Principles of Mechanical Measurements

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Lecture No. # 03

We have seen earlier about the concept of signal. That is signal is one which carries an information or a message and an example we have seen is the signal in a traffic situations. So there are a few roads which are meeting at a junction, we have got signal. Why we call it signal even though they are only colours green or red or amber. They are only colors since they tell us to go ahead when it is green or they tell us that we have to stop the vehicle when it is red or we have to start when it is amber. That is this color tells us some information or certain message. Hence we call that as green signal. Why we added signal to the color green? Since green tells us a massage or information so we called it as a signal.

Similarly we have seen another example as volt meter where the current is going through the coil when we supply a voltage to the voltmeter. Since the message of voltage is carried by the current flowing through the coil, the current is called current signal. Again why we add signal there? Because the magnitude of the voltage is carried by the magnitude of the current, so we say current signal then the current signal when it is flowing through the coil which is positioned between North Pole and South Pole, a torque is produced. Now the torque we add again signal because the torque carries information of voltage because current is proportional to voltage and torque is proportional to current.

So each one is carrying the first information of voltage so we added the word torque signal and later on when the torque is taken up by the spring which is connected to the coil mounting, the torque is transduced again into a rotatory angle theta, so theta carries the again information of the torque, torque again carries from voltage so theta carries information of voltage so call these as rotatory angular signal, theta is an angular signal. Then the theta is given to the pointer, pointer moves over the scale through a distance. This distance again tells something about the voltage hence we call that displacement signal. So from voltage signal, the voltmeter has processed the signal for a displacement signal. Signals are processed within the voltmeter there by the voltage signal is changed into a displacement signal.

So what we write on the scale of the voltmeter, even though pointer moves over the scale in terms of distance but we write there as volt. This is the point I want to stress now, while drawing the signal flow diagram that the output signal should be written in terms of the physical parameter. This is one point while we draw the signal flow diagram; this is to be noted down. That means if you draw the signal flow diagram for the voltmeter, see voltage then current i, current signal which gives rise to torque signal, torque signal from there you got theta, from theta we have got d say, d is the displacement.

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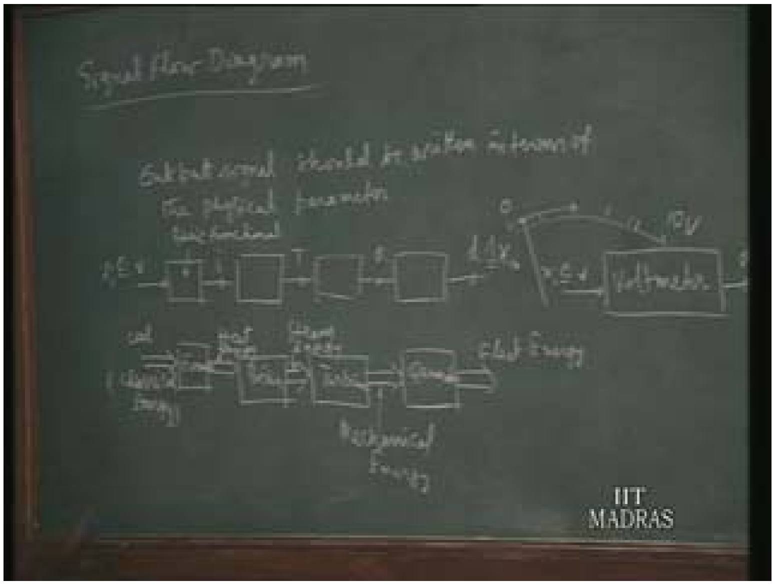

This is the scale so we have written here zero voltage and 10 volts but actually the pointer is traversing a distance so we don’t write voltage here. Voltage is only in the input side but the output we should see the physical parameter, physical parameter in only displacement. So we write here as distance d and again we designate it as output signal v as the input signal. So this is one point you have to note, even though the scale is written in terms of voltage but actual parameter is displacement. So we have to write the output signal as displacement. This is very important for designing an instrument or in understanding the functioning of instrument; this is to be noted down. The signal flow diagram also it is analogous to power flow diagram in a power plant.

In a big power plant what we do say if we are using a coal for power we are using two lines for arrow so this is the coal from there we have got the chemical energy, coal is converted into chemical energy they process in the furnace. So coal is in the form of chemical energy, chemical energy in coal is converted into heat energy in the furnace, this is the energy processing. So from heat energy we get say steam energy then by using steam energy, this is the steam energy what we have got. We have got the mechanical energy, this is mechanical energy, by using turbine here we are converting the steam energy into mechanical energy and by using alternator we have got electrical energy, this is electrical energy. That is how the energy is processed within a power plant.

This is alternator or generator, this is your turbine, heat energy steam energy is boiler (Refer Slide Time: 07:42) so here we have got furnace. So at different places the energy is processed. Similarly in an instrument signal is processed at different places. So if voltage is converted into current by the coil and the current is converted into torque by the coil and magnet and a torque is converted into angular rotation by the spring and the theta is converted into displacement by the pointer mechanism. So this is how the signal is flowing within the instrument.

So what we have drawn for the voltmeter, that is the detailed signal flow diagram. That is what we have drawn is in terms of basic functional element. We learnt earlier what is basic functional element; this is a basic functional element. This is the most detailed signal flow diagram for the voltmeter; there are different ways of drawing signal flow diagram. The roughest way of drawing signal flow diagram is for voltmeter you simply write designate or indicate the voltmeter by one block itself, you give voltage and get output. So this is our output signal, this is your input signal this also we call it a signal flow diagram or block diagram but this is the roughest. The whole instrument is represented by one block whereas when we see the detail how the signal is processed I mean in the most detailed form, so 4 blocks are there.

One more point what we have to notice, see for achieving each function, signal is from voltage to current we use coil one physical element achieves one function, transducing function or one basic function but there are in senses we have an example in terms of the electronic pressure gauge where one physical element can process more than one basic functions. For example consider the diaphragm in that electronic pressure gauge, this is a diaphragm and the pressure is acting here. So I will again draw the signal flow diagram. So for this is the pressure and here what you got is force that is the area of the diaphragm converts the pressure into the force. So the physical element here it's diaphragm.

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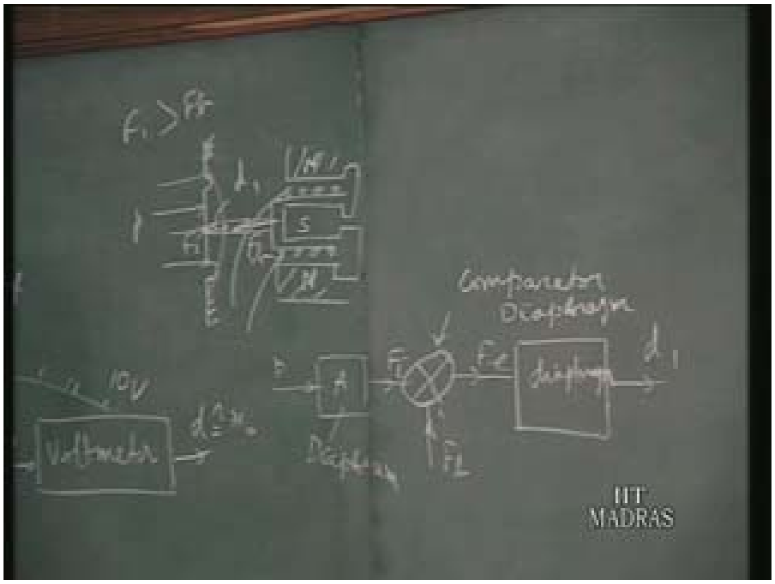

So diaphragm area achieves the function of transducing pressure to force. Now as I told it also functions as a comparator and another force comes here F_b I call it as F_i and F_e the difference between the two forces. Now this force F_b comes from the extension of the coil mounting so we have got coil here and which is positioned between the force of a magnet, this what we have seen earlier. This North Pole, this may be South Pole here also we have the North Pole.

Now whenever a current flows in a coil a force is developed, this force acts in this oppose direction, the coil winding is in such a direction. When current flows in the coil, the force acts here this is our F_b and these forces due to pressure it is moving in this direction. So this is our F_i, F_i is equal to P into A. So to compare these two forces the comparator happens to be here, diaphragm itself. This is comparator; this is again diaphragm which already achieved one function of transducing the pressure to force. When second function it does is, the two forces are compared with diaphragm and suppose F_i is larger then F_i minus F_b will be in the same direction of F_i. So it deforms that is again it does another function that F_e is there in the diaphragm and that itself converts into displacement d_1 this is again diaphragm.

To convert that F_e resultant force say when F_i is larger than F_b so then F_e is acting in this direction and it deforms to the distance of, this is our d_1. So this function converting or transducing the force into displacement is again achieved by diaphragm. So we find here it does three functions, one physical element achieving 3 basic functions. This is the way we have to draw the signal flow diagram. In many instances it happens. There are many places where you will find one physical element does three different basic functions in an instrument, this is typical example. So this is the way what we are supposed to draw this signal flow diagram and because of the importance of the signal flow diagram I will give one or two examples where you will learn how to draw the signal flow diagram for an instrument. First we will take a pneumatic type pressure transducer, examples for drawing signal flow diagram.

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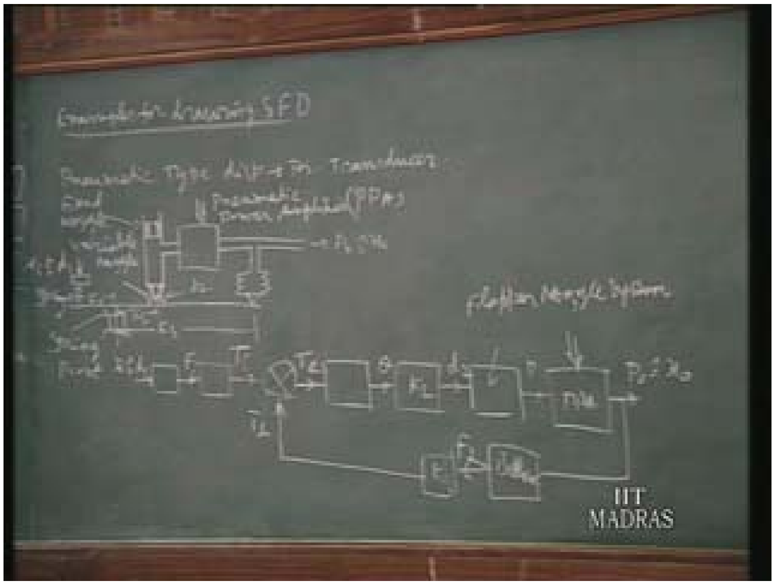

So first is pneumatic type displacement to pressure transducer. So pneumatic type unit looks like this, a typical unit, spring displacement d_1 is given, x_i is in terms of displacement d_1 at the end of a spring. Spring is mounted over a lever and you have got the spring pivot, this is the spring pivot and so to say we have got a flapper nozzle system to transducer. This is the fixed nozzle and this is called a variable nozzle.

Then pneumatic power amplifier, signal goes and from this a bellow is connected for the feedback, this is the output signal x_0. So this is a pneumatic displacement to pressure transducer suppose we are asked to draw the signal flow diagram for this, how to go about drawing signal flow diagram. We have to draw a signal flow diagram in terms of basic function element so we start with input signal always so input signal is our displacement, x_i is displacement d_1. This is spring, when you give a displacement to a spring what happens, it is transduce into a force F. So by using a spring displacement transduce into a force, when there is a force at this pivot lever this is straight lever of course then it is converted into a torque. This is leverage, with leverage say let us call the leverage as k_1 here K_1 up to this point so F into K_1 will give you a torque T_i, I will call T_i.

Now actually the lever forms as a comparator here and there will be T_b also coming, the backward torque that we will see little later how it comes. The difference between two torques in these levers will be T_e so T_e is the resultant torque which is taken up by the spring pivot. So again the lever converts the T_e into theta, net torque deflects the lever somewhat like this. So this theta times this distance say K_2 you will call K_2, theta times K_2 will be the displacement d_2. Here this is our d_2, say K_2 we have got d_2. Now these displacement by the flapper nozzle system transduced into a pressure, this is actually our flapper nozzle system is converted into P pressure and this pressure is multiplied in the, this is pneumatic power amplifier PPA let us write (Refer Slide Time: 18:10). Then we have got P_0 as the output signal, see power amplifier we indicated like this, this is an output signal P_0.

Now from P_0 it's fed back, when P_0 is acting over the bellow this is our bellow. Bellows area is multiplied with P_0 we have got the force $F_,$ I will call this say here we have called F_i, let us call F_i and this I will call F_2 for example or some something like this F_2 different from this F_i and this F available and through a distance of I will call it K_3 parameter, time K_3 leverage K_3 we have got out torque. This force times this distance is equal to torque so that is our T_b. It's a typical close looped type of instruments what you have learnt earlier it's one of the close looped type instruments but how the signal is processed in minutest detail we have seen. The displacement we have given that converted into force here, this force gets converted into torque and another torque they are compared here by the lever.

One simple lever is used in processing signals or difference stages. This is the way we are supposed to draw the signal flow diagram. It gives the leverage for the designer to change the different lens of the lever at different times. That is how the signal flow diagram if you draw in terms of basic machine element it is very useful for the designer as well as for a person who wants to understand how exactly this transducer is functioning. So another typical example is hydraulic type of displacement to pressure transducer.

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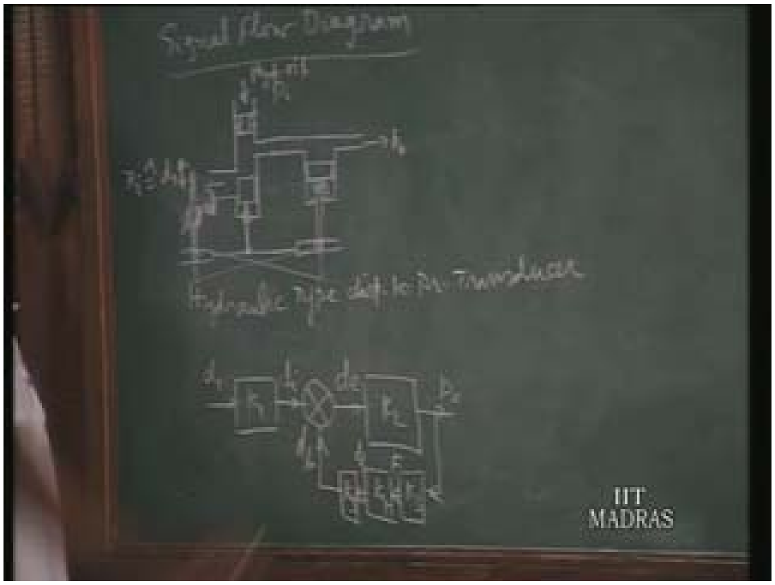

Now for a second example, we see the hydraulic type displacement to transducer because they are very commonly used transducer in pneumatic and hydraulics. Here we find hydraulic oil, this is hydraulic oil is there which is supplied from the compressor. Now this is displacement which has to be transduced into pressure P_o, now we give the displacement here to this pointer, to the lever. So it tilts this linkage and then distance is taken up by this is actually a flapper nozzle corresponding to pneumatic system. The flapper nozzle is realized in terms of piston and cylinder assembly in hydraulics normally. Whatever the displacement is given in terms of leverage that is what is indicated by K_1 in terms of some leverage, so if you give 1 mm, the 1 mm tilts the lever like this. This 1mm if it is a middle point, so 0.5 mm will go here. So 0.5 mm is given to the piston and it moves, correspondingly we will find the hydraulic pressure oil so probably this is P_i at certain pressure, P_i is coming.

So some other pressure is developed at this point, that is our P_o depending upon displacement this goes to atmosphere. This is atmospheric condition so the leakage to atmosphere is controlled there by pressure is varying P_o. So that is how the K_2, the flapper nozzle system which is realized in terms of the piston and cylinder assembly. So d_e which comes, the d_b we will see little later. So by the difference between these 2 displacement, one displace coming from here, another displacement from feedback loop which we see later and these two differences are realized at this point and proportional to difference the pressure is developed, this is our straight loop.

So d_e and P_o, when the backward loop what happened is when the pressure is transduced into force by the piston area say we call it K_3 as piston area, we have force and this force when it acts over the spring converted into displacement, some displacement actually it is to be sorry this should be force (Refer Slide Time: 22:32). Pressure is converted into force, this force is again by using this is spring K_4 corresponds to spring constant so the force acting over a spring converted into a displacement d_2 this is our d_2 at this point we have got d_2.

So much distance when lever is here, when it moves down like this and it tilts like this. The difference between these two displacements are available here, that is leverage here from this to this point leverage, for this whatever it is that's our K_5 and these two displacement are compared at this point and resulting displacement d_e is converted again into P_o. So it's again another closed loop instrument or device, converting the displacement into a pressure. So now what you have drawn? We have drawn the signal flow diagram in most detail or in the basic functional element. So these are the two examples which make the drawing of a signal flow diagram very clear.

Then next concept is signal relation, so this is our second concept first one signal then signal flow diagram and now signal relation, third one is signal relations. Now signal relation tells about the relation between the input and output signal of a single block. There are two instances, here we have got say 5 blocks are there, each block what is relation between d_1 and d_i? That is given by K_1. That is the input signal multiplied by the output signal gives raise to the output signal, input signal times the gain. Whatever we write here that is inside, it is gain so say typical example we will see another instrument where it measures pressure. Say piston and cylinder type of pressure gauge so the spring is here, spring is there and we have got a pointer mechanism. This pointer comes, this is your scale pressure gauge so P_0 to say 10 bar for example.

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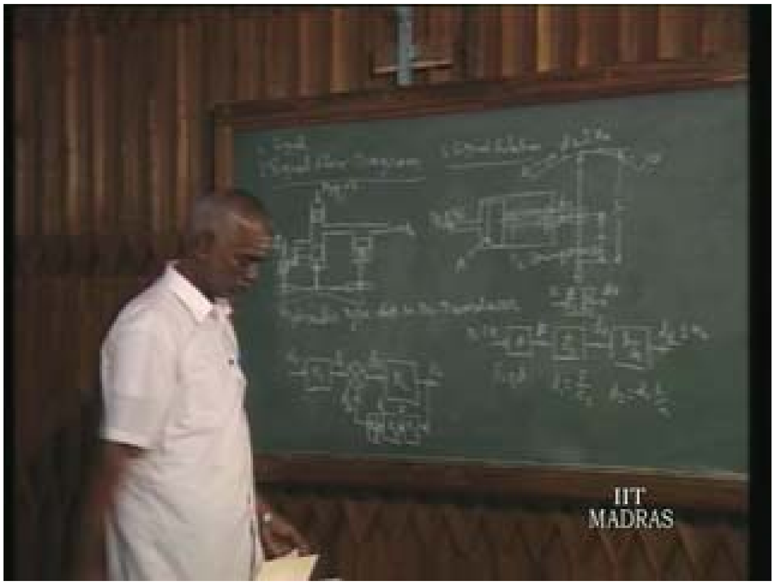

It's a pressure measuring instrument P_i, it's an input signal. So for this whole instrument we can have one signal relation. So this is our d_2 for example, output signal is in terms of displacement. We have seen that output should be given in terms of physical parameter. So this is our x_i to x_o that is this is the instrument processing the pressure signal into the displacement signal. So signal relation for the whole instrument as pressure gauge also we can write. So p_i to d_o that is signal relation, whatever you are going to write inside or when we draw the signal flow diagram for this instrument is, it comes like this P_i is our input signal and we have got the force is the output signal of the first block.

First block this is our piston area so A is the area, this is the area of the piston A, P_i into A is the F so that is signal relation of the first block is F is equal to P into A. That is A is called the gain of the block, the gain is one which when multiplied with the input signal gives raise to output signal. So that is what you have done P_i into A is equal to F that is how the signal relation is written for individual block. Similarly we will write for all the blocks. Now F by C_s, C_s is the spring constant this is our C_s spring constant of the spring. So 1 by F into spring constant is in terms of Newton's per millimeter say F into 1 by C_s Newton's per millimeter will gives raise to millimeter that is our d_1 ,d_1 is there as the displacement in the piston. So this is our d_1, the force acting over the spring gives raise deformation that is a distance moved by piston as it is that is d_1.

Now this d_1 is available in this whole piston and piston rod because one solid piece, at this d_1 at this point is multiplied by this leverage. We call leverage of the point as a and b, so b by a is the leverage. Now we find b by a is the leverage, so it is multiplied to get the output signal d_2, this is our output signal. So b is twice as a then we find d_1 is multiplied by two, twice the distance we have got for any small motion 1 mm for example we get 2 mm here because of the leverage. Now this A and 1 by C_s b by a are the gain of the individual elements in signal flow diagram. So to say the signal relation of the second block is d_1 is equal to F by C_s and signal relation for the third block d_2 is equal to d_1 times b by a.

That is the signal relation of each block specifies the relation between the output of that block to the input of that block and when we want to write for the whole instrument since it's a linear, most of the instruments is linear in character. So we can multiply all the gains of the blocks that is A by C_s into b by a, this is for the whole instrument, gain of the whole instrument is that is d_o is equal to P_i times A by C_s and b by a that is for the whole instrument. So signal relation is written for individual block as well as for the whole instrument. This is an instrument typical instrument in open loop condition that is instrument function in open loop condition. Suppose we have an instrument working in close loop condition, how to draw the signal relation for the whole instrument?

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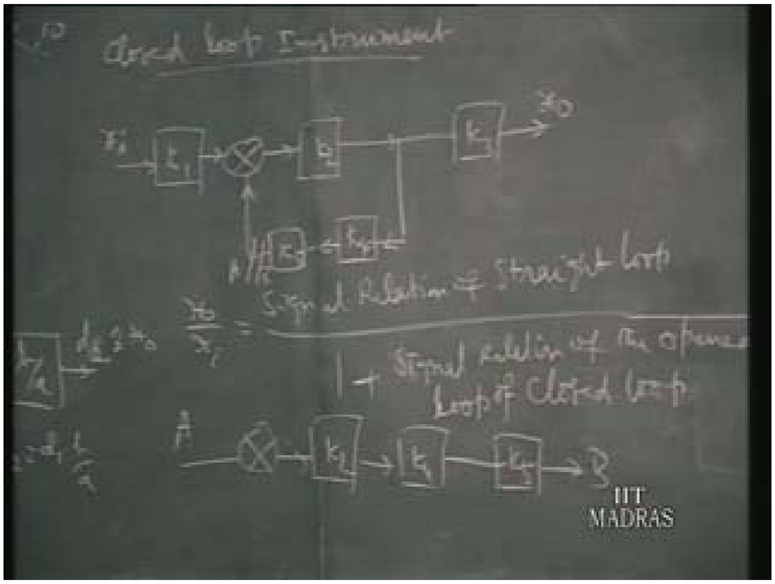

So we will consider a typical example say it's a closed loop instrument. As a general instrument say we will call this parameter as gain as K_1 so this our input signal and it goes to the comparator. So we have got another block say K_2 and say K_3 it goes, this may be the output signal. From here we take the feedback loop so we have got again 2, 3 blocks K_4 K_5 (Refer Slide Time: 29:30). So suppose this is an instrument, how to find out the signal relation of this instrument? We have got simple thumb roll that is x_o by x_i, signal relation it is also expressed in terms of ratio of x_o by x_i is equal to signal relation of the straight loop. So we call signal relation of straight loop, we call it straight loop. That is x_i to x_o straight line that is the straight loop divided by 1+ signal relation of the opened loop of the closed loop.

That is you have to open this close loop somewhere. Say I open it here say A and B, I cut it here then draw the opened loop of the close loop from A to B. So somewhat like this A, from A I am going through the close loop only then I come to K_2 then it comes to K_4 and then K_5 and then we have got point b. So A to B is the opened loop of the close loop. So that is now as for this equation what we have got now the signal relation is somewhat like this.

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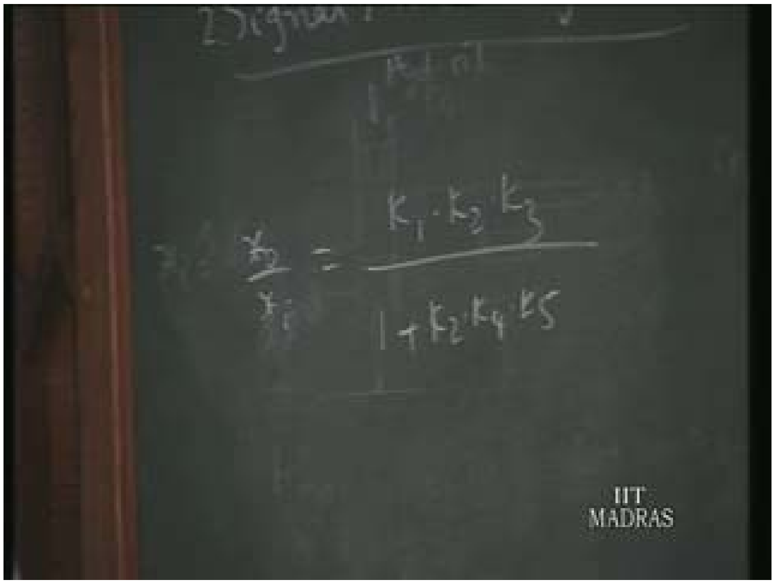

That is x_o by x_i as per this equation, signal relation of the straight loop. Straight loop is K_1 into K_2 into K_3 divided by 1+ signal relation of the opened close loop. That is now we have got K_2 into K_4 into K_5 so that is how we write the signal relation for the close loop. So that is regarding the signal relation, writing the signal relation of the instrument whether it is in open loop or close loop but always we assume that all these elements are linear elements. They hold good only for linear elements. Next concept is sensitivity. Sensitivity is one of the important properties of the instruments. It is analogous for a person also; we say person is very sensitive. When we when we say like that? When he reacts violently or he reacts more than a normal man then we say a person is more sensitive for certain situations.

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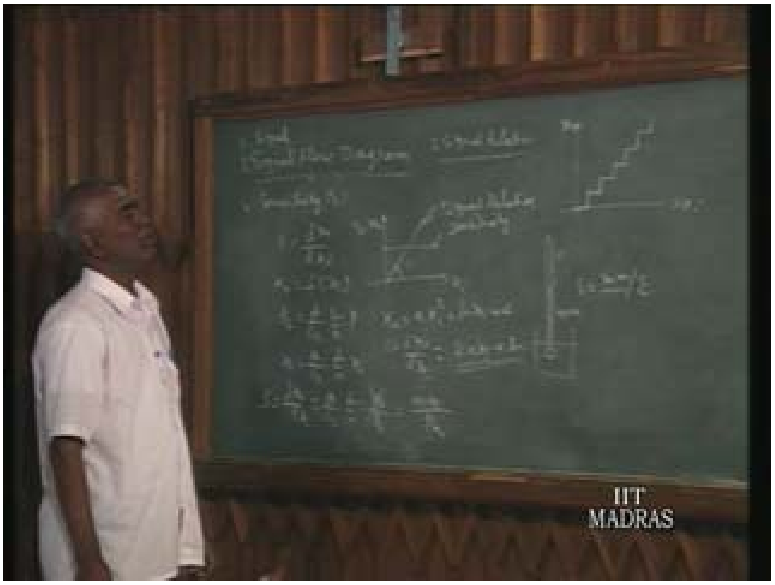

Similarly we say an instrument is more sensitive when that instrument reacts more or for a given inputs signal it gives more output or more deformations then we say that instrument is more sensitive. So the mathematic definition of sensitivities, if you call S as sensitivity, S equal to dx_o by dx_i where x_i and x_o are input and output signal respectively and dx_o is the differential output signal and dx_i is the differential input signal. That is for a differential input signal of dx_i it gives a differential output of dx_o. Suppose there is a relation that is x_o is equal to function of x_i this is our signal relation, this signal relation x_o is a function of x_i signal relation. In this situation sensitivity is equal to S equal to dx_o by dx_i and this happens to be an equation what we have seen earlier, for each block or for whole instrument we can write x_o is a function of or some constant times x_i we can write.

So once we write like that for example in the piston type pressure gauge where piston cylinder and all are there, we know the displacement d_2 is equal to A by C_s into b by a into pressure. Now what is d_2? This is our output signal dx_o is equal to A by C_s into b by a, P is our input signal x_i. So now we will find x_o is a function of x_i, a constant time x_i that is what is meant by signal relation. Once you have got such a signal relation then sensitivity is equal to dx_o by dx_i then for this signal relation dx_o by dx_i is equal to A by C_s into b by a, this is our signal relation. Sensitivity for the signal relation, this is our sensitivity S that is sensitivity depends upon the parameter of the instrument, parameters are the area spring constant b by a, the leverage of the pointer this decides the sensitivity of the instrument.

Here it's a linear instrument where the characteristic goes like this say x_i to x_o if you plot, so it's goes through the origin. So to say dx_o by dx_i this is the slope of the signal relation. This curve is signal relation, in the slope of this is equal to dx_o that is our sensitivity that is equal to A by C_s into b by a and this particular example S equal to dx_o by dx_i also is equal to x_o by x_i. When the characteristic curve is through the origin that happens to be x_o by x_i sensitivity.

Definition of S is never x_o by x_i, this is way it should not be defined. This to be defined always dx_o by dx_i because this will be made clear if you consider a nonlinear signal relation. For example suppose x_0 is equal to a x_i squared plus bx_i plus c, suppose this is signal relation for an instrument we find s equal to dx_o by dx_i is equal to for this signal relation 2 ax_i plus b. This is the signal relation or this is sensitivity for this type of instrument. Earlier S is a constant A by C_s there are parameter it's constant, it remains constant throughout the range or slope is constant. This straight line slope is constant, I can also plot this S also as another y axis, another scale I can have and write this is signal relation, write it as signal relation and this is the sensitivity which is constant (Refer Slide Time: 36:27).

When the instrument is linear, sensitivity is constant but when the instrument is nonlinear then it is no more constant it is again the y is equal to mx plus c formula, so it is a straight line varies with x_i (Refer Slide Time: 36:43). In nonlinear instrument sensitivity is no more constant it varies with x_i and one more thing what we have to point out is sensitivity has a dimension, the x_o by x_i. Suppose for this pressure gauge same instrument pressure gauge what is the output signal? Output signal is in terms of millimeter though it is written in terms of pressure, for signal flow diagram it is a displacement is the output signal. That is in terms of millimeter which is divided by dx_i that is our Pascal. Sensitivity has got a dimension, millimeter per or the unit of the output signal divided by the unit of the input signal, millimeter per Pascal.

Similarly mercury in glass, the thermometer. This is the thermometer, a bulb and when we immerse in a bath this raises so the output signal here see even though it is written in terms of degree centigrade, output signal is terms of millimeter motion it's only motion. So millimeter so there sensitivity is equal to millimeter per degree centigrade or per degree centigrade. Sensitivity has got dimension and what we have seen is for the analog instruments. For analog instrument signal relation is like this, suppose we have got digital instruments. What is sensitivity of a digital instrument? For this we just see how the instrument functioning, this is our x_i, this is x_o and for digital instruments as we have seen earlier digital and analog instruments, the change in output signal is in steps not smooth variations, it is in steps.

So if we find steps, we find the slope is either 0 or 90 degrees, zero or one. So naturally there is no sensitivity for digital instrument hence we will find no digital instrument is given the specification of sensitivity. Sensitivity is applicable only for analog instruments. So that is regarding the sensitivity, another good example is suppose we have got 2 instruments, instrument 1, instrument 2 and this is signal relation of the two instruments. Naturally we find instrument 1 is more sensitive for instrument 2, it is because for a given differential change this is our dx_i that represent dx_i, for a given input change the output signal varies for first instrument only through say delta x_o or delta x_oII for second instrument, this is the output motion for the second instrument. For the first instrument we find so much output motions, this is delta x_0I. So if it happens to be 1 mm and the first instruments is going to give say 2-3 mm and suppose difference change is 1 bar. From 2 bar to 3 bar when we change the input signal, what happens? The output motion for that instrument two is only 1 mm, for the first instrument is 3 mm.

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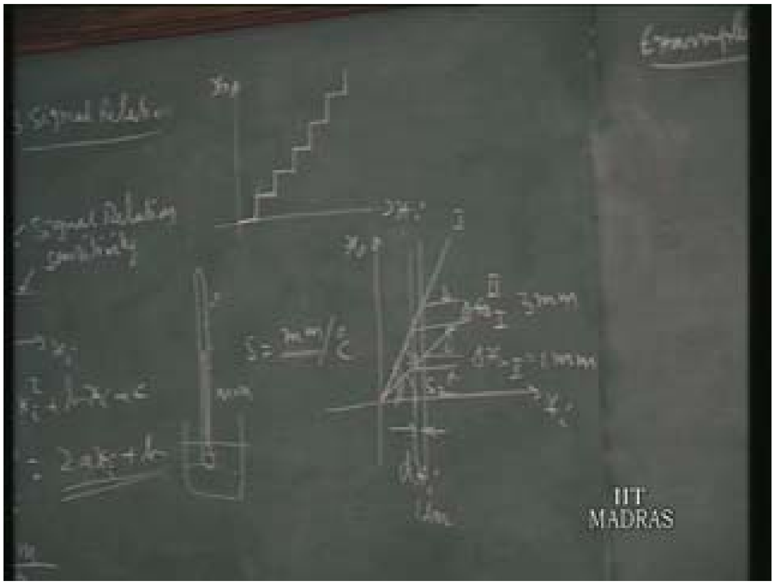

So for the same input of one bar, first instrument gives 3 mm reaction or output signal where as second instruments give 1 mm. So we say the reaction is more in first instruments so it is more sensitive and also we can see slope of this s_2, slope of instrument one is s_1 so slope is more. That is how we say slope of the instrument represents sensitivity and higher sensitivity instruments gives rise to more output signal. And a next concept is our least count. Even though least count is understood but it is to be defined once again.

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What is meant by least count of an instrument? That is say fifth concept is least count. The definition of least count is the least count is the minimum input signal which can be read in the given scale. Now certain instrument have got one main scale and vernier scale and here least count refers to whatever the minimum input signal which we can read with the help of the vernier scale also. So for example we have got this say the length measuring instrument and main scale may be in terms of 1 mm and with vernier we can read up to 0.1 mm. So the least count of that instrument with vernier scale is 0.1 mm that is minimum input signal which can be read in the instrument in terms of the two subsequent graduations or if there is only one scale suppose I have got so many graduation in vernier scale so zero to say it may be 20.

The distance between two graduations, so this may be one. The two graduations, subsequent graduations what it represent in terms of input signal. See now we should not see in terms of millimeter so this represents one bar and this is two bar that is two subsequent graduations represent one bar input. So that is the least count least count is in terms of input signal minimum input signal which is represented by two consecutive graduations in this scale that is our least count.

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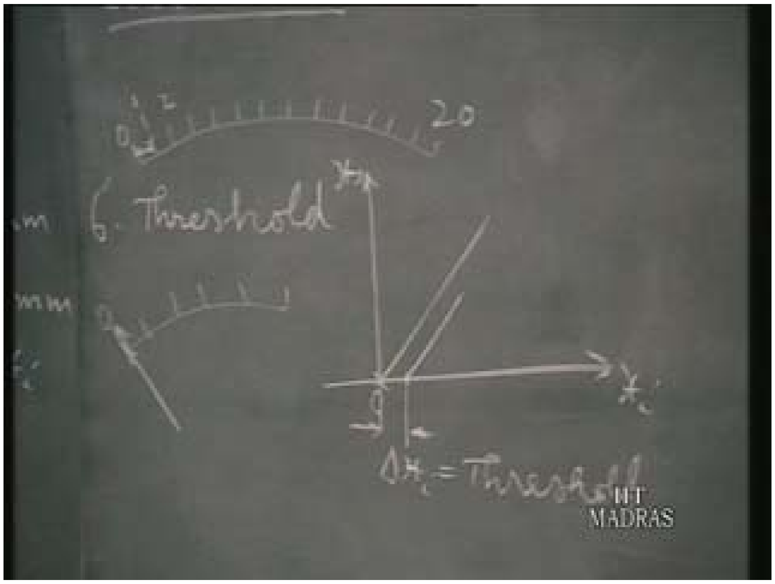

Now next concept is threshold, threshold of an instrument. Now to explain this, let us consider an instrument say x_i and x_o and that signal relation is like this. When we start this input signal from zero onwards, this is zero reading. Suppose we give the input signal, in case it represents a pressure gauge we give the pressure to the instrument and from 0, 0.1, 0.2, 0.3 bar Pascal like that we increase and until pressure increased to a certain point, we will say delta x_i, the pointer has not moved and then for the further increase only the pointer moves that is starts moving. The pointer moves x_0, x_o is not there until the pressure is increased or x_i is increased from zero to delta x_i and this is our threshold.

So threshold represent the minimum increment in input signal from zero value of the instrument make the pointer move. Threshold is nothing to do with the least count, least count represents the input signal between two graduations but previously suppose, this is the scale zero. The pointer is standing against zero, when the delta x_i is obtained then this pointer starts moving, we can see the motion. The pointer has moved from zero whatever that is minimum requirement in input signal to make that pointer move out of zero that is called threshold value. So threshold value is the minimum increment in input signal makes the pointer move, visible movement in pointer if it is there then that is the threshold. It need not move up to one graduation that is always misunderstood, to move the pointer one, then it became least count. Here it is the increment required to make the pointer move from zero, visible motion that is our threshold value. I think we will stop here.