Process Control and Instrumentation
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Lecture No. # 41
Transducer Elements

In we previous lecture we started talking about, Transducer Elements. We define Transducer Elements as those devices which receives, strain or displacement as input and gives us electrical output. In general transducer elements are those devices which converts the form of the signal to a more convenient form. However, we are interested in those electro mechanical transducers, which gives us electrics electrical output and receives displacement or stray in as output.

We said that will discuss one pneumatic transducer namely flapper nozzle systems and various electro mechanical transducers such as, LVDT or linear variable differential transformers strain gauge, piezoelectric transducer and capacitive type transducer. We started our discussion on flapper nozzle systems.

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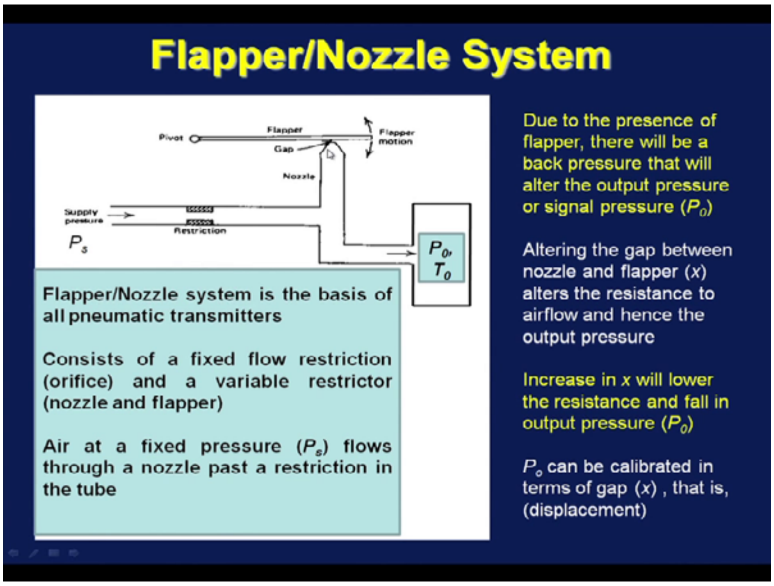

So, let us continue with Flapper Nozzle systems. Flapper nozzle system is the basis of all pneumatic transmitters, it consist of a fixed flow restriction. Which is an orifice and a variable restrictor in the form of a nozzle and flapper. Here at a fix pressure say, P s flows through the nozzle pass this restriction given by RFS.

Due, to the presents of the flapper there, will be a back pressure. That will alter the output pressure or signal pressure. Altering the gap between the nozzle and flapper, alters the resistance to yet flow and hence the output pressure. Increase in the gap between nozzle and the flapper will lower the resistance and fall in output pressure. Therefore, the output pressure or signal pressure represented here, by P0 can be calibrated in terms of the gap that exists between flapper and the nozzle which is displacement.

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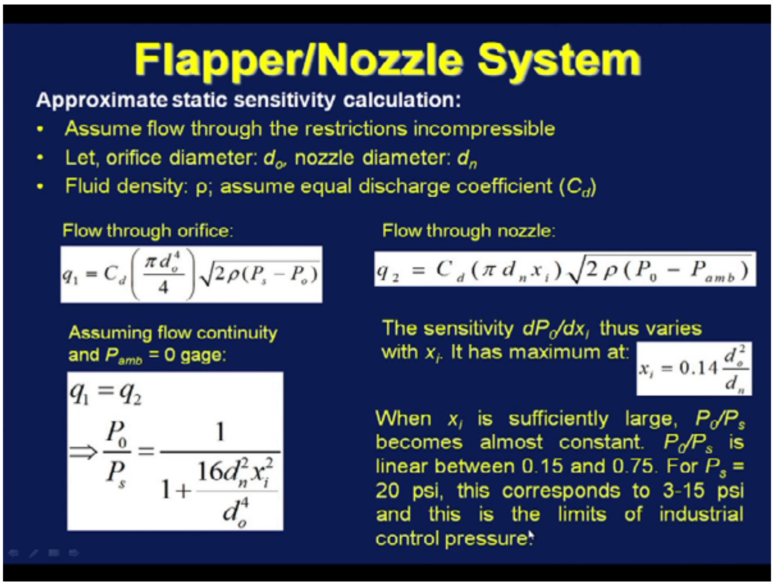

Let us, we try to find out Approximate static sensitivity for Flapper Nozzle system. Let us, assume flow through the restrictions incompressible. So, we assume flow through orifice and flow through nozzle incompressible. Let the orifice dia the represented by do and the nozzle dia be represented by dn. We represent fluid density by rho and we assume that, the discharge coefficient for orifice and the discharge coefficient for nozzle are same.

So now, flow through the orifice can be represented by this equation. So, flow through orifice q1 is equal to discharge coefficient multiplied by phi d0 to the power 4 divided by 4 into square root of 2 into rho into Ps minus Po. Where Ps is the separate pressure, and Po is the signal pressure. Similarly the flow through nozzle can be represented by this equation. Which is q2 equal to Cd multiplied by phi times dn times xi into squire root of 2 into rho into Po minus P ambient.

Where Cd is different coefficient dn is the dynamiter of the nozzle, xi is the gap between the nozzle and the flapper rho is the fluid density, Po is the signal pressure and P ambient equal to ambient pressure. Now, if we assume flow continuity the flow through orifice should be equal to flow through nozzle. If we assume P ambient equal to 0 gauge pressure then, we can equate after equating q1 equal to q2 and after some rearrangement we can write P0 by Ps as this equation.

So, we assume flow continuity and P ambient equal to 0 gauge pressure. So, equate q1 equal q2 with P ambient equal to 0. Then we do some rearrangement and can write P0 by Ps equal to 1 by 1 plus 16 into dn square into xi square divided by do to the power 4. Now, Po is the signal pressure and Ps is the separate pressure. So, P0 by Ps can also be taken as normalized signal pressure or output pressure.

So, now clearly seen that the sensitivity which can be represented as dd xi of this where is we xi. So, the displacement sensitivity of the flapper nozzle system, which can be found for this equation as dd xi of this part of the equation. And it can be seeing that sensitivity has the maximum at xi equal to 0.14 into do square by dm. When xi is sufficiently large P0 by Ps becomes all most constant. So, for sufficiently large value of xi or sufficiently large displacement P0 by Ps which is normalize output pressure becomes almost constant or in other words tend to saturate. However, P0 by Ps is linear between 0.15 to 0.75 for (Refer Time: 08:18) pressure Ps equal to 20 PSI this corresponds to 3 to 15 Psi, and this is the limits of in the scale control pressure.

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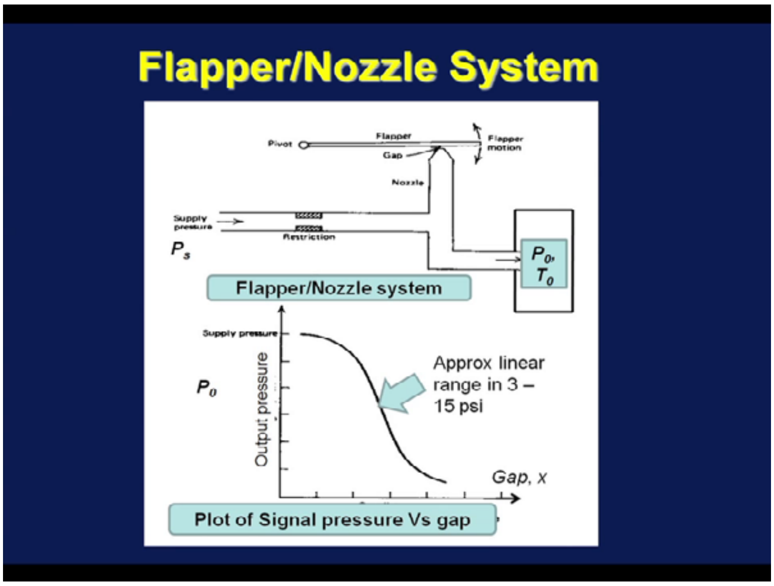

So, this is the plot 1 of tends when 1 plots output pressure or signal pressure, but this the gap between the nozzle and the flapper. It can be seen that for large value of gap or the displacement this part of the graph tend to saturate. So, it will become almost constant. But, it has the linear part which is this part and it is a proximally linear in the range of 3 to 15 PSI. Flapper nozzle system as an important application in converting the current signal to pressure signal.

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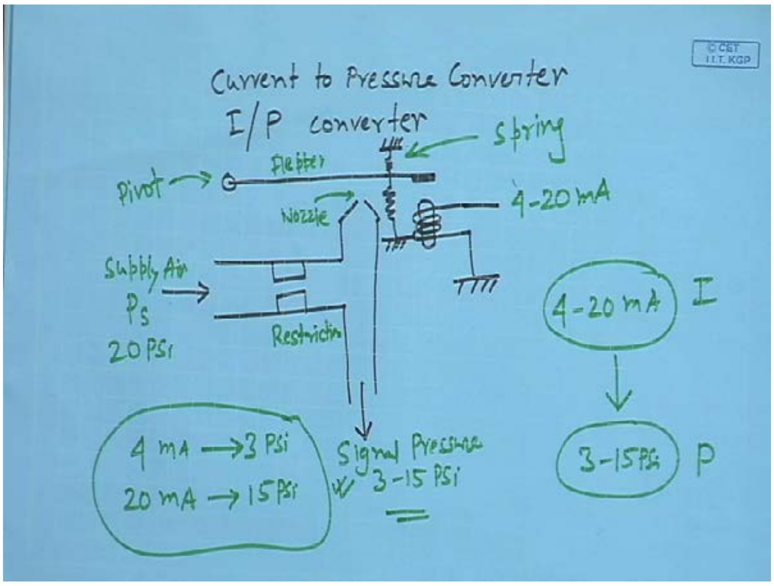

A Converter is converts Current signal to Pressure signals, finds important applications in process control system. We can use a flapper nozzle system to make such a device which will receive electrical signal and gives as pressure signal as output. We call them current to preserve converter or I of lig P converter. This works as for us, so we have a flow restriction here. This is supplier 20 PSI this is the nozzle and this is Flepper and this is the Pirot, this is the Signal pressure or output pressure. this is a spring. Frequently will may be interested in converting a current signal to a pressure signal. IP converter gives a linear way of translating 4 to 20 mile ampere current to 3 to 15 PSI pressure signal.

If, I send 4 to 20 mile ampere current through this coil a force will be produce that will pull down the flapper. As it pulls down the flapper the gap between the flapper and the nozzle changes. So, the signal pressure accordingly changes high current will produce high pressure. So, adjustment of the spring can be made such that, I can calibrate the system so that 4 mile ampere corresponds to 3 PSI pressure and 20 mile ampere corresponds to 15 PSI pressure.

So, I can convert a current signal between 4 to 20 mile ampere to a pressure signal between 3 to 15 PSI. So, it is working principle is very simple is essentially a flapper nozzle system. Here, we have passing a current through this coil which produces of force which pulls down the flapper.

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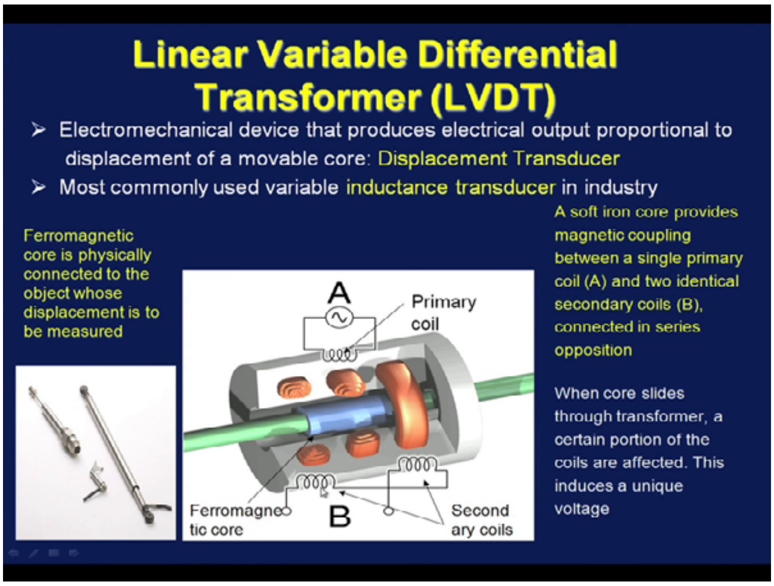

As a pulls down the gap between the nozzle and the flapper changes. Which will cause a change in the signal pressure, adjustment of the spring can be met. So, that we can celebrate the instrument such that, 4 when I, am passing 4 mile ampere current through this coil the signal pressure will be 3 PSI and when I am passing 20 mile ampere current the signal pressure will be 15 PSI. So, 4 to 20 mile ampere current signal can be converted to a 3 to 15 signal PSI pressure signal.

Let us now talk about, another electrical transducer and we talk about, Linear Variable Differential Transformer commonly known as LVDT. LVDT is an electronic mechanical device that produces electrical output proportional to displacement of a movable course. So, it is a displacement transducer is most commonly used variable inductance transducing industry. So, is an inducting type transducer, or variable type in the variable inducted type transducer. LVDT looks like this. And if you look at inside of this, we see that there is a soft iron core or ferromagnetic core and there is a primary coil represented by A here and there are two identical secondary coils.

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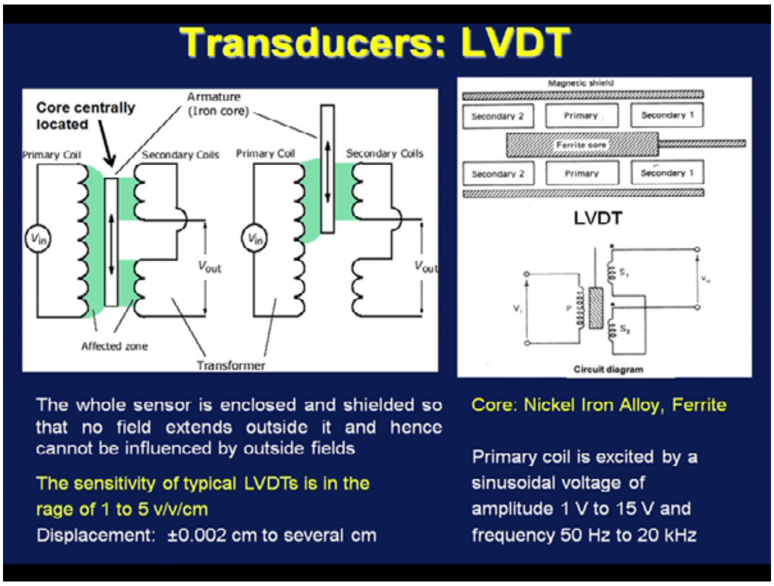

So, this soft iron core provides magnetic coupling between a single primary coil and two identical secondary coils. This two identical secondary coils are connected in serious opposition. So, when the core slides through the transformer shorten portion of the coil affected and this induces a unique voltage. This core is physically connected to the object, whose displacement is to be measured. So, is the object move the core also slides for the transformer. So, certain portion of the secondary coils are effected which will induce a unique voltage. And this voltage will be taken as a direct measure of the displacement.

So, this is the primary coil and these are two identical secondary coils. Which are connected in serious opposition. That this two secondary coils are connected it is serious opposition is clear from this circuit diagram. Usually the core is measured of alloy nickel iron alloy ferrite, primary coil is excited by a sinusoidal voltage of amplitude 1 volt to 15 volts and frequency 50 hurts to 20 hertz. The whole sensor is enclosed and shielded. So, that no field extends outside it and hence can all influence by outside fields. Look at this two circuit diagrams, in one case the core is centrally located. When it is centrally located equal parts of these two secondary coils are affected. When the core is pushed up, only this part of the only this secondary coil is affected, but the other secondary coil is not.

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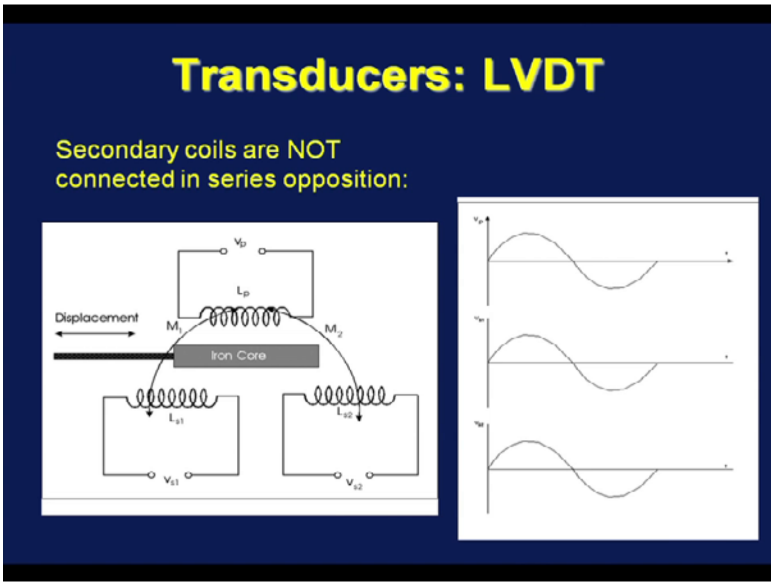

The core will move up or come down as the object moves as the object changes position. Because, this core is physically connected to the object. So, different amount of voltage will be induced in this two coils and thus the output voltage will change as the position of the core changes. LVDT is a highly sensitive instrument for highly sensitive transducer, the sensitivity of typical LVDT is in the range of 1 to 5 volt per centimeter.

And it can measure a displacement as low as plus minus 0.002 centimeter and can measure up to several centimeters.

Let us now, consider the circuit diagram of the LVDT again. So, this is the primary coil and these are two secondary coils. This is the iron core, which is connected physically to the object whose displacement I want to measure. So, this core moves like this or this. For the time being let us, assume that the two secondary coils are not connected in series opposition. Since, this two secondary coils are identical in all respect equal amount of voltage will be induced in both the coils. So, if I excite the primary coil by this signal I may get these signals for the secondary coils. Now if, there connected in series opposition since, the magnitude are equal and since there connected in series opposition the output voltage will be 0.

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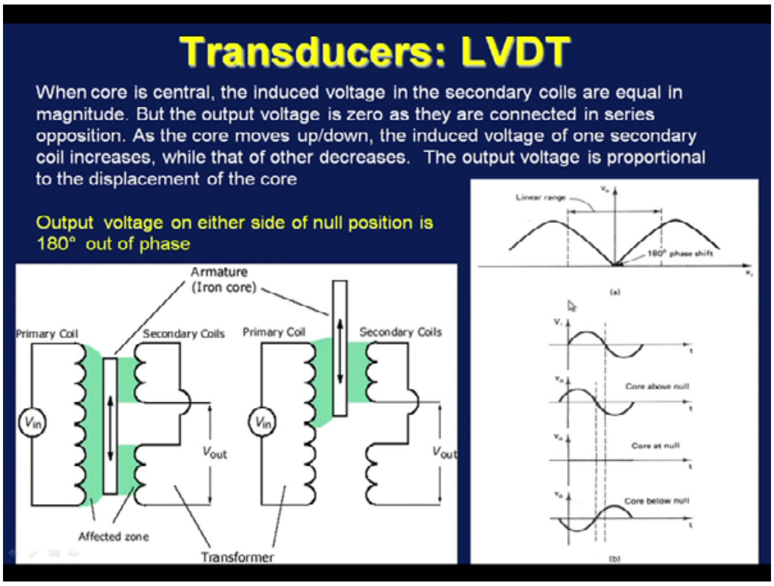

As can be seen from here, when the core is central the induced, voltage in the secondary coils are equal in magnitude. But, the output voltage is 0 as there connected in series opposition. As the core moves up or down the induce voltage of one secondary coil increases that of other decreases. The output voltage is promotional to the displacement of the core. If you look at this, plots when the core is centrally located output voltage is 0. Because equal amount of voltages are induced in both the secondary coils. And since, secondary coils are connected in series opposition the output voltage is 0.

So, if I excite the primary coil by say this signal, I will get 0 voltages output. When the core is centrally located or we say core at null. If the core moves up or comes down, I will have non0 voltages output. Because as the core moves up or comes down the induce voltage of one secondary coil increases while that of other decreases. So, when the core is above null position which shown by this figure. I will get output signal like this, while core is below null. So, when this core is push down I will get output voltage as this. Output voltage on either side of null position is 180 degree out of phase, as you can see. When we plot the output voltage verses the displacement of the core. So, as if I start from here, I push the core down it takes centrally located position I push it further it goes below null. So, the output voltage will undergo 180 degree phase shift. If you look at this figure and this three figures we understand that the output voltage will undergo 180 degree phase shift.

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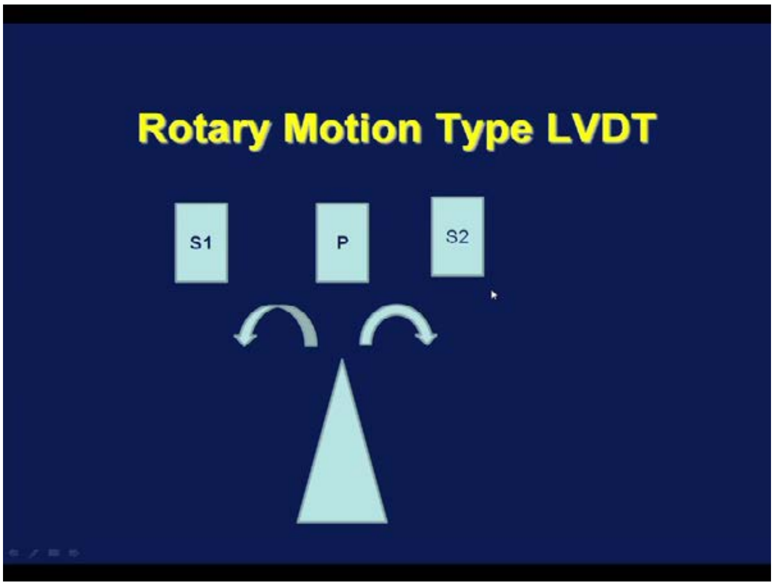

We can also have Rotary Motion type LVDT which is schematically represented by this. We have a primary coil we have two secondary coils, and this is connected to the object whose rotary motion I have to measure. So, as it rotates like this different portion of this two secondary coils are connected. So, output voltage changes accordingly.

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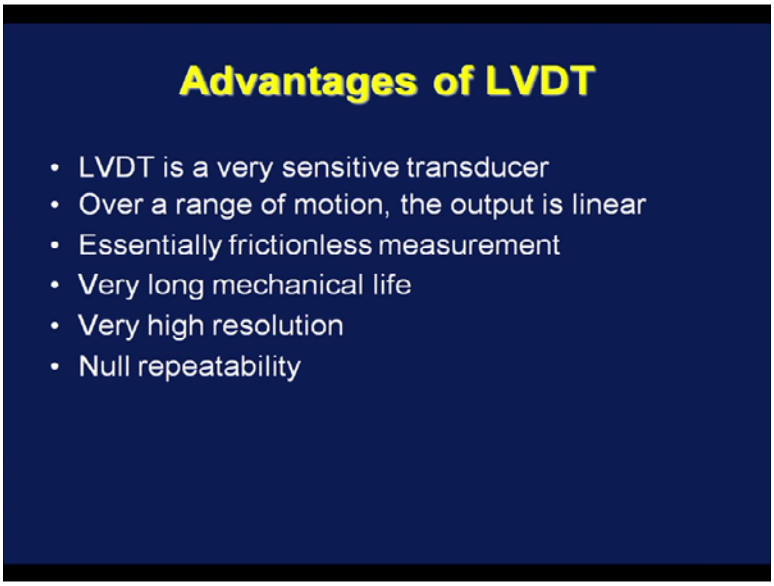

There are several advantages associated with LVDT. LVDT is a very sensitive transducer is sensitivity is the rage of 1 to 5 volt per centimeter. Over a range of motion the output is linear, you can see here over a range of motion the output is linear. So, we have a linear range it offers essentially frictionless measurement. It has very long mechanical life, it has very high resolution, it also has good null repeatability.

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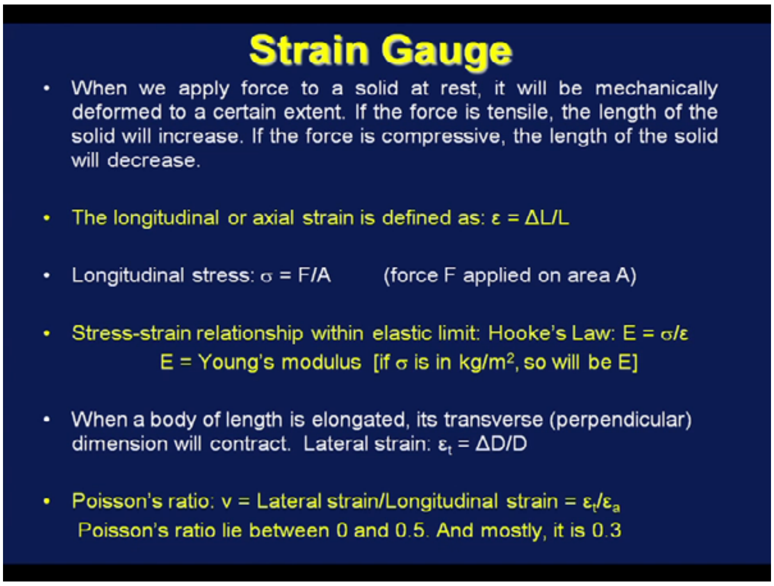

Let us now talk about, Strain Gauge which is another electrical transducer which receives strain as input and gives us electrical signal as output. Let us, start with some basic definitions that you are already familiar with. When we apply force to a solid trays it will mechanically deformed to a certain extend. If the force is tensile nature, the length of the solid will increase if the force is contrastive. The length of the solid will increase. The longitudinal strain or axial strain is defined as change in length divided by original length. So, we represent axial strain or the longitudinal strain as delta L divided by L. Longitudinal strains is defined as force divided by areas. So, forced F applied on area A. Force divided by area is longitudinal stress the stress-strain relationship within elastic limit is given by Hooks law with says, youngs modulus E equal to stress divided by strain. Strain is unit place because it is ratio of two lines.

So, if stress is in kg per meter square youngs modulus also be in kg per meter square. When a body of length is longitudinal its transverse or perpendicular dimension will contract, we call this lateral strain. Which can be represented as delta D divided by D when delta D is the change in diameter and D is the original diameter. Poissons ratio says, poissons ratio is the ratio of lateral strain to longitudinal strain. So, poisson ratio new is F silent t by F silent A is the ratio of transfer strain or lateral strain to longitudinal strain. We write new equal to minus F silent t by F silent a where F silent t is the transfer strain and F silent A is axial strain. Poisson ratio lies between 0 and 0.5 and mostly it is 0.3.

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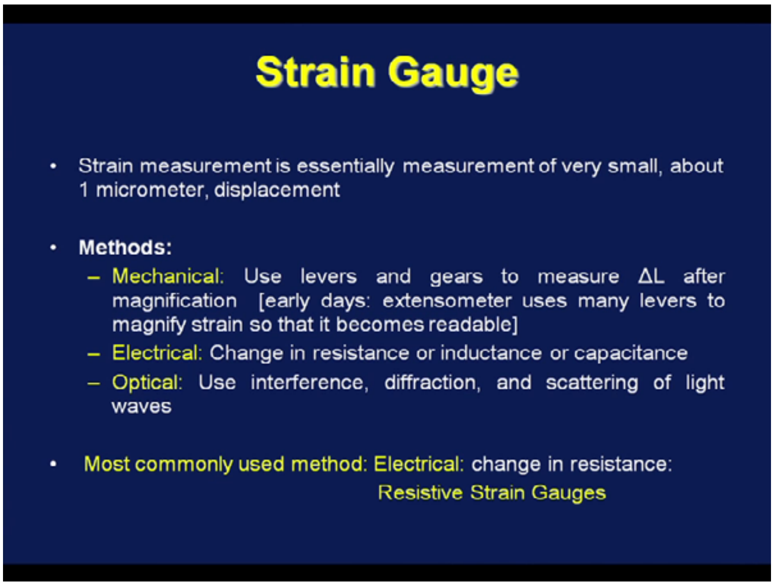

Strain measurement is essentially measurement of very small displacement by very small we main as small as 1 micro meter. There are various methods for measurement of strain there are, mechanical methods, electrical methods, as well as optical methods. Mechanical methods use levers and gears to measure change in length after magnification. For example, early days we use extensometer to magnify strain extensometer uses many levers to magnify strain so, that it becomes readable. Electrical methods uses the properties such as, change in assistance or inductance or capacitance to measure strain. Optical methods use uses interference, deflection and scattering of levers. The most commonly use method is electrical method that uses change in resistance of a resister when it is strain. Using this principle we have Resistive Strain Gauges transducer.

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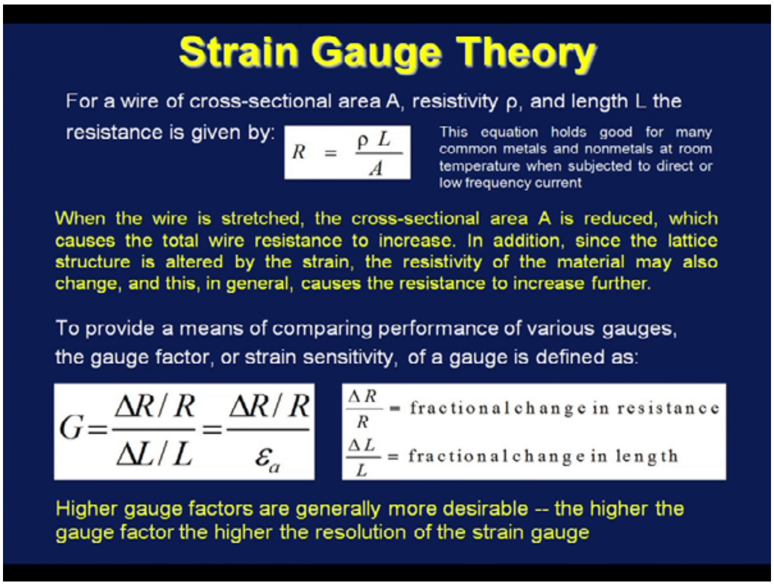

For a wire of crosssectional area A resistivity rho and length L the resistance will given by the familiar equation R equal to rho into L divided by A. This equations holds good for many common metals and non metals at room temperature when subjected to direct or low frequency current. When the wire is stretched the cross sectional area is reduced, which causes the total wire is resistance to increase. So, when the wire is stretched, we increase the length reduce the area and the resistance does increases. In addition since, the latistructure is altered by the strain the resistivity of the material may also change and this in general causes the resistance to increase further.

To provide A means of comparing performance of various gauges. Let us define something called gauge factor or strain sensitivity. The gauge factor or strain sensitivity can define as, delta R by R over delta L by L. So, this is the fractional change in resistance which is delta R by R by axial strain or longitudinal strain, which is fractional change in length delta L by L. So, we define gauge factor is fractional change is resistance divided by fractional change in length. In other words fractional change in resistance divided by axial or longitudinal strain. Higher gauge factors are generally more desirable the higher the gauge factor the higher the resolution of the strain gauge.

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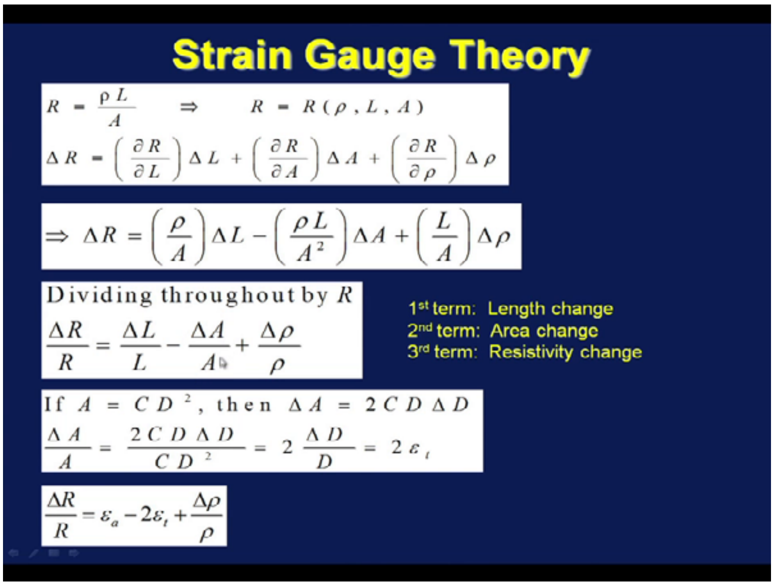

So, you have a functional relationship between resistance and resistivity length and area. So, we can find out change in resistance delta R as del R, del L times delta L, plus del R del A times, delta A plus del R, del rho times del rho, delta rho. Now this partial derivatives can be found out from the equation R equal to rho into L divided by A. So, if I find out this partial derivatives we can write delta R as rho A into delta L minus rho L by s squire into delta A plus rho by L by A into delta row.

If I now, divide this equation throughout by resistance R. We will have delta R by R which is fractional change in resistance as, delta L by L minus, delta A by A plus, delta rho by rho. So, the first term delta L by L is fractional change length. The second term this fractional change in area. And the third term is fractional change in resistivity. If we assume the relationship of area with diameter s A equal to some constant C into discover then, you can write delta A as 2 into C into D delta D. So, then it becomes possible for us to find out delta A by A. And we will see by delta A by delta A is to C D delta D divided by C D square A is C D square. Which is 2 delta D by D and delta D by D is nothing, but lateral strain or transfer strain epsilon t. So, delta A by A becomes to epsilon t. So, the fractional change in desistance delta R by R can be written as epsilon a minus 2 epsilon t plus delta rho by rho. So, this is axial strain minus twice lateral strain plus delta rho by rho.

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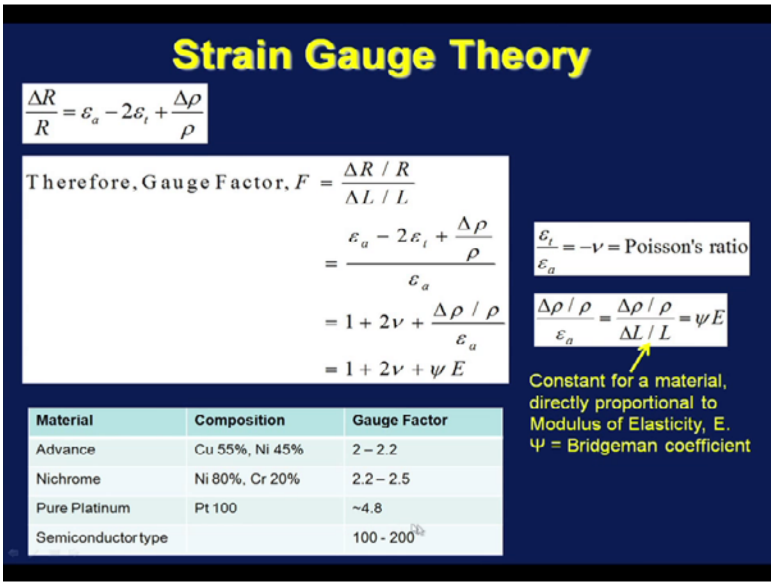

So, the gauge factor which is delta R by R divided by delta L by L. Can now be found out as epsilon a minus epsilon t plus delta rho by rho divided by axial strain. Which will become 1 plus 2 nu where nu is the poisson ratio, epsilon t epsilon a equal to minus nu plus delta rho by rho epsilon a which axial strain. Now, this term which is delta rho by rho divided by epsilon a, which is delta rho by rho divided by delta L by L is constant for a material and this directly propositional to modulus of elasticity. And the propositional laity constant is known as Bridgeman coefficient.

So, the gauge factor is finally defined as, F equal to 1 plus 2 nu plus epsilon E. I repeat the gauge factor is finally, found out to be as F equal to 1 plus 2 nu plus shy which is Bridgeman coefficient times E which is modulus of elasticity. If I, look at gauge factor of some of the materials that are used for strain gauge. We see that advance which as compassion as copper 55 percent and nickel 45 percent as the gauge factor increase 2.2.

Similarly nichrome which is an Li of nickel and chromium with nickel 80 percent and chromium 20 percent as gauge factor of 2.2 to 2.5. Pure platinum has higher gauge factor above 4.8. Semiconductor materials are also use for construction of strain gauges. And semiconductor type strain gauges have extremely high gauge factor of the order of 100 to 200.

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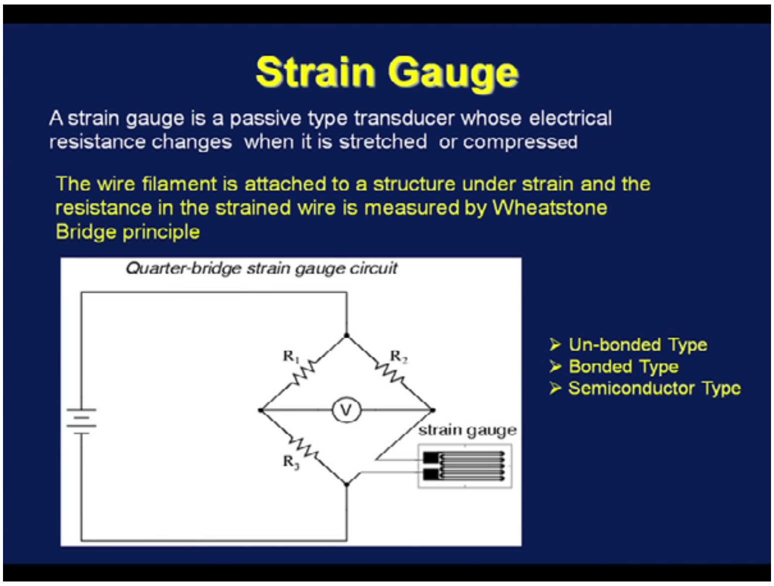

So, How do I measure state with help of a strain gauge? Strain gauge is usually in the form of a wire filament. It can be have various types like bounded type, unbounded type, or semiconductor type. Let us, consider this as strain gauge so, this consist of a resistance of wire. Let us, say the wire filament is attach to a structure which is under strain. And the resistance in the strain with is measure by the Wheatstone bridge principle.

So, we take the wire filament which is the strain gauge, attach to the structure whose strain I want to measure. Before the strain gauge is under any strain, we balance the bridge. Now, the strain gauge is strain so, there will be change in resistance and there will be an unbalance current in the Wheatstone bridge. And the unbalance current will be takes as a direct measure of the strain.

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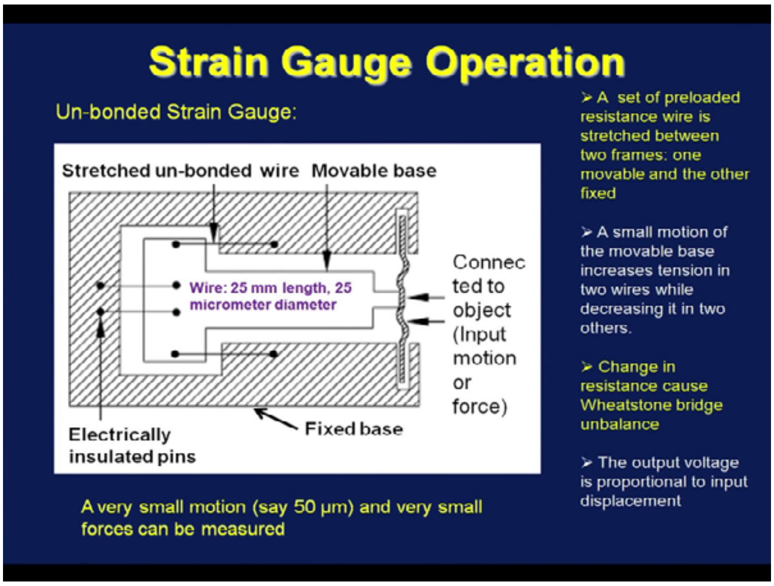

This is the schematic representation of unbounded strain gauge. It consists of a set of preloaded resistance wire, which is starched between two frames. One is movable and the other is fixed. So, a set of preloaded resistance where is starched between two frames. One is movable and the other fixed. Typically the wire we use is a 25 millimeter length, and 25 micrometer diameter.

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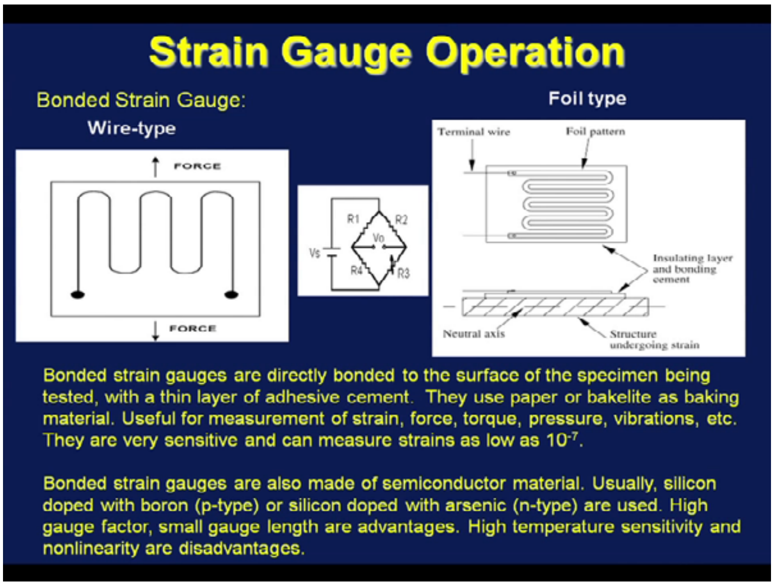

The movable base is connected to the object. So, this receives the input motion or force. So, this unbounded wires will now, be stretched. That will cause a change in resistance of the wires. And change in resistance will cause Wheatstone bridge unbalance. The output voltage is propositional to input displacement. A very small motion up to 50 micro meter and very small force can be measured.

These are schematics of bounded strain gauge, it can be of wire type or it can be of coil type. Bounded strain gauge is a directly bounded to the surface of the spacemen being tested, with a clean layer of adhesive cement. They use paper or bakelite as backing material. So, they use paper or bakelite as backing material, it should be backing. The bounded strain gauges are useful for measurement of strain, force, torque, pressure, vibrations etcetera.

They are very sensitive and can measure strains as low as 10 to the power minus 7. So, this is the structure this undergoing strain. And this is the foil which is bounded on the surface of the structure undergoing strain, with adhesive cement. These are terminal wires which is connect to the 1 arm of the Wheatstone bridge. Bounded strain gauges are also made of semiconductor material. Usually silicon doped with boron gives us P type semiconductor strain gauge, and silicon doped with arsenic gives as n type semiconductor strain gauge. High gauge factor and small gauge length are its advantage. However, How temperature sensitivity and non-linearity are disadvantages?

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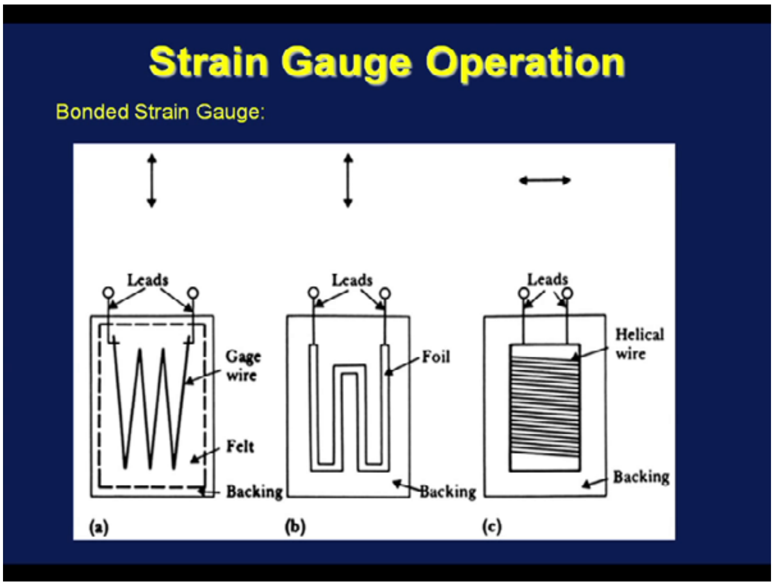

This figure again schematically represents various bounded strain gauges. So, these are the gauge wires, this is backing and this is cemented with this. And this leads are connected to the one arm of the Wheatstone bridge.

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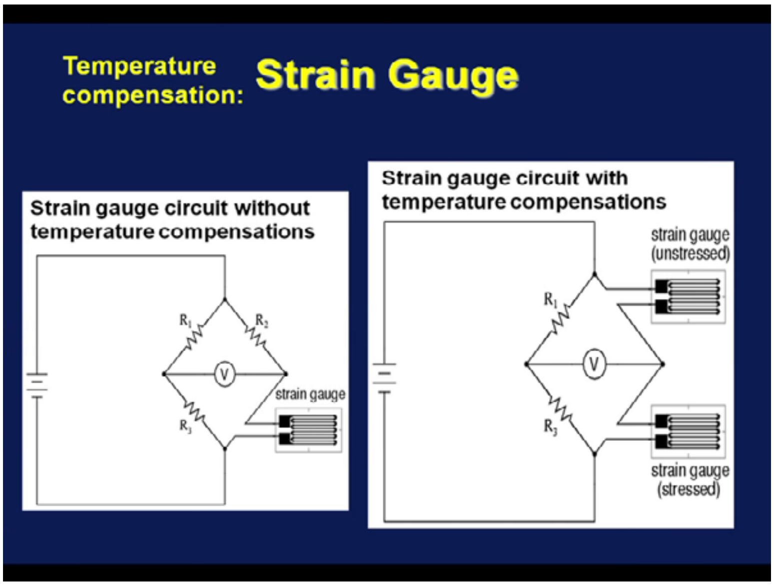

Now, the resistance of a wire can also change with changing temperature. So, there is any change in the ambient temperature that will, also try to change the resistance of the strain gauge. So, is not only the strain that will try to change the resistance of the strain gauge. But, also the temperature will also change try to change the resistance of the strain gauge. So, we need to compensate for the changes in temperature. So, this is the circuit diagram we previously discussed. Which does not have any temperature constants compensation. So, one arm of the Wheatstone bridge has the strain gauge. To have a temperature compensation we take two identical strain gauges connected to, 2 arms of the Wheatstone bridge. One strain gauge is stressed so, this is attach to the spaceman whose strain we are going to measure and other one is not strain. So, this is unstressed.

Now, the effect of temperature will be same in both the strain gauges. So, changes in resistance of the strain gauges by temperature alone will be same in both the same gauges. But, the strain gauge that is strained or stressed will have additional change in resistance, which comes from the strain. So, the changes in resistance due to temperature change will be nullified by the change in resistance of this strain gauge cause by temperature which is not strain. So, this way by putting two identical strain gauge. But, using only one to connect to the spaceman, whose strain I want to measure I can compensate for the changes in temperature.

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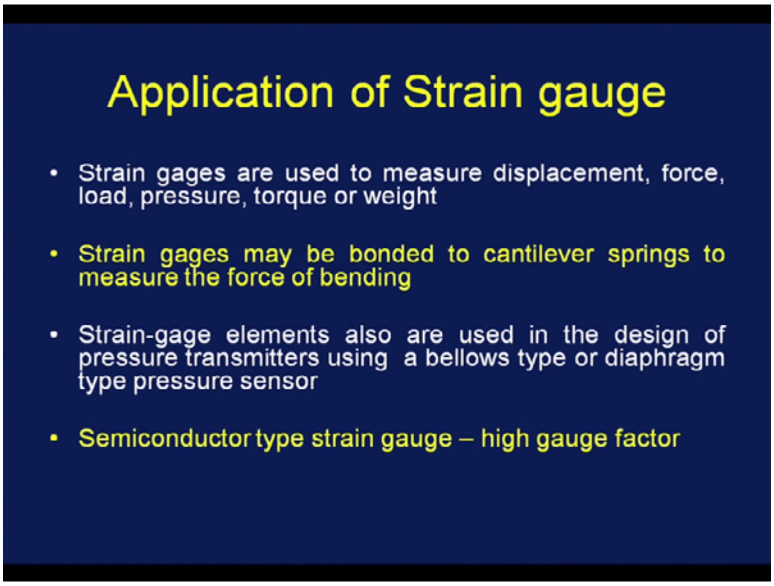

Strain gauge is the used to measure displacement, force, load, pressure, torque, weight. Strain gauges may be bonded to cantilever spring to measure the force of bending. Strain gauge elements are also used in the design of pressure transmitters using a bellows type or diaphragm type pressure sensor. Semiconductor type, strain gauge as very high gauge factor.

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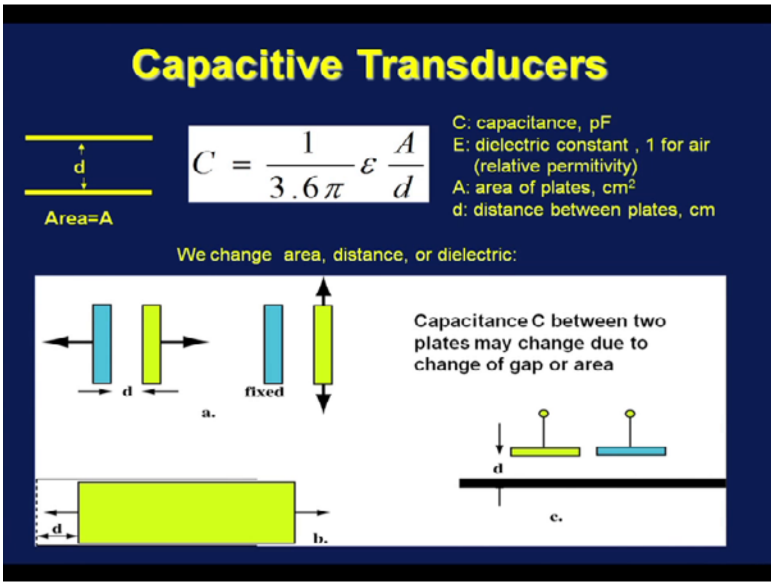

Let us now, briefly talk about capacitive type transducers. We are familiar with this equation for capacitance. Which relates capacitance, to area of plates distance between two plates and the dialectic constant or relative permittivity. So, if we take two plates which is separated by distance d and has area a. The capacitance in peck of ferrate will be 1 by 3 point 6 phi into epsilon, which is directly constant into A by d. Where A is area of plates in centimeter square d distance between plates in centimeter.

Now, we can make capacitance transducer by changing area or distance or dialectic medium. Any change in area distance all dielectric, will cause change in the capacitance. Next for example, if this two plates moves in this directions the gap within this two changes. So, there will be changing capacitance. If one plate is fixed anotherchanges the area between the two plates are changing. So, there will be capacitance change. So, I can have variable area Capacitance Transducer or variable distance capacitor transducer.

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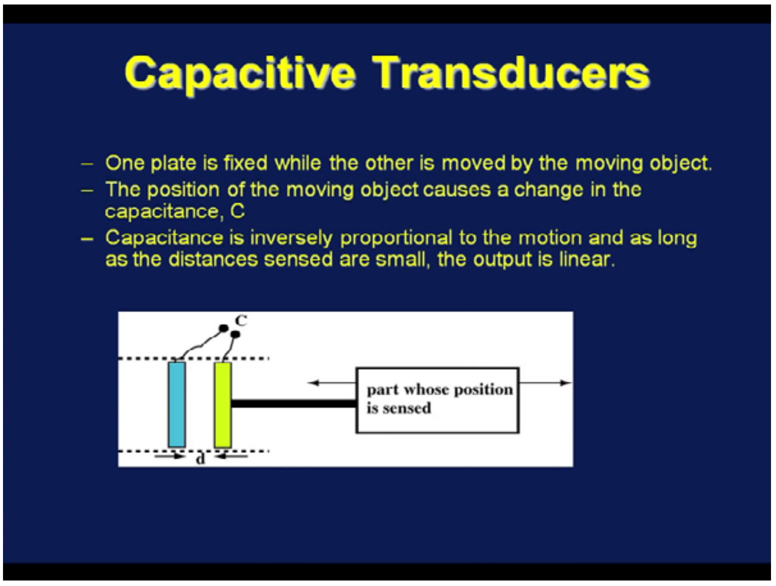

Suppose one plate is fixed when the other is moved by the moving object. So, the position of the moving object causes the change in the capacitance C. Capacitance is involves propositional to the motion as long as the distance is sensed or small.

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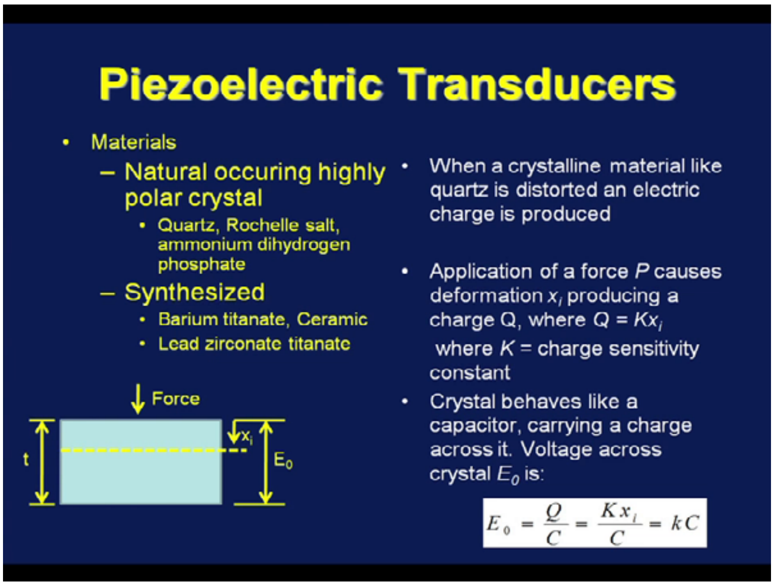

Finally let us briefly talk about, Piezoelectric Transducer. When a crystalline material like quartz is distorted an electric charge is produced. Application of a force P causes deformation xi producing a charge Q and we can write Q equal to K into xi. Where K is the charge sensitivity constant. The crystal now, behaves like a capacitor carrying across it. So, voltage approach crystal Eo will be Q by C and Q is K xi. So, we can write P 0 equal to K xi by C which can be K by C can be consider is another constant K. So, E 0 equal to K into C.

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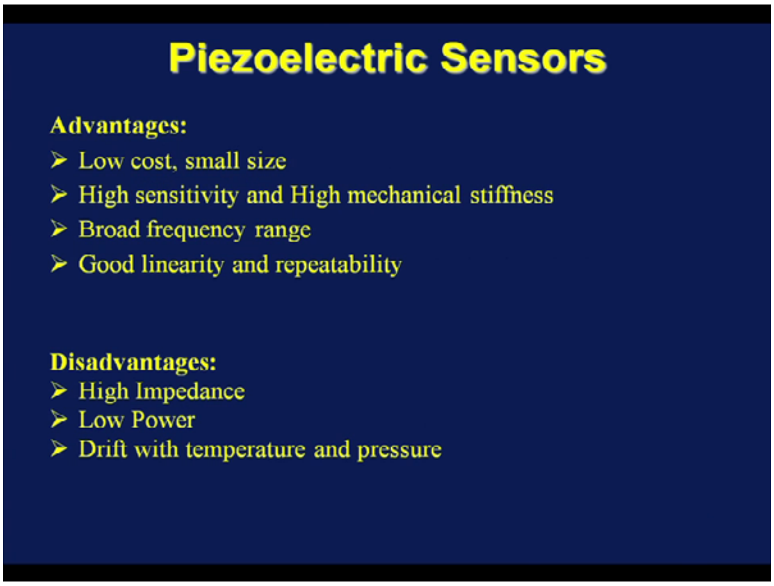

So, the voltage that is produced is propositional to the charge. Natural occurring highly polar crystals like quartz, Rochelle, salt, ammonium dehydrogenate phosphate. or synthesized material like barium titanate. Ceramic. lead zirconate titanate. are used for piezoelectric transducers.

Piezoelectric Sensors are advantages like it is have low cost small size high sensitivity and high mechanical stiffness, broad frequency range, good linearity and repeatability. However, it has some disadvantages as well it has high impedance low power and drift with temperature and pressure.