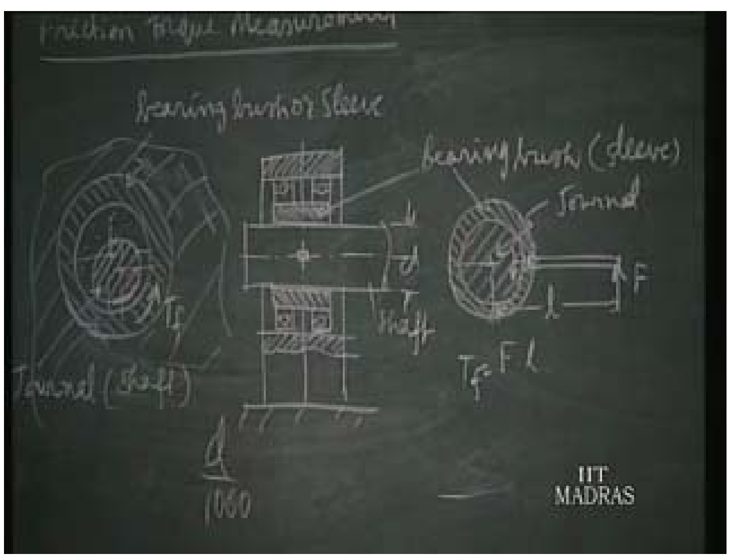


So this is rotating inside and we have the lubricating oil so as the shaft rotates in this direction because of edge formation shaft is lifted. So when it is lifted it is rotating but due to viscous friction of the liquid lubricant, you find the sleeve also will be under the action of the friction torque, there is no torque will be there.

This is normally the sleeve is fixed to the wall, this is wall so normally fixed to the wall. So the frictional torque is taken up normally absorbed by the wall. Since the sleeve is transmitted to the wall. So the phenomena here is due to the friction torque the sleeve will try to rotate along the shaft but it is not allowed since it is precipitated but when we want to measure that friction torque naturally don't fix it to the frame and mount it as we have learnt in the reaction principle. Here we mount the sleeve on two ball bearings; we can call it trunnion ball bearings. So that now the sleeve is allowed to rotate in the same direction of the journal, this is the journal, this is the shaft or journal, the portion of the shaft inside the bearing is called journal that's all. So there will be gap but here I have exaggerated clearance but normally the gap will be of the order of d by 1000 this is the diameter clearance in any bearings.

If the d is diameter of the journal then the clearance will be d by 1000, if 10 mm shaft means 10 microns will be the clearance inside the bearing. So within which the oil is there it will create the wedge formation and hence the relative motion is allowed there. Now due to this rotation suppose it is rotating in this direction. Direction is shown here so the sleeve also will be trying to rotate but it is not allowed to rotate by having suppose I take the cross section here, one lever is fixed to the fixed to the sleeve that is bush. When the bush tries to rotate, it is not available to rotate by supporting it at a distance l and you can use any force measuring technique that is any load cell.

So that what is the force due to this toque at this leverage l? So if F is the force F into l will give you the friction torque in the sleeve that is how we use this method of fixing a lever and measuring at the distance to measure the friction torque on the sleeve bearing that is one method. Here the error is the trunnion bearings whatever we got the error, whatever we have the friction in this ball bearings that will be the error in the measurement but we know that in ball bearings the friction coefficient is very small compared to, this is sliding bearing, sliding bush or bush type or sleeve type bearings are called sliding bearing their friction will be much larger. So that friction torque is larger one. So that will be smaller portion of I mean ball bearings friction will be much smaller. Hence it is under allowable error limit that is error source and another better method than this method is called pendulum dynamometer.

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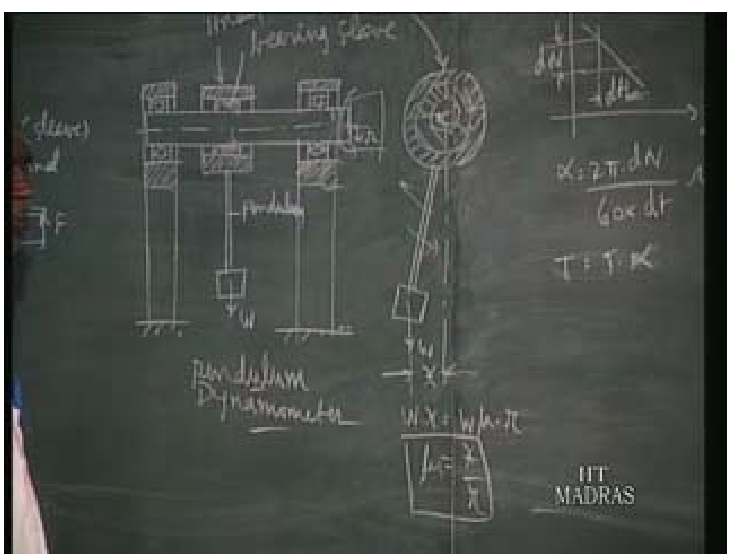

For small bearings less than 10 mm means a diameter bearing you can use it, there are other technique you can use any bearing, any size. So small bearing so this is the bearing you can call it bearing sleeve and this is the holder, this is the pendulum, this is the weight of the pendulum; pendulum is fixed to the holder bottom. So what happens when this is support bearings. So the shaft is rotated by, you will have the motor fixed here. So it will be rotated and due to that rotation the sleeve also will try to rotate along the shaft due to friction torque. So when the sleeve tries to rotate suppose this is rotating speed so that I will hatch it and this is the sleeve, sleeve is in this direction this is the bearing bush or bearing sleeve, bearing sleeve is mounted in the bearing holder. So this is the bearing holder, at the bearing holder bottom you have fixed to the pendulum.

So suppose this is direction of the journal so the sleeve also will try to rotate and when it rotates the weight which is at the bottom is moved by a distance x, the moment it has moved it applies a restoring torque. So you find the friction torque is trying to rotate the pendulum in this direction whereas the weight is trying to bring it to the original position when both of them match it will stand there. So you will find this is a measure of the friction torque so w into x is the moment restoring and deflecting torque w mu into r, r is the radius of the journal. So mu is the coefficient of friction between the journal and the bearing and w into mu friction force into r will give the friction torque. So friction torque will be w into x that is w into x is equal to this under equivalent condition.

Just under the equivalent condition measure this x, from the neutral position how much it has deflected. So from that mu is equal to coefficient of friction between the journal and the bearing bush is x by r that is how the friction torque and the friction coefficient of friction is found out. Here the error more or less is not there, except the measurement technique may have some error in this measurement or length, this is second method. Third method is coast down analysis this is mainly used in electrical motors. What is the friction torque in the electrical motor? So technique is you switch off the power supply to the electric motor, now the electric motor decelerates.

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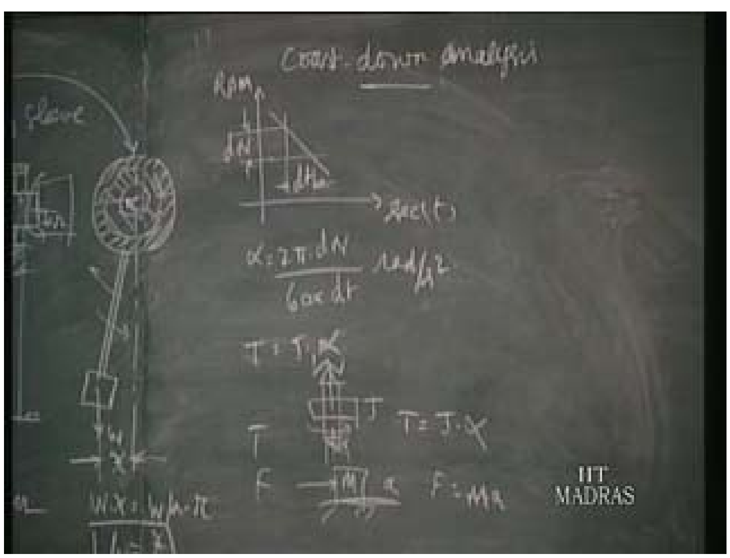

What is the speciality of torque, how the torque and force are analogous to each other? If force when you apply on a body, the body moves on a linear line with an acceleration a. Similarly you have got a mass on a shaft and it is pivoted and now we apply a torque, m is the mass here so F is equal to M into a for linear, when we apply a force on a mass that mass accelerate through a along linear axis whereas linear direction. Whereas torque when you apply on a body like this with a polar movement of inertia J then it accelerates in an angular direction. That is force and torque imparts acceleration, effects acceleration along the linear direction, torque gives acceleration in the rotary directions with the equation T is equal to J into angular acceleration alpha.

You can use torque to accelerate or decelerate also, that is what is made use of here coast down analysis. Whatever available the friction torque when once you cut the power supply to the motor that the rotor decelerates that deceleration is proportional to the friction torque that is the principle. Assuming that there is no windage loss in the motor, it is only friction torque which is causing the deceleration then you will find deceleration. Plot the variation of the rpm of the motor with reference to time that you can by giving a tachogenerator that voltage is you can plot in a strip chart recorder. For a few seconds let the deceleration, that the rpm be plotted and from that you can find out the acceleration or deceleration. The deceleration is negative; reducing acceleration is called the deceleration.

So if dn is the rpm difference for a duration of dt say probably 100 rpm difference for a 5 seconds. So 100 by 5 put it here so that is rpm and is converted into second by 60 then rps then 2 pi you multiply, you get the radian per second square. Then you will find friction torque is equal to J, the rotor movement rotor polar movement say it is given by manufacturer J then multiplied by the deceleration will give the friction torque $T_F$. So that is how we arrive at the friction torque in electric motor that by coast down analysis, after cutting the power supply allow it to decelerate and that rpm is plotted from that we can find out what is the friction torque in the bearings. Now it is very important for a mechanical engineer to design the tubular member when you want to measure the torque in any transmitting shaft.

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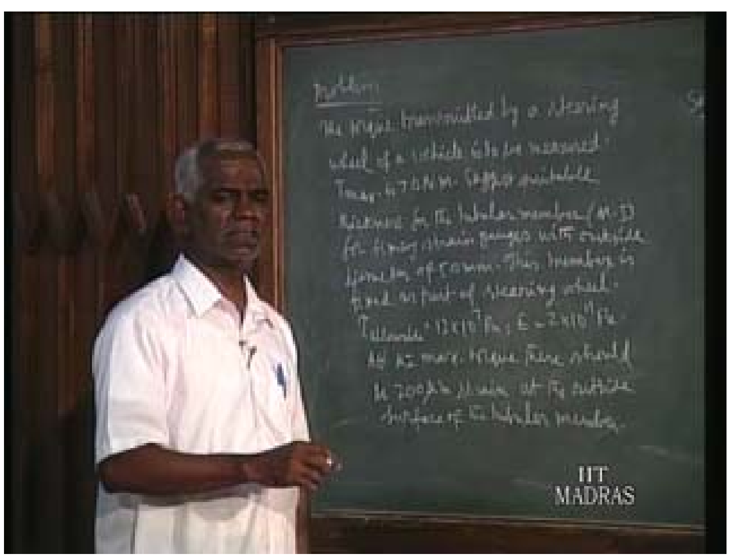

So as I already mentioned for the strain gauge torque meter that where we want to paste the strain gauge it should be made tubular structure so that we have sufficient strain there. Secondly tubular member will have large area so that we can easily fix the strain gauge, if you go for solid shaft then it will be very small diameter to produce sufficient strain and in the small shaft you cannot paste the strain gauge that is the problem. To avoid it we go for the tubular member, it will be weak at same time we have got sufficient area. So to illustrate that we have worked one problem here that is this is actually an industrial problem. The torque transmitted by a steering wheel of a vehicle of a car is to be measured and maximum torque in that steering wheel in a very rough road condition is around 70 Newton meter. Suggest suitable thickness for the tubular member made up of mild steel for fixing strain gauges with tubular member outside diameter being 50 mm.

This member is fixed as part of the axle then only the whole torque will go through the strain gauge through the instrumentation. So it is part of the steering wheel and tau allowable that is to say maximum shear stress in this mild steel is 12 into 10 to the power of 7 Pascal and Young's modulus of steel is 2 into 10 to the power 11 Pascal. At the maximum torque there should be 200 micro strains that we know because the strain gauges we paste, it measures principal stress pension as well as compression and that strain should be around 200 micron that we normally adapt for instrumentation. same thing we did for force measurement also worked out problems.

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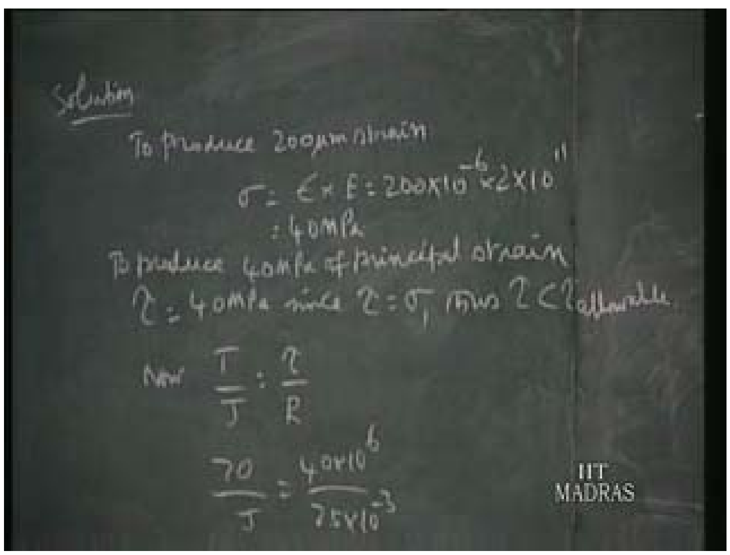


So now the solution is to produce 200 micro strain necessary stress should be 40 mega Pascal that should be the principal stress and to produce that principal stress, we know the other rectangular common end zero, the tau$_{xy}$ that is shear stress should be of the same principal stress. So tau is also of the same order so that is a shear stress and this much produce a equal principal stress which we have seen previously in the equation. So the corresponding to principal of 40 mega Pascal shear stress should be 40 mega Pascal same since tau is equal to sigma, sigma is principal stress. Now the problem it is given tau maxim, tau allowable is 12 into 10 to the power of 7 and we here we have got that is 120 mega Pascal, here we have only 40 mega Pascal.

So tau is less than tau allowable that means we can go for 200 micro strain so that we have checked. Now we go for the equation for the torque T by J polar moment of inertia is equal to the shear stress by radius or the outer surface or whatever it is, the radius. At particular radius what is the shear stress this is the equation well known. So T maximum is 70 Newton meter and J is the polar moment inertia of the cross section area and the shear stress is 40 mega Pascal so the radius that is outside diameter is given as 50 millimeter. So it gives rise to a radius of 25 millimeter that is in terms of meter, 10 to the power minus 3 gives rise to a J of 43.75 into 10 to the power of 3 millimeter to the power of 4 that is the polar moment inertia. That is the area so the annular area should give rise to a polar moment of inertia of so much.

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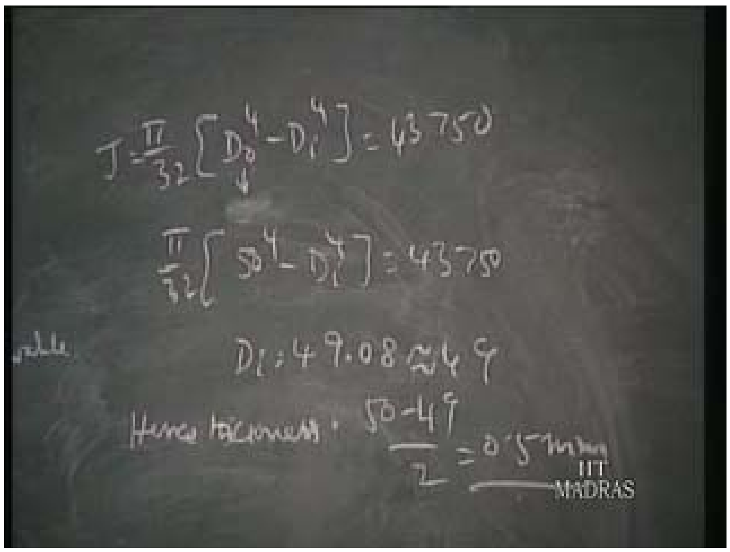


If that is the case then J is the polar moment inertia in terms of $D_o$ and this is $D_i$ and outside is $D_o$. So if the $D_i$ $D_o$ are the say inside and outside diameters then polar moment inertia is given by this equation. So $D_o$ is given as already 50 mm so $D_i$ from this equation you get 49.08 you can take it as 49 millimeter. So thickness for outside 50 and inside is 49 divided by 2.5 mm.
So that should be the thickness of the tube then only you will have sufficient stress and sufficient strain. Our instrumentation will have sufficient sensitivity so that we can measure the full range of the torque up to seventy Newton meter here. So that is how we have to design the primary transducer, transducing the torque to strain.