Principles of Mechanical Measurements
Prof. R. Raman
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Lecture No. #06

We have seen yesterday how a spring loaded scissor gear is made up of. I drew it on the board, today I have brought the piece itself. You can see gear is there under two oval holes and you see the spring also. So spring one end is here, other end is taken backside and fixed to the other disc. Here also you have got the spring starting here fixed there at the other end.

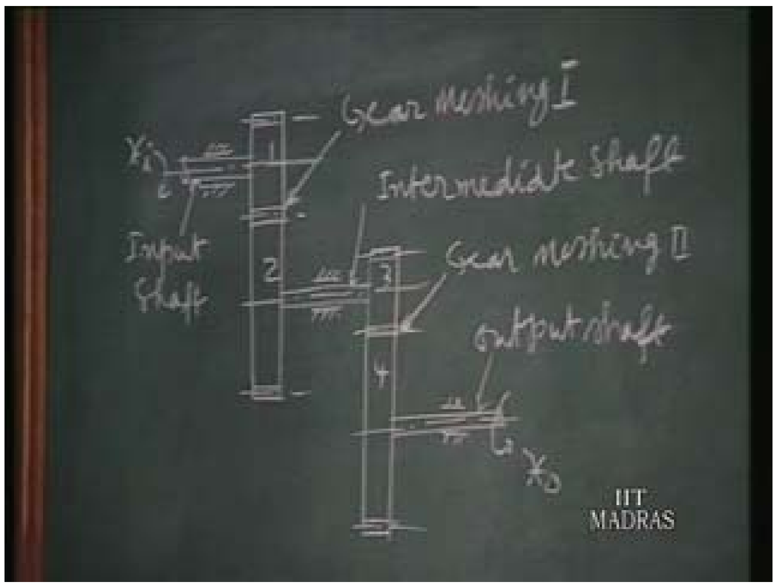
(Refer Slide Time: 00:01:36 min)

So one of the disc is free on this shaft and other is fixed to this. This is just I want to demonstrate how the spring loaded scissor gear looks like. Now we can go to the next topic. That is when there is only one gear meshing; we can make 1 or 2 gears. A gear meshing for example 3 and 4, there are 2 gears. This is a gear meshing, when there is one gear meshing, one of the two gears can be made up of the spring loaded scissor gear but when there is a gear train like this. Here we have two gear meshings, this input shaft this output shaft it's a gearbox having two gear meshings.

In such cases how to reduce the effect of backlash, there by using this spring loaded scissor gear we eliminated the backlash. There is no backlash when one of them is made up of spring loaded scissor gear but in case of gear train how to go about. This is what we are going to analyze now. Now we see from input output it's a speed reducing gear box. Suppose here we are dealing with displacement signal, rotary displacement signal then the backlash in this gear meshings will give rise to error. How to reduce or eliminate the error due to the backlash, this is our analysis now. Assume there is a backlash in gear meshing one. Hold the gear 2 and rotate the input shaft, this is your input shaft.

Rotate it and there you will have a free motion of delta X_1. This is the backlash that much rotation will be there from the middle you will have the rotation delta X_1 this side and the other side. So delta X_1 is the play or the backlash in the input shaft, due to the backlash at gear meshing 1. That is we are holding this fixed and we can rotate plus delta X_1 and minus delta X_1 from the middle position, that is due to play. That much play in the input shaft, at the intermediate shaft the play will be equal to delta X_1 into the velocity ratio which is equal to velocity ratio V_1 is equal to T_1 by T_2 where this is number of teeth in gear 1 divided by number of teeth in gear 2, this is the velocity ratio. So delta X_1 into V_1 will be the equivalent motion of this play at the intermediate shaft.

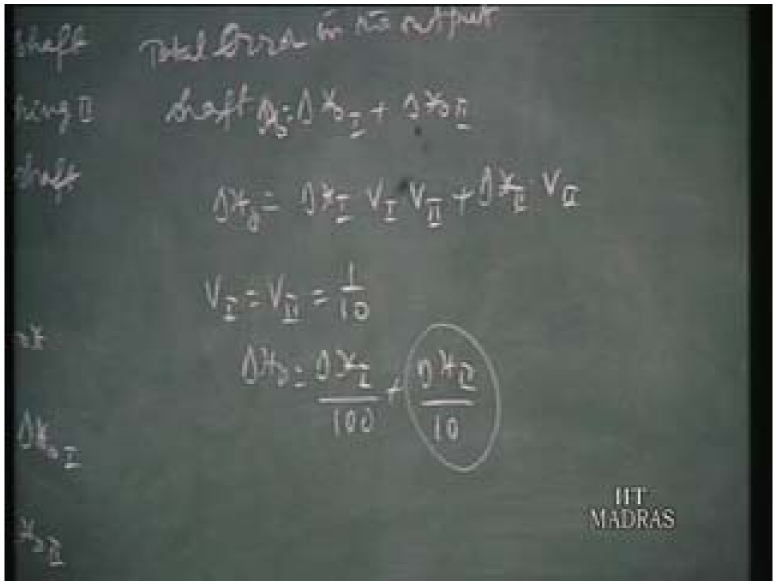
(Refer Slide Time: 00:02:21 min)



Similarly if N_2 or V_2 is velocity ratio at the gear meshing 2 then this this much of motion at the output shaft it will be the equal to into V_2. So this is the equivalent motion of delta X_1 at the output shaft. So I will say delta X_{o1} that is we are finding out what is the error in the output signal due to a backlash of delta X_1 at the gear meshing 1. Similarly consider gear meshing 2, you are considering this gear meshing and assume this shaft doesn't exist at all and hold this 4 you will know due to backlash there will be small rotation of delta X_2, due to backlash there is a rotation of delta X_2 plus or minus delta X_2 at the gear 3 or pinion 3. So that much motion of delta X_2 at the intermediate shaft that is at intermediate shaft is equal to into V_2 will be the delta X_{o2}. That is at the output shaft delta X_{o2} you will have an equivalent rotation of delta X_2 into V_2, V_2 is the velocity ratio of gear meshing 2.

What is the total error in the output shaft? Total error in the output shaft is equal to delta X_{o1} plus delta X_{o2}. So that is now all these things that is delta X_1 into V_1 into V_2 plus delta X_2 into V_2. Suppose velocity ratio V_1 is equal to V_2 is equal to 1 by 10 that is the velocity reducing. Velocity is reduced from this shaft to this shaft, again this shaft to this shaft. So now delta X_o is equal to this much. Now delta X_o will be equal to delta X_1 divided by 1/10, 1/10 that is100 plus delta X_2 by 10.

(Refer Slide Time: 00:07:51 min)



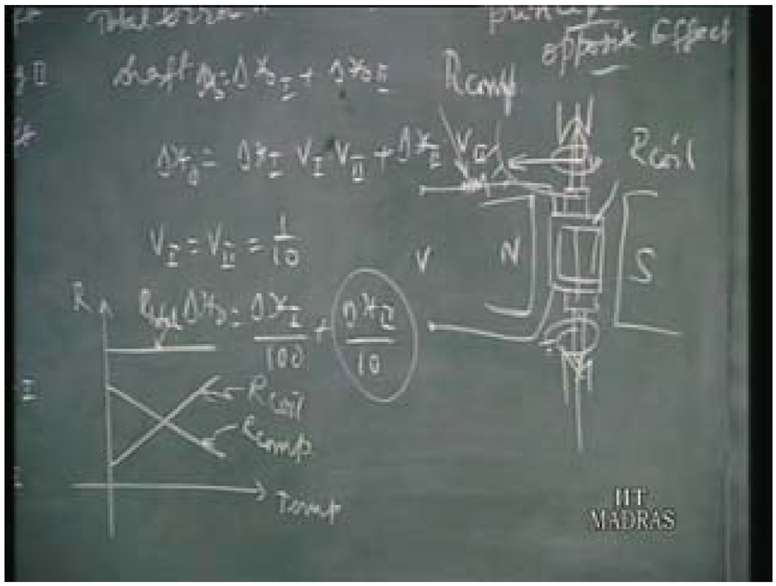
Now the total error is made up of delta X_1 by 100 delta X_2 by 100. So major part of delta X_o comes from the second gear meshing that is a last gear meshing. Similarly if we consider a velocity increasing instead of velocity speed reducing unit, so the velocity speed increasing unit at that time you invert this, X_i and this will be X_o. From here to here when the motion goes velocities is increased at every stage. Then you will find that the total error here will be made up of, major portion of total error in the output shaft will be made up of a backlash at the first gear meshing. That means for the reducing gear drain the major error is made up of the last gear meshing and increasing gear drain the first gear meshing will contribute to the maximum error.

So now if you eliminate for example in the speed reducing unit it is like X_o and X_i. Since major error comes from last gear meshing and make one of the 2 gears as spring loaded scissor gear. Then here you will not have any backlash this will be over and only the error in the output shaft will be from the gear meshing 1 and that is already divided by 100 times. So net effect in the error in the output shaft will be very very small negligible and such an error may be tolerable in many instrumentation. So you find in such a gear box design, we analyze where is the maximum error source and in that error source you use one of the two gears as the spring loaded scissor gear, what you have seen earlier with two disc and the spring loaded opposite directions. So that one disc moves relatively to the other one and the meshing gear sits exactly within the adjustable gap of the spring loaded scissor gear.

So that is for the play, so we have seen for frication what are the methods you should adopt to reduce the effect of friction or eliminate the friction by using the repulse force of magnet or the Todd band barring or here in the play how to eliminate play in case of linkage mechanisms and in case of gears we have seen.

Next one is temperature, how to reduce the effect of temperature. Now to compensate for temperature effect, the principle of opposition is made use of. It's normally adopted to compensate for the temperature. That is if you consider moving coil voltmeter where coil is there and we know it is North Pole and South Pole and this is your pivot bearing pivots and we know this is the coil, to the coil we connect our voltage source. This is your R coil, so this R coil, resistance of the coil is in this form and it rotates within the South Pole and we have got this spring.

(Refer Slide Time: 00:10:30 min)

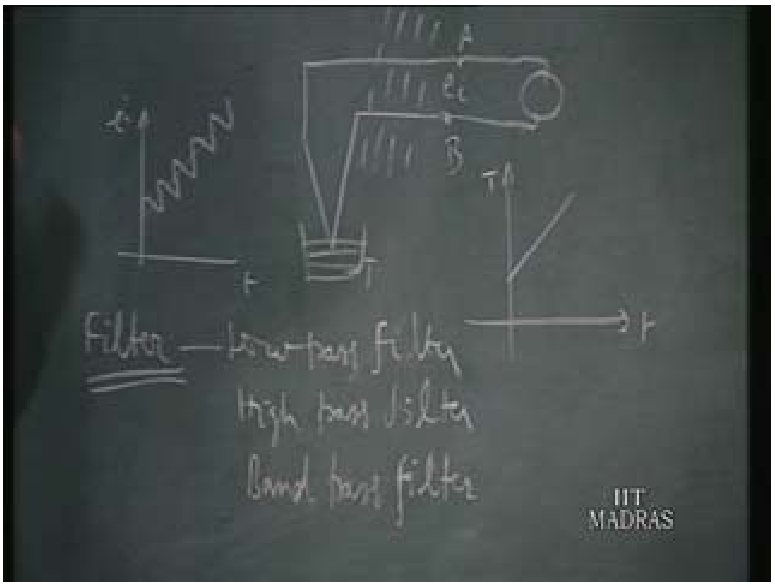


This is a construction of a moving coil voltmeter, now due to temperature what happens R coil is increased. So it increases somewhat like this. So this is R resistance and this is with the temperature. So it increases somewhat like say R coil increases. So when temperature is increased, R coil is increased. For a given voltage input we find that when R is increased then current through the R coil is reduced. When current is reduced, the torque is reduced and then deformation that is this pointer motion over the scale also reduces. For the same voltage when temperature is larger, amount of deformation in the pointer will be smaller. So that is the error due to temperature. How to compensate for this? For that purpose what they do, they connect another R compensating, this is R compensating in this series with the coil and that also will be same temperature of the coil. So R coil will be somewhat in this fashion, it will vary. R compensating will have a characteristic just opposite to that of the R coil. Now total resistance of the coil circuit is you have to add at each point.

So now more or less this is the R total. To the extent the R coil resistance has increased, to same extent R compensating is decreased so R total remain same. Now that is the opposite effect we have to select such a compensating resistor which will reduce the resistance to the extent R coil has increased due to temperature. That is the opposite effect put opposite effect in series and R total remains constant.

Now in respect to temperature of a functioning where the instrument is made use of temperature atmosphere, the voltage you will get the correct reading irrespective of the temperature. For a given voltage the R total remains constant, current will be already same for a given voltage irrespective of a temperature. This is the principle of opposite effect that is the temperature. When there is AC power line, the effect of this high voltage power line will be felt in modifying the voltage in any wire.

(Refer Slide Time: 00:13:37 min)

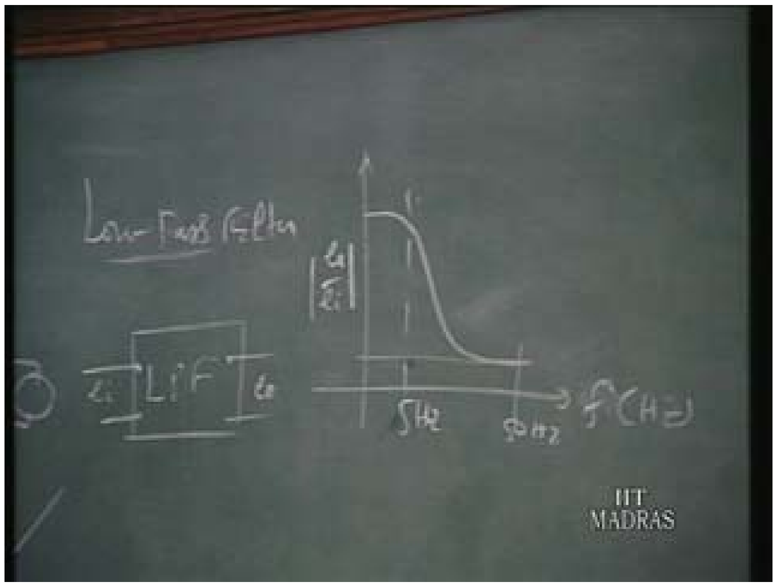


For example you have the thermocouple wire. So in a bath and this we are connecting to a voltmeter for example, a millivoltmeter say A and B. Due to this power line you have this magnetic lines. So kilovolt power line is there, so you will find the E_i. Suppose the temperature T is increasing like this, the E_i will be because of this superimposed, this may be 50 hertz nearby power line, magnetic lines are but 50 hertz and you will find E_i will be varying like this. So E_i versus T time instead of, we are supposed to have E_i proportional to temperature T but because of superimposition you will find, this is the variations what we get. The E_i will be varying like this; this is our variation because in this the 50 hertz is superimposed. This is due to the nearby AC power line.

How to get rid of this varying voltage? For that we are using so called filter, selective filters. In this we have got three types, the low pass filter and high pass filter and band pass filter. These are the three major filters available. Mostly in mechanical measurements we are going for low pass filter because our mechanical signal will be normally of low frequency. So as per the name low pass filter, it will pass the low frequency signal alone high frequency will be stopped whereas high pass filter as per the name it will pass the high frequency signal and low frequency signal will be cut off and band pass filter as per the name only between bandwidth I mean frequency within a bandwidth alone will be allowed to pass. That is lower than the range will be cut off and higher than that band will also be cut off. So that is one but in this application we are supposed to use a low pass filter.

So low pass filter will have a characteristic somewhat like this. Low pass filter characteristic will be, suppose this is the frequency omega, a frequency R. I will say f in terms of hertz. Suppose low pass filter if you indicate by a block like this suppose E_i is our input signal low pass filter and the output will be E_o, if it is like this then E_o by E_i that ratio will be somewhat, the low pass filter will have the following characteristics so it will be like this. That is this may be say 5 hertz, any signal more than 5 hertz it will be filtered that magnet will be very very small.

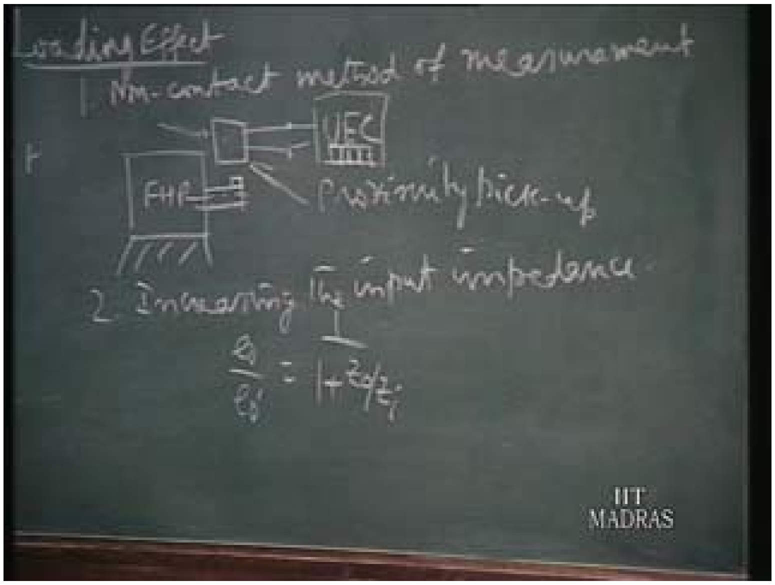
(Refer Slide Time: 00:16:54 min)



So 50 hertz somewhere here, if it is suppose 50 hertz that is very small ratio will be allowed to go through. So low pass filter will allow only low frequency signal more than 5 or 6 it will completely eliminate. So interpose now between the voltmeter and the thermocouple terminal, interpose this fold, instead of reading to the connecting to voltmeter directly interpose this low pass filter and then connect it to the voltmeter, this is voltmeter, connect to the voltmeter. So you have the reading, that is how the AC power line effect, the superimposition of the 50 hertz is eliminated and then we are seeing the correct reading. That is error due to the nearby AC power line is eliminated by using low pass filter. That is first we saw within the instrument, this outside instrument, next we will see loading effect.

What are the methods adopted to reduce or eliminate the loading effect? There are 4 methods; first one is go for the non-contact method of measurement. In this the instrument doesn't come in contact with the measured medium. For example we had this fractional horsepower motor shaft, when you want to measure the RPM of this motor, when you bring a ordinary tachometer it stops. Instead of it you can also have a, suppose you fix here bolt to the shaft and a proximity pickup. This is a proximity pickup and impulses will be there, you can read it in an instrument.

(Refer Slide Time: 00:18:40 min)



So by using proximity pickup, this is your proximity pickup, for each rotation one pulse will be made and this is given to universal electronic counter there you can read how many rotations it has gone. So you will have the window and the numbers will be there. That is this instrument doesn’t come into contact with the rotating system which is a non contact of type of measurements or some light source. You can allow the light source; use the light source as a medium to measure the rotating speed. For that you have to connect a disc and make hole and light source on one side the side is some pickup photo cell. Then whenever the hole comes in line with the light source and the photo cell you will have one pulse. So such methods we can go for it, where there is no loading effect at all.

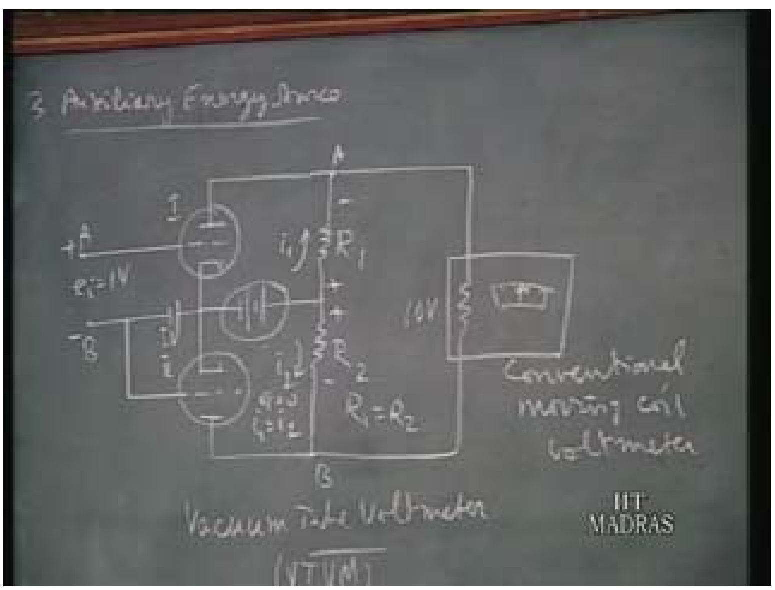
The second method is increasing the input impendence. That is we know loading effect E_o by E_o dash in voltage measurements, 1 over 1 plus Z_o by Z_i. We have learnt earlier class that is when input impendence is very large that is the instrument that is voltmeter which we are bringing in to measure the voltage. If it is containing large, if it is made of a large resistance or impendence then Z_o/ Z_i will be some negligible because Z_i is much larger Z_o. Then E_o by E_o dash will become 1, that is E_o will approach E_o dash. What is the problem in such a measurement? When Z_i is too large we assume our moving coil voltmeter that your R coil is very large, Z_i is very large means said R coil is very large. So for a given voltage when R coil is large, current flow will be small.

When current flow is small then torque produced is small and deflection will be smaller. So when Z_i is larger the deformation for a given voltage becomes smaller or sensitivity becomes smaller. To bring the sensitivity back what you should do? You should change the spring to a softer spring. So for a smaller torque the coil will deform more but what we have achieved in this. The amount of torque deflecting torque has become small and the ratio of suppose say M_f is the friction in the pivot and M_f and the deflecting torque DTD, this ratio becomes larger.

When M_f to T_d depleting torque ratio becomes larger then error of the instrument is larger and also you find since the amount of torque handled is smaller and the instrument has become less rugged and more delicate. So in order to have larger impendence what you have achieved finally is less rugged instruments and more delicate instruments and they are to be handled normally very carefully. So that means Z_i cannot be increased as you like, if you increases Z_i sensitivity come down then somehow you have to bring it sensitivity back and you are bringing all other problems. So that is why Z_i is normally made up of, is equal to R or it is around 10 times Z_o, this is normally adopted. When you know the circuit output impedance as Z_o and then 10 times the Z_o you have the R coil for the voltmeter or voltmeter should have the 10 times this, then you will find this becomes 1 by 10. So 1/1point near about E_o is very near to E_o dash. That is more than sufficient; this is what is normally adopted in practice. This is second method, increasing the input impedance to 10 times the output impedance of the circuit.

Third method is using axillary energy source. For this the principle is as follows. Why there is loading effect in measurement? Since the instrument what we are using for measurement takes some energy from the medium, when it takes the energy from the medium what happens, the parameter of the medium gets reduced. So we are measuring only the reduced value of the parameter. That is because we have drawn some energy from the measured medium.

(Refer Slide Time: 00:23:46 min)



Suppose we find a way that we don't take energy from the measured medium we take energy from elsewhere to operate the instrument then the measured medium is not disturbed, and also parameter that we want to measure is also undisturbed. So undisturbed parameter we can measure, once we can find some other energy source. That is where we call auxiliary energy source. A typical example is here, vacuum tube voltmeter we call VTVM, vacuum tube voltmeter VTVM.

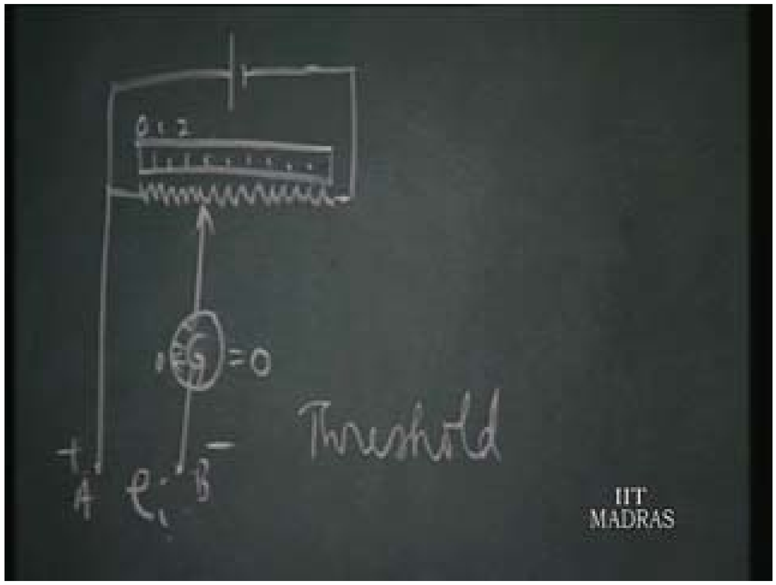
Now a days we have got equivalent transistor and solid-state circuit but the principle same principle used there, hence we are using the circuit of tube to explain the functioning of a VTVM. Here you will find the energy for, this is conventional voltmeter. This is conventional conventional moving coil voltmeter which will draw energy from the medium of measurement, if we connect directly there. So instead of connecting this conventional voltmeter to this VA, e_i is the voltage we want to measure instead of connecting a voltmeter, we are connected after a circuit only, this is main difference. By this circuit we don't load this medium at points A and B. This is the voltage source which you want to measure and we are not loading it. I will explain how it is achieved.

Now this input voltage e_i is given across the grid, we know grid to cathode is of a nearly open circuit, so input resistance is very large. When resistance is very large and current flow will be of the order of negligible value or in terms of micro amp, few parts of micro amp very small value. That means this is not loaded but how this circuit is functioning. Consider the two tubes, triode tubes and now the applied voltage is used across the tube one and tube two has got the constant grid voltage. So when we short circuit A and B that means same cathode voltage is there, grid to cathode voltage is there in both the tubes. So current flow through the cathode to plate current will be same, so i_1 is equal to i_2. When e_i is zero, i_1 is equal to i_2. So voltage drop across R so I will this R_1 and R_2 whereas R_1 is equal to R_2. Voltage across drop this will be, so this is plus terminal minus because current flows in this direction will be same and equal to two batteries with opposing polarity connected in series.

So you find the voltage across AB will be zero, voltage same with opposite polarity. So voltage across A and B will be zero, for even e_i is zero, voltage across A and B will be zero and so the conventional voltmeter will show zero reading here. Suppose we give you a voltage e_i equal to one volt, to that extent you will find this grid voltage in tube one will be smaller by, suppose this is 5 volt, here you will have only 4 volt whereas here it is same 5 volt. Now you find i_1 will be larger than i_2 because smaller grid voltage. So here i_1 will be larger so here voltage drop will be larger than the voltage drop here that net difference alone will appear here. So you will have say for 1 volt probably you will have 10 volt here.

Similarly you will find if e_i is 2, here we will have 20 and 3, 30 and so on a proportionate relation is maintained. So now you can calibrate this in terms of so 1, 2, 3, 4 even though the 10 volt is there you can write here as 1, it's a calibration. So when you apply one volt, reading also will be one volt but what happens to the moving coil voltmeter, from where it draws the energy. It's not from the source but from the auxiliary energy source. This is our battery, supplying energy to the whole circuit, so the current flow here is due to this battery. So the whole instrument function with energy of auxiliary energy source and not loading the measured medium. That is how by using auxiliary energy source, we can reduce the loading to a very, near about zero. So loading effect due to this open circuit is near about zero. So you can get correct value without any loading effect, get the correct value for the reading. So this is the third method.

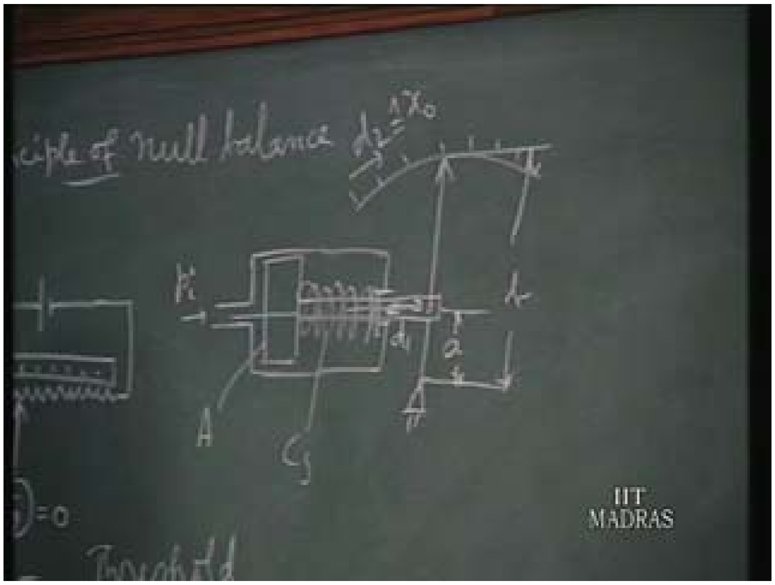
(Refer Slide Time: 00:28:38 min)



Now the fourth method is principle of null balance. For this consider the potentiometer circuit for voltage measurement. So this put plus and A and B and connect a galvanometer, this is a galvanometer. A and B is the terminal where we want to connect our voltage source. This is our e_i, this is what you want to measure and here along the resistance you have the scale. So we know by moving this contact, we can measure the voltage e_i. How the measurement is made? Until the reading in the galvanometer is zero, you are supposed to adjust it, when it is zero where it stops that is will be in terms of voltage. So 1, 2 like that will be there, you take the reading. What happens now? This is input medium, we draw zero current, the galvanometer is an ammeter, when the reading is zero means absolutely no current is drawn from here and in that situation we are measuring what is the voltage. So it is equivalent to the input impedance for this measurement is infinity. So you find this is null balance, there we are making the reading zero by adjusting this contact. So you will find loading effect is zero. Is it really zero? No, because you know any instrument has a threshold value. We learnt what is threshold value. Threshold is the minimum increment in input signal to make the pointer move.

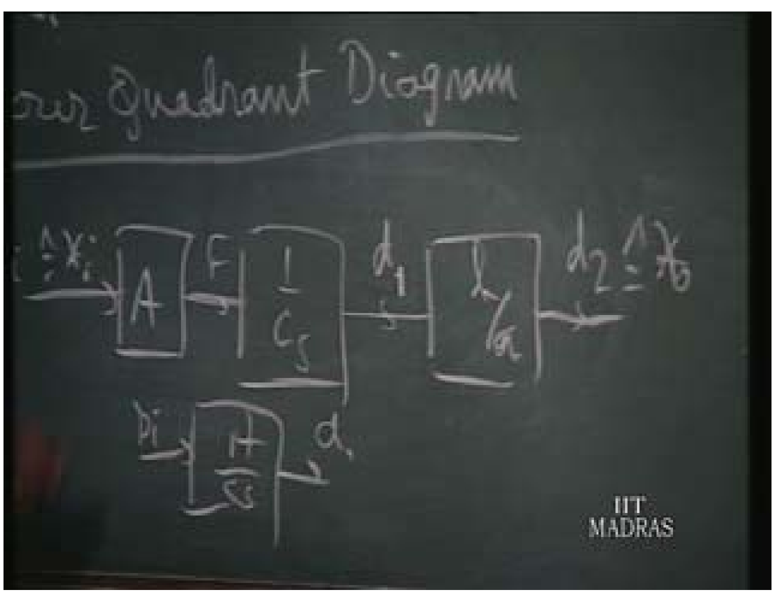
After all the zero reading which shows but probably the current may be smaller than threshold value. So when the current is smaller than threshold value you don’t had the reading here but that much current, equal to threshold value the current can flow through the galvanometer not showing any reading. What is the order of threshold value? It will be of the order of few micro amp, it will be very small value. So it is loaded only to the extent of micro amp as in the case of the VTVM. It will not draw in terms of amperes only when you draw current in terms of amperes this measured voltage reduce to a lower value and you will measure in the lower value. So these are the 4 methods by which we can reduce the loading effect. So now we have learnt the different methods of reducing or eliminating the error sources, effect of error sources or the error sources may be itself we can eliminate. Now we are going to learn a new technique called four-quadrant diagram.

(Refer Slide Time: 00:31:32 min)



The main use of the four-quadrant diagram is, we know the different error sources in an instrument and due to the error sources, what is the error in the instrument and based upon the error how the instrument is designed, for its least count and the graduations. That is what we are going to learn. Best example is our old piston and piston and cylinder type pressure gauge. I will draw once again piston and pressure type, cylinder type pressure gauge. This is a spring and then you have your pointer moving over the scale and the parameters are, this is P_i input pressure, this is the area, this is spring constant C_s. We have the displacement here as d_1 and the ratio is a and b, leave a ratio for the pointer a and b and this is our d_2 millimeter that is our output signal. For this instrument we are going to draw the four-quadrant diagram. Four quadrant diagram looks like this.

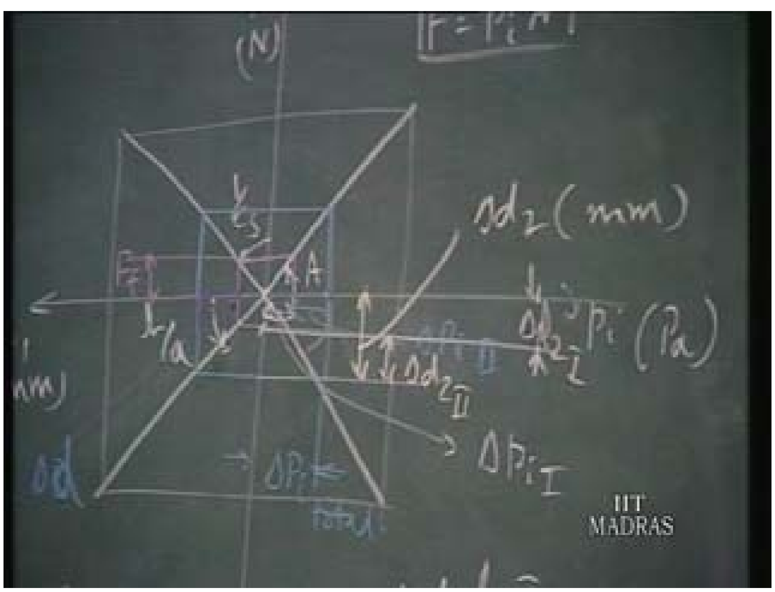
(Refer Slide Time: 00:32:51 min)



It contains four quadrants, the first quadrant, second quadrant, third quadrant and fourth quadrant. There we want represent this instrument, first draw the signal flow diagram for this instrument. That is now you have drawn already that is a piston area, piston area is A, so this is our input signal, this is P_i gives rise to F force. This is the first block of this instrument in terms of basic function elements. Next one is spring, spring has got C_s is the spring constant. So F by C_s will be our d_1 and then probably I will draw little smaller here. That is our A P_i X_i then F, 1 by C_s and then d_1 and then we have got this lever ratio. Then we have got d_2, this you have seen already earlier how to draw signal flow diagram. So this signal flow diagram for this instrument, to draw the four-quadrant diagram we should have 3 such blocks.

Suppose in an instrument we have more than 3 blocks, what you should do? Combine these two blocks into one block. Suppose four blocks means any two blocks combining. How to combine these two things? These two things can be combined as A by C_s, say multiply both the gains, here you will have b P_i and you will have d_1, like that you can combine any two blocks and make finally into 3 blocks but here fortunately we have the three blocks alone. There is no need to combine any blocks, so as it is we can draw it. Now the principle is this each block is represented in the first three quadrant. So the first block goes into the first quadrant, this first quadrant and then write the signal relation. What is signal relation for the first block? Signal relation is F is equal to P_i into A. This is our signal relation for the first block. So this we are supposed to write here that is F is equal to P_i into A. This is our signal relation for this first quadrant that means we are representing this equation in the first quadrant so the X-axis will be P_i, Y axis is F so you will find and a will be slope, for this conveniently I will draw within a four quadrant diagram. Suppose I am going to start like this, this is your A, slope between input axis and the characteristic curve is our slope A. That is A, y is equal to mx formula.

(Refer Slide Time: 00:35:19 min)

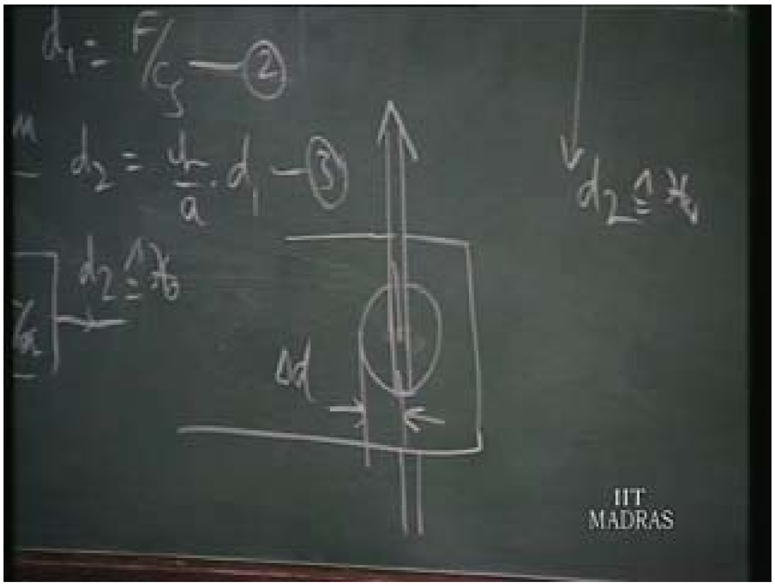


So we have represented the signal relation of the first block in the first quadrant. Then second quadrant is made up of d_1 is equal to F by C_s. This is our signal relation for the second quadrant but the slope will be 1 by C_s, so output of the second quadrant is d_1. F is your input axis, d_1 is the output axis for the second quadrant, so slope will be 1 by C_s from the input axes so it will be somewhat like this. So this slope is 1 by C_s, it is supposed to be straight line so 1/ C_s is the slope from the input axis for that quadrant that is F is input axis. Similarly the third quadrant is d_2 is equal to b by a into $d_1$this is our signal relation for the third quadrant.

So output axis is d_2 and input is d_1 and the ratio is b by a, this is b by a. That is a slope for the third quadrant that means three quadrants for three blocks and the fourth one is the whole instrument normally it is, the fourth quadrant represents the whole instrument. That is the input axis is P_i that is input signal, d_2 is output signal. So fourth quadrant represent the whole instrument and the characteristics will be somewhat like this and we know what its value a by C_s into b by a, slope will be a by C_s into b by a, that is representing the whole instrument but we will not consider that now. You will see how to make use of these three quadrants here to fix the amount of error due to error sources. What are the error sources in the instrument that to for that purpose we should know what are the signals there and the error source should be of the same nature of the signal. Now you have got the signals as force and displacement.

So naturally friction force F_f it's an error source for force signal and we have got some play. This is a hole, suppose I draw the bigger view of this, the pointer comes like this and hole is somewhat like this. This is your pointer. This is our piston rod end and this is your pointer that goes to the pivot, this goes to enter like this (Refer Slide Time: 38:64). So suppose in the middle position we have got a play of, so much play so I will call delta d as the play.

(Refer Slide Time: 00:38:14 min)



Until the delta d is overcome, movement is there pointer is not going to rotate. That is how the delta d becomes an error in this instrument. Since displacements are there, play is an error, since force force is there friction is an error. So how to represent the friction and the play in this quadrant? We will take first friction F_f, F_f is a force since it is a force, represent that F_f in the force axis, so this is your F_f. So this much distance is F_f and using the characteristic slopes curve that is a line through origin that is for a first, second and third, all these things are liner characteristics, a line through origin use these two bring it equal (Refer Slide Time: 39:62), what is the corresponding error in the input signal? You project it corresponding to input axis and also to the output axis using this characteristic that means now for F_f, amount of error here is I will call it as delta P_{i1}. F_f is the first error source and d_2 is actually in millimeter, in unit this will be in terms of millimeter, here you will have Newton is the force and here again millimeter, here millimeter these are the units. Here may be Pascal, a mega Pascal or atmospheric pressure these are unit. So you will find the corresponding to it may be some 1 or 2 Newton, correspondingly you have got so much Pascal here as the input error and output error will be so many millimeter for this much of frication force.

Suppose we have overcome the friction force, after overcoming the friction force the piston starts moving, still the pointer will not move because you should have the motion of delta d before the pointer moves. That means after overcoming friction you have to again move the piston so long until this is overcome. So it is in series, that is delta d is a displacement. It is a displacement that take place in the piston rod and the d_1 is the piston rod motion. So you have to put the delta d after corresponding point, put this delta d, this should be delta d. Then, that is after friction what our corresponding friction in the axis of d_1 afterwards you have to put delta d and now from this point, find out what is the total error in the input and output signal. Now this is the total error. That is this much comes from the play and earlier we had already input error due to the friction both put together, so now this will be total delta P_i, this is delta P_{iII} due to second error shows this much, so this will be total (Refer Slide Time: 42:44). That is so much Pascal will be lost in overcoming the friction and play.

Similarly how many millimeter of motion is lost, that is equal to again you find here, I will use yellow color. So here this output error previously delta d_{2I}. Now this is your delta d_{2II}. So both put together so this will be delta d_2. Total error in terms of millimeter from both the error sources, one with a friction and the other with the play. So much millimeter will be equivalent error in output reading for these two sources. In instruments there is a principle, the total error and the least count of the instrument decided on the following principle. The least count should be equal or larger than that is the principle is least count should be equal or larger than the error. Least count cannot be smaller than the error because dividing within error it’s not permitted. So least count should be equal or larger than error.

Since we have found out what is error, now it is possible to fix the least count because from this you know the total error and delta P_i we know and it is equal to so many Pascal or so many bar. That is the error.

Suppose say 2.5 or 1.5 bar, delta P_i is equal to 1.5 bar then least count should be equal to 1.5 or it can be larger but normally the least count is in terms of full number, so next take higher number will be two bar. So select the least count as two bar. So for this instrument now you will have a least count of 0, 2, 4, 6, 8 and so on. So to fix the least count we have made use of the four quadrant diagram. For this two bar when we have this two bar and also there is another condition in international practice, for this least count we should have a minimum distance of 1.5 mm. This is another condition; between two graduations we should have 1.5 mm so that we don't strain our eye when we take reading.

So how to check whether there is 1.5 mm or not, that is our delta d_2. Now you have increased to 1.5 whether 1.5 bar, earlier before selecting two it was 1.5. What is the distance that is delta d_2. How many millimeter is there? You can read it is a scale, output scale is plotted here so much output error. Actually what is the term in terms of millimeter, you can find out. If it is 1.5 or more than 1.5 you can find. Suppose if it is less than 1.5 mm then here also graduations is going to be less than 1.5 mm, you are not permitted, so for the same input error, output corresponding displacement should be more. How to do it? By increasing the characteristics of the three blocks. That is A can be increased to A dash or 1 by C_s can be increased to 1 by C dash or b by a ratio can be increased. If C_s is changing means, you have to change the spring and area means you have to go for different types of cylinder and piston they are very costly. So changing the lever edge is simpler. So larger b or smaller a, you can have and can have another slope for it that is our changed pointer that is b by a dash. Now this is same, you find, you have got another, this is d_2 dash so you will find since it is increase, you will find the corresponding output displacement is increased to a larger extent.

Now see whether it is more than 1.5 mm. So four quadrant diagram we are making use of, not only fixing the least count also we can check whether there is 1.5 mm otherwise by changing one of the characteristics, we can make that equivalent distances as 1.5 or more and then select a new element. That is here pointer is changed to another pointer, so that you have got a larger scale thereby you will get a distance of 1.5 mm between two graduations. So that is how we make use of the four quadrant diagram but here it is linear characteristic instrument. In linear characteristic instruments we need not go for the graphical construction, we can compute also. If it is nonlinear characteristics, suppose it is somewhat like this, in nonlinear characteristic computation will be very laborious and in such instances four quadrant diagram is very handy. We can have the nonlinear characteristics and again plot and find out the error and all but in case of linear instruments we can also compute. So that we will see in terms of worked example, 1 or 2 worked examples for this chapter, under that we will see for a linear instrument how to find out equivalent errors in input and output signal and how to design the pointer length to achieve 1.5 mm of the distance. We will close here.