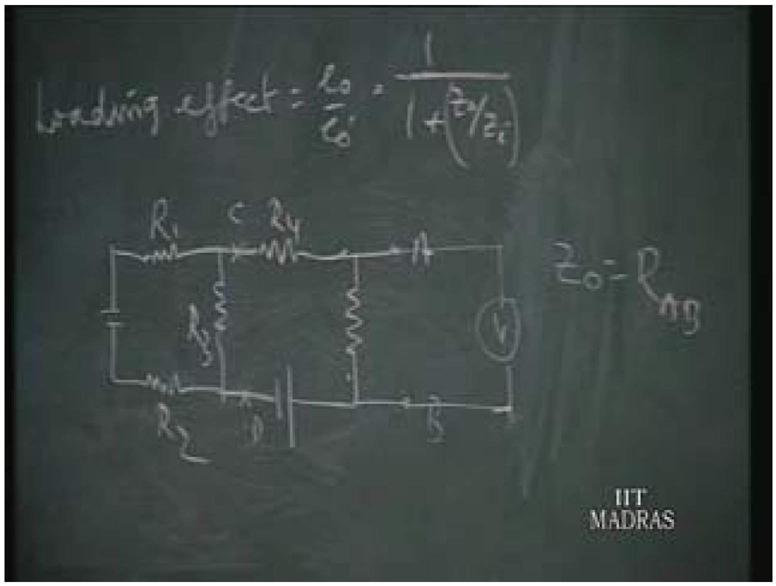
Principles of Mechanical Measurements

Prof. R.Raman
Dept. of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture No. # 07

Having learnt the concept of loading effect, error and least count now it is time for us to work out some problems because these concepts are very important in the field of measurements.

(Refer Slide Time: 00:01:44 min)

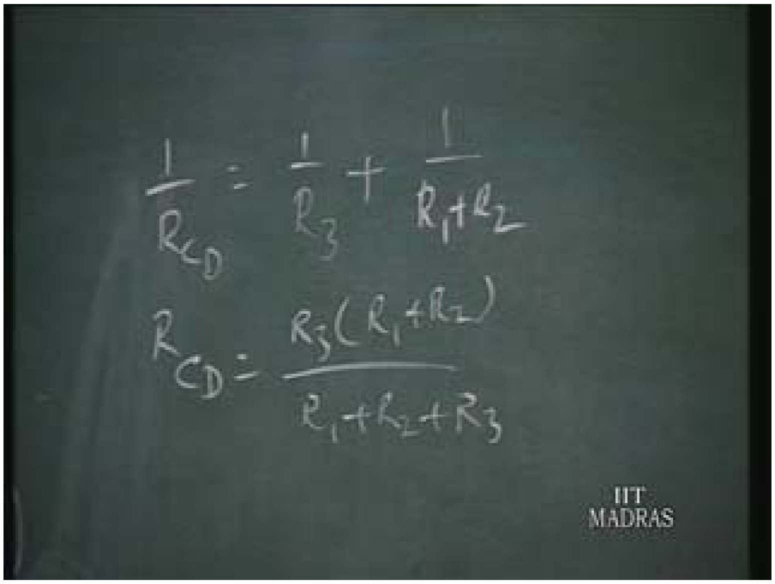


So we know the loading effect is given by the ratio e_o by e_o dash equal to 1 over 1 plus Z_o by Z_i this is what you have learnt under loading effect. So if at all you are interested to find out the loading effect we are supposed to know these two values the impedance, output impedance as well as input impedance. Unless we know this we cannot find out loading effect in a measurement. So let us work out one or two problems or let us see one or two important circuits in finding out what is Z_o of the circuit so that we can select suitable instrument which will have 10 times Z_o as the impedence that is our idea. For example let us consider this flowing circuit R_1, there is a battery source and another resistance R_2 and R_3 across and R_4 and it goes to the terminal A across which we are going to measure the voltage here another battery source and B.

Now the problem here is we want to measure a voltage across A B, there are two battery sources and so many resistances are connected in the circuit. Now we want to connect a voltmeter and what should be the resistance of this voltmeter you have to find out. For this unless we know the resistance of the circuit as reflected across AB we cannot select the instrument so that is so to say R_{AB} that is our Z_o is here R_{AB}, Z_o is equal to R_{AB} here it is purely resistance circuit as seen from AB what is a resistance of this. So how to find out that is what we are going to learn. In such circuits its better we find part by part. So call this point C, D these two points and across C, D suppose this right hand side doesn't exist and across C, D what is the reflected resistance of the circuit across C D?

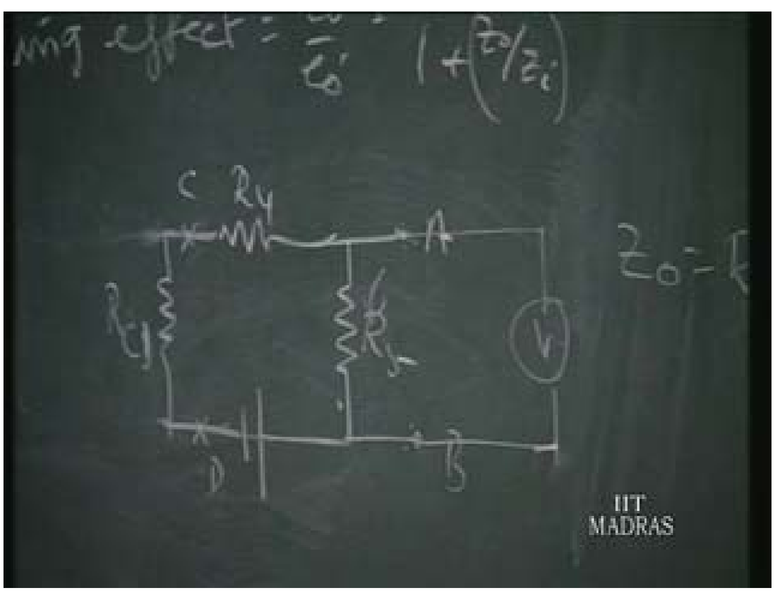
That is R_1, R_2, R_3, for this purpose we normally use a thumb rule, start from one point C try to reach the point D now how many paths are there, so many parallel paths then find out the equal resistance of the parallel paths.

(Refer Slide Time: 00:04:27 min)



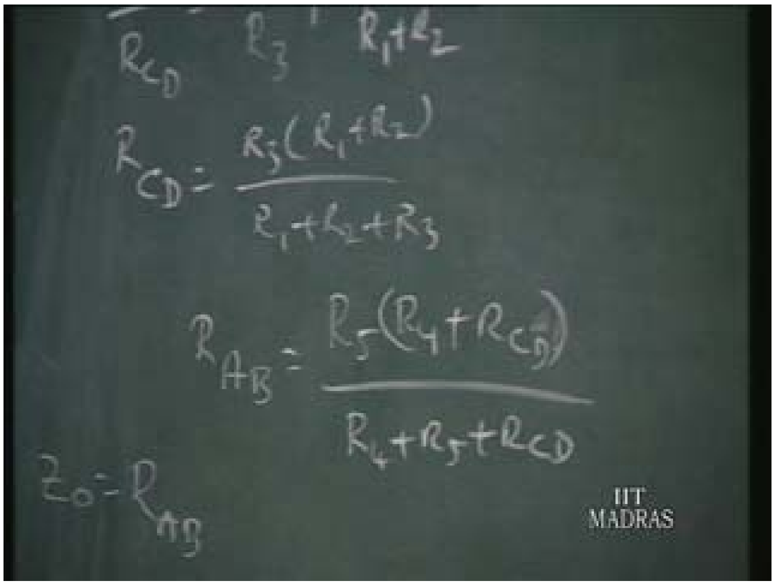
So if you call R_{CD}, one by R_{CD} is equal to one by two parallel path so 1 by R_3 is one path. The other parallel path is R_1 + R_2 so 1 by R_1 plus R_2. So now from here R_{CD} is equal to R_3 into R_1 + R_2 divided by R_1 + R_2 + R_3. So simply we say parallel paths of two resistances R_A R_B so R_{AB} is equal to R_A into R_B by R_A + R_B that is the formula that is what we have used here, finding the equivalent resistance of a two parallel paths.

(Refer Slide Time: 00:05:12 min)



Now as well as I can forget this now, instead of the whole circuit I simply write this R_{CD}, R_3 I can write it R_{CD} because it's equivalent valve I have put here, the whole circuit is put as R_{CD} whose resistance is so much. Now it is simpler circuit, now from A to B how many paths we have got? One path is this is the resistance R_5 so from A to B one path is through R_5 another path R_4 R_{CD} and this for that equivalent circuit we always R circuit, the battery source so we short circuit this. So now here again we have got two parallel paths.

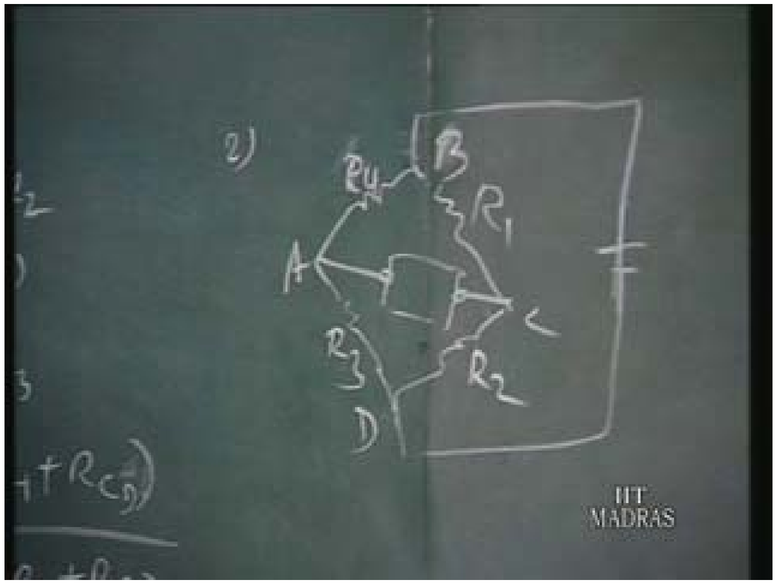
(Refer Slide Time: 00:05:51 min)



So R_{AB} is equal to R_5 into the other parallel paths that is $R_4 + R_{CD}$ that's all, R_{CD} divided by $R_4 + R_5 + R_{CD}$. So R_{CD} you can substitute so that we can have always the R_{AB} in terms of the given resistances. So R_{AB} is equal to our Z_o so this we find out from this given values and then ten times this we select as the volt voltmeter resistance. So that is how we find out the output resistance of the existing circuit. Having learnt this process now you have to apply to the conventional circuits which are often used in mechanical measurements. One of the important circuit is bridge circuit because bridge circuits we are using for converting the resistance change into a voltage change.

So let us consider the following bridge circuit, this is second problem this problem 1, problem 2, we are just working out few problems so that the concepts of load loading effect and error on least count are clear.

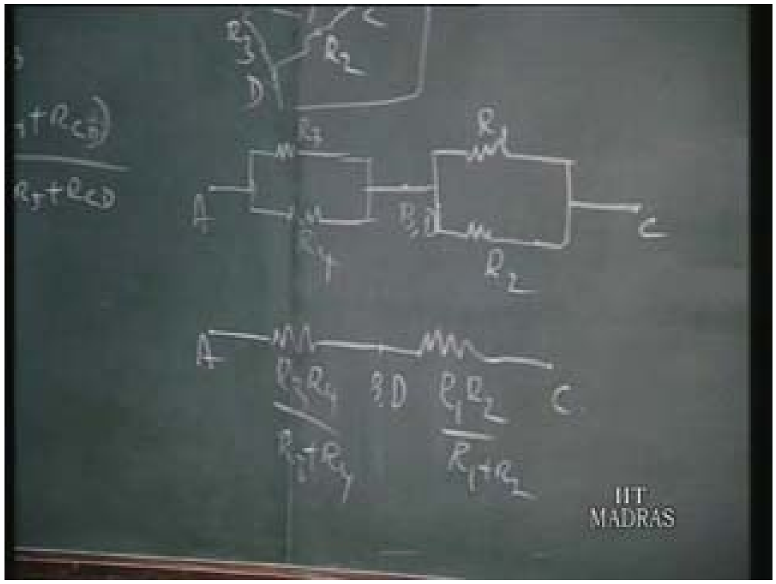
(Refer Slide Time: 00:07:15 min)



So I will consider the following circuit, bridge circuit. So this is the excitation, I will start here from A and this B, C, D four corners across AC the voltage output is obtained. Voltage output is there, so two corners opposite corners for excitation and the other two corners for output signal. Now here we should know what is the reflected resistance across AC because here only you have to connect the instrument. So when you want to select that instrument what is the output resistance of the bridge circuit that should be known, otherwise we cannot select the instrument. That's what you say R_{AC} should be known, now let us draw the equivalent circuit. For finding out the output resistance normally we short circuit the battery source.

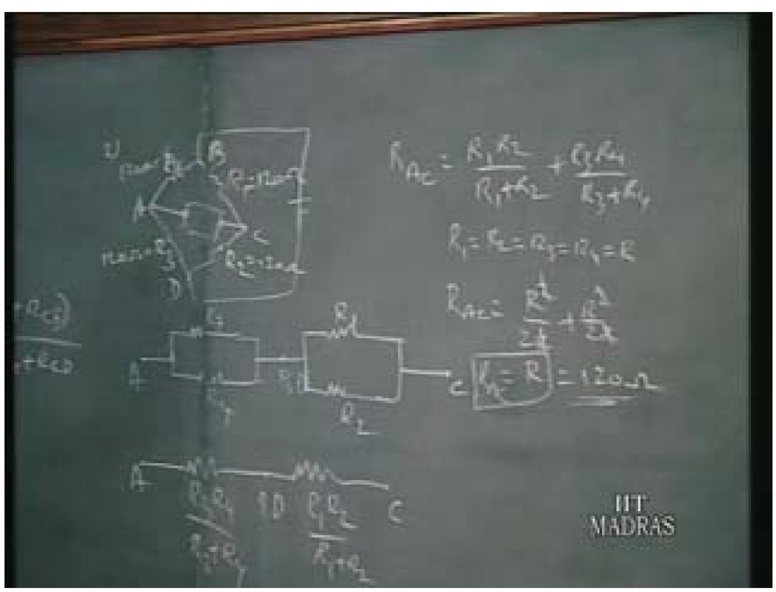
Now as we have done earlier these are the two points A and C, across AC we have to find out. So start from one point and try to reach the other point, how many paths is there so many parallel paths and find the equivalent distance that is the way we are going to adopt. Now starting from A, I can go to B or D through say I will call this R or I will call this R_1 R_2 R_3 R_4 these are the four resistances. So to reach C I have to start from A, so through R_4 or R_3 I can reach the point B or D and since it is already short circuited the battery source B and D remains the same potential or same point, having come to BD either through R_3 or R_4 then again to reach C from BD I can come either through R_1 or through R_2.

(Refer Slide Time: 00:09:18 min)



So to say I start from point A and I have got two paths, one path is R_3 another path is R_4 to reach the point B, D. Having reached BD then to reach C, again I have two paths that is R_1 and R_2 and this is our C that is how we draw the equivalence and by using thevenin theorem that is short circuiting the battery source we start from A reach C. Now if you find out the equivalent resistance of this circuit which is easier, we know what is the resistance across AC so to say now we can write it, starting with point A this equivalent resistance is I can draw one that is R_3 R_4 by $R_3 + R_4$ that is the resistance of this parallel path. You have reached BD and now this resistance equal to R_1 R_2 divided by $R_1 + R_2$ so we have reached this point C.

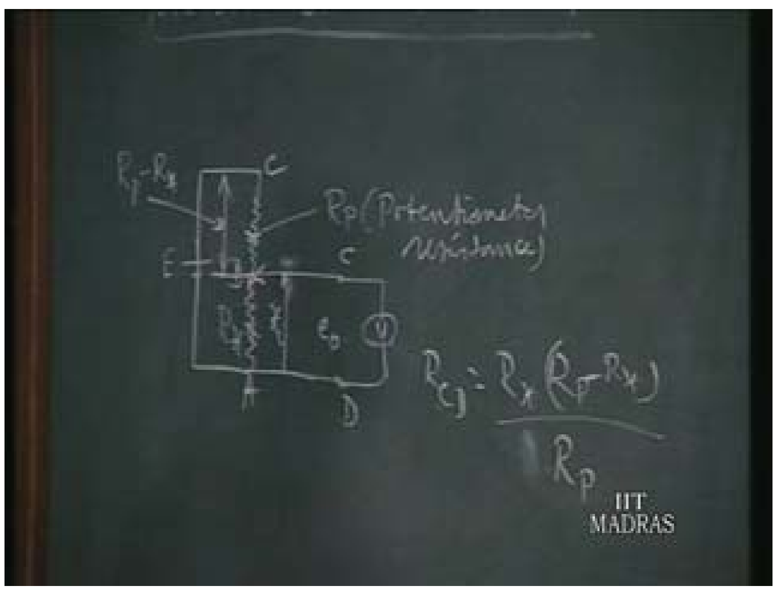
(Refer Slide Time: 00:10:25 min)



So now total resistance R_{AC} is equal to R_3 or I will write this first, R_1 R_2 by R_1 + R_2 + R_3 R_4 by R_3 + R_4. Now this is the equivalent resistance of the bridge circuits across AC where we are going to connect our voltmeter, voltage output; voltmeter we are going to connect. In the normal practice you find R_1 is equal to R_2 is equal to R_3 is equal to R_4 is equal to R, in strain gauge applications we normally purchase four strain gauges of 120 ohm and there a bridge is made up like that so we will call R_1 to R_4 is equal to R, in this situation R_{AC} is equal to R squared by 2 R + R squared by 2 R. We have got R by 2 R by 2 is equal to R, so R_{AC} is equal to R, it is simple to remember.

Suppose the four arms of the bridge is made up of equal resistances then the output resistance of the bridge is same as the resistance of one of the four arms. Suppose if it is equal to 120 ohm, each one is made up of 120 ohm then R_{AC} also will be equal to 120 ohm that's how we remember, what ever be the strain gauges that has been made use of for all the four bridges and resistance of one of them will be, because all of them equal will be the equivalent resistance of the bridge circuit, so here R is equal to 120 ohm. Now once we know the resistance of the bridge circuit as reflected across AC then the voltmeter should be having at least 1200 ohm that is what we have learnt, the resistance of the meter should be at least ten times the existing resistance or output resistance of the circuit.

(Refer Slide Time: 00:12:29 min)



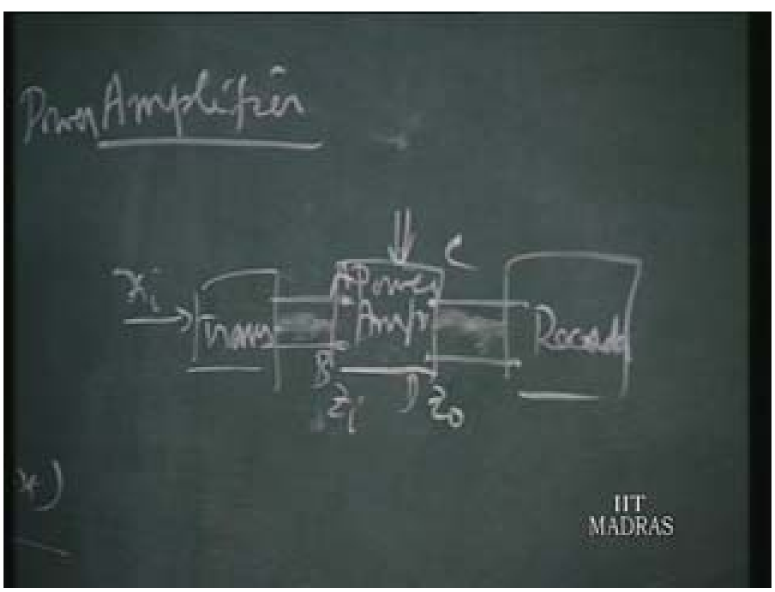
Now the second important circuit is potentiometer transducer which is often used in mechanical measurements that is it is a transducer used to sense or transduce a displacement probably it's a displacement from this, displacement of x into a corresponding voltage say e_o that is a displacement x_i this is the output voltage. This is the potentiometer which has got its own excitation voltage, this whole voltage is proportionately distributed along the resistance and when we move this contact up and down proportionately we have got a voltage output. So many millimeter of motion is equal to so many volts we get it here that is so weak, transduce a displacement into a corresponding voltage.

Suppose we want to connect a voltmeter then naturally we should know how the output resistances of this in circuit varies accordingly we can select the resistance of the resistance of the voltmeter. Now we have to see how it varies, the output resistance varies. For that you call this resistance up to this point from A at some operating point call it as B, this as C, A B C. Now we want to connect the voltmeter across CD, a same principle we use it to find out the equivalent resistance that is from C to D we have to reach in the existing circuit how many paths are there, one path is through B to A I will call R_x and then if you call this whole resistance is R_p, R_p is the resistance of potentiometer then the resistance from B to C is $R_p – R_x$.

The whole resistance is divided in two parts one is R_x and the remaining part is R_p minus, R_p is the potentiometer resistance. So here we find equivalent resistance R_{CD} is equal to now you have got two parts one through this, another through the other because we are short circuiting this battery source. So one path is through R_x, so R_x and the other path is $R_p – R_x$ divided by $R_p – R_x + R_x$ so giving rise to R_p alone. So this is the equivalent resistance of this potentiometer circuit across CD. Now what is the property of this R_{CD}, now as we as we vary x_i the input displacement, R_x is varying. So you find since R_x is varying R_{CD} is going to vary, so in selecting this voltmeter you have to see what is the maximum value it can have, maximum it can have R_p.

So naturally you go for 10 times R_p but suppose if it is varying between two intermediate points then for the particular application you are supposed to find out the variation of the R_{CD} and accordingly you have to select it but the main point to note here is in a potentiometer transducer where the potentiometer circuit is used for the transducing a displacement to a voltage, we have got a varying output resistance this is the important point. Hence we find the loading effect also will be a varying one that is sufficient now to know about the circuit. Later on when we take out some problem you will find when there is varying loading effect how to make measurements.

(Refer Slide Time: 00:16:37 min)



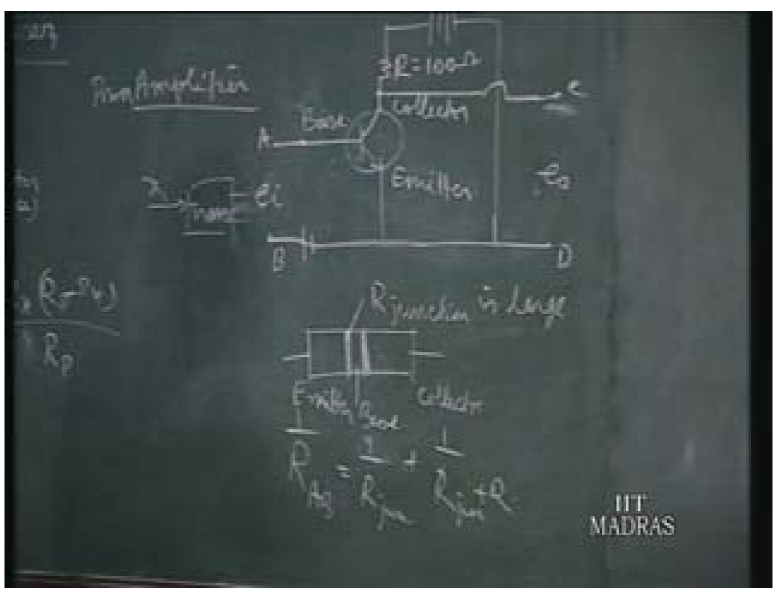
We will go to the other circuit. Now it is another circuit what we often used in the measurements is amplifier. Now the amplifier has got some unique property.

What we have learnt so far the circuits, the first circuit some random circuit I have picked up and second circuit pertain to bridge circuit, the third circuit is for the potentiometer transducer. They all have constant or little varying one, output resistance, it's a unit having a given output resistance in two three cases it's constant otherwise it is varying. But here is a unique then amplifier which normally in amplifier interposed between how the amplifier is made of. We have got the transducer where we give our input signal and then normally we will have the power amplifier this is the amplifier or we can also call it power amplifier so where we inject power then it goes to some other actuating probably this may be a recorder. Consider this is an instrumentation now we find it has power amplifier that has to be matched on both the sides say before power amplifier you have got one unit and after power amplifier you have another unit.

So this is an instance where it should possess two important characteristics. When it is looked from transducer it gives certain Z_i, it should possess certain Z_i and when it is seen from recorder it should possess certain Z_o. Now what should be the values of Z_i and Z_o? The Z_i should be very large compared to transducer output resistance or impedance and the Z_o should be very small so that we can select ten times Z_o for a recorder that means the amplifier is supposed to possess two characteristics simultaneously. That is Z_i should be large for this power amplifier at the same time R or I will say transducer, I will consider two terminals here also I consider two terminals which is the actual case. So when the amplifier is seen across the terminals A and B the circuit should possess a large value that is Z_i should be very large and similarly if I consider the two points C and D output points of the amplifier, when the amplifier circuit is seen from C and D it should possess a smaller value or Z_o should be small and here Z_i should be very large this is the characteristics what is required.

Inherently it is there in the amplifier circuit for that I take one simple amplifier circuit and demonstrate it is there, high Z_i is there at same time high low Z_o is there. For this one simple transistor circuit I will take it.

(Refer Slide Time: 00:19:36 min)



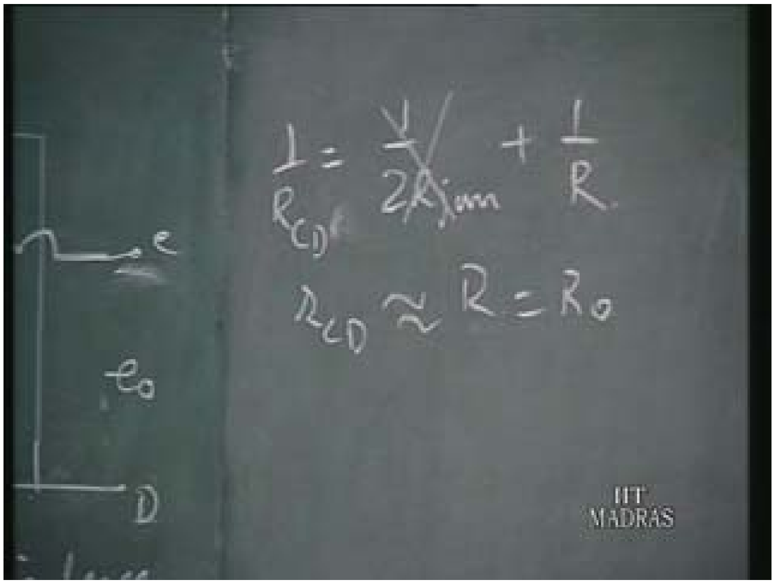
So it is like this or I will draw on the other side. This is the base point A and point B is the constant here hence it comes here so this is your output point which is C and D and A B is the input terminals for the amplifier. You should remember the earlier diagram that's the A B C input terminal and CD are the output terminals of the power amplifier which you have earlier interposed in an existing circuit. Now we will see what is the value of R_{AB} or Z_{AB} and then Z or Z CD output impedance or as is here it is purely resistance what are the resistance values R_o and R_i and R_o that is R_{AB} and R_{CD}. Then say we will follow the same principle so call it R, same principle, this is a transistor, this an emitter and then this is collector terminal, this are the base collector and emitter terminals and we know in a transistor circuit construction between emitter and collector there is an insulating layer and between collector and base there is an insulating layer but in base and emitter there is also insulating layer.

That is base is the middle and it is somewhat like this, base is the middle this is base and this is a emitter this is a construction of a transistor, this is the collector portion it and we have the insulating layer here, these are the insulating layer between base and emitter insulating layer, base and collector insulating layer. So these are two layers are there so each one is separate and we say this R junction between these two junctions where it's a large value R junction is a large one is large compared to R value. R is of the order of say about 100 ohms or 200 ohm like that. Now compared to that the junction or the insulating layer between this three compartments are large that is what we are supposed to know in the transistor circuit.

Now we find out what is the resistance R_{AB} from R_A, after you go to R to A, A to B we can go first to base and then through emitter, base to emitter, base to emitter and come back to point B. This is our input voltage for this power amplifier and this is the output voltage. So there is one through the R junction or we will call R junction, so R_{AB} is equal to R junction I will say R junction or one by R_{AB} is equal to 1 by R junction resistance and other one is through base to collector another R junction is there. So then we can come through R and then to here and then back to this we can short circuit that means plus 1 by R, one R junction is there between base and collector R junction plus R and when we compare R to R junction this may be neglected. So you find R_{AB} is equal to R junction divided by 2, when R junction is large so R_{AB} will be moderately a large value. That is our input resistance, R_i is relatively large value and now we see what is the resistance output for this power amplifier. Again we use the same principle.

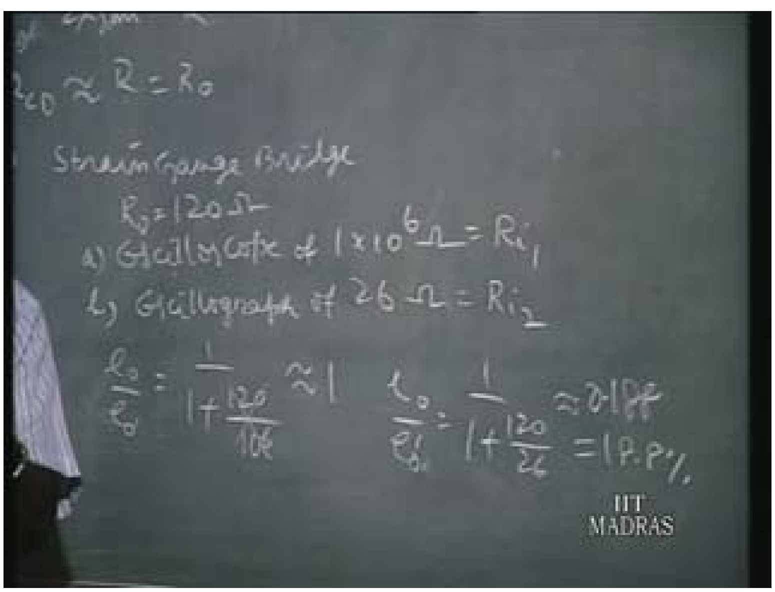
So R_{CD} is equal to we go through one or say one by R_{CD} let us put. We have got one junction collector to base and then from base to emitter another junction, there are two junctions one by twice R junction, from C to D we have got two junctions and then come to D. Another path is we can go through this and take the path through R and this we are short circuiting come back here, come to D that is plus one by R. So now you find when this value is very large twice R junction then this will be too small compared to because R is small value, one by R will be a larger one, so you will find R_{CD} is approximately equal to R.

(Refer Slide Time: 00:24:04 min)



Now R is of the 100 ohm so 100 ohm for example so you find R_{CD} is equal to R_o output resistance is smaller one where R_A is a larger one, made up of junction resistance. That is how we see an amplifier possess simultaneously a higher input resistance so that it can be connected to transducer, it may have ten times resistance of the transducer to connect it and it has got a lower output resistance so that ten times the smaller resistance can be the input resistance for the recorder so it possess both the characteristics. So we will see how this loading effect can be made use of in measurements. We take the first problem, so problem on a strain gauge bridge say problem one.

(Refer Slide Time: 00:26:04 min)



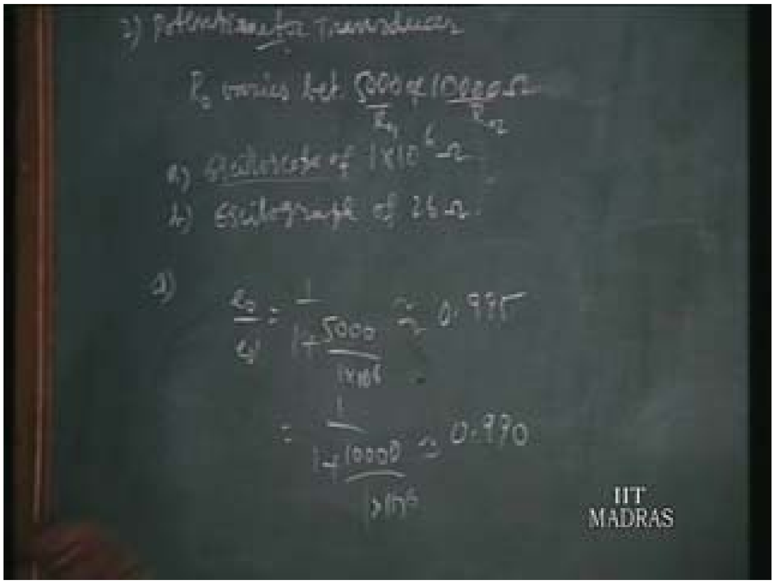
There is a strain gauge bridge with R_o is equal to output resistance as 120 ohm that means this strain gauge bridge is made up of four arms, each arm being 120 ohm. So output resistance of the bridge circuit you have learnt already it is 120 ohm. Now this bridge for reading the output voltage of this bridge there are two possibilities, one possibility is an oscilloscope of resistance of 1 into 10 to power 6 ohm this is one possibility. Another possibility is oscillograph of 26 ohm, this is instrumentation once bridge output is read with an oscilloscope or in other instance it is read by oscillograph where it is recorded. Question is what is loading effect in these two cases? It is simple here because R_o is given, this actually is R_i seen in first case and this is R_i in the second case and use this formula loading effect is equal to e_o by e_o dash is equal to 1 over 1 plus, so you take the first case R_o here is 120 and R_i is equal to 1 into 10 power 6 but this is too large number 10 power 6 compared to 120.

So this will be near about zero so you will find actually its value is about one only 120 volt or 10 to power 6 is negligible so it is near about one. So in case of oscilloscope we find since the input resistance is much larger than the output resistance 10 to power of 6 means near about 10 to power 4 or thousand times or somewhere like that, we want only 10 times it is much more than this so in such instances we should see the loading effect is negligible that is what is demonstrated here. Suppose the input resistance is very small this is a typical case compared to the output resistance what is loading effect, we know there will be a very large loading effect that is what we are finding out now. That is e_o by e_o dash is equal to 1 over 1 + 120 Z_o by Z_i is 26. Now this works out to be 0.188 that means e_o will be in terms of percentage this is equal to 18.8% or say one fifth of the e_o dash if it is 20% so e_o will be one fifth of the theoretical value.

Suppose the e_o dash is going to be 5 volt and what we get in this instrumentation is only 1 volt, 4 volt is lost by loading effect. So heavy loading effect is there since the input instrument has got very low resistance. So we normally say such instruments should not be there but here there is a special property. Since the resistance is a constant one 26 ohm is constant we are going to always get one fifth of the voltage which is constant ratio. Once we know the constant ratio where the instrument is going to show one volt, write it as 5 volt that is called calibration process. By the process of calibration we can write this one volt output from this instrumentation that is from the oscillograph write it as 5 volt, 2 volt as 10 volt like that.

So the constant loading effect can be compensated at the time of calibration, this is possible but if we don't do the calibration we say there is error. If you do the calibration the error is removed since it is a constant error, we can always remove it by the process of calibration. So in the absence of calibration you have to say the error is there but once we calibrated there is no error but if the loading effect is varying whether it is possible to eliminate this error. That it's not possible that is what is demonstrated in the second problem. Second problem illustrates that loading effect in instrumentation where the output is going to vary that is our typical potentiometer transducer you cannot compensate that is not possible we will see it.

(Refer Slide Time: 00:30:50 min)



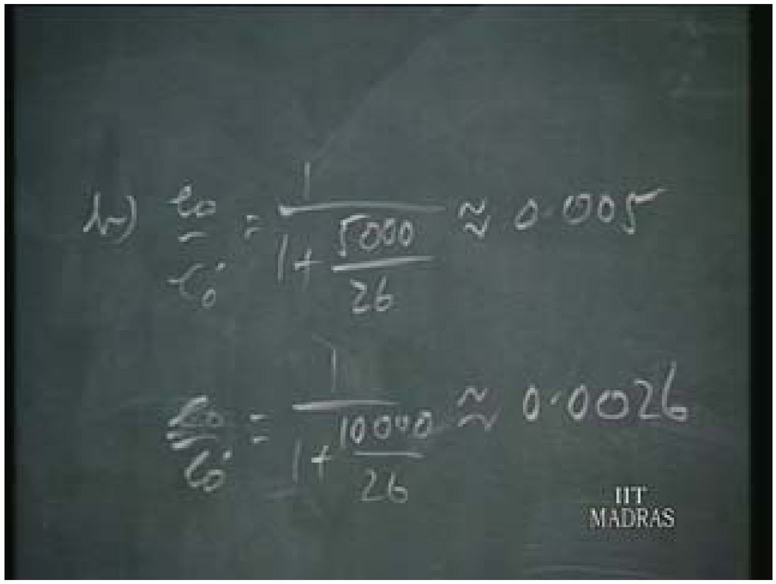
Now we are going to see in a typical measurements where this loading effect cannot be compensated. Now we have already seen for a potentiometer transducer the output resistance of the potentiometer circuits varies as the displacement varies, input displacement varies that output resistance also is varying. In that case the loading effect is going to vary that what you learnt there qualitatively but now we are going to see quantitatively. Now R_o that is the displacement is more within the potentiometer but in points A and B but at the point A it is 5000 at the point B for example 10000 ohm. Here you are not asked to find out the R_o, the problem here itself given the valves are given and the instrumentation is two type of instrumentation.

One instrumentation is oscilloscope with that it is again as in the previous case. In the second instrumentation we use to oscillograph of this to record the output voltage. Now what is the loading effect in these two instrumentations separately? If you see take the first case oscilloscope, the loading effect because R_o he has got two extremes the loading effect also is varying between the two extremes. Now that is R_{o1}, this is R_{o1} you call it R_{o2} in 2 instances. So now you take that is for instrumentation a e_o by e_o dash is equal to 1 over 1 plus Z_o or R_o, R_o is now say 5000 and then R_a is 1 in to 10 to power 6. So this is about 0.995.

In the second case that is the next to extreme one, this is R_{o1} next extreme case is 1 over 1 + 10000. Other extreme case of R_o is 1 over 10000 same instrumentation is equal to it is approximately equal to 0.990. Now here we have to learn one point. Since the input impedance is of the order of 1 mega ohm and the output resistance is few thousands of ohm only, though loading effect is varying but it is near about one only, the ratio is near about one that means e_o will be very near to the e_o dash. It is because the input impedance is very large, so 10 to power of 6, so 10 to power of 100 times we want only 10 times more only but here it is 100 times and more. So in the input resistance is more than hundred, you know hundred times or something like that then you will find though it is varying loading effect but the actual output voltage is near about the actual theoretical voltage because loading effect is become very negligible though varying what is varying only third decimal it is varying.

It is because the input resistance too large, very large compared with the output resistance with potentiometer transducer but when the input resistance is small, this varying output resistance the effect is magnified that is the case now that is instrumentation b says e_o by e_o dash is equal to 1 over 1 + first case is R_o, R_o is 5000 when the displacement is at point A in potentiometer transducer divided by this 26.

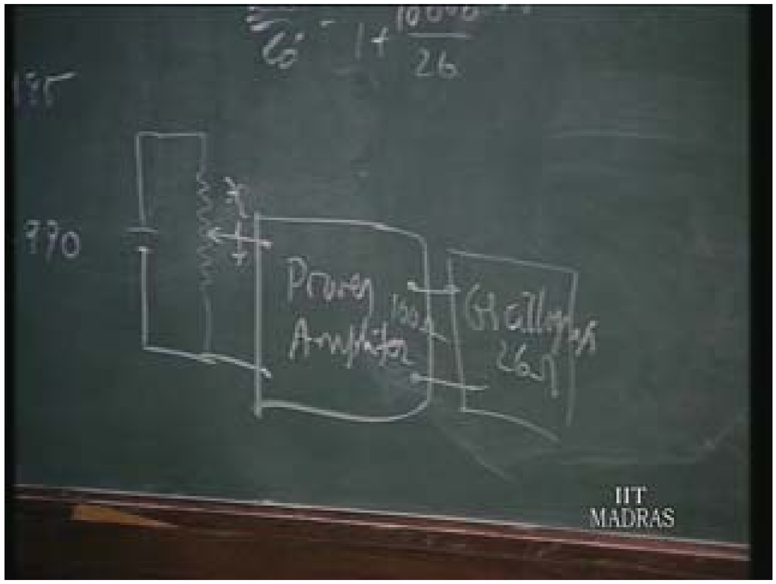
(Refer Slide Time: 00:34:10 min)



Now it is only 26 ohm, now it is smaller, the input resistance we expect to be ten times larger than the output resistance but here it is much smaller it is just opposite effect. So this gives rise to a very attenuation and it is around 0.005 that is equal to 0.5% say if the theoretical voltage is 100 volt the e_o is going to be 0.5 volt that is its high reduction of the actual value when compared with the theoretical value so highly attenuated nearly zero. Similarly you will find e_o by e_o dash for the other point of operation in the potentiometer transducer is 1 over 10 to the power of 10000 by 26, this is around 0.0026. So this also if it is 0.2% that is for 100 theoretical voltage, 100 volt the voltage output will be only 0.2 volt previously it was 0.5 volt for 100 volt theoretically value it is 0.2, still much reduced.

So you find when the input resistance of the instrument is very small compared to the output resistance, the loading effect is enormous and not only enormous it is varying with a wide limits, the 005 is around nearly twice this value. Previously you find it’s a near about one, both of them nearer one near about one of the same magnitude but here in this case one is half the other value this is half this other value. So the loading effect is very large and varies widely. So this is the situation and it cannot be compensated, this cannot be compensated by calibration. So you have to adopt some other method of avoiding loading effect and for that the clue is obtained from the first instance, when we connect to this varying output voltage a very high input impedance then this varying effect is not found in the output of the high resistance device, that is what you have learnt and that is to make use of this what is done is we draw this again the potentiometer transducer with its excitation voltage.

(Refer Slide Time: 00:36:53 min)

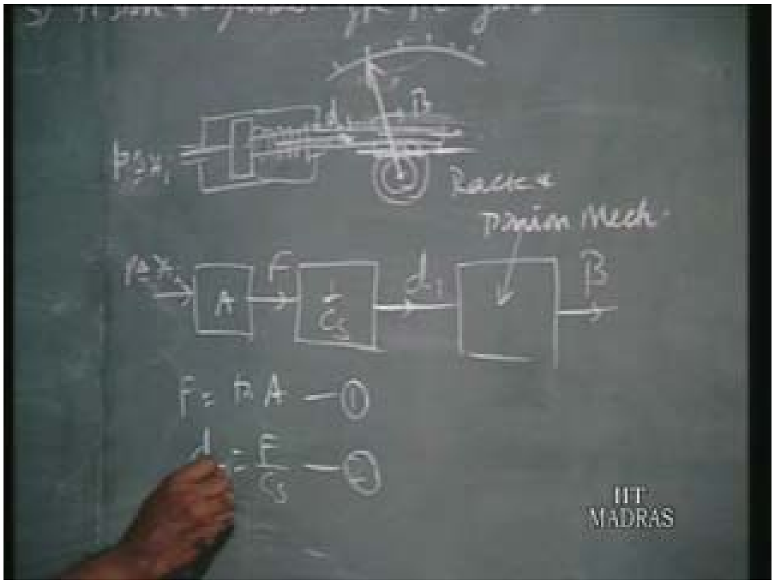


This is your output terminals, this your our xi input distance is given here we have got the output voltage, instead of reading through oscillograph where the loading effect is varying and also wide limits instead of connecting oscillograph, you connect a device which will have a high input impedance just like oscilloscope but it's a different one. We want to make use of here oscillograph, so naturally what we have got is power amplifier. We have learnt already power amplifier is a device which has got a very high input impedance, with very high input impedance the output voltage is not going to vary widely as in this case of oscillograph. Now we know this output impedance of the power amplifier is also a small one this may be order of 100 ohm.

Now to this you connect your oscillograph, it is now of 26 ohm it's one forth but you find the hundred is constant and 26 a constant. So you find loading effect even though there is loading effect, as our first case first problem it is a constant value. So this can be easily be calibrated, since loading effect is constant in between these two instruments can be calibrated and these attenuated value can be written as the theoretical value as you have done in the earlier case. So this is the solution for that instrumentation where you have got a very high loading effect and varying limits so that is all regarding the loading effect and its instrumentation in measurements in mechanical measurements.

Next we are going to see how to make use of the four quadrant diagram. We already learnt four quadrant diagram where the different error sources within the instrument are identified by drawing the signal for diagram and find the total effect of the error source on the input signal and from the total error we obtain a suitable least count and that is what you are going to use it when we manufacture the instrument, that is a design problem. How to decide the least count of an improposed instrument. For this we take this same conventional example what we are seeing from the very beginning a piston and cylinder type pressure gauge.

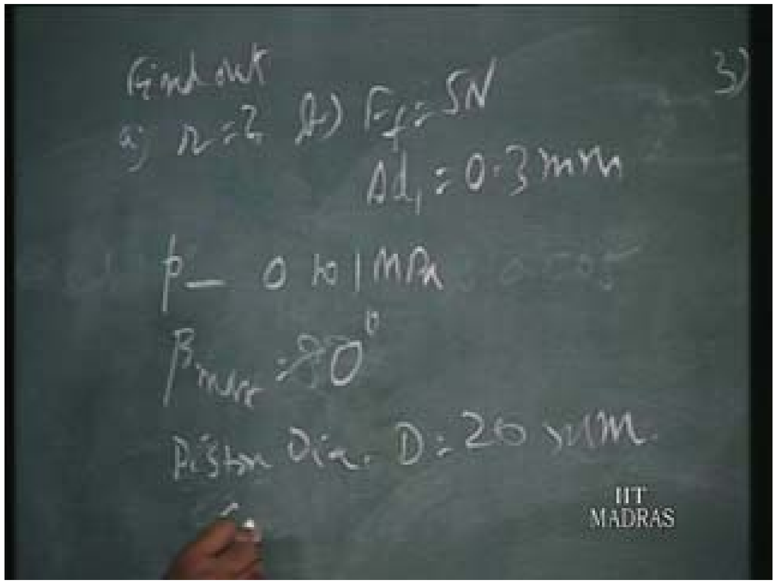
(Refer Slide Time: 00:39:24 min)



That is the say third problem piston and cylinder type pressure gauge. The diagram is like this, we got the spring to convert the force to displacement and instead of a pointer mechanism directly correctly connecting here, we have a rack and pinion mechanism, it is little different and you can draw the rack the other side and then a pinion. Now for this motion it will rotate in this direction, so you have got pointer and the scale this is called rack and pinion mechanism. Instead of simple lever mechanism we use at the end of the piston rod rack and pinion mechanism. So the P is our input signal x_i as we are told for drawing the four quadrant diagram we should represent the whole instrument in three blocks.

So first one is our piston area, this is your piston area A, x_i that is our pressure and from here we have force and force to we have got displacement d_1 this is d_1 and d_1 is converted into by using this rack and pinion mechanism we convert it into beta that is beta rotation. This is the instrumentation and again we draw the signal relation for each block this is our one by C_s spring. So first equation is F is equal to P into A this is equation one. For second block d_1 is equal to F by C_s this is second signal relation for the second quadrant d_1 and then beta is equal to pinion, if you call pinion radius R, R beta is equal to d_1 R into… So that is d_1 is equal to R into beta so beta is equal to d_1 by R so here you will have one by R as the gain. So beta is equal to d_1 by R, these are the three signal relations and which we are going to represent in a four quadrant diagram but instead of going for four quadrant diagram since it's a purely linear instruments we can analytically compute the values.

(Refer Slide Time: 00:42:37 min)

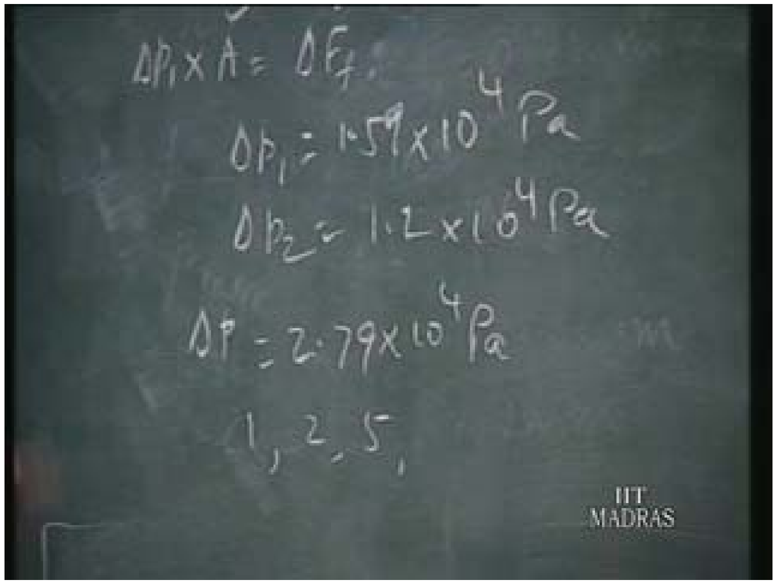


Now what is asked in this problem is find out a radius of the pinion r, r is equal to how much and then b for here total friction that is delta F, F is the force and friction force F_f is equal to friction force is 5 Newton and then rack and pinion machine we have got the backlash. We call it delta d_1 backlash is equal to 0.3 millimeter, backlash equal to 0.3 millimeter. So these are the error sources within the instrument because we know F friction force is there, displacement is there. For force friction is error and for displacement backlash is error which we have learnt already. So these are two error sources and how much should be the least count that is our problem. So before that the radius of pinion is to be found out, the given data are the pressure P varies, P that is a pressure varies between 0 to 1 mega pascal that is one of the data.

The beta maximum is equal to 80 degree, that is beta maximum angular rotation is 80 degree and the piston diameter this I will call it capital D piston diameter D is equal to 20 millimeter. So these are the given data and the spring constant C_s is equal to 12.56 newton per millimeter. So that is the given values of the given values of this instrumentation and the error sources are given. Now we are asked to find out what is the total error in terms of input signal and then what should be the least count. Now to obtain that we use the maximum values, P maximum is known one mega pascal, beta maximum is known and area is known since piston diameter is given so area is known. So for a P maximum of one mega pascal, what should be the F maximum? We can find out from this equation. So F maximum if you find out it is around 314 newton you can get it.

Once F maximum is there and d_1 maximum you can obtain because C_s is given so d_1 maximum is equal to F maximum by C_s and that is equal to 25 into 10 to the power of minus 3 meter so it is a 25 millimeter. So d_1 maximum is known, beta maximum already given as 80 degree, we convert in terms of radians. Then R is known so by using this equation d_1 is known and beta maximum is given so R is equal to we have to obtain as 17.9 millimeter that is one of the missing data we can find out by using this signal relation of the individual block. Once you find out this latter on now you can find out the error in the input signal.

(Refer Slide Time: 00:46:19 min)



By using these signal relations see delta F is given that friction force is given, from the friction force we can obtain the delta P. So delta P_1 if you call delta P_1 into A is equal to our delta F or F_f. Now area is found out and delta F is given as 5 newton that is friction force. So delta P_1 if we find out by using the given values, delta P_1 is equal to 1.59 into 10 to power 4 pascal. That is a friction of 5 Newton is equal to a pressure of 1.59 or 0.15 atmospheric pressure being, one atmospheric pressure ten to power of 5 Pascal so the error in the input signal will be 0.159 bar around that; that will be the error due to the friction force.

Now the next error is given is in terms of delta d_1, delta d_1 is given delta C_s is known we find out what is the delta F for this delta d_1. Once the delta F is known, due to this delta d_1 and we can find out what is delta P_2 so because area is given. So that is how we find delta P_2 so delta d_1 if you find out, delta P_2 equivalent is 1.2 into 10 to power of 4 pascal. That is an error of 0.3 millimeter that is when the backlash is 0.3 millimeter that 0.3 millimeter is equal to 0.12 bar approximately in terms of the input pressure. So the total error in the input signal due to both friction as well as the backlash is equal to addition of these two things. So you find 2.79 into 10 to the power 4 pascal. We know when we draw the four quadrant diagram we have to add this effect because you have to overcome this first and further this has to move to overcome the backlash so it is additional, all the error is additional so 2.79 or 2.8 pascal but this is the error in input signal.

Now how to decide the least count, can you put the same thing as least count? That is not allowed, least count always in terms of units 1, 2, 5 and multiples 10, 20, 50, 100 or thousands or 0.1, 0.01, see these are the number normally used for least count. This you might have noted in usage of instrumentations. So what is the number which is nearer to this number, because least count should be equal to or larger, it can be larger than error. So which number is larger than this? So only you have got 5, so now least count take it as, least count is equal to next larger number is 5 it's because three is not used for least count.

So 5 into 10 to power of 4 pascal that is equal to approximately 0.5 bar because one bar is equal to 10 to power 5 pascal, so 0.5 bar instruments are there. So for this instrument least count should be 0.5 bar that is what you have decided. If you decided the least count and then what should be the graduation length that is another aspect it should be 1.5 mm, if it is 1.5 mm and if L is the length of the pointer then we should know what should be length L for this least count. So for that if you find out, it comes it can calculate it and that R is equal to we know for this error, if you consider this delta P as 0.5 bar, for 0.5 bar what should be the rotation beta you can get it. You can get for the whole instrument the gain, from the gain we know for the 0.5 input pressure what should be beta then L into delta beta is equal to our length. So L its coming about 21.4 millimeter, converting this L_c in terms of beta that is output angle we can calculate this L.