**Principles of Mechanical Measurements**

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**Lecture No. # 05**

So far we have learnt the introduction of the topic and then basic concepts. Now we are going to the third important topic, sources of error. I told it is very important in the sense without understanding this source of error one cannot design an instrument. When we design an instrument we want to make certain measurements that measurement should be within certain error. If the error is too much that reading may not be useful for us. So to design an instrument within certain error limit, the designer is supposed to know what are the error sources within the instrument or coming from outside and other factors. So unless he is able to identify the error sources he cannot properly design instrument within the error limits. Hence this topic is very important for any designer sources of error. Now what is the definition for source of error?

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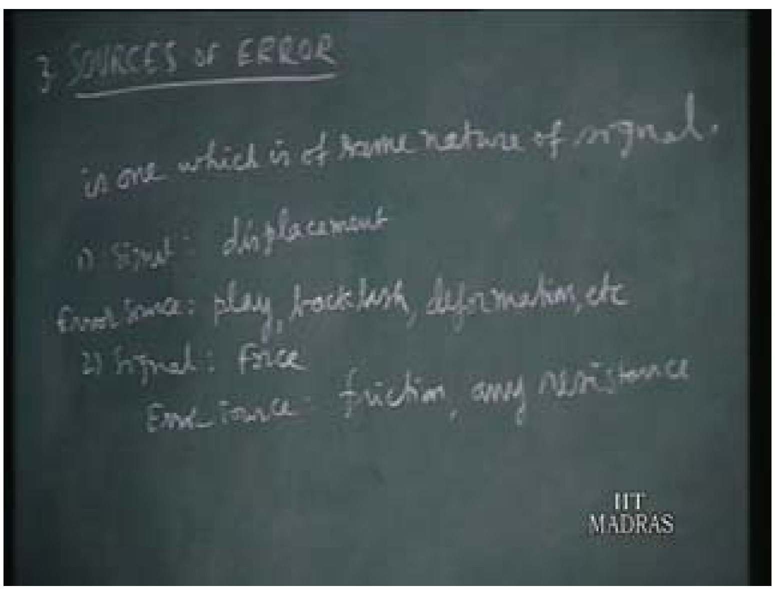


Source of error is one which is of same nature of signal. This is the definition. Source of error is one which is of the same nature of signal that is the error source should be of the same nature. Further we can clarify that suppose signal is displacement, according to this definition the error for the displacement signal should be also of the same nature. So what is understood by that? For a displacement signal say play, now error source can be a play. What is play? Play is an empty gap, empty distance without any material. So it is a distance where there is no material that is how play is essentially of the same nature as distance.

Next thing is backlash, so play is in the joints linkages whereas play in gear machines we call it backlash that is technical term. Backlash is again play in a gear machine and deformation. Suppose there is a link during the functioning of the instrument, if the link deforms and if that link carries displacement signal this deformation is an error source because deformation is distance compressed by an element so it is a distance. So you find play, backlash, deformation, etc which are essentially of the distance or the displacement in nature, distance in nature. They can form error for displacement signal.

Suppose signal is force, a force signal then error for the force should be also of the same nature of force. What it can be? So error source for force signal is friction, any resistance. That is friction will oppose a motion so motion is there on a body only when the body is acted upon by a force and when the body has to move over a surface, friction is there opposing the motion. So the net force alone will move it.

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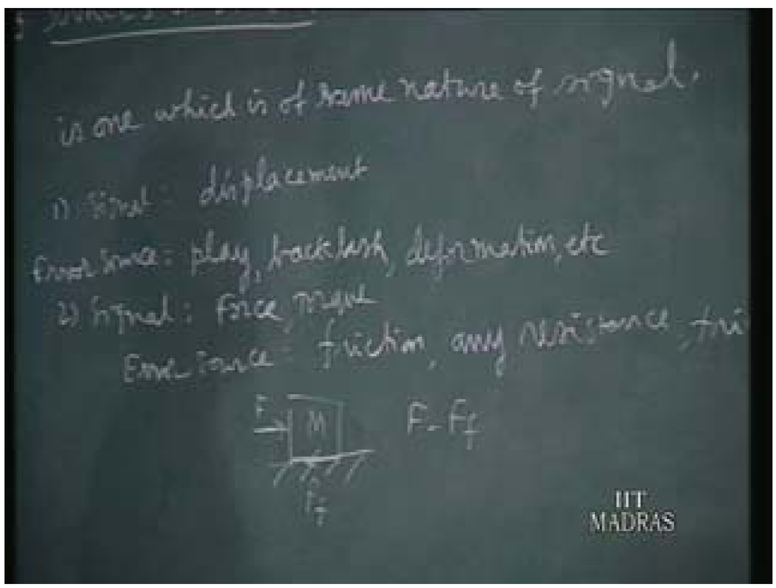


Suppose F is the applied force, it moves over a surface and F is the force and $F - F_f$ alone will be responsible for the movement of the mass M. So this much force is acting against it. So if friction is of the same nature of the force hence friction is an error source for force signal. Similarly torque, force torque, so frictional torque. So this can be error source for torque. What is torque? Torque is nothing but force acting at a distance from a rotating axis, so essentially they are same. Force is one acting along a line; torque is again a force acting at a distance from the mounted axis that's all.

So friction is for force and frictional torque is for the torque signal. So that is the definition and also the definition excludes any other error source. What does it mean excluding? A friction cannot be an error for displacement signal and a play or backlash cannot be an error source for force signal that is the excluding. The error source for a signal can be only of the same nature of the signal, any other source cannot be an error source for a particular signal. So friction cannot be error for displacement and play cannot be an error source for force signal.

That is how we are able to identify the error sources. Now what are the steps in identifying error sources? Naturally unless we know the signals in an instrument, you cannot identify what are the error sources. How to know the signals in an instrument? We already learnt how to draw a signal flow diagram. What we obtained in a signal flow diagram. When we draw a signal flow diagram in terms of basic function element, all the signals within the instrument are brought out there. Once if you bring out the signals then we know what are the corresponding error sources. So that is how within an instrument the error sources are identified. How the error sources are classified? It is done under three ways. I mean we have to look for error sources in three different situations.

First we will say error source within the instrument and second error source outside the instrument and third we will call it error due to loading effect. These are the three ways in which error sources appear in an instrument. Now for the error source within an instrument we will consider an example, a dial gauge. I have brought the dial gauge in the earlier class with the backside open and we know we have seen a set of gears are there and such a diagram is drawn here. A dial gauge when you open it back side then you will see set of gears and schematically it is represented here. This is the plunger one where you give your displacement motion.

Once you give displacement motion, the rack which falls part of the plunger moves up and down. When it moves up and down the pinion two rotates so for any 1 mm motion this rotates through an angle say few degrees and 2 and 3 are compound gears. So same rotation will be there whatever pinion rotates same rotation will be there in gear three. From gear three motion goes to gear four so magnifications is taking place and from there pinion 4 axis is connected to the pointer, pointer moves over the scale. These are the elements within a dial gauge.

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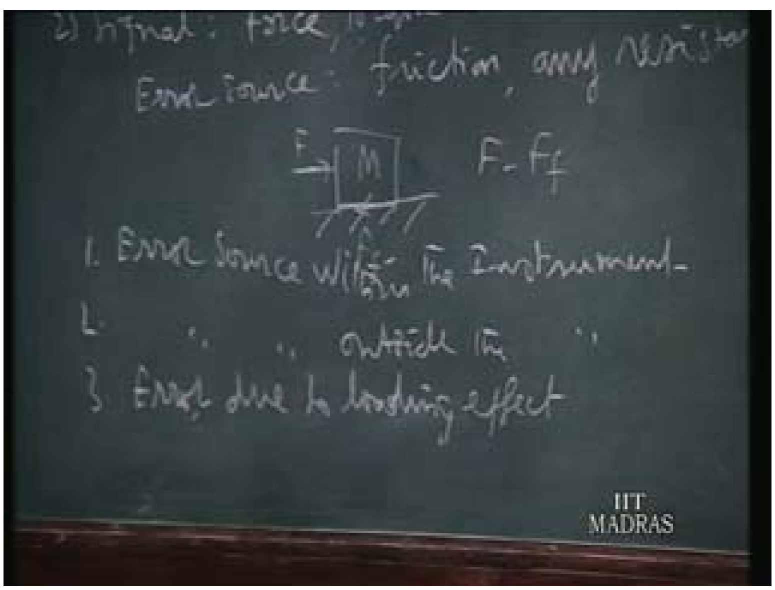

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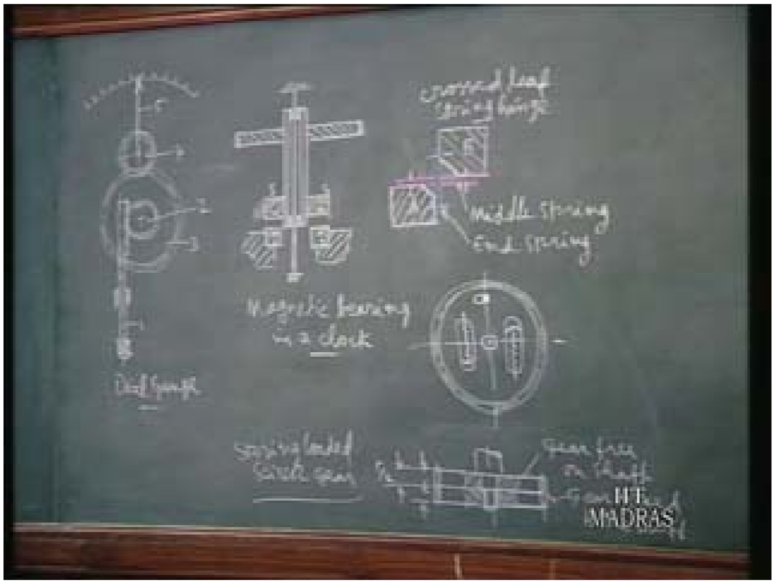


Now to understand the errors sources within the dial gauge naturally we should draw the single flow diagram of the dial gauge. How do you draw the signal flow diagram? Suppose $x_i$ is the input signal displacement $d_1$ so that is our input signal that is what we give say plunger plus rack or we will call it rack and say rack forms part of the plunger so we will write rack plus pinion 2 that is our input signal $x_i$ which is our displacement $d_1$. That is given to this rack and pinion 2 and gets converted into an angular rotation $theta_1$ that is our $theta_1$. Here it is the $theta_1$, for pinion output motion is $theta_1$.

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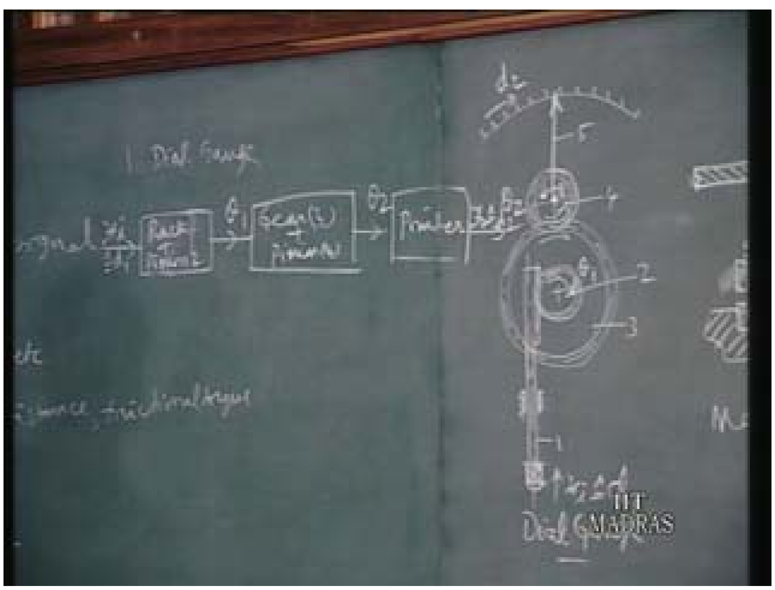

So gear 3 also $theta_1$ will be there and when it goes to the pinion 4 for this type of rotations in this way, so pinion 4 it is magnified so now gear 3 plus a pinion 4, you have got the magnification from $theta_1$ to $theta_2$. So this is our $theta_2$, rotation $theta_2$ in pinion 4 and then $theta_2$ with the pointer, this is pointer we get the output signal $x_o$ same as $d_2$. This is $d_2$, this is $d_1$ so $x_i$ is $d_1$. So $d_1$ to $d_2$ the magnification has taken place through a set of rack and pinion and gears. Now what are the signals here? We have drawn signal flow diagram in basic function elements. What are the signals? Displacement, linear displacement, rotary displacement, rotary displacement, linear displacement along the arc (Refer Slide Time: 00:12:11).

So all the signals in this instrument are of the nature of the displacement and for a displacement signal we know the error sources are play, backlash, deformation, etc. Now we have to look at what are the elements we have. Gears mainly gears, within the gear we know the error source is backlash because what is backlash, play between the machine gears. So there will be play between the machine gears. Since the play is of the same nature of the displacement here either linear or rotary displacement so if it is of the same nature then it is going to be error. So backlash is naturally an error source for all the signals. How do we explain physically that the backlash is an error in a dial gauge?

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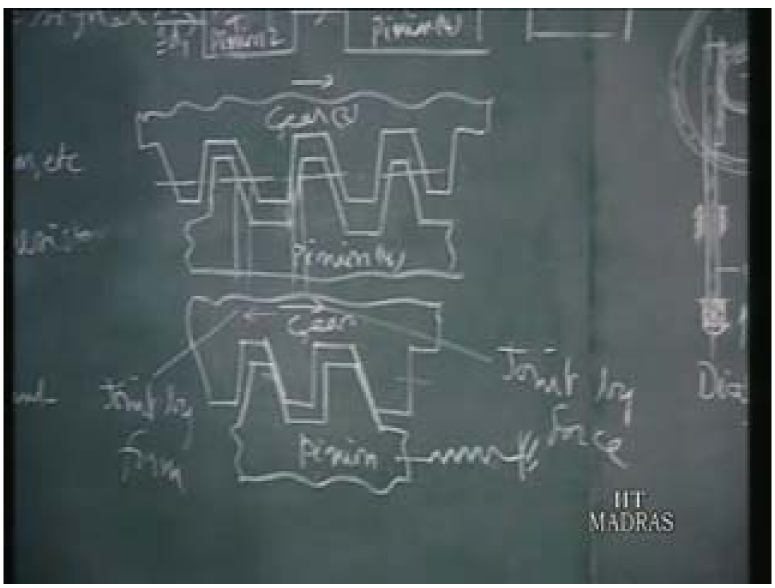


For this we draw the developed view of the say a gear and the pinion, developed view. So for example this is gear, from gear motion goes to the pinion 4. Suppose this is pinion 4, gear and pinion 4. This is gear 3, so when the motion goes from gear 3 to pinion 4. After all we give the motion here, it has to be transmitted through the gears to the pointer then only we will get the output signal but what happens if there is play. It gets lost, once any motion is lost somewhere, pointer will not move, with that extent even though even input signal it has not come to the output side so error is there. You have given input, output is not there so that is the effect of error. Now we will find how it is lost. Suppose this is the pitch line of the machine, the gear is rotated for example left to right it has rotated but this play is backlash when the gear is in the middle we call the play is backlash.

So due to this backlash when the motion is from left to right so much distance it has to move before the flank come into contact with the flank of the pinion force. So much distance it has move which is equal to backlash. Until gear moves or until it rotates the motion is taking place but pointer is not showing. Hence the error is there due to backlash. How it is avoided? In the instruments you will find a spring is attached to the pinion, a higher spring is attached to the pinion last gear of the gear drain. In such situation we will find that the effect of even though that is backlash, the effect of backlash will not be felt or there will not be error. Once you connect a spring like that then it will not be felt.

So in that case how it looks like? So again I draw it, this is the gear and I will draw another color pinion, probably same because pinion is spring loaded. Suppose in developed view it is spring loaded like this, there it is hair spring and if it is spring loaded in this direction then you will find machine is there always only one flank. This is the flank where machine is there because it is been pulled constantly. When the reading is zero it is spring loaded, under strain the spring is assembled that means machine is always maintained at one of the flanks. In such situation you find even though the backlash is there, all the backlash is pushed to one side because of the effect of spring.

Now what will happen suppose motion is there in the gear? You will find motion is not lost. Suppose motion is there from left to right again, the moment the gear moves, this is the gear and pinion. This pinion since it is under tension, the moment it moves this also will follow the motion of gear because it is already in tension, there will not be any gap. So left to right when the motion is there pinion also move to the same extent, when pinion moves the pointer will rotate. Suppose the motion is there in the opposite direction, suppose from right to left what will happen? When the gear moves from right to left that is already meshing, there is already meshing no motion will be… This is we say a joint by form (Refer Slide Time: 17:30).

So for this, what is there is joint by form. For this motion there is already joint by form because they are already hooked together, no motion can be lost. Whereas in the other direction when the gear moves in this direction because of force we are already under torque or force and the joint, the contact is maintained. So we say for this motion joint by force. So in one direction the contact is maintained by joint by force in another direction the contact is maintained by joint by form, this is the phenomena. So you find when the last pinion is spring loaded, no motion is lost even though there is backlash. This is (Not understandable) (Refer Slide Time: 00:18:12) of attaining the accuracy in dial gauge. You will find invariably in all dial gauges, the last gear of the gear train will be spring loaded. Practically what they do? Since this is going to rotate for so many rotations, it may break. This spring may break, for that they connect another gear and the spring load this auxiliary gear.

But anyhow the effect is, the torque will be transmitted to the gear tray that is the effect this is the practical consideration otherwise it is equivalent to connecting a spring to the final gear of a gear tray. So that is how the error source within an instrument exists. This is an example. Similarly you will find in many instruments for example in a piston and cylinder type pressure gauge we know there are… Now here you find it is only displacement are signals. Whereas in a piston cylinder type pressure gauge, you can analyze yourself. We have got the pressure signal, force signal and then displacement $d_1$ and final displacement for the pointer.

So you find a force signal is there and displacement signal is there in a piston cylinder type pressure gauge. So you will find any play within links will be error source and since force signal is there, the friction between the piston and cylinder, piston cylinder will be a force will be (Refer Slide Time: 19:38). Friction is a force since force is already there this friction forms an error source. So that's how we identify the error sources within the instrument. Now the error source outside the instrument they are the temperature.

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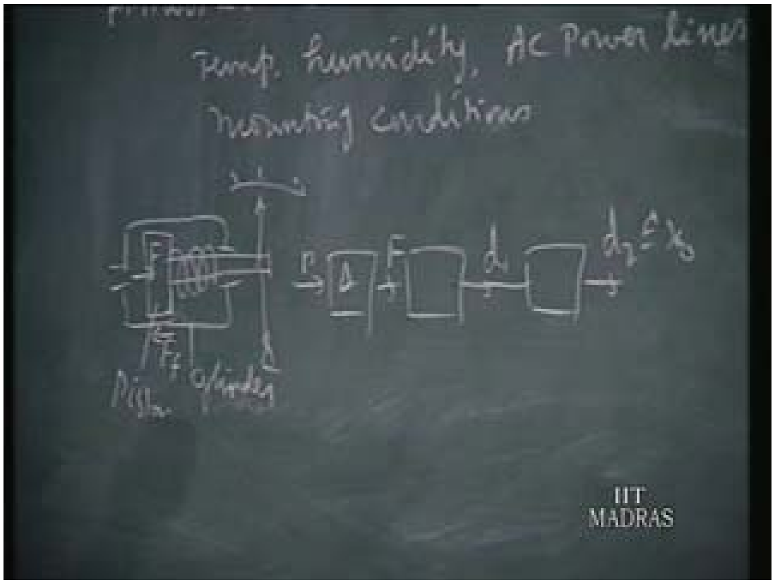


Now we have seen the errors within the instrument, friction play and so on. Now we see what are the error sources from outside the instrument. Naturally outside the instrument we have got atmospheric conditions. Which are the conditions which will affect our instrument functioning? Temperature, humidity these are the some of the atmospheric condition. Also we may have some AC power lines sometimes mounting conditions. These are the some of the outside factors which may give rise to error sources within the instrument. For example, temperature. How the temperature gives an error inside the instrument? For example we can consider our same piston and cylinder type pressure gauge where you got a spring and then pointer over the scale. Now you find when the temperature gets increased the play between the piston and cylinder may reduce. When the play reduces we find that friction has increased.

Now friction for this motion say $F_f$ is an error source for a force signal and we know the signal flow diagram say P to force with area we got $F_f$ and then you have got displacement $d_1$ and then with the pointer we have $d_2$ these are the output signal. So when force signal is there within the instrument, the friction is changed due to temperature so that's how the temperature gets into the instrument and it causes error. We have defined already an error source should be of the same nature of the signal but temperature is not of the same nature of signal. How it entered in instrument? Though temperature is not of the same nature of signal but it has caused an effect there which is a friction force, friction which is of the same nature of signal. That is how the temperature mostly you will find it's a secondary error source. It causes some other phenomena which may be of the same nature of the signal.

Since it has caused a friction which is the same nature of the force so temperature has indirectly caused error to force. Similarly you find humidity also. In case you have a bearing in terms of plastic bushes and humidity due to humidity plastic bush may expand and then they will play in a bearing again reduces so friction increases. So when the bearing carries a torque signal and this frictional torque will cause error. Similarly AC power line, nearby we have got some say 10 or 20 or 100 kilovolt power line and such a 50 hertz line may also produce some magnetic… that magnetic lines interactive within the instrument so there may be some coil within the instrument. When the magnetic line interacts within the instrument we may have some AC voltage developed in the coil which may send some current AC current. So this gets superimposed over the signal current or signal voltage. So hence we find near by power lines causes some error or it forms an error source.

How it has formed error source? Because there is a voltage signal and these varying signals get superimposed so this varying signal is of same nature of the voltage. So AC power line is an error source. Similarly some mounting conditions especially when we find some instrument is mounted in a moving vehicle, suppose we have got a monometer mounted in a moving vehicle which moves at a very high speed acceleration. Suppose the L is the distance between the lengths then the height due to the acceleration of the vehicle itself you have got a displacement height in the manometer. Even though the $p_1$ and $p_2$ remain same for the monometer, due to acceleration itself we have got this height h equal to a into L by g.

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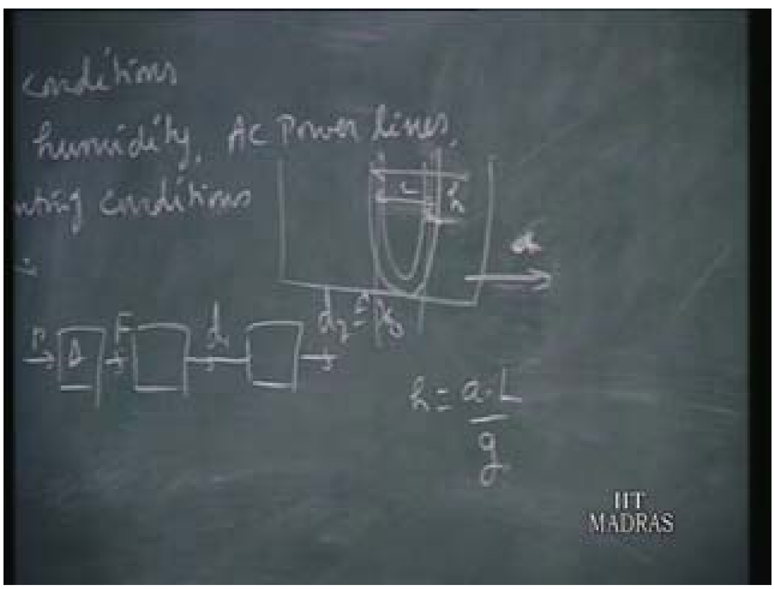


So much difference comes due to acceleration, this is acceleration of vehicle, if it accelerates twice the acceleration due to gravity we find twice L will be the height it is shown. So these are mounting conditions. These are some of the error sources which may come into the instrument from outside the instrument.

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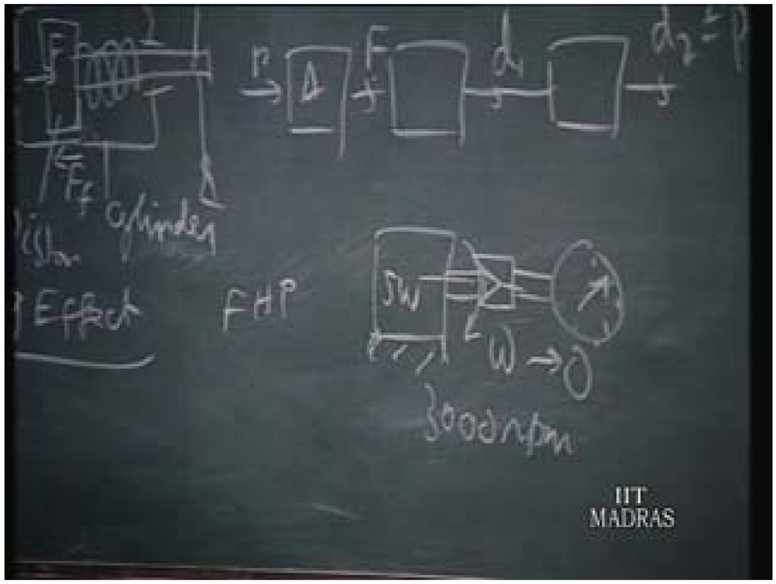


Now third error source is loading effect. What is loading effect? Loading effect causes the change in the parameter to be measured. A typical example is a fraction horse power motor FHP, consider a fraction horse power motor it is rotating at a suppose (Not understandable) (Refer Slide Time: 00:24:58) it is rotating at particular speed omega. We want to measure the speed and what we do conventionally, we bring a tachometer with its own bush and press the bush against the rotating shaft and we want to measure the speed but the moment you press this brush against the rotating so what happens? It may be a 5 watt capacity.

The moment you press this tachometer the speed reduces to maybe nearer to zero, it may reduce sometimes. Previously it was rotating so 3000 RPM and the moment you bring the instrument in contact with the parameter to be measured that is rotating shaft, the speed has reduced this is due to loading effect. So in such instances we cannot use this type of instrument, we should go for certain other type of instruments. Another typical example is voltage measurement.

Suppose we have got a voltage source and you want to measure this voltage source with voltmeter say it may be say 1.5 volt. The moment you bring a voltmeter in contact with this terminals AB it is drawing a current i, since there is a current flow the 1.5 volt that is we are taking energy from the medium where we want to measure a parameter. The moment current is drawn it may become 4.999 whatever it is. So now what we are measuring is not 1.5 volt the reduced voltage alone we are measuring. That is the process of measurement itself affects the parameter to be measured. So this is what is loading effect and to get an expression for loading effect we will just consider this small circuit. So $e_o$ dash and we will call it $z_o$ is the output impedance called output impedance, $e_o$ dash is the the voltage, theoretical voltage we want to measure. To measure this we are bringing an instrument with an impedance of $z_i$, $z_i$ you can call it input impedance or instrument impedance whatever way you would like to remember.

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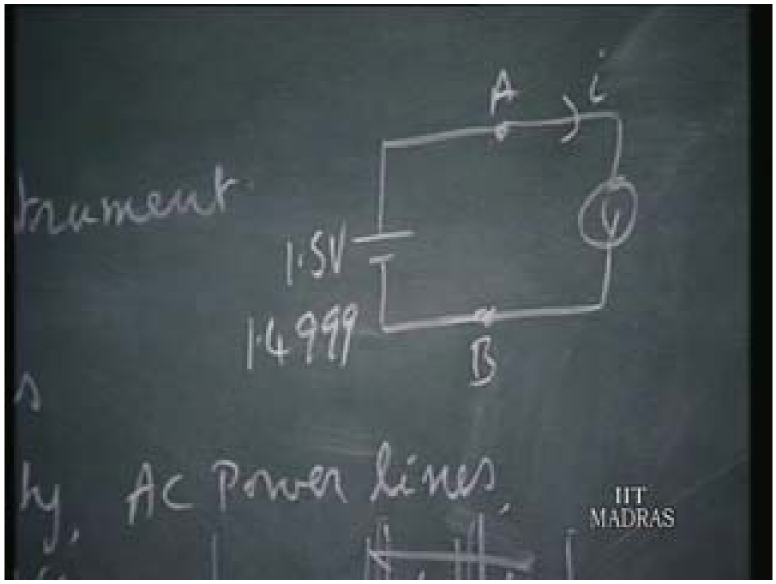


So zi is the impedance of the instrument or input impedance. Now what is the loading effect in this circuit? Now using Kirchhoff's law we can just write it $e_o$ dash minus i into, suppose i is the current flow when we connect this instrument voltmeter to measure the voltage, i into $z_o$ minus i into $z_i$ equal to zero or the voltage source equal to the voltage drop. So $e_o$ dash equal to i into $z_i$ plus $z_o$. Now again what we are measuring here across these two terminals AB and we are going to get $e_o$ as the voltage. Now $e_o$ again is equal to, this is equation 1 and $e_o$ is equal to i into $z_o$. This is how we are measuring $e_o$. So $e_o$ dash our reading is $e_o$ is equal to i into $z_o$, so this is 2.

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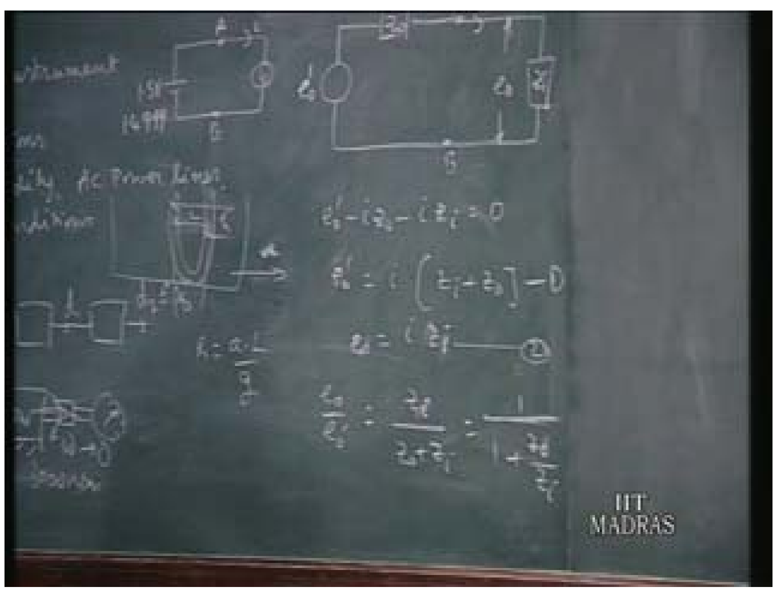

Now $e_o$ by $e_o$ dash, so $e_o$ is $z_o$ by $e_o$ dash is you can write $e_o$ and this is $e_o$ dash sorry $e_o$ dash, so i i get cancelled out (Refer Slide Time: 28:28). So $z_o$ plus $z_i$ is equal to 1 over 1 plus $z_o$ by $z_i$, $e_o$ by $e_o$ dash $z_i$ so 1 over 1 plus z $z_i$ by $z_o$ no dash $e_o$ dash into z $z_i$. The $e_o$ is equal i into $z_i$, $e_o$ is equal to i into $z_i$ so $e_o$ is equal to i into $z_i$. So 1 over 1 plus $z_o$ by $z_i$ and now this is the expression for the loading effect $e_o$ by $e_o$ dash is equal to 1 over 1 plus $z_o$ by $z_i$ from this equation. Now what does it mean?

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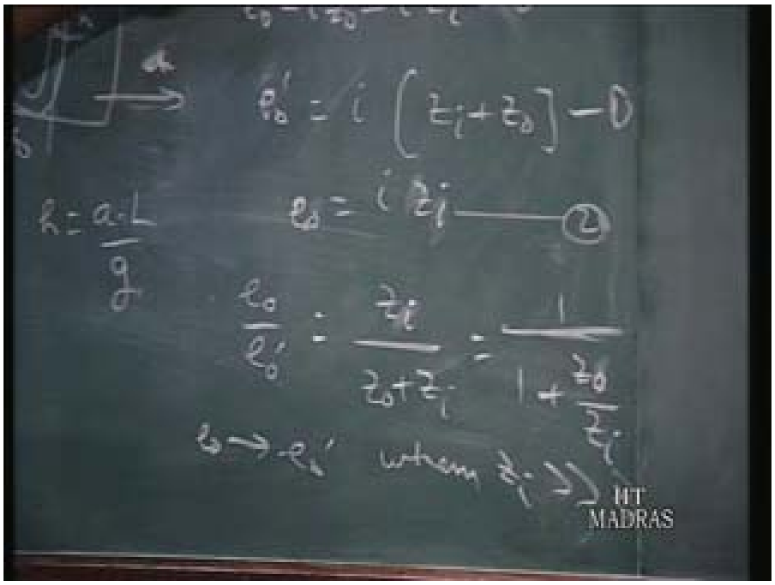


The loading effect will be small or $e_o$ will approach $e_o$ dash when $z_i$ is much larger than $z_o$. So if suppose $z_i$ is infinity then this will become zero and then we will find $e_o$ is equal to $e_o$ by $e_o$ dash equal to 1 or $e_o$ is equal $e_o$ dash. That means to have a small loading effect in this measurement we should select a voltmeter with very high input impedance compared to the output impedance of the circuit. Similarly you will find in current measurement it is opposite it will (Refer Slide Time: 29:53).

Suppose you have a voltage here, voltage source we are measuring, again $z_o$ is the output impedance of this circuit and we bring this ammeter with $z_i$. Suppose this capital E and AB are the terminals, this is for voltage measurements. When voltage is signal this is circuit what we are using, when current is the signal current measurement. What is the loading effect? For current measurements the loading effect is found out as follows.

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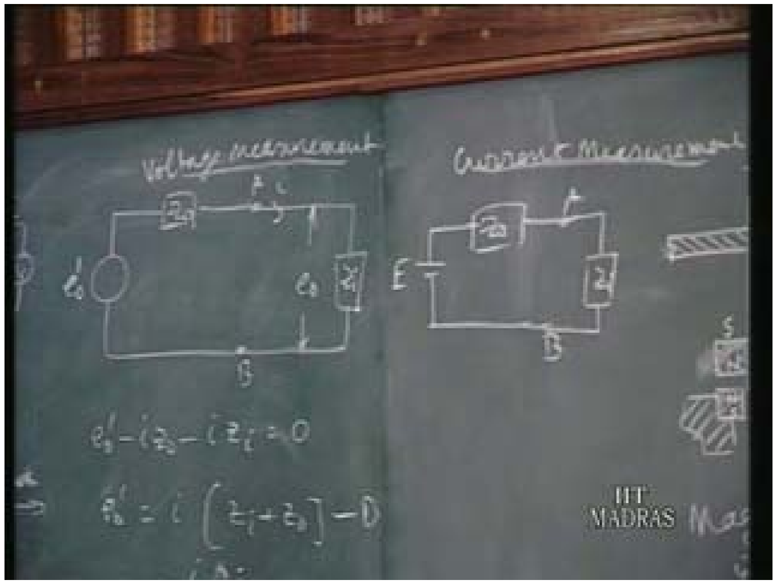


Suppose e is the voltage source and we are measuring the current through an ammeter having an input impedance of $z_i$ and this is circuit, so i is equal to E by $z_o$ plus $z_i$. Suppose i dash is the current flow, when you short circuit this may be if you don't connect the instrument what will be the current in this circuit? For this we will call it i dash. The current flow without instrument short circuit, i dash will be the ideal current flow if the instrument is not connected only short circuiting then it will be equal to E by $z_o$ because this is only impedance. So instead of this current i dash what actually flows is i only.

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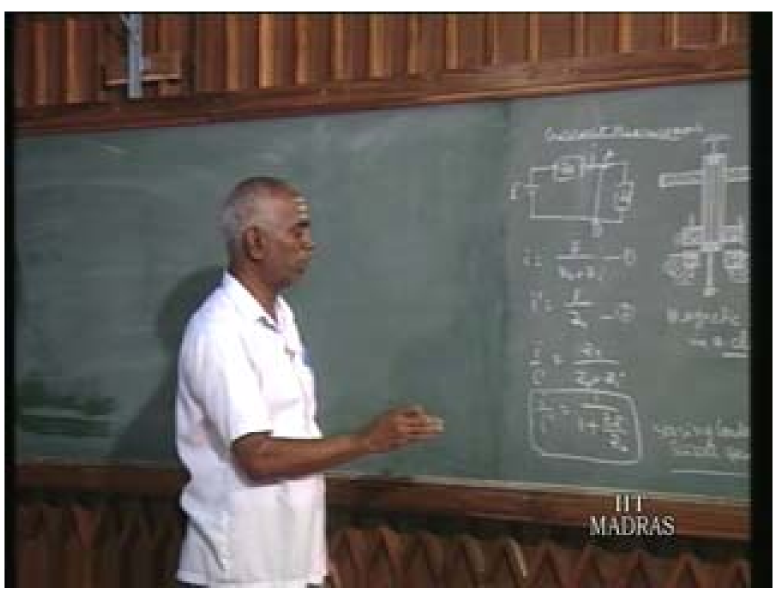

So finding the ratio i over i dash, so $z_o$ is the from these two equations we can derive this one that is i by i dash equal to 1 over 1 plus $z_i$ by $z_o$. Now you will find the ratio, previously we had for voltage measurement $z_o$ by $z_i$ but here $z_i$ by $z_o$ that means $z_i$ should be as small as possible when compared with $z_o$. Hence we find the, condition for loading effect reducing load effect in current measurement is just opposite to that of the voltage measurement but in mechanical measurements mostly we go for the voltage measurement and hence we find when we select a voltmeter it should be much larger than the circuit impedance as reflected across the two terminals where we are going to connect the instrument. So this is the expression for loading effect. So having seen all these error sources now we will see what are the methods.

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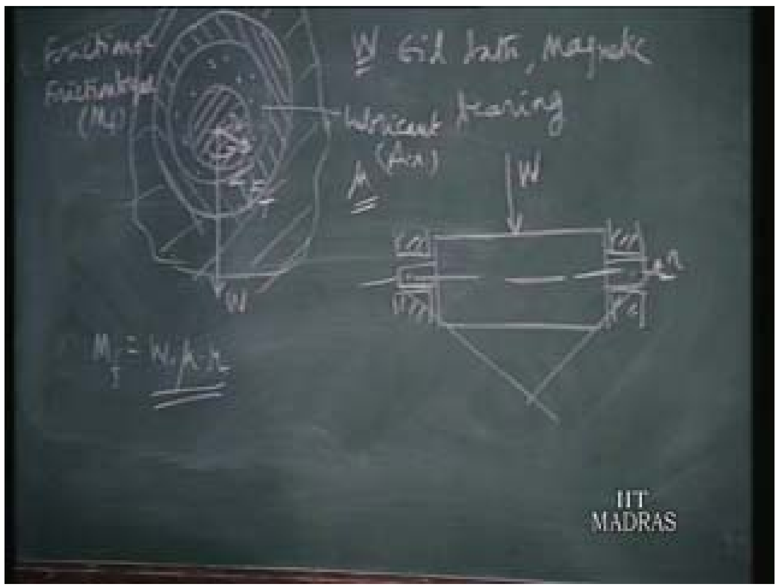


Methods for reducing the effect of error source or we can also call methods for eliminating the error due to error source. So this is important, these are the steps one should take while one designs an instrument. First he identifies the error source then he takes step how to reduce these effects of error source or is there any possibility to eliminate the error source itself. So all these possibilities should be looked into. So first we will consider friction. We are going to narrate the different methods adapted to reduce the friction or friction torque but when it is to be adopted? Only when there is a force signal, when there is force signal friction is an error source. So to reduce the effect of this error source friction what are the steps we should take? I am narrating that but you should adapt at only when friction is an error source that is when force is there within the instrument.

Suppose we consider a bearing. This is the journal rotating inside a bush, this is the bearing bush, it is mounted in the frame of the instrument. So this is the bearing bush and this is within the frame of the instrument. So load is there, W is the load and this is the general shaft rotating in this direction and you have got a friction force here we call it $F_f$. So here I say friction or friction torque because here though friction is there, it is felt to be the generalized friction torque. So friction torque we call $M_f$ which is the friction torque.

Friction torque $M_f$ is equal to W is the low into mu, mu is the coefficient of friction between the journal and the bush into r which is the radius of the journal. This is the friction torque in a bearing. Suppose this friction torque is an error source within the instruments and the instrument carries a torque signal, we know in a voltmeter torque signal is there. We have seen the coil is mounted between two bearings and the coil is between North Pole and South Pole and the torque is there on the coil and friction between the two pivots will be an error source. In such instrument these are the considerations for reducing the effect of error source or reduce the error in such instruments functioning. So there the friction moment is equal to W load of the coil, weight of the coil and mu is the friction of the bearing, r is the radius of that journal or the pivot where it sits.

Now if we want to reduce the moment due to friction then we can reduce any one of them or any combination of these three parameters. Since these three parameters give rise to the friction torque and by reducing any one or any combination may be we are reducing this. So how to reduce all these parameters that is three parameters are there. To reduce W there are many ways, One you can immerse the whole setup. In case if it can be immersed in an oil bath that is the case in case of gear train. Gear train are supported in bearings and when the whole gears are immersed in an oil bath the gear weight is reduced, when gear weight is reduced then you will find the net force on the bearing is reduced. Hence you will find by immersing in oil bath the buoyancy force lifts the member and hence the load on the bearing is reduced. So that is one way.

Second way is magnetic bearings. Again a clock that is what is shown there in this instrument, this magnetic bearing in a clock that is our balance wheel and you have got the spring which will be here coil spring. So this is conventionally mounted on two pivots top and bottom, instead of it suppose we want the clock to run very precisely then we should go for a magnetic suspension of the… (Refer Slide Time: 00:37:35). This is rotor or the balance wheel precisely it is a balance wheel balance clock. Something like rotor but technical term is balance wheel of a clock. So you find the whole weight and this is the tube, this dead weight now it is balanced by the repulsive force of the two magnets. One magnet is connected to the shaft where the balance wheel is fixed the other magnet is to the frame. So the repulsive force, this will be pushed to this direction this also will be pushed so it is fixed here. So the whole weight is balanced by the repulsive force of the two magnets, cylindrical magnets by using cylindrical magnets you can support it. So to say there is no force at all; no force coming down it simply floats in space.

To guide this location we have got a steel wire which doesn't take up any vertical load it's only the guiding without any lateral motion that is only for guidance purpose. So here the whole weight W is zero there. So W is zero and hence you will find friction moment also is zero there. These are the ways one can reduce the effect of W, by reducing W, $M_f$ is reduced. Next mu which is the coefficient of friction which is reduced by selecting proper lubricant, this is lubricant oil. Going for less and less viscous lubricant you will find that mu is reduced, when mu is reduced $M_f$ is also reduced or the fluid which has got lowest viscosity is air. You can also have air that is aerodynamic bearing, in aerodynamic bearing mu is very very small so $M_f$ is reduced.

Third one is radius. Suppose we reduce this diameter where the bearing sits say suppose the bearing shaft may be like this and where it sits in the bearing there alone it's reduced. This is the bearing, so here if it is r then as we reduce the radius $M_f$ also is reduced. By reducing this $M_f$ you don't bargain in the or we don't reduce the strength of the shaft because any load coming here then bending movement diagram if you draw it will be somewhat like this. So the stress induced at this support is very small hence the strain or stress also will be small. So by reducing this to a tolerable limit we can reduce the friction without sacrificing the strength of the whole supported rod. So these are the three ways by which we can reduce the friction or friction torque. That is for the friction, when friction or friction torque is an error source these are some of the methods.

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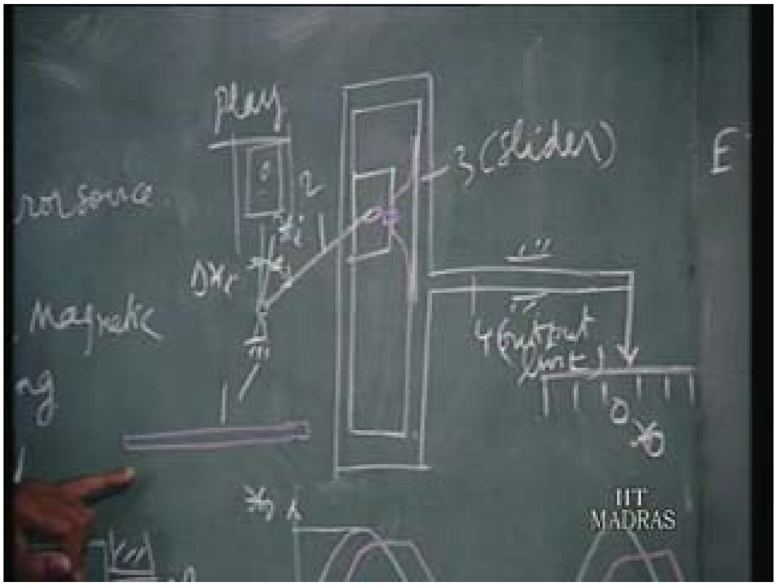


Next error source is play, play will be an error source when there is displacement signal and I had considered a linkage mechanism, a fore bar linkage mechanism. Suppose this is your fore bar linkage mechanism, here it is a rod say it's a sign mechanism and this is our $x_o$ this is our $x_i$. Rotation of $x_i$ gives rise to a motion of $x_o$ at the end of the mechanism. So this is 1, it is link 2, link 3, this is link 4 and hence it is called forbore linkage mechanism and the play invariably exists between the slider, this is 3 slider. The 4 is your output link, between the output link and the slider normally we have the play. If you don't have play what will happen as this rotates it will find lot of friction within the slider. So the effect of this play is somewhat like this. It is a sign mechanism; we are supposed to have a output motion like this. This is our $x_o$, this is our $x_i$. So zero angle, sign zero is zero so probably zero is somewhat in the middle, this is plus maximum, minus maximum this side. That is $x_o$ plus maximum this is $x_o$ minus maximum (Refer Slide Time: 42:40).

This is the motion what you are supposed to have because of this play what will happen? Suppose it is zero position, the slider will be somewhat like this, the output link will have the play. Now you find until this slider rotates a small angular delta $x_i$, the surface will not be going to touch this output link, so delta $x_i$ will be lost.

Hence you find, the curve will not start like that, it will be starting somewhere here. It will go like this so you find the effect of play is, the output link is distorted. You find it is starting after delta $x_i$ because delta $x_i$ is the motion necessary to make the slider contact this output link then only output link is going to move. So this much error has come so you have got a distorted one. Thus you will find the play is an error source here also and how it is eliminated. For this we connect a spring to the slider in the following way. That is this is your slider and connect a spring to the slider, have a leave spring bent in this direction. What is leave spring? It is only a spring material bent in this direction, a flat strip made up of some spring material say spring steel or phosphor bronze and you bend it in this fashion and fix it here and we will assemble it, let there be compression.

Now you will find due to this compression, the contact is maintained only between the slider and the output link only in this phase. So play is there but play is pushed in one direction that is what we have done in dial gauge by connecting a spring we pushed the whole plate to one side. Similarly here are also we achieved the same thing by some other spring. Now in this situation we will find the moment this rotates, the motion also will be transmitted to the output link. In both ways it will be effective. So this is the way, the effect of backlash is eliminated. So there is no error, the effect is completely eliminated. So that is within the instrument what you have seen is within the instrument. We have seen how to reduce the friction force in a bearing.

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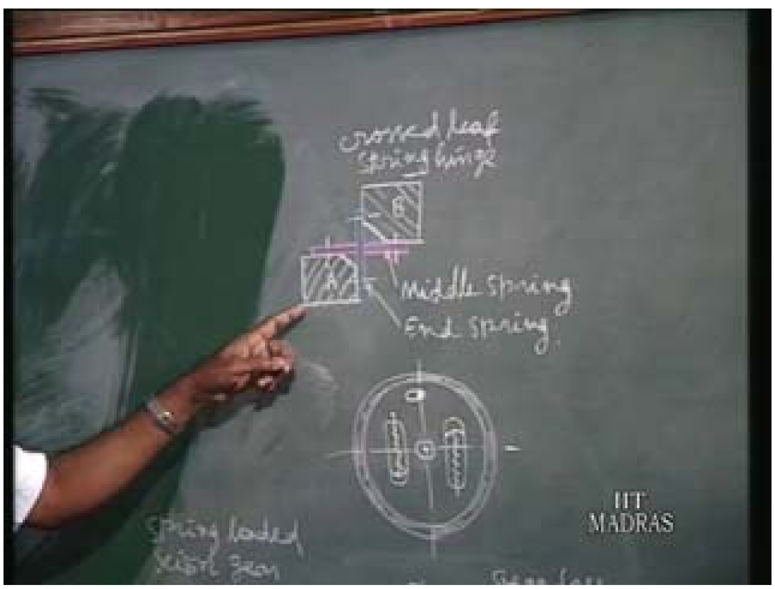


Also wherever we want to such bearings we can also go for a cross leaf spring hinge or you can also call it bearing, cross leaf spring bearing where the friction is not there at all. This obtains, block B is supposed to have a relative motion with reference to the block a which is fixed, this is a fixed one. So it is a fixed block and we can have a bearing or we can just connect these two things by a set of springs. Suppose this is a middle spring and two end springs that is the blue color is end springs, two end springs and the middle you have got. This middle spring will have twice the width and end springs two numbers of width B, such a way if we connect so it should coincide.

So this way if we connect it later by fixing this you can rotate this. That will be about this point the whole block will have. That means what is a bearing? Bearing is one where the relative motion is allowed but now with reference to block A, this block B can move relatively but here you find there is no friction at all. It’s only whatever the torque we give and the proportional to the spring constant it just deforms. So we have not lost any torque, normally T minus $T_f$ where where $T_f$ is the friction torque that will be lost in bearings but here since we don’t have any conventional bearing we have got a spring hinges and we say the whole torque is used to deform it, without any loss of friction torque. So such a friction free bearings also are available.

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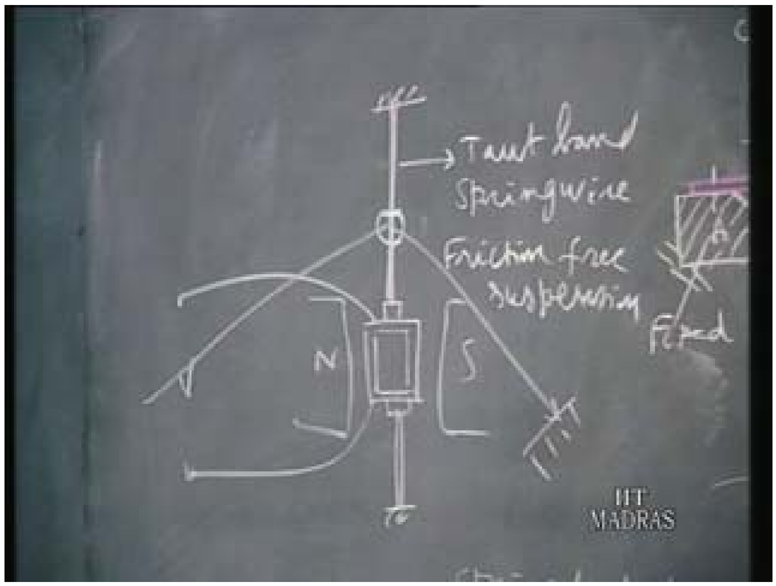


Also we find taut band bearing that is a spring wire is used to connect say coil. This is your instrument coil say North Pole and South Pole and this if you can fix it, this is a taut band within in a voltmeter. Taut band is nothing but spring wire. Previously you remember this is mounted over two pivot bearings, earlier diagrams I have shown mounted, this will give the voltage here. The voltage is applied here for this coil. Previously we had a pivot bearing with the spring and now that is replaced the pivot bearings and spring are replaced by a simple taut band spring wire. Here it is a friction free bearing; it is called friction free suspension or bearing. We eliminated the effect of friction at all, the pivot bearing.

Now the whole torque is used to deform or deflect this wire so normally we will have a mirror. A light will fall here and fall over the optical scale that is how it is used there, the taut band bearing, taut band suspension. Since there is no conventional pivot bearing, by using a taut band we eliminate the effect of friction, so friction free suspensions. So wherever we find, we don’t eliminate the friction we can go for such as cross leafs bearing or for the taut band suspension. For the play we have seen for the linkage, for the gear also there is play that is backlash. When there is backlash we know that gives rise to error source, to reduce the effect of backlash or to eliminate the backlash we can go for the spring loaded sensor gear.

It is nothing but two speed gears combined together, this is a gear with thickness T but it is made up of two gears but in these two discs one disc will be free on the that is shaft gear free on the shaft, this is shaft and this is fixed to the shaft and you will find two oval (Refer Slide Time: 00:49:18) holes are cut on the disc of the gear and two spring loaded both of them are spring loaded. So that one gear can shear against this, just like in a scissor one disc rotates with reference to other one that is the pin coming from the bottom one sits over a hole here until then it will rotate. That is how you see the gap here. Such an arrangement gives rise to a gear arrangement like this.

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Suppose this is one gear and the bottom gear is moved relatively so it is coming like this. This is the bottom gear for example, a two disc this is bottom gear, this is top gear because of this shearing action you will find the one gear has moved into the other disc. So net you will find the gap between the two gears is reduced. So when the machine gear comes, this machine gear when you insert it, you will find since it is spring loaded it gives way, just moves leftwards and then gives way for hole thickness, the hole thickness of the machine gear is completely gripped between the two relatively moving disc. That's why it's called spring loaded scissor disc. It just adjust to the thickness of the machine gear giving rise to no backlash between the machine gears thereby we eliminate the effect of backlash in such gear machines. This is the case when single gear machine is there; one of them can be made up of spring loaded scissor gear.