Principles of Mechanical Measurements
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We have seen earlier the finest division of instruments in terms of transducers, transformer, power amplifier, modulator, demodulators, differentiator, integrators and so on. That is the finest division of any instrument with which the whole instrument is built up. So to say we have seen as a building block for a big building raised by stacking bricks, in terms of bricks the building is realized. Similarly an instrument here is realized by arranging different such basic function elements like transducers, transformer and so on, a whole instrumentation is obtained. Now we are going to see how an instrument is roughly divided into 3 groups that is the whole instrument is divided into 3 rough groups. What you have seen earlier is very fine division but this is a rough division.

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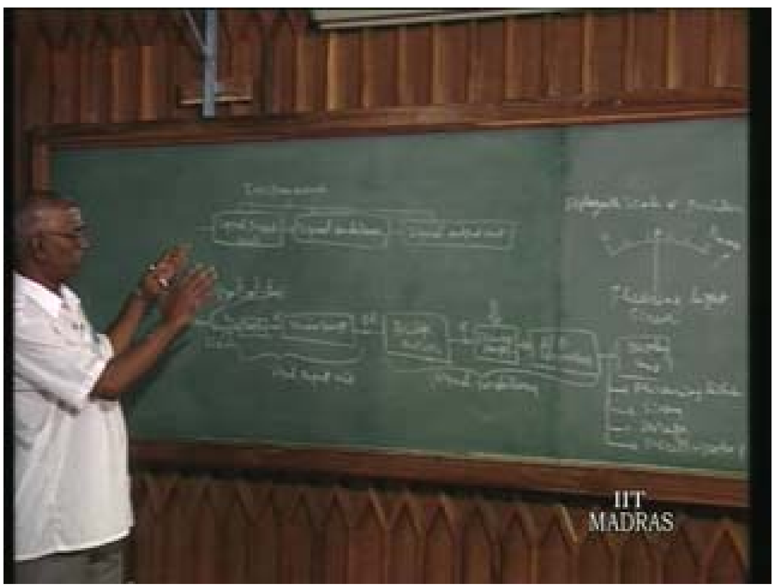

The signal input unit, signal conditioners and signal output unit that is the whole elements within the instrument is divided into these 3 groups. Now what are they? First the signal input unit comes into contact with the measured parameter for example a thermocouple. What we are measuring is temperature and thermocouple junction is dipped into the bath whose temperature we are interested. So the signal input unit comes into contact with the measured parameter. Mostly you will find the signal input unit uses whatever you have learnt under physics or chemistry, a physical happening or chemical reaction. These are the basis for tapping of signals. One good example is the humidity of air makes our hair longer. So that is physical effect, the humidity affects the hair to become longer. Such a physical effect or chemical effect and these are what is made use of in signal input unit. So mostly you will find signal input unit is mostly a transducer.

It may be one transducers; some times there are two transducers in a signal input unit. For example in pressure measurement we have a diaphragm, the pressure acts over the diaphragm. That is our first transducers in pressure instruments. So what it does? The diaphragm on receiving a pressure on one side it deforms because of deformation the diaphragm is subjected to strain at different locations strains. So what do you achieved by this diaphragm is signal pressure is transduced into a strain epsilon. This is a diaphragm and by using diaphragm we have transduced the pressure into a strain signal say transudation because one physical parameter into another physical parameter. Now this epsilon the strain is made use of by using a strain gauge. Normally it is pasted near the end of the diaphragm circumference and also at the middle strain gauges, these are the strains gauges.

So by using this strain gauges the epsilon, the strain available at the diaphragm is converted in to a resistance change say delta R. The strain gauge is made up of resistances of say 120 ohm, strain gauge of 10 ohm. So the 120 ohm will become 120.1 or 120.2 ohm. That is epsilon is converted into a resistance change that means in signal input unit for a pressure gauge consists of 2 transducers diaphragm plus strain gauge. So this is our signal input unit. Now what we are doing is we are dividing the whole instrument in 3 rough groups, first is signal input unit comes into contact with the measured parameter. Now the signal conditioner takes up the output signal of the signal input unit, so I can also draw the signal flow diagram by using this.

So here it is one input signal and then it goes to the signal condition, signal input unit gives the output signal and that will be input signal for the signal conditioner. What does signal conditioner achieves? It conditions the signal so that it can be accepted in the signal output unit. Now in signal output unit there are different types which we are going to see, depending upon that type the signal conditioner should condition the signal which is coming out of the signal input unit and prepare it for the signal output unit. A bridge network is a typical example. What it does? It takes the signal in terms of resistance change and converts it into a voltage change e, that is what it does. So signal conditioner also can contain transducers, transformers, power amplifiers and so on.

Now the signal output of the bridge network normally is very small unit. So what is done is power amplifier. A power amplifier is the commonly is the next unit for such instrumentation. This also belongs to civil condition because what it does is it magnifies the output signal of the bridge network, bring it to a level where it can be further processed. Probably if a signal output unit is a digital unit then we have to go for the AD converter. All these things are signal conditioners, now this is your signal input unit and this may be signal conditioners. From this it goes to the signal output unit. How many types are there in signal output unit? Signal output depends on the parameter. Suppose in a chemical industry the measured parameter is a very risky one. For example pressure in a pressure vessel, it is supposed to be maintained at particular level. Suppose it increases beyond certain level, there may be different level of dangers involved. It may explode or it may give rise to leakage of some poisonous gas. So depending upon situations we can design the output unit.

For example if there is no danger at all so what we normally do is display the parameter in a scale, that is our monitoring instrument. So that is our scale, the pointer moves over the scale zero to so P_{max} for example, so it may be 100 bars something like that. In that case there is no danger even if the pressure increases beyond P_{max} there is no danger at all. So it can go here also, no danger. In such cases we say scale and pointer. That is the display unit, display with scale and pointer is sufficient in case the measured parameter is not giving rise to any risk. Suppose that is the output will go to an instrument, converter here its AD converter so it is more or less display unit. It's the same thing, display unit. This is the case when the measured parameter that doesn't give rise to any danger or anything like that, no risk is involved.

Suppose it is going to explode, some local damage may happen. In such cases what we can go for instead display with a scale and pointer; we can have a flickering light. See the display unit normally the operator in the control room will note down the reading in the pressure gauge and he will be satisfied that the pressure is as per the requirement. Suppose the pressure increases and if the operator fails to note it, how to draw its attention? Because if it increases beyond that value it is going to explode. So we have to draw the attention, for that purpose we can give the signal of the signal conditioner to a flickering light, the red lamp. Naturally the attention of the operator will be drawn towards the flickering light and you will immediately know something is going wrong. So the second way of output can be a flickering light.

Suppose it is a poisonous gas, it's going to explode and also poisonous gas is going to spread over the whole vicinity. Now the damage is not only inside the factory but the nearby villages or nearby residence may also be affected. In such cases all people should be warned, in such cases siren. So when the measured parameter increases beyond that level immediately a siren blows out and all people in the vicinity, inside the factory also outside the factory they are all informed something, some catastrophe is going takes place. Be prepared and all. So immediately correction work can be started. We find now there are 3 ways, the output signal can be displayed either display unit as an instrument where a pointer moves over a scale and the operator is supposed to note it or it is in conversion and the measured parameter is risky then a flickering light will come and attract the attention.

So immediately the corrective action is done or in case of very dangerous exploration a siren is blown even when operator sleeps, he will be woken up and the residence also are informed and something is going to happen, to do something. So these are 3 ways apart from these three ways the output signal can also be analyzed in an oscilloscope. So output signal AD converter or from the power amplifier it can be taken to oscillograph or a oscilloscope where the variations can be noted or if it is a dynamic variations probably you may not be able to load, it has to be recorded in an oscillograph where it is recorded, later on it is analyzed. Nowadays we have got floppy it is nothing but magnetic tape where massages are stored or sometimes the message can go to a printer, printer in terms of page printer or in terms of a recorder, strip chart recorder. So these are the various type of signal output unit.

So signal display unit or a siren, it can be given to a flickering light or it can be a siren or it can be storage in a floppy or for analyzing oscilloscope or stroke oscillograph. So these are the signal output unit. So this way the whole instrument can be divided within the instrument into 3 rough groups that means now the signal from signal condition it goes to the signal output unit. This is the rough classification of the instrument. Now having seen the finest division, having seen the rough division within the instrument now we go for whole field of instrument. How the whole field of instrument is divided? Now the whole field of instruments is divided like this, first based on the elements, types of elements within the instrumentation, the whole range of instrument is divided into mechanical instrument, electrical instrument, electronic instrument, optical instrument and hydraulic and pneumatic type of instruments as it is shown here mechanical, electrical, electronic, optical, hydraulics.

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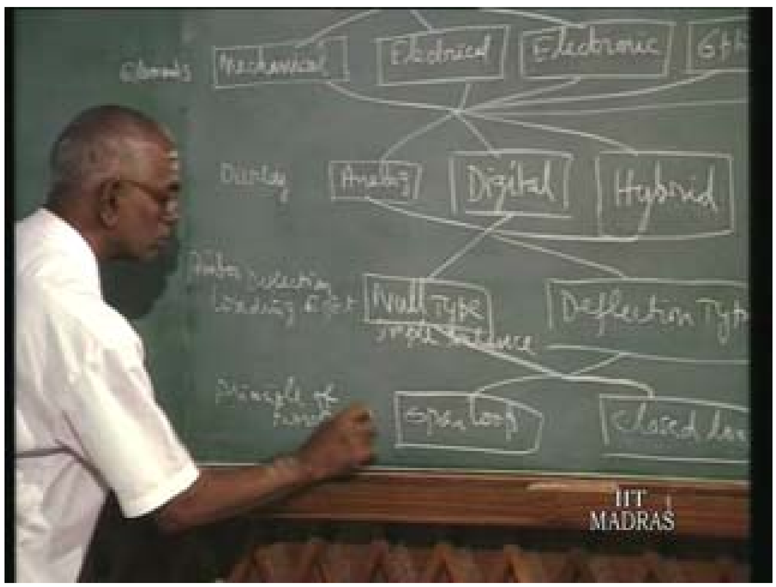

That means the elements in those instruments made of for example mechanical instruments only mechanical elements. Typical examples I have got 3 units, this is a pressure gauge say pressure gauge containing only mechanical elements. So we find bent tube in c form and a linkage and gear segment and the gear. It’s a bigger gear and the smaller pinion is their inside, the pinion axis is connected to the pointer, this is the pointer (Refer Slide Time: 16:28). So we find it’s only purely mechanical elements say pressure gauge made up of mechanical elements and more example is we have got a dial gauge. This is a dial gauge normally students are using in the work shop where any displacement here is shown by the moving pointer so it’s a dial gauge, where you will find the elements are shank or plunger and you find inside this back cover is open and you find inside some axis and gears and leavers say purely mechanical elements.

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Another example is a screw gauge; you find screw gauge is made of bolt and a functional nut here so it's a screw thread principle. So when the screw rotates one full rotation, it forwards or reverses by a distance of one pitch. So screw thread principle so it's a purely mechanical element. So these are some of the examples for the mechanical instruments where the elements are made up of mechanical or linkages gears and so on. In electrical instruments we have got say coil for example voltmeter or a ammeter or a power meter or gauss, I mean mechanical field or some measuring instruments.

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So they are the electrical parameters where voltage current and so on are measured by such instruments and electronic, you have got calculators computing and teleprinters, electronic devices, power amplifiers and many of the power amplifies now its electronic of course we have 1or 2 pneumatic and hydraulic power amplifiers but mainly we have got power amplifiers made of electronic elements and analog digital conversions. All these things are electronic in nature and optical instruments, surveying instruments and coordinating machines I mean diameter measuring universal microscope. So all these things are optical instruments and hydraulic and pneumatic very famous instruments are load cells of high capacity load cells compact and high range can be obtained in hydraulic and pneumatic devices.

So based on the elements, there are hydraulic and pneumatic pressure here. So based upon the elements used in the instruments, the whole field of instruments is classified under these headings mechanical electrical and so on of the hydraulic and pneumatic. Second way of classification is depending upon display. Now this is depending upon display, so here again you insert instrument the second way, a new way of dividing instrument a whole field of instrument is analog instrument. Typical example is a watch we says it's a even though the second hand moves every second but hour and minute hand we don't see the step motion. So the hour and minute hand we say it is moving in an analog fashion.

So that is analog, analog instruments, the pointers moves continuously without any steps that is analog display. Whereas digital display, the pointer moves in steps say the second hand it moves in steps and also display here is numbers. The digital display is in terms of numbers and in analog display we have got only the hour and minute and motion. So what is the advantage or disadvantage of these two types? In analog instruments even though there is a wall clock there, even without reading the numbers I can have a rough idea of the time, time is around 10:30.

So it’s alright if its 29, 31, 32. It does not matter. As far as I see the approximate time, many instruments it is more than sufficient. We did not know the time up to second approximate time. So what is time like? It is around 10:30 that is sufficient; such information can be obtained only in analog type of display where as if you are interested in precisely the time, at that particular instant then its better always we have 10 hours 20 minutes 55 seconds. So that is precise reading can be obtained only in a digital display but what is the drawback of digital display. You have to read all the 6 numbers, so it should be readable distance; it should be enough of any illumination because in some liquid crystal display of some watches if the atmospheric light is not sufficient you cannot read it. Because we don’t have enough light, to read the digital display you require light, certain distance all these are requirement and we have to concentrate more than that. You have to concentrate and take a reading; you cannot get a reading in digital display by just a glance that is possible only in analog display. Digital display requires your full attention and full environmental situation where you have to make reading.

So that is a disadvantage, disadvantages of digital display is you have to read all the numbers whereas in analog you need a just a glance is more than sufficient to tell the time lag. So what is achieved in hybrid is more than advantages, analog as well as digital display both of them are combined together in the hybrid type of displays. So that means the same wall clock you will have somewhere near the middle just below you will have window where you have the readings of the time also 10 hours 20 minutes 55 seconds. It is also there. So if you want to have the time like, just see the hours and on minute hand or if you want to read exactly then read that window, whatever the number is there. So that is both the display are available in the scale or in the display. Both of them are available. Analog display is there and digital they both combine together gives rise to hybrid.

So based on this display, instruments are divided it’s a digital instrument voltmeter. It’s a digital instrument or analog instrument or hybrid instrument that way it is classified. Then another way of classifying whole field of instrument is either it is a null type of instrument or deflection type of instrument which is based upon the deflection whether deflection is there are not that is pointer deflection is there are not. Typical example is in grocery shop whatever we have the weighing machines, not weighing machines we have got simple balance. That means in one of the pan we put our standard right and we put our commodity in the other pan until the pointer comes to zero position. At zero position standard weight and the commodity weight both are equal. That is measurement is made by bringing the pointer to zero that is there should not be any deflection of the pointer. So that is called null type of instruments. Whereas in deflection type that is a simple balance. Here it may be a spring balance whereas in spring balance we have got basically a spring and it will have a hook and in the hook you put your commodity.

So the other end of the spring, the bottom end of the spring is connected to a pointer. The pointer moves over a scale but the thing is we don’t say all these inside, these all are covered that’s all. So when the pointer moves over the scale now how much it has deflected that is seen here in terms of, this is zero kilogram, this may be 20 kilogram force so it may be say about 10 kilogram.

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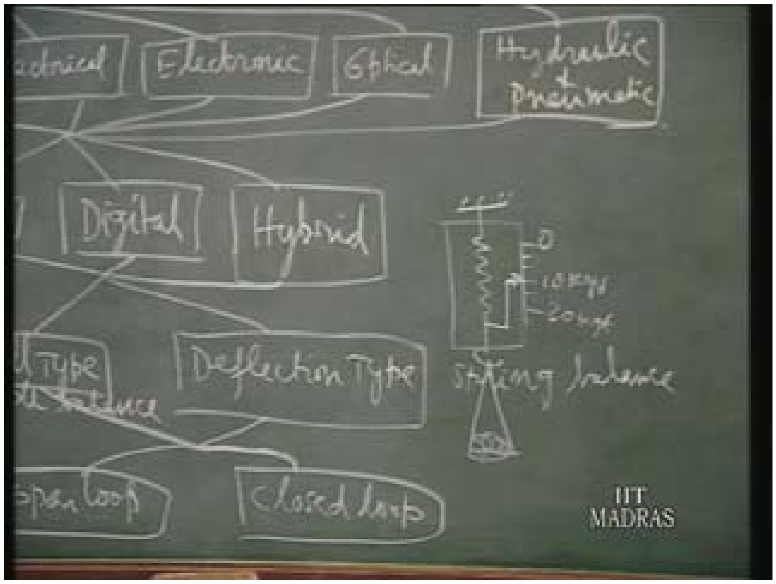

That is where the pointer stops that gives the reading of the instrument, that’s deflection type where the deflection stops that gives the reading whereas here the measurement is made by bringing the pointer to zero. What is the advantage and disadvantage of these things? Say null type we say, we are going to learn later a loading effect. Loading effect is nearly zero in terms of null type of instruments and deflection type we have some loading effect with which we will see later. That is depending upon the pointer deflections, instruments are called null type of instruments and deflection type of instruments and at the last the instruments again can be classified into open loop instruments and closed loop instruments. This is the principle of functioning based upon the principle of functioning open loop instrument and closed loop instrument.

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A typical example is what you have seen earlier a pressure gauge. It's a pressure gauge kilo point; it is kilogram force per centimeters. This is a 1 bar, 2 bar, 3 bar, 4 bar, 5 bar, 6 bar its range is 6 bar. It's an instrument pressure gauge typical instrument and if you open the back side you see all these elements.

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Now this is based on principle of functioning. What is principle of functioning? When you give the pressure here it is connected to this hollow tube, this is made up of spring material, spring steel or a phosphor bronze material and this is the closed end shield here. So it is something like a tube, a cycle tube if it is zigzag without any air now when you put air it assumes a perfect round. Similarly when pressure air comes here, this end you know it tries to move. If it is closed one it will assume perfect round and if it is a free end, this free end will be trying to extend. So when pressure is their it is trying to extend. So this motion is picked up by the linkage and then it is given to again pivot mechanism and this pivot, at the end of the pivot we have got the gear. So I will draw it on the board, it is simple this is an open loop for instrument.

So what we have got is c type tube, here we connect your pressure here and pressure is acting over the hollow tube so this try to move this direction and it is taken by a linkage and here we have got gear and with this gear a pinion is made to engage and pointer is attached to the pinion. So this is our scale. So to say it's a signal flow diagram. A signal flow diagram helps us to understand how the instrument is functioning. For example now the tube transduces the pressure into tube, transduces the pressure into a deflection d, deformation or deflection d.

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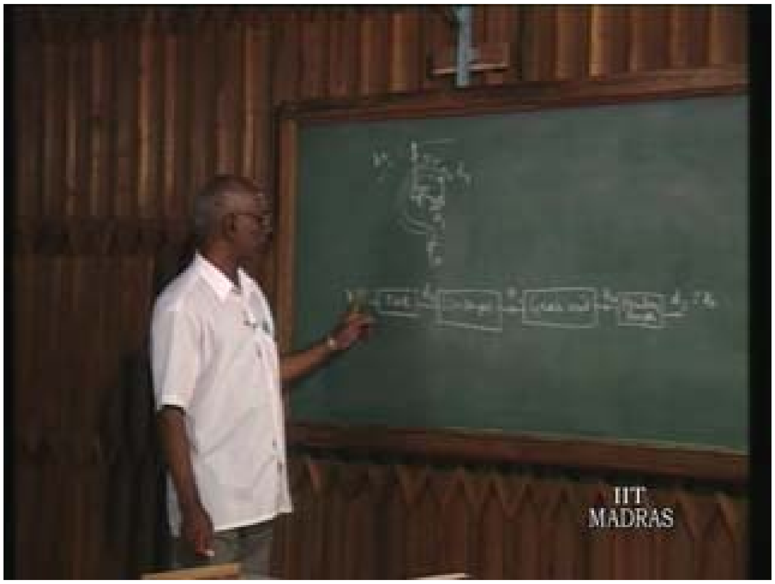

At this d, a displacement is taken up by the linkages so linkages converted into an angular rotation theta. So here you have got theta, d is converted into angular rotation theta. This theta is magnified by the gear and pinion mechanism and a rotation theta say $theta_1$ and this is $theta_2$ and this is gear unit which converts $theta_1$ into $theta_2$ and this $theta_2$ is converted into displacement d_2. You call this d_1 and this is d_2 that is the motion of the pointer over the scale distance. Even the distance is distributed over circular scale, the actual length, linear distance we call it d_2 that is by using the pointer length, this is pointer length.

Now using pointer length we get the output signals, so to say the output signal x_o and this is our input signal x_i. So now to understand the instrument how it functions, we draw the so called signal flow diagram and from pressure to displacement, displacement to angular rotation, angular to another angular rotation and then another displacement. So we call it an instrument working in open loop condition because the signal flows from one end to another end, it's the open loop. It just goes straight and it's an open loop. In contrast to that, you have got another instrument also used for pressure measurement but it works in closed loop condition. For example say electronic pressure gauge.

It functions in closed loop condition. The construction is as follows. We have got again a diaphragm and we have got a contact with a coil over it and it is positioned in between poles of a permanent magnet. These are the contact point so this is a diaphragm where the pressure acts. When the pressure acts the diaphragm deforms, this deformation is picked up by the sections and rod which forms part of a coil and this is a north pole and this is South Pole. This is your permanent magnet and this rod extension rod there is one more extension, bell crank lever like that and this motion is picked up by a displacement transducers.

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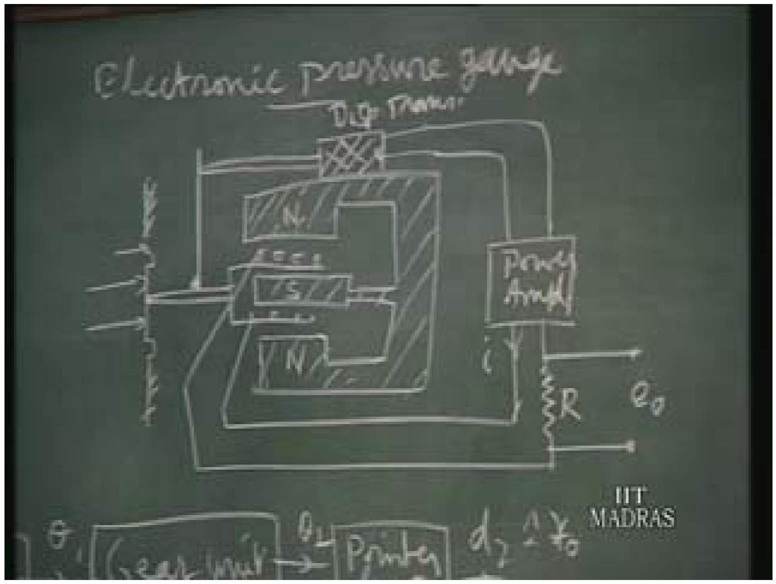

Displacement transducer picks up the motion of this extension rod which follows the deformation of the pressure diaphragm and this gives rise to signal. That is displacement is converted into a voltage and it goes to a power amplifier, this is the power amplifier. So it amplifies the voltage developed by the displacement and this is displacement transducer and the current flow from the power amplifier is given to this coil through a constant resistor. This is a constant resistor R, the current i when it flows through the constant resistor R a voltage output e_o is obtained. So this is the construction of an electronic pressure gauge. How does it function? To understand that you have to draw again signal flow diagram.

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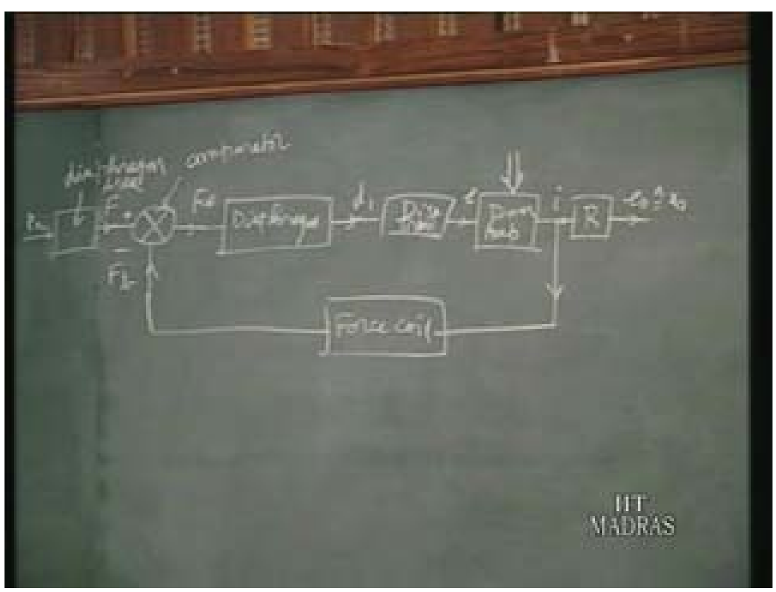

So first one is pressure is transduced into deformation. So pressure is transduced into deformation so that is what it happens here, it deforms like this. So that is a say distance d_1 for example. So diaphragm transduces the pressure into a displacement and this displacement before that before that sorry. The diaphragm transduces first, before a deformation what it does? This diaphragm area by using the area it gets converted into say a force. Pressure into area will give you force. Now you have got another force here but that will come little later. So here say it is plus and minus and another force is coming it's called F_b we come to that little later but because of this force the diaphragm deforms or 2 forces, one force is coming from the pressure another force from the force coil. This is the force coil coming from the current flow through the coil within the magnet. So these 2 forces are compared again by the diaphragm which is functioning as comparator, this is comparator (Refer Slide Time: 34:30).

So it compares the two forces, a force from the force coil and force from the pressure, net force Fe is taken up by the diaphragm again and gives rise to displacement d_1. That's how d_1 comes, d_1 comes not straight from the pressure, pressure gets converted into a force and two forces are compared and then finally the resulting force is causing deformation in the diaphragm and this deformation is picked up by the displacement transducer and converted into a voltage e somewhere here and this when multiplied by R or power amplifier when it goes to the power amplifier, energy input is there and then we have got a current flow i, as the output from the power amplifier and this current flow is taken to the force coil and this force coil gives rise to F_b but when that current flows through a resistor R it gives rise to e_o that is our output signal.

So this is the signal flow diagram for this electronic pressure gauge. Now what is the difference between signal flow diagram of that electronic pressure gauge and bourdon pressure gauge? Now here the signal diagram straight whereas here you find there is a loop in the signal flow diagram. Hence we call it, this is an instrument based upon closed loop condition and bourdon pressure gauge is an instrument based upon open loop instrument. So this way also the whole field of instrument is divided, instruments working in closed loop, instruments working in open loop condition. What is the advantage and disadvantages of this two set up? Now an instrument working in open loop condition normally very cheap but the accuracy is not high whereas in instruments working in closed loop condition we have got very good accuracy of the order of 10.

Say if it is 1% accuracy open loop, corresponding instrument can work in 0.1% accuracy and naturally it contains more elements to an instrument working in closed loop condition so it is costly. So instruments working in closed loop condition are generally costly but of high accuracy and instruments working in open loop condition they are cheap and have less accuracy. So that is how the whole field of instruments is divided. So this comes to an end on the chapter of introduction of measurements. Next chapter is basic concepts. Before I start these basic concepts I would like to give some of the important reference books, some of you interested to see the reference books to enhance their knowledge. So I will just write down the reference books. So now it's better if we see some of the important reference books in this subject so that those who are interested can read further about this topic.

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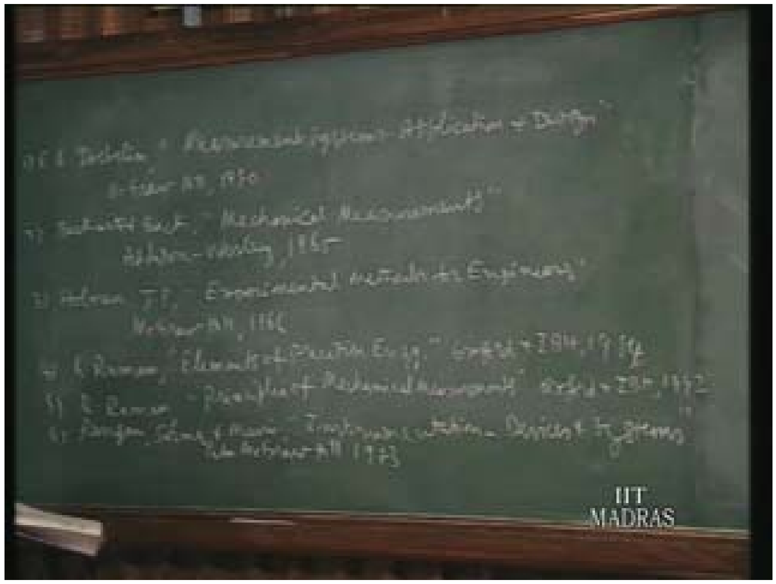

The first and fore most book and we also called in our institute as bible of measurement is by Doebelin. That is E O Doebelin, the topic is measurement systems application and design. There are various editions, our latest that is McGraw Hill 1990. The second important book is Beckwith and Buck, his topic is mechanical measurements and publisher addition- Wesley say 1965 and third is by Holman J P, experimental methods for engineers. It's also a McGraw Hill book, McGraw Hill in 1996 and by Indian authors. First two chapters in my book on precision engineering elements, it will be very useful first two chapter, the elements of precision engineering, Oxford and IBH 1984 and the other book of measurements which I published recently in 1982 that is principles of mechanical measurements, same publisher Oxford and IBH 1992 and other Indian authors. So 6 Rangan, Sharma and Mani, the topic is instrumentation devices and systems Tata McGraw Hill that is in 1983.

So these are the some of the important books and one more book is by A K Sainy that is a course in mechanical measurements and instrumentation. A course in mechanical measurement and instrumentation that is in 1989. These are the important books and Sainy especially has worked out number of problems in each chapters and Holman also works out numerical problems and Doebelin as I told he has dealt the topic in very much in detail and he gives number of problems to be worked out also. Doebelin gives number of problem to be worked out by the students whereas the examples I have worked out already in my book also, in some of the chapters principles of mechanical measurements. Some of the important chapter I have worked out problem and apart from that Rangan and Sainy and Holman, these are the books where we can see the worked out examples. So this is to enable the students who want to read some more material on measurements. Now we go to the basic concepts.

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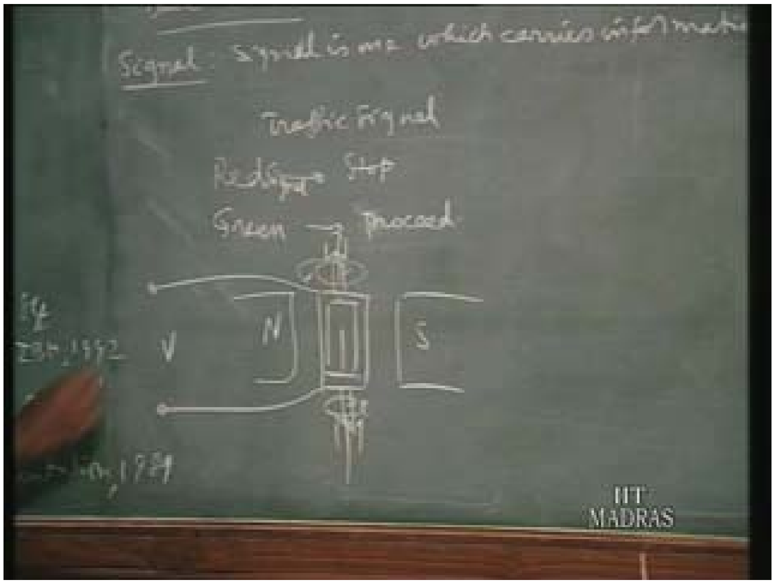

So you have to understand the basic concepts, to understand any subjects then only we can appreciate the contents of subjects. So in measurements there are certain technical terms which are very essential to be appreciated by the students. Understanding of the concept is very important so that the whole field of instrument is properly understood and first and fore most definition or concept is signal. Even though we have used the word signal very often, we will see in detail what the signal term stands for. The definition of the signal is as follows; signal is one which carries information, this is definition. You can call it a signal only when it carries some information and a typical example is the traffic signal. We call it signal there because it tells us some information. So there is red, red means it carries information of stop, stop your vehicle.

What is the parameter there? It’s only color, red is colour it is not a signal, colour but when that color carries the information for the road uses that you are supposed to stop then it become signal, so we call it red signal. Why we call it red signal? Since a red color carries information to stop your vehicle. So here parameter is colour but colour has become signal when it carries the information or tells information for all the road users, stop your signal. Similarly green green is also a colour but it become signal when it conveys the message that start or proceed here it is actually proceed. You can go head or when it is under under yellow or something like that we say start. That is here they are only the color but they carry the information, we call it signal.

So signal is one which carries always information. This is the basic definition and a typical instrument where say voltmeter, so we have got a coil. What is voltmeter? Volt voltmeter made of permanent magnet, North Pole South Pole and we have got this coil assembly pivoted between 2 bearings and we have got a spring attached to the coil. This is your central line and to the coil we supply your voltage to be measured, this is your terminal.

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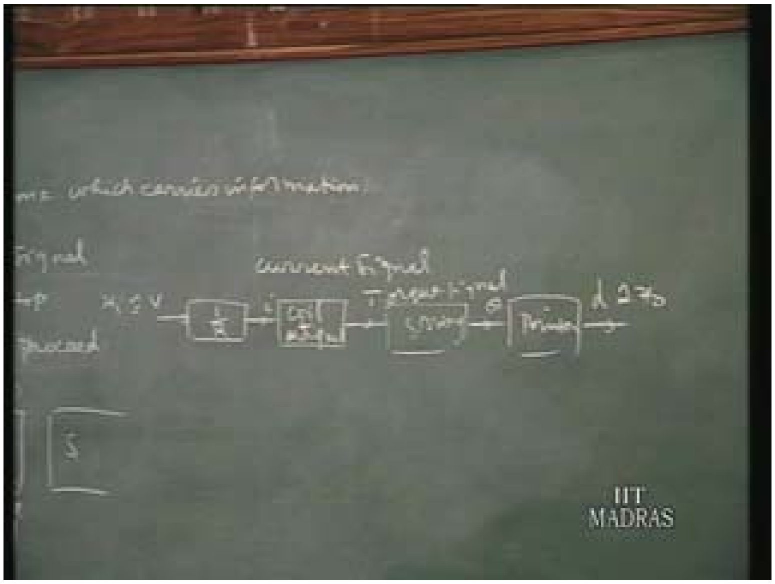

So when you supply voltage what happens that is it is a voltage you supply and we call this as here also, we call it signal because its voltage is given. So since we are going call everything as signal here also it's called input signal. Now the voltage is given the coil resistance R, 1 by R, v by R gives rise to current. Now the current becomes current signal it is because the current carries the information of the voltage. Since it carries the information of voltage, how much voltage? Higher the voltage, higher will be the current so it is proportional quantity. So current carries the information of voltage hence it is called current signal. Since the physical parameter carries the information of voltage regarding magnitude it becomes a signal. So it is the current signal so from voltage signal we have got a current signal and this signal is further converted into a torque by use of the coil plus magnet, coil plus magnet converts that into current, current to torque.

Now torque is proportional to, high torque will be there for higher current, higher current will be there higher voltage. So finally we find torque carries information of voltage so this information of voltage is carried down by this parameter so it becomes your torque signal. So torque signal is there in the assembly and when it is given to this spring then you have got the rotation theta. So theta is the rotatory signal, carrying the information of the proportional torque we have got the voltage. Having the pointer we have got the output voltage d_2 or d this is our output signal. So this displacement carries information of the voltage that is output signal we have connected to a pointer here, the pointer moves over the scale, this is your d. So finally we have got the output so we find this parameters current, torque, theta, d are carrying the information of the voltage. They are all called current signal and so on. So with this we will close today.