Transducers For Instrumentation
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Lecture - 25
Magnetic Sensors: Magneto-resistive type

Hello, welcome to the course transducers for instrumentation. Last lecture we started the magnetic sensors, and we discussed some property for example, magneto-elastic property and discussed a sensor based on that property. Magneto-elastic is the property when we apply a magnetic field and the dimension of the specimen or the material changes according to applied magnetic field. This property is reversible so if there is a change in the dimension accordingly there is a magnetic field change or the magnetic flux changed passing through that material and we discussed a torque sensor using yaw coil based torque sensor and we measure that if there is a torque on a shaft the dimension of the shaft actually changes because of this applied high torque and because of this change in the dimension there is a flux linkage which is different than in the neutral condition when we do not apply a torque. So when we apply a torque versus when we do not apply a torque there is a change in the dimension and accordingly the flux changes. So that was a torque sensor. Though the problem with measuring these change in the dimension is for example, we are applying a torque on the shaft and there is a 1 micrometer kind of small change is there in the dimension. So sometime it is difficult to detect that small magnitude of change in the dimension. So we go for a different kind of property something called magneto resistive property. Magneto resistive property is something when we apply a magnetic field on a material and the resistance of this material changes.

So this property is magneto resistive property and the materials which show these properties are magneto resistive materials and we can make sensors using this property. The easy thing about the change in the resistance is this can be electrically measured. We can apply a certain bias across the material and how much current is flowing that gives us the value of resistance and if there is a change in the resistance even if it is a small change in the resistance that can be easily captured by the electronics what we use for biasing. So we go for these magneto resistive based sensors. So today we discuss magneto resistive sensors on this property of a material changes with an applied magnetic field is known as magnetoresistance. So there is a change in the electrical resistance of material when we apply the magnetic field. However, the materials when we apply these magnetic field they also have some amount of magnetostriction. Magnetostriction means there is a change in the dimension. So when we apply a time varying magnetic field such as in transformers for example when this magnetic field is changing with time accordingly let us say sinusoidal wave there is a change in the dimension of these material and that change in the dimension is also oscillating because this change is because of that magnetic field and the magnetic field itself is time varying. So the dimension which is changing this is also time varying because of this change in the dimension and this is periodic change.

So magnetic this material this is oscillating this is sometime it is increasing and sometime it is decreasing based on the magnetic field which is sinusoid it increases and decreases sometime. So this material because of continuous compression and expansion this material is also like oscillating it is shaking. So because of that because this is a physical change in the dimension this material loses energy in terms of this mechanical waves. This material is sitting on some other surface is in the proximity of some other materials. This magnetic material now starts losing energy to outside environment because of changes in this physical dimension and this is a loss happening because of this oscillation that when we apply magnetic field we do not want the energy to be wasted to outside environment from this material but because of magnetostriction there is a change there is a transfer of energy this mechanical energy to outside environment. So we have something called magnetostriction which we discussed earlier as well. The phenomena in a material changes physical dimension by an applied magnetic field is called magnetostriction and the ferromagnetic materials lose energy to heat from the physical expansion. And contraction of the material caused by the magnetic field. This is particularly important for power distribution applications. Power transfer efficiency.

Is a critical factor. So we discussed that there is always a contraction and expansion in the material when we apply a time-varying magnetic field, and because of this the material actually loses energy in terms of heat to outside environment. It shakes, it vibrates and there is a kind of mechanical transfer of energy from this material ferromagnetic material to the environment. For power distribution systems and these application there is a critical factor of power transfer efficiency how much power we transfer using these materials and these materials are very much used in power distribution system for example the transformer. So electrical transformer is nothing but there are two windings one is primary one is secondary and we convert a high voltage from the primary to a low voltage in the secondary.

In the transformer we use a coil to kind of link the flux from primary to secondary and this core this is made up of magnetic material which is used for proper linking and this material is chosen so that there is a maximum flux linkage from primary to secondary. It means that the magnetic properties of this core should be changing very highly and instantaneously with the applied magnetic field or the electrical field on the primary. Now if the material this core material also has certain amount of magnetostriction means the size the dimension of this core also change with applied signal applied signal at the primary, then there is a continuous compression and expansion and this core loses this energy to outside environment in terms of mechanical vibrations. So very common example of this is when we go for go near to a very big transformer on the street or on somewhere then we see a humming sort of noise that is because of these magnetostriction because when this transformer is continuously converting this electrical energy from one high voltage to low voltage, then because of this frequency of electrical power supply there is a continuous contraction and expansion in the core, and that gives rise to that humming sort of sound, and this is nothing but the losing of energy to the outside environment. So for power distribution system this is a very critical factor and we want to have such type of material when there is no magnetostriction, or the amount of magnetostriction is very less so the core does not lose energy to the outside environment in terms of heat or vibration.

So one such material is the called nickel-iron alloy which we use for making the transformer cores. So we have a nickel iron alloy which is nothing but nickel 81 and iron 19 was found to have essentially zero magnetostriction and widely adopted as transformer core material. Allium alloy is the name given to this material. For approximately 80-20 nickel iron alloy. So we have a alloy which is almost 81% nickel and 19% iron.

So this composition of these metals which makes this alloy this is found to have almost zero magnetostriction it means when we apply a magnetic field, it does not change any dimension it does not create any kind of oscillation if we apply a time-varying magnetic field. So this alloy is very much useful for making these transformer cores because it generally does not lose any energy to outside environment in terms of mechanical or heat. So this is very much used this nickel-iron alloy for transformer cores, and it is a name given to this alloy which is perm alloy which is roughly 80 and 20% of nickel and iron. So this is a magnetic material which does not have any magnetostriction. Now these magnetic materials what we are going to discuss there are two types one is the hard magnetic material and one is the soft magnetic material.

Hard magnetic material is what we have to apply a very high magnetic field to polarize them to convert them into a permanent magnet and soft material are such materials we need a very small amount of magnetic field and they those materials get magnetized. So according to this we have two types of magnetic materials one is the soft type and one is the hard type. So hard and soft magnetic materials. Though these terms are kind of poorly defined. A soft magnetic material are easily modified by an external magnetic field.

Soft materials may even be affected by the internal field from the device. These soft magnetic materials typically have a relative permeability of greater than 1 typically 10 or higher. So these soft magnetic materials they can be easily modified by applying a small amount of magnetic field and even that small magnetic field can be even generated within the device itself due to some external factors and typically these magnetic materials have a relative permeability in the order of 10 or even higher may be 1000 value. These are the soft magnetic materials because they are easy to be magnetized by the small magnetic field. They can be characterized by essentially. being immune to the effects of internal or external magnetic field. And the relative permeability of hard magnetic material are nearly unity. So these are hard magnetic materials. They are very difficult to get magnetized and they are very immune to even internal or externally applied magnetic field and the relative permeability of these hard magnetic materials are almost close to unity. Now, if we want to make a permanent magnet, for example in the speaker phones or we need a permanent magnet, which is always there.

So it is good to make these permanent magnets using the hard materials or hard magnetic materials because once you get them magnetized, it is difficult to get them magnetized, but once you magnetize them demagnetization is also not easy. So you magnetize them once, and they retain this magnetization for almost for a very long time. So permanent magnets they are made up of hard magnetic fields or hard magnetic materials. On the other hand if you have some sort of a transformer action where you are changing the magnetic property using a time varying magnetic field, and you want to change it very rapidly. Those materials need to be soft materials so that it is easy to magnetize and demagnetize them.

So we have permanent magnets which should be made using the hard magnetic materials and for example the transformer code that should be soft magnetic materials. We have permanent magnets are typically hard magnetic materials and per this permalloy is considered a soft magnetic material. So we saw that we have two types of materials magnetic materials hard type and soft type is easy to magnetize one compared to the other one. Now we will see how to make a sensor using these magnetic materials. The sensor is something now on which we will apply a magnetic field from outside and we will measure how much is the magnetic field apply on these materials.

So the property of these materials will change as per the applied magnetic field. Now let us see how do we make these sensors. So the first thing is we use these materials but we want to have a very small size of sensor. So typically we go for the deposition of these materials on a certain substrate for example let us say silicon we have a silicon substrate and on top of them we deposit these magnetic materials a very thin layer using the metal deposition and then we will kind of do photolithography to etch out the extra material and we pattern these magnetic materials on the silicon that is our sensor. Now, we apply a magnetic field on this patterned magnetic material and see how much the change in the property.

For example the resistance of this material how much is change. So let us see how do we make this sensor. So the process is the film deposition. So we begin with a substrate on which or a base on which to create the magnetic field. This substrate is sometimes glass or ceramic. But if the permealloy to be integrated. With an active device active device or circuit. Such as amplifier the substrate need to be silicon. The substrate must be smooth because the film is very thin. The permalloy is deposited for example, by sputtering on substrate. For many magnetic films the deposition is performed with a magnetic field. To create a preferred magnetic direction. Often referred to as easy access. Alternatively. The preferred direction may be created after deposition also.

By heating the film. In the presence of external field. So when we make the sensor we begin with a substrate on which we deposit this material magnetic material to make a sensor and this substrate is sometimes glass or ceramic. But sometime we want a active circuit as well for example amplifier because the signal generated by these materials are very small. So we want to have immediately an amplifier stage to boost this signal immediately. So this active circuit sometime we want it on the chip itself because if we use a discrete amplifier the signal will fade away when reaching from the magnetic material to the amplifier.

So sometime we want the circuit or the amplifier right very close to this magnetic field. So if we want to integrate this magnetic field along with the active circuit then we need to go for the silicon only because on silicon only we can make all these integrated circuits the amplifier. And the substrate must be smooth because the film we use of this magnetic material is very thin. So the substrate must be very smooth so that we can lay down a layer which is very thin. And this permalloy is deposited generally as a thin magnetic material often by sputtering there are multiple process but sputtering is generally used for the permalloy deposition on the substrate.

When we deposit these materials on the substrate for example by sputtering so sputtering is nothing but this material actually we bombard this material and this material actually kind of go out in the inside that chamber and stick to our substrate. While this material is sticking to the substrate at that point itself we apply a magnetic field in the chamber so that when this material is actually depositing on the subset that if that point itself it is magnetically kind of aligned all the domains they are already aligned so we get a easy access which is our preferred access in which we apply the magnetic field accordingly the material will be deposited. So by default there is a magnetization of this material while deposition itself. So this is what we do when we deposit these materials on substrate. This is sometime difficult because applying a magnetic field while doing the sputtering this can be a little bit challenging sometimes.

So this can also be done after deposition of the film what we can do we apply a high magnetic field and we heat up the material this thin film we will do a little bit of heating so that all the atoms or all the domains magnetic domains magnetic dipoles they are they have this kind of this thermal energy to move there and we apply a magnetic field so that they get aligned to that magnetic field and then cool it down so that they remain there so this magnetic material actually get magnetized even after the deposition by heating it up using the applied external magnetic field. So this is how we deposit these materials on a silicon or any other substrate which is a very thin film. So now we have these magnetic field measurement and let us first discuss about this measurement along the hard axis with a magnetic field applied perpendicular to the mechanical length. perpendicular to the mechanical length in the hard axis direction the response of the device is shown below. So for example we have this graph on the x axis we have the angle which is let us say given in 0 degree 0 10 20 30 and so on.

This axis is let us say given in worsted and on the y axis we have delta R by R in percentage so let us say this is at 0% this is minus 0.5 minus 1 minus 1.5 minus 2.0 and the graph actually look something like this at this 0. So this is the graph of delta R by R with applied magnetic field when this magnetic field is changing this angle from let us say minus 20 to plus 20 this is the response of the magnetic material. So the resistance decreases with applied field the resistance is maximum at 0 applied field. The maximum change is approximately 2.5%. And this change is film thickness dependent.

Up to a bulk level of around 3%. And thicker film typically has a higher delta R. So, in this case we make this sensor using this magnetic material and we measure along the hard axis. The hard axis is what this is the axis which is perpendicular to the physical length. So for example we fabricated that the sensor which has a magnetic material deposited in x direction. So the dimension perpendicular to this for example y dimension this is the hard axis for this sensor.

Now we apply the magnetic field along the hard axis. So this is not along the mechanical length this is perpendicular to the mechanical length and we are applying a magnetic field on this material. Now if we change this magnetic material let us say for minus 20 to 20 for example we change the dimension the direction in negative it was like in let us say in the negative y direction in when it is 20 it is in the positive y direction. So when this magnetic field is applied on along the hard axis there is a change in the resistance of this magnetic material and this change is typically shown with this graph. This is maximum at zero applied magnetic field and when we apply the magnetic field in either of the direction there is a change in the electrical resistance it decreases by approximately 2% if we apply a magnetic field even in the positive or as well as negative the direction the change is same we see the bell shaped kind of curve which is symmetrical along the zero axis.

So it shows the direction of the magnetic field does not matter but there is a change in the magnetic field when we apply along the hard axis and the magnitude of this is typically 2% which is good enough for detection using the electrical amplifiers or so we can detect this 2% change in the magnet in the resistance using our electronic circuits. So we have this maximum applied field at the zero and decreases to 2.5% this change is also the film thickness is dependent if we deposit a thicker film it typically gives a higher change in the change in the delta R by R so this change is also the thickness dependent how much thick we have deposited the this magnetic material. So now the magnetic field measurement along the easy axis along easy axis. So when a field is applied along the mechanical length then it is along the easy axis.

So, along the mechanical length in the easy axis direction. The figure below shows the change in the resistance along the easy axis. So, we have this is the zero. And this is 10, 20, 30 and this is in the reverse direction minus 10, minus 20, minus 30 and the y axis is delta R by R. And the change is a little complicated than the hard case while going higher this is the zero point while going higher it shows this kind of behavior and then goes like this. This is while going this direction while coming back let's take the different color because this shows different path while coming back. So while coming back this comes like this and decreases here and it goes like this. So here we see when we change the direction of magnetic field while going on towards negative to positive this dip or the decrease in the delta R by R it happens at let's say 15 value. But while coming back from positive to negative this does not happen at the same point but now it happens on the between minus 20 or minus 30 or so. So this has different path for going high and going low this is we call the hysteresis it means that the device shows the hysteresis effect and this kind of behavior of this graph sometime we call it the chirp.

So this is how the magnetic field of these sensor changes we have we fabricate these the strip the very thin film of these magnetic material on the substrate. And when we apply a magnetic field the resistance of these which we can measure using our biasing circuitry we apply a constant bias across it and measure the current flowing through this. Now the effect when we apply this magnetic field this depends on in which direction we are applying the magnetic field if it is along the hard axis then we have shown that bell shaped curve that is the change in the resistance and if we apply the magnetic field in the easy axis or on or the along the mechanical length then the resistance change shows this kind of typical behavior and we call this something called chirp. So this is how the magnetic sensor works more specially specifically the magneto resistive sensor works where the change in the resistance of the magnetic material when we apply this external magnetic field.

So, this is all for today.

Thank you.