Principles of Mechanical Measurement

Dr. Dipankar N. Basu
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Module – 05
Displacement Measurement
Lecture – 03
Piezoelectric & nozzle-flapper transducers

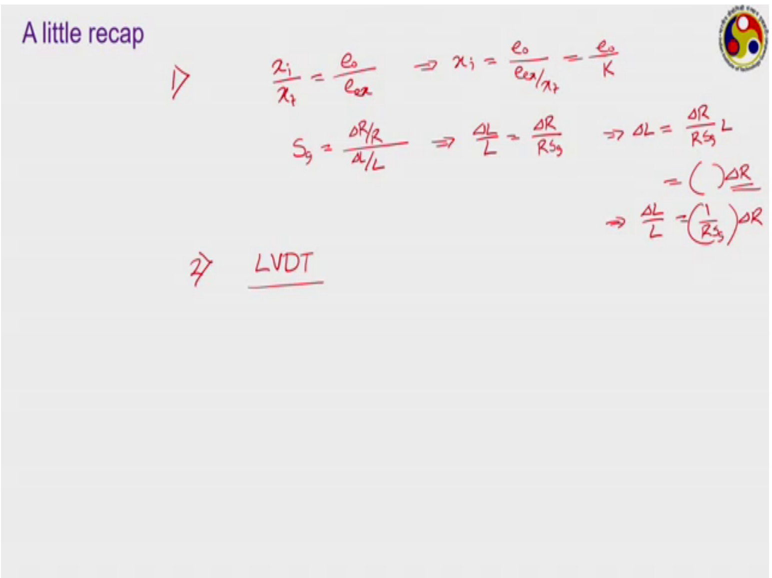
Hello everyone. Welcome back to the third and last lecture of our week number-5, where we are talking about displacement measurement. My initial plan was to take two lectures in this particular week to cover this particular topic, but here as we are talking about several kind of instruments, and more importantly this being the first kind of proper measurement that we are discussing about. So, I thought about taking a bit of time, and to go a bit slowly.

Because several measurement principles that we are discussing in this particular module, they will be employed in the subsequent weeks as well. Like here we have discussed about a few resistives or inductive based instruments or like if you remember that in the previous lecture, we have discussed about the optical method of displacement measurement.

Now, optical method is generally used in several other parameter measurement as well like temperature or pressures etcetera. And the same principle will be applied there as well. We have or I have decided to take a third lecture on this. Here we shall be discussing about two very interesting methods of measurement of displacement or distance, and a very small introduction to metrology, they are very rounding of this particular week.

Now, instead of doing any exercise, I shall be starting with a bit of recap today. There is no point doing any further mathematical calculation, we have already discussed about some small problems and one or two more will be there as a part of the assignments that you will be solving after to this today's lecture. But let us just quickly recap what we have discussed this week.

(Refer Slide Time: 02:13)



Here we have discussed the first group of method we have discussed. They are basically depending on the resistance based measurement that is with the change in the position, the resistance of the conductor changes which gives a proportional output voltage. And accordingly, the output voltage can directly be calibrated in terms of the displacement.

There we have discussed about two different instrument. One is very common, actually both of them very common. One is potentiometer, we generally used for larger displacement measurement whereas, the other is resistive strain gages, where we can measure extremely small displacement as well. Strain gages will be coming back again in the next week, when we shall be talking about stress and strain. Truly speaking strain gage is a more relevant to stress and strain measurement, but as the term displacement, here we are using in one generalized form. To refer to any kind of parameter, which is having a dimension of length, so I thought about discussing strain gage here itself.

So, what we have got in case of potentiometer, we have seen that the displacement x i can be related to the output voltage as something like this, where e e x refers to the excitation voltage, x is the total length of the resistor or we can also write x i upon e naught to be equal to or I better I write this way say x i is equal to e naught divided by e e x upon x t.

Now, what is this e x upon x t excitation voltage divided to the length of the resistor, something you have decided rather we have defined as a potential difference or potential gradient. So, this is e naught upon naught l, generally is the symbol K, and this K comes from the manufacturer. Therefore, just the measurement of this output voltage e naught, gives you an idea about the displacement x i. And it is a perfect example of a 0th-order instrument.

However, we have discussed in detail in the first lecture that the 0th-order behavior appears or is relevant, only when you are talking about an open circuit voltage e naught. However, we always have to measure this voltage by connecting some kind of voltmeter or similar voltage measuring instrument, which itself will be having some kind of resistance, there by inducing the loading effect. And that loading effect can significantly alter the behavior from the 0th-order nature. The other one that we have discussed is the resistive strain gage, where we generally define a gage factor S g, which is defined as delta R upon R divided delta L upon L.

So, the change in length delta L upon L can be related to delta R by R into S g or delta L can be related to delta R by R S g to L. So, S g is something that comes from the manufacturer, R is generally also specified; because that is the nominal resistance of the corresponding register, L is the initial length or unstressed length. So, all these parameters generally come from the register, thereby giving you something into delta R.

So, if we can properly measure this particular delta R quantity, using some Wheatstone bridge kind of arrangement, we can get a direct measurement of the corresponding change in their length or if your objective is to get a measurement of the strain, then we can just stick to this relating 1 by R S g into delta R. So, we shall be talking about this a bit more in the next week, when you talk about the stress and strain measurement as I mentioned. But, I hope you have got the idea, S g is the gage factor which directly comes from the manufacturer. So, this was the first group of instruments, which based upon the change of resistance.

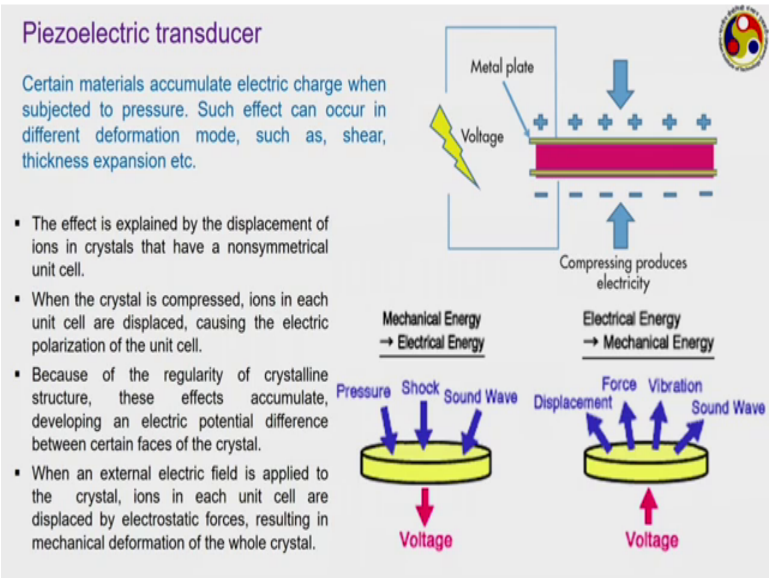
The second group of instrument, where we talked about the LVDT which actually depends on the change of inductance with the change in length, we have discussed in detail about this about, how we can how it gives a linear behavior that is without change in the core position, the voltage induced in the secondary side changes. And with the proper arrangement generally the series opposed of configuration, we can get a perfect linear representation that is output voltage can become a linear function of the displacement.

The other one is the inductosyn, which can also which is also a very popular one, and quite easy to use. Then we have also discussed about the capacitive instrument, we have discussed about the optical group of method, and also the ultrasonic group of method. All are quite common, but still generally the LVDT potentiometer and strain gages are the most common, three instruments which are used for displacement measurement.

Actually, there are probably infinite types of instruments, which you can use to measure displacement. Any parameter which show some kind of response with a change in its position can be used for potential measurement of the displacement or distance. However, there is no point discussing all of them, because here we are not doing any kind of research on displacement measurement, rather we are just trying to get an idea about possible methods to measure displacement.

So, not only this week, in all the subsequent weeks also, we shall mostly be focusing to understand some of the most common methods of measuring the constant the corresponding parameter like displacement in this week. And the three we shall be discussing in detail three or four, which are the most common one. Like here we have discussed about the strain gages LBDT’s and the potentiometer. And a discussion related to the others like the capacitive gage, the optical method etcetera will be just very brief mentioned, unless that is very important in the concern parameter.

(Refer Slide Time: 08:25)



So, with that recap, we can go to the topic of today's discussion. Today, we are going to discuss about two very interesting ways of measuring displacement. The first one is the piezoelectric transducer. Now, the pin the topic of piezoelectricity is something like a hot kick in nowadays, because not only displacement, you can measure several other parameters like pressure, temperature, etcetera using piezoelectric transducers. And so this topic will be coming back again maybe in some of the subsequent weeks.

The idea of piezoelectricity is that there are certain materials particularly crystalline materials that when they are subjected to some kind of pressure, they develop electric charge. The effect can occur in different deformation modes such as there can be shearing action, there can be thickness expansion, etcetera, but the principle is the same.

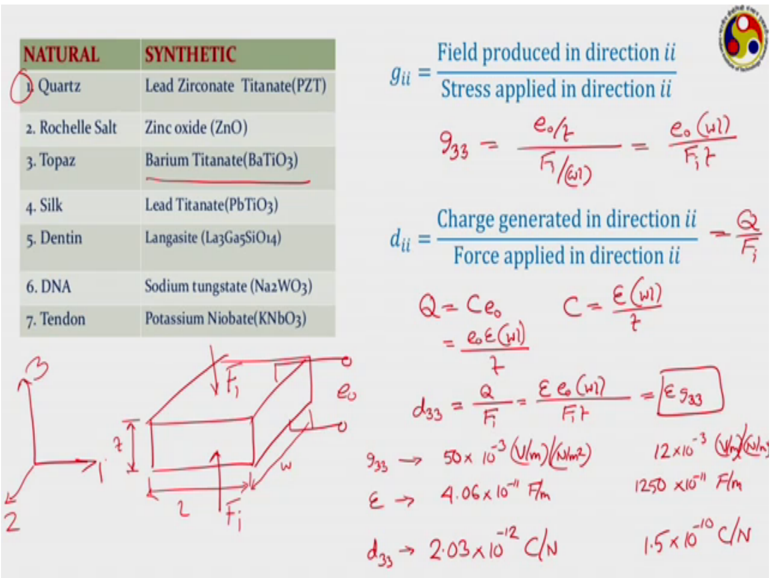
Like the if this red one is the piezoelectric material, some kind of piezoelectric crystal, then when you are subjecting this one to some kind of compressive load or some kind of tensile load, depending upon the magnitude of the load, a proportional amount of electric charge will be developed. There by creating a potential difference across the two plates or across the two sides of the crystal. We can measure this voltage or this potential difference, and that can directly give you an idea about the amount of force that you are inducing onto this. And that force can subsequently be related to the displacement of the plates.

The effect can be explained by the displacement on the ions in the crystal that have a non-symmetrical unit cell, it does not happen with symmetrical configuration. Only if it is a non-symmetrical configuration, the ions will get displaced inside the crystal. And now when the crystal is compressed, ions in every unit cell are displaced, causing an electric polarization that is positive on one side, more positive ions on one side, more negative ions on the other side, thereby creating a distinct polarization.

And because of the regularity of the crystallized structure, these effects accumulate, developing an electrical potential between the two opposing phases of the crystals. And this particular effect actually is reversible, reversible means just like by putting pressure we can develop electric charge. Similarly, if we subject the crystal to some kind of electric potential, then it will experience some kind of stress and it will start to deform. So, it is possible in both ways, just like this.

When you are subjecting the crystal to some kind of mechanical input like pressure or saw a shock wave or even sound wave, because how waves are nothing but vibration. So, when it is subjected to this kind of waves that will lead to a voltage, thereby giving a conversion of mechanical energy to electrical energy. Whereas, in the reversible effect if it is subjected to some kind of electrical input, then that will lead to a conversion to mechanical energy. And that mechanical energy by suitable configuration can be converted to several usable forms like displacement or force or vibration or even sound waves as well, so that is how these electric transducers work.

(Refer Slide Time: 11:09)



So, these are certain examples there can be several natural piezoelectric materials as well like Quartz, Silk, DNA is a very interesting example, whereas there are several synthetic materials as well. Also like some of the example shown here, here particularly this one is a very common example of piezoelectric material.

Now, to understand the method characteristic of this, generally we use two parameters, one is a g parameter, one is a d parameter. We shall not be doing any detailed mathematical analysis of this, just a very brief idea about how piezoelectric transducers work or what are the how we characterize them. Let us consider a crystal with rectangular cross section, let us draw a crystal something like this. So, this is a crystal, let us say these are our coordinate direction, this is 1, this is 2, this is 3, you can give x, y, z also.

If you want, so the dimension in the direction three, let us denote this 1 to be say t, dimension parallel to the x-direction is L, dimension parallel to the oh sorry not x one direction dimension to the two direction is W. Now, this crystal is now subjected to some kind of compressive force. So, this is the force that you are putting, let us say if i is the force that you are putting in both direction, so that will lead to the creation of some kind of electrical potential. So, e naught is let us say is the corresponding potential.

Then g parameter defines the ratio of the field produced in the direction ii divided by stress applied in a direction ii. Now, here the force in which direction, we are applying it in the direction three. So, we have here g 33 g 33 will be equal to stress applied in direction three oh sorry first is the field produce. So, in the numerator how much is the field that is produced is the potential divided by t is a corresponding lane scale.

So, this is the electrical field that has been produced in the direction 3 divided by the stress applied, how much is the stress F i is the force that you are putting in divided by the area w into l, this is the total force total area, and so this is the goniometer refers to the stress that you are applying there. So, if you simplify this one, so we have e naught into wl in the numerator and F i into t in the denominator. So, this is the first parameter.

And the second one is the d parameter. d refers to the charge that has been generated in that direction divided by the force applied in that direction. Let us say Q is the charge that had got generated in a three direction, and we are applying a force F i in this. So, d 33 refers to Q by F i. Now, how we can relate this charge Q to this potential e naught, if we assume this to be like a capacitor, where the two opposing phases are waves like the two plates of the capacitor, and in between portion like a dielectric medium.

Then the capacitance or rather the charge Q can be related to C into e naught C being the corresponding capacitance. And what is C, C will be equal to the dielectric constant into the area divided by the distance between the plates that is epsilon wl by t. So, Q refers to e naught into epsilon into wl divided by t. So, if you are putting back this to the expression of d 33, then d 33 will be Q upon F i. So, you are getting epsilon e naught wl by F i into t, and just comparing the earlier expression. So, this is equal to epsilon into g 33. ah

So, if we know the value of the dielectric constant of the corresponding material, and some idea about this g, then we can measure this d. And this d then subsequently can be related to the displacement, which we are not discussing here. Now, the value of g generally comes from the manufacturer. We can talk about two very common materials. One is Quartz, and other is this synthetic one the Barium Titanate BaTiO 3.

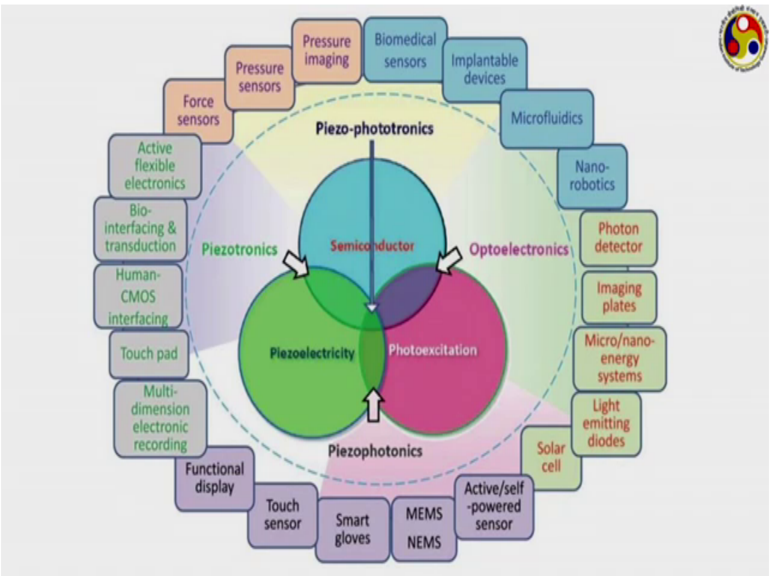
So, for Quartz kind of material, the value of g 33 for Quartz the value is given as 50 into 10 to the power minus 3. And what should be the unit, just look at what you have in a numerator of the field, which is volt per meter. And in the denominator you have the stress that is Newton per meter square, so that is the value of g for Quartz.

Whereas, for barium titanate, it is 12 into 10 to the power minus 3, the same unit in volt per meter by Newton per meter square SI unit, so this is g. And epsilon the dielectric constant for quartz the value of dielectric constant is 4.06 into 10 to the power minus 11 farad per meter, whereas it is much larger in case of Barium Titanate. It is 1250 into 10 to the power minus 11 meter. So, you can easily calculate the value of d 33, this because d 33 will be just a product of these two quantities like this.

So, if you take a product, so it will become 2.03 into 10 to the power minus 12 coulomb per Newton, whereas in this case it will be equal to 1.5 into 10 to the power minus 10 coulomb per Newton. So, this way we can calculate the charge, we can get an idea about the how much charge that has been developed inside this.

And for every Newton, and once we get the measure of this value of e naught, we can easily calculate the value of we can easily add that to the corresponding value of d. And once we know the d, then the there we can relate that to calculate the corresponding force, which can subsequently measure to the displacement, actual to know the displacement we also need to know the value of the young's modulus of this.

(Refer Slide Time: 18:05)

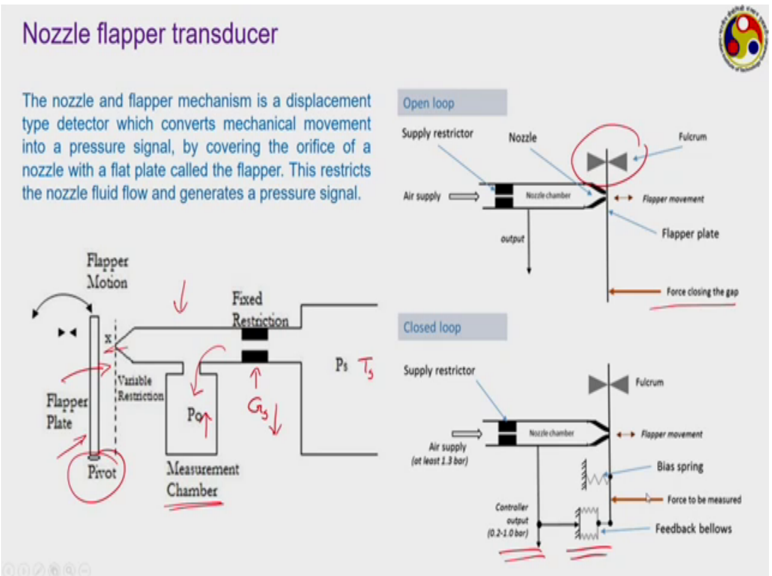


But, we are not going to the details of this discussion, because this one will be coming back later on in one of the subsequent modules, where we can discuss a bit more probably on piezoelectric crystals. But, piezoelectricity is one of the most important mode of measurement nowadays. Particularly if we combine this one to say other domains, like there are generally three domains which are considered together; one is piezoelectricity, one is photo excitation, another is the semiconductor.

And we can combine any two of them, like when we combine the semiconductors with the piezoelectricity, we call that particular study as piezoelectronics or piezotronics, where a semiconductor combined into the photo excitation is called optoelectronics. And p electricity combined with the photo excitation is called piezo photonics.

And when we combine all three together, then this comes under the purview of piezo phototronics. See how many areas that we are talking about here. Like if we are talking about say piezotronics, then that goes to the active flexible electronics, bio-interfacing, and transduction, touch paired, multidimensional electrosonic recording etcetera. Whereas, for optoelectronics we have photon detector, imaging plates, solar cells, light emitting diodes or LED's all goes under this optoelectronics. So, this three branch together actually governs the not only measurement rather several other kind of application areas together, so that is all about piezoelectric sensors or transducer that we would like to discuss here.

(Refer Slide Time: 19:23)



Now, let us talk about another very interesting kind of transducers, which uses a completely different kind of principle. Now, just think about what kind of output that we are talking about so far. Displacement remains the input to the transducer, but most of the transducers that we have discussed here are generally electro mechanical in nature that is displacement is the input, but output is some kind of electrical quantity. Like all those resistive or inductive or capacitive based measurements, we have voltages the output primarily.

Even when we go for some kind of optical method, there also we get generally the voltage as the output. The one that we have just discussed the piezoelectricity, they are also final output comes are in terms of the voltage or maybe charge, we generally measure the voltage itself. But, the one that we are going to discuss here, there we generally do not use any kind of electrical conversion, rather we use pressure as the output quantity or we get we measure the displacement in terms of pressure, such kind of devices are called pneumatic devices or pneumatic transducers.

So, this nozzle flapper transducer is the first example that we are going to talk about regarding the pneumatic transducers, it is the one which is used for displacement measurement. The operating principle is very interesting, look at what we have here. Here we have a tank, which contains some kind of fluid, generally some gaseous medium at some pressure Ps.

So, Ps is the pressure, let us temperature can be Ts also. These two are generally fixed which does not depend on the measuring quantity, and therefore their values always remains constant. Now, the working medium is allowed to pass with two restrictions. First we have the fixed restriction here, we have a fixed nozzle kind of device, through which some gas comes out.

Let us say G s refers to the corresponding flow rate of the gas. So, on which is G s should depend G s should be decided depending on the value of this P s, and the downstream pressure which is P naught. Now, this P naught here, actually refers to the pressure of a measurement chamber which we have located in the downstream of this nozzle. So, the G s generally is the function of this P naught, because P s always remains a constant, but P naught keeps on changing.

How the P naught is changing, because as the gas comes out of the fixed restriction a part of that enters a measurement chamber. And rest of that starts flowing through this, there is another outlet at the other end of this particular channel, and the there is another restriction. But, this restriction is not a fixed one, this restriction is a variable one. Here we have a flapper plate this is the flapper plate, which is connected to the location where you want to measure the displacement.

Depending upon the displacement in that specimen, the flapper plate keeps on moving, thereby it changes the opening of this particular restriction that is the amount of opening that we have available here that keeps on changing, depending upon the location of the flapper. Thereby indirectly relating the or thereby directly relating this opening with the displacement of your specimen.

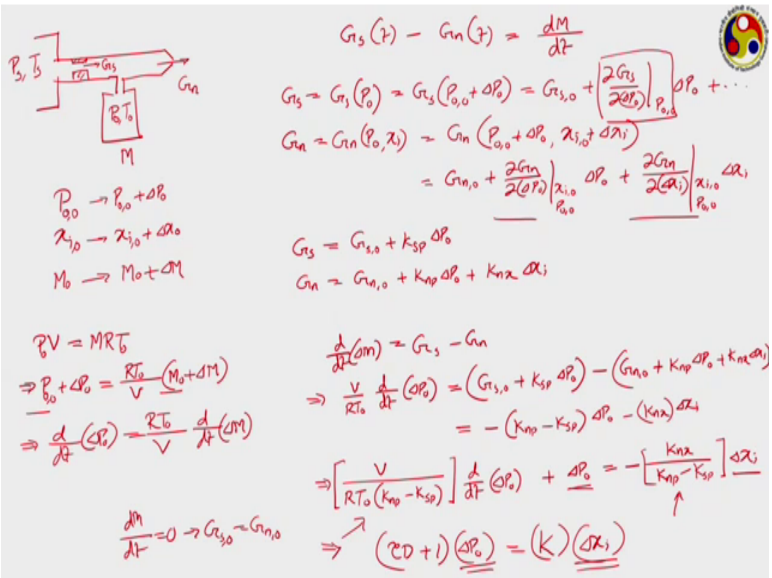
Now, as the opening changes, then the corresponding amount of mass of the gas that can go out through this restriction that also keeps on changing. So, the quantity of mass that get can get stored in the measurement chamber that also changes, there by causing a change in the value of P naught. Like suppose, in a situation if the flapper plate moves in the inward direction.

If the flapper plate is moving in the inward direction, then the total amount of mass that can come out through this that will keep on going down, as that goes down more and more amount of mass starts entering to this to this measurement chamber, thereby causing an increase in the value of P naught. But, as the P naught increases that will also reduce a value of this G s itself, thereby creating some kind of in equilibrium into this.

And depending up once the flapper plate location becomes fixed, then ultimately it will it will become stabilized. But, how the pressure this outlet pressure is changing, and correspondingly how the value of quantity of mass that is stored in a chamber that changes that can directly be related to the displacement of this flapper plate, which we shall be seeing seeing very shortly.

Generally, we can have two types of configuration of this nozzle flapper transducer. One is the open loop, just like the what we have discussed. Here the force that is coming from the movement of the specimen closes the gap, and the flapper movement flapper generally is fixed by fulcrum, like a pivot somewhere here. So, the opening or this a at the extreme position of this nozzle chamber that keeps on changing whereas, the other can be a closed loop where we actually have a nozzle controller here, which is also related to the flapper by some kind of feedback below this etcetera. So, giving some kind of feedback action, and a different way of measurement.

(Refer Slide Time: 24:43)



Let us quickly see, how we can if we can get an idea about the a working principle of the flapper through mathematics. Let us consider a very simple situation, just the drawing that we had in the previous slide that I am drawing again. Here this is the chamber, pressure Ps, say temperature is Ts. Temperature is irrelevant here. So, this is your nozzle, this is the fixed restriction. So, the mass that comes out of this fixed restriction is G s.

And actually, I have to keep an opening here. Here we have the chamber the measuring chamber, where the pressure is say P naught pressure is P naught, the temperature may be T naught again temperature irrelevant. The mass that is going out through this is G say n going out to the nozzle is G n, G s is a mass supplied towards the chamber side.

Now, the amount of mass that is stored there stored in the chamber is capital M, the value of capital M will keep on changing depending upon the value of G s and G n. So, if we write a mass balance for the chamber, what we can write G s at a given time minus G n at a given time will be related to rate of change of mass. Here G s and G n are the mass flow rates, and capital M is the amount of mass stored in this chamber, so that is how we can write a simple mass balance equation.

Now, let us say when the system is in equilibrium, then the mass sorry the pressure in the chamber is P naught P o 0, corresponding position of the flapper is x i 0, and quantity for corresponding quantity of mass is M 0, this is when the system is in perfect equilibrium. But, now the position of the flapper changes x i 0 by some delta x naught amount, correspondingly there is a change in the pressure also by delta P naught. And there will be change in the mass also, any of them can be negative as well.

So, if we now write say G s, G s is a function of what? P s being constant, G s is a function of P naught only. So, as the pressure changes, we can write this to be something like this. So, if we expand this assuming delta P naught to be very small, if we expand this following Taylor series. If we write this one to be as G s naught, which is actually the value of G s under equilibrium plus dou G s dou delta P naught corresponding to P 0, 0 into delta P naught plus higher order terms.

Similarly, G n now g now G n depends on what, G n is a function of both this pressure P naught, and the nozzle opening that means, we can write G n to be equal to when there is a change delta P naught, and x i plus delta x i is x i 0 the equilibrium position like this. Now, if we expand this one, we have G n 0 which refers to the equilibrium position that is when pressure is equal to P 0 0. And flap proposition is x i 0 plus dou G n delta P naught at this x i 0 P 0, 0 into delta P 0 plus dou G n dou delta x i. At again the equilibrium position delta x i.

Now, generally this all these gradients that is the first one that we have written here, and the two which we have written here. All of them are represented by some kind of coefficients, thereby giving G s to be equal to G 0 plus let us say small k sp refers to the corresponding pressure coefficient into delta P naught. Similarly, G n will be equal to G n 0 plus k n p into delta P naught plus k n x delta x i. Here of course, we are neglecting all the higher order terms second order onwards.

Now, now let us assume the gas, which we are using as a working we name an ideal gas. Then for an ideal gas, we can easily write for the tank or the measurement chamber. We can write as RT, where V is the volume of the tank, and T 0 is the temperature there, M is the mass or now here with the change your pressure becomes like this. If the mass change from M naught to something like this that is because of this change, your mass has changed from M naught.

Initial mass was M correct it was correctly written, but somehow I initial was m naught, now it has changed to M naught plus delta M. So, now if we differentiate both side, with respect to the I with respect to time. Now, this P 0, 0 and M 0 this refers to equilibrium quantities. So, these are independent of time. So, by differentiating with respect to time, we have d dt of delta P 0 will be equal to RT 0 by V into d dt of delta M.

Now, here R is the gas constant of the corresponding gas that you are using, V is the volume per tank, which is constant, and temperature T 0 can also be taken to be constant, because there is hardly any change in the temperature in the measurement chamber. So, again we know that the rate of change of mass can be related to this change in G s minus G n, therefore we can write that V by R T 0 into d dt of delta P 0 should be equal to the what we derived earlier G s is this minus G n is this like this.

Now, when the system is under equilibrium, then G s and G n should be such that there is no mass accumulation in the tank that is when the system is under equilibrium dm dt is equal to 0, thereby giving G s naught to be equal to G n naught. So, making use of that we have or rather on the right hand side, we have what we have minus of k np minus k sp into delta P naught minus k n x into delta x i or if we rearrange this a bit, then what we have we have V by RT 0 into k np minus k sp into d dt of delta P 0 plus delta P 0 is equal to minus of k nx by k np minus k n k sp into delta x i.

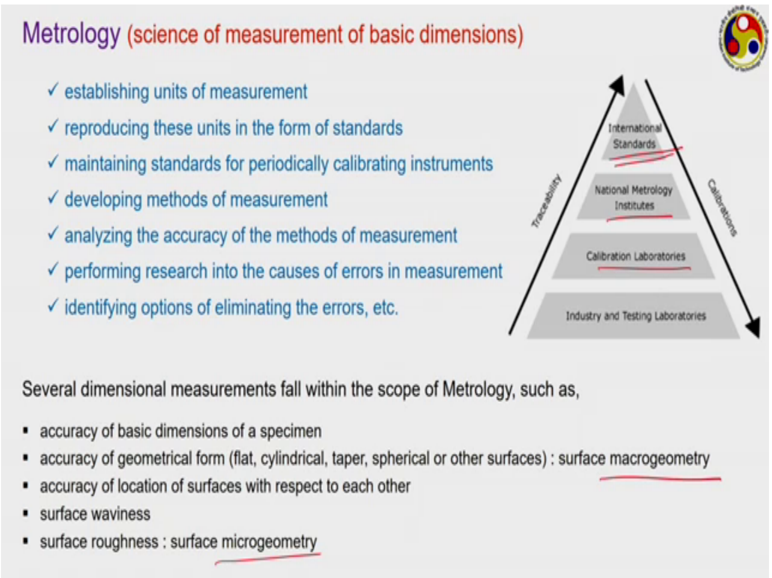
Now, how this equation is looking like, have you seen this form of equation earlier? Just look at the terms error if we neglect the bracketed terms, then delta x i is the input to the system the displacement, delta P 0 is the corresponding output from the system. Then cannot we write this equation as something like tau d plus 1 of delta P naught which is your output is equal to capital K into delta x i, which is your input that is it is like a first order system, where this particular thing is the tau the time constant, this particular thing along with the minus sign is the corresponding gain delta x i is input, delta P naught is the corresponding output that is just by measuring the pressure.

Once we have this idea about this time constant in the static gain, then just by measurement of the change in pressure in the tank, we can measure the corresponding displacement. It is a perfect example for a first order system a very interesting example of displacement measurement using pneumatic transducers.

Some other pneumatic transducers also we shall be discussing later on, but this kind of devices can be very very accurate highly sensitive, because any small change in the flapper position will cause a change in the pressure inside the tank. And thereby we can get almost instantaneous measurement that is a very fast dynamic response along with high accuracy. Of course, the resolution of the instrument will depend upon the resolution of your pressure measuring tool. But, if you have a sufficiently high resolution for the pressure measuring tool, you can have very high resolution of the displacement measurement from this.

So, here though our objective is to measure the displacement on the flapper side, actually the tool that you will be using is something that gives a pressure at this particular tank. And once you have this pressure measuring tool working properly, you have an excellent option of displacement measurement, so that takes us towards the end of our discussion about displacement measurement something I shall be discussing very briefly which is about metrology.

(Refer Slide Time: 35:30)



You may have heard this term metrology. Metrology refers to a science of measurement of basic dimensions and therefore, it is an integral part of this displacement measurement. However you have to understand that here we are talking about measuring the basic dimensions of some specimen and not any kind of movement. Dimensions can refer to any kind of length scale either linear or rotary length scale like dimension diameter, inner or outer diameter of a pipe or something like that, or we may be talking about angles as well. So, metrology deals with all such kind of measurements.

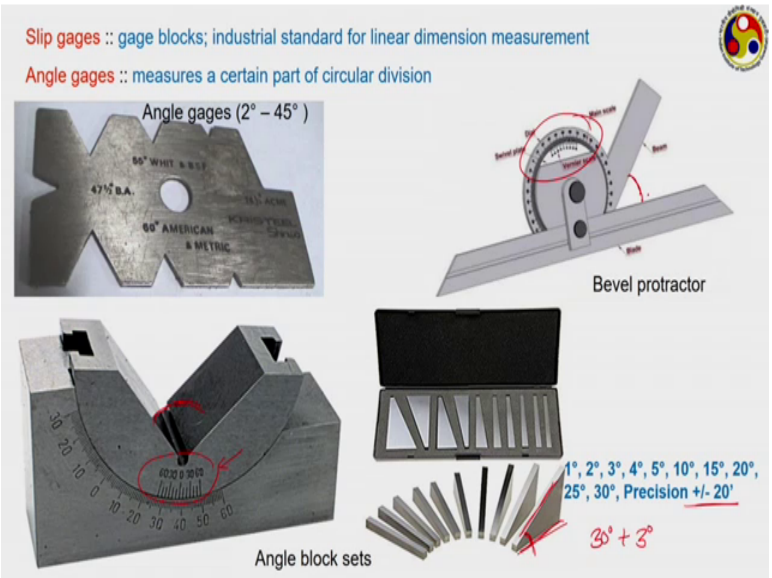
Under the metrology there are several objectives that generally we look for. Firstly, establishing the units of measurement, and then reproducing these units in the form of standards, like in the first lecture here we have discussed about the standard for denoting meter and those all these definitions comes under the scope of the metrology. The maintaining the standard for periodically calibrating instruments is another very important objective of metrology.

We have already discussed you know first week itself about different kinds of standards like industry and testing laboratories used the lowest level standard, but as we go along we can have the international standards, like the disc we have discussed about the standard for meter in the first lecture here about the which is defined in terms of the velocity of light in vacuum so that is the international standard. Every country has its own national standard which is kept in national institutes, from there we can have calibration laboratories, finally coming to the industry. And all this comes within the scope of this metrology.

Metrology also helps developing the methods of measurement and standardizing them to analyze the accuracy of such methods. And it performs research to identify the probable causes of errors that can appear during measurement, and also suggest options of eliminating those errors. So, all this comes under the scope of metrology.

Now, several dimensional measurements falls in the scope of metrology such as accuracy of basic dimension of its specimen. Basic dimension as I mentioned about it can be something like linear dimension, length, width, or diameter of something, or we can may be talking about say the periphery of a sort of an arc something like that. Accuracy of a geometrical form flat, cylindrical taper, a spherical which comes falls under this surface macro geometry. Surface roughness which falls under surface micro geometry; surface roughness measurement is probably the most important part of metrology. Accuracy of location of surfaces with respect to each other, and also the waviness of surface.

(Refer Slide Time: 38:06)



There are several kinds of gage that are used on metrology, we shall be this being a huge topic, we shall just be mentioning about very few basic gages that we very commonly identify in workshops or different mechanical laboratories. First is slip gages which are used for linear dimension measurement. Now, you already have been introduced to the slip gages which are nothing but the gage blocks. You know how the gage blocks work where we have the each of them having a particular standard thickness. And by combining the gage blocks, we can form any kind of linear dimension.

Next we have the angle gages. Angle gages are used as a name suggest to measure certain angles, angles of certain machine sections etcetera. There are several kind of in gages, you can find like the angle gages mentioned here shown which can generally measure up to 45 degrees, but certain cases can go to even higher ranges as well.

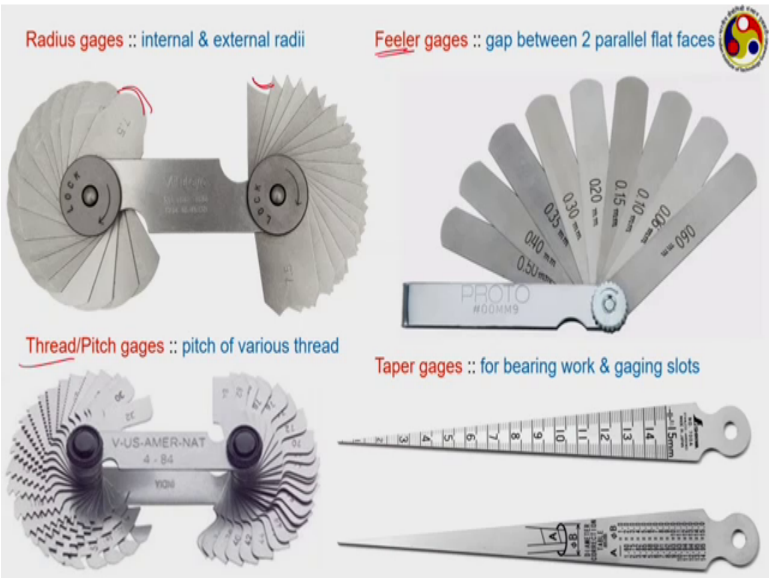
Angle block sets, these are angle block sets, where you can change the position of one of these two plates. One is fixed; the opposition of the other can be changed. And then from the scale we can directly are the position of the other can be changed to and get it aligned to the machine surface, which you want to measure the angle, and from then we can directly get it from the scale here.

Also there can be block states quite similar to the gage blocks each of the surfaces have a particular angle this particular angle that we are talking about. So, if we align this surface to align, say this block this particular surface to the portion where you want to get the measurement arrive the matches perfectly, of course, with this part surface of being perfectly horizontal, then we get this angle. These are different standard angles with which we can get these sets.

And suppose our objective is to measure an angle which is not there. Say we want to measure 33 degree, you can easily combine one 30 degree block and one 2 degree block to get this 33, sorry, not 2 degree, a 3 degree block to easily get a 33 degree. They generally are highly accurate, precision being in the range of just a few arc seconds. ah

We can also have this bevel protractor quite similar to the protractor that you use, but they generally have a vernier scale in corporate in this where they have a fixed blade, and then there is this beam which keeps on rotating, and one by properly aligning them we can get the measurement from the scale. These are angle gages.

(Refer Slide Time: 40:37)



We can also have radius gages which are used for measurement of the internal and external radius. Here on the same gage you can have there, you can see there are two kinds of blocks. This side these are used for internal radius measurement, whereas these surfaces are used for external radius measurement. You can there are several blocks as you can see each of them having a different radius. And depending on which one matches to the profile of your surface, you can lock it in that position and get their measurement done.

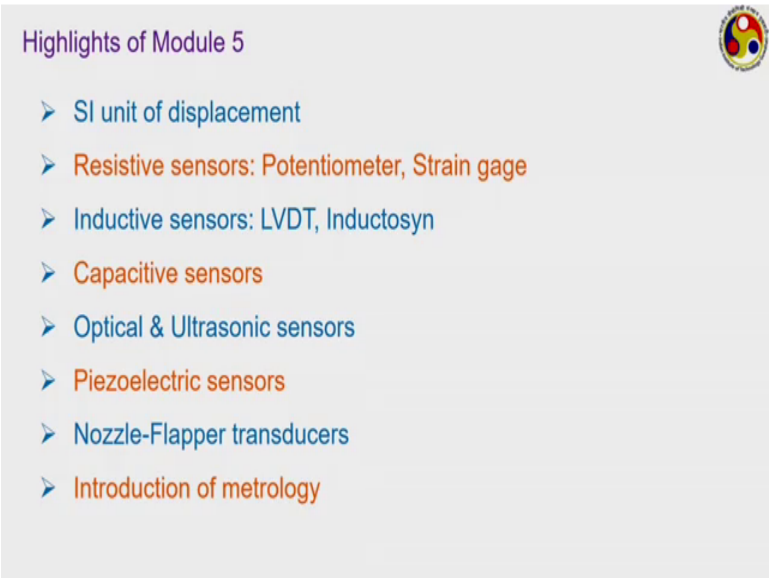
Feeler gages, feeler gages are used to identify the gas between two perfect flat faces. Now, as the name gives actually here the measurement is based upon feel. Like think about one engine cylinder, inside the engine cylinder we want to measure the distance between say the two walls or maybe the distance from the piston to the bottom surface of the cylinder, then we insert one of those gages, and the insertion should be such that they are not get the blades are not getting compressed properly and also they are not there is no gap left, that is they should be just something like called gage fit, means the gage should just about fit there. And whether it is in that particular position or not that we have to understand from our feelings, it requires a bit of expertise to make use of these feeler gages.

We can have the thread or pitch gages which are used to measure the pitch of various kind of threads. We can have taper gages like which are used in bearings etcetera. They can be inserted to understand the degree of taper that can be present in a surface. We can also have several other kind of gages like radius gages as shown. We can sometimes are called thread gages etcetera are also there. This is a thread gage we can also have wire gages for very fine samples to measure the diameter of the wire or we can make use of those gages etcetera. So, these are just some of the very common gages that we do use in the scope of metrology.

So, this takes us to the end of our discussion on displacement measurement. Here I repeat I have already as I have already told here I have tried to get to introduce to several methods of displacement measurement without getting into the depth of most of them. But the ones which are most important we have tried to discuss about that like the potentiometer or LVDTs are very important measurement tools. So, we have discussed in detail about them.

Today we have discussed about the nozzle flavor transducer which is a very interesting type of pneumatic conveyor or pneumatic transducer. And this principle will be used later on also for measurement of other quantities through pneumatic ways. So, the same principle will be followed and there. So, we have discussed in detail about that and finally got a brief idea work metrology and different corresponding metrological gages.

(Refer Slide Time: 43:41)



So, what we have got in this particular module we started discussing about the SI unit of displacement and then we talked about different kind of displacement measuring tools. Like the resistance based sensors, potentiometer and strain gages, inductive sensors like LVDTs, and inductosyns, capacitive sensors. Do you have any example or sorry do you know any example of handling any kind of capacitive based instrument? I am sure all of you have the experience, like the mobile screen or touch screen that we use, their working principle is based upon capacitance only. Like as we keep our finger on the screen the distance between the finger and the inner surface that acts like a capacitor.

And a charge is accumulated there, and as the finger is moved the position of the charge changes and the magnitude of the charge changes and giving the corresponding response. And this capacitive sensor works in the same way as well. We have talked about the optical or ultrasonic sensors also very, very briefly. Then we have discussed about piezoelectric sensors I repeat piezoelectric sensors will be coming back in one of the later modules. And then we have discussed in detail about this pneumatic transducers which we called nozzle flapper transducer, finally a very brief introduction to metrology.

So, that takes us to the end of module number 5. I would like to thanks for your attention throughout this module, and yeah please go through the lectures, try to solve the assignment properly. And if you have any question please write back to me. It is important to understand the working principle of the instrument that you have discussed here, because similar principles will be again used in the subsequent modules. So, I am signing off from this particular weeks work. We shall be back very shortly in the next week or I shall be talking about the measurement of stress and strain.

Bye for now.