Transducers For Instrumentation
Prof. Ankur Gupta
Centre for Applied Research in Electronics (CARE)
Indian Institute of Technology, Delhi
Lecture – 24
Magnetic Sensors: Magneto-elastic type

Hello, welcome to the course transducers for instrumentation. Today we are going to talk about the magnetic sensors. Magnetic sensors are the sensors where we where we use the magnetic properties of a material to sense a measurement. So magnetic properties is we can classify broadly in two terms one is when a change in the magnetic property give rise to change in the size or the dimension of the material and the second is when we apply a magnetic field and the magnetic property give rise to a electrical change in the material property. So there are two ways we can use a magnetic material to make a magnetic sensor. So the first one is the magneto-elastic property where the dimension of a the sample or the magnetic material is changing when we apply a magnetic field. So today we are starting magnetic sensors and in this we use magnetic properties of material to make a sensor for sensing of measurement. So the first one in this is magneto-elastic properties or magneto-elastic effect. These are the effects when there is a change in the sample dimensions. Q2 applied magnetic field.

So this is magneto-elastic effect and the reverse of this effect is elasto-magnetic effect when there is a change in magnetic susceptibility. Due to applied mechanical stress. So, here we have two effects magneto-elastic effect when we apply a magnetic field and the sample dimension the length and width of the sample actually changes because of the application of this magnetic field that is called magneto-elastic effect and the reverse of this is elasto-magnetic effect when we when we apply a mechanical stress when we compress the material by applying force or we expand it because of the change in the physical dimension of the material it develops certain change in the magnetic properties such as the magnetic magnetic susceptibility. So this effect is called elasto-magnetic effect. Let us see how this happens actually in the materials. So in the materials we have generally the dipoles magnetic dipoles inside the materials and this happens due to the alignment of these dipoles when they are aligned then the dimension actually changes of these material and when they are in the random fashion there is a different length. So let us see in by a cartoon how this happens actually. So for example we have a certain material which is magnetic material here and inside this we have magnetic dipoles. So when these magnetic dipoles are not aligned so let us say this is one dipole and the direction is like this we have second dipole. So right now they are randomly arranged but if we apply a magnetic field and all these dipoles within this material they align to that magnetic field then they look something like this.

This is first dipole, this is second dipole. So if we see on the bottom when we apply a magnetic field all these dipoles are aligned in a line and they take let us say a distance of L which is the dimension along x axis. This is the length f of this material L of this material but when we do not have a magnetic field all these dipoles without magnetic field they are random in nature they are aligned randomly. Because of that if we see there is a difference in the distance how much area they occupy or how much length they occupy in x direction we see they occupy somewhat smaller length than L and this is let us say the error or the extra length which is caused because of the application of magnetic field. So here H is 0 and here is H is applied which is a vector quantity. So here we see because of the application of magnetic field all these dipoles are aligned and when they get aligned they take up more length compared to when they were taking without the magnetic field. So because of this change in the length of this dimension the x direction of this material changes it increases when we apply a magnetic field. So this effect is called magnetostriction when the length of a material changes with application of a magnetic field. So we have a effect something called magnetostriction. This is the property of ferromagnetic material. Which cause them to expand or contract in response to an applied magnetic field. So here we have a property which is called magnetostriction.

This property actually because of this property a ferromagnetic material changes its dimension because of the applied magnetic field and how does it change that we have shown in this figure when the dipoles which are there in the ferromagnetic material when they get aligned they take up a different length and when they are not aligned they take up it something smaller length and because of this delta the change in the length this is this property is called magnetostriction. Now magnetization when we apply a magnetic field there are two types of materials one material is they because of the application of magnetic field there is a change in the magnetic property of that material and the second type of materials is when we apply magnetic field there is a change in the electrical properties of those material for example the resistance when we apply a magnetic field there is a resistance change of those materials. So there are two types of materials based on the what is the output of those materials. So magnetization changes or produces effects which are mechanical or electrical in nature. Then the first one is magnetic elastic field sensors. These are the sensors when there is a change in the Young's modulus with magnetization. So there is a change in Young's modulus with magnetization. This is also called delta y effect. And these sensors are often termed as acoustic delay line components. So acoustic delay line components or ADLC. So this is first type of sensors. The next we can make torque or force sensor using magnetic materials. So these are torque or force sensors.

The torsion is produced using a ferromagnetic rod carrying current when subject to a longitudinal field. So these are torque or force sensor. The third one which we are going to discuss in this in these lectures are magnetoresistive sensors. When there is a change in the electrical resistance. When subject to a magnetic field. So these are magnetoresistive sensors. And the fourth one is the Hall sensors or the Hall effect sensors or we can also call them magneto galvanic sensors or we call them magneto galvanic sensors. In these sensors there is a crystal carrying a current. Produces a transverse voltage. When subject to a magnetic field. So these are the four types of sensors where we have the first one is magneto elastic. Then there is a change in the Young's modulus of the material when we apply a magnetic field. So this is called magneto elastic field sensor. This we are going to discuss. The second one is torque and force sensor when we apply a torsion in the ferromagnetic material.

Then there is a kind of change in the property of material. This is torque and force sensor. The third one is magnetoresistive sensor when the electrical resistance of the material changes with the applied magnetic field that is magnetoresistive sensors. And the fourth one is the Hall effect sensors or we call them magneto galvanic sensors. There is a material which is carrying a current and we apply a magnetic field on this crystal or on this substrate. There is a transverse voltage which develops in the material. So this is based on the Hall effect and we call it the Hall effect sensor or the Hall sensor. So let us discuss magnetic field, magnetic field sensors in detail. And this delta y or the change in the Young modulus is an effect of the outcome of magnetostriction. So, a demagnetized ferromagnetic material. When undergoes a mechanical stress. It develops two types of stresses. So, when we have a ferromagnetic material and we expose it to a mechanical stress, there are two types of stress actually developed within this material. One is the normal stress which is developed in all the materials and the second one is this is special stress which happens because of the magnetoelastic strain because the dipoles are actually aligning because of that there is a extra stress which is developed inside the material which is special only for the ferromagnetic material. So when we expose this material to magnetic stress, there are two types of strain which is actually being developed. One is the normal one which happens in all the material and the second one is special to magnetic materials because of this alignment of dipoles. So we have two strains developed. The first one is the plane mechanical elastic strain. Let us say we call it epsilon s and the second one is the magnetoelastic strain epsilon m which is the result of reorientation of those dipoles. Reorientation of those magnetic dipoles or magnetic domains by the applied stress and let us call the applied stress as SA.

So we can write the overall Young's modulus for this magnetized material. So overall Young's modulus of the demagnetized material. So the overall Young's modulus of this material is given by capital Y which is the Young's modulus is equal to SA the applied stress divided by the total strain which is developed and the total strain is epsilon s plus epsilon m. So the Young's modulus here is different than the normal material which is SA over epsilon s. For the magnetic material this is SA upon stress strain developed because of the plane mechanical stress and an additional strain which is epsilon m. So the Young's modulus is now a function of this special strain as well. This delta Y effect occurs in nickel iron based crystalline alloys. And in some amorphous alloys. Such as this alloy where the iron is let's say 40% nickel is 38. So this delta Y effect occurs in nickel iron based crystalline alloys and some other amorphous alloys. For making magnetic field sensors and one typical construction is the delay line sensors. Delay line sensor is very much similar to what we discussed in acoustic sensors. In delay line sensor we have a substrate which in our case now is a magnetic material and on top of it we put IDT structures. So this is a typical delay line sensor where in this case we have a magnetic material and we apply a electric signal on the left and we measure at the right side using some instrument voltmeter or so and there is a wave which is propagating on this material. Now when we apply a magnetic field on this magnetic material there is a change in the length because of the magnetostriction.

This length of this magnetic material will change and if the length of this magnetic material will change the delay reaching from the input to the output will change. So this is called delay line sensor and this delay which is produced by because of the change in the length. This change in the length is proportional to the applied magnetic field. So we apply a magnetic field higher magnetic field then the elongation will be more and it will produce more delay in the measurements. So in this way we can measure the applied magnetic field using the delay line sensor.

So this is our delay line sensor. The sound velocity or in fact sound is a mechanical wave so the velocity of this mechanical wave is given by V is equal to under the root Young's modulus Y over rho which is the density of the material where this rho is the density of the material. And the change in the velocity delta V is given by delta V over V is equal to delta Y the change in the Young's modulus divided by the original Young's modulus. in V of about 10% can be obtained. So here we see a delay line sensor where we use the magnetic material as a substrate. When we apply the magnetic field there is a change in the dimension change in the length of this magnetic material. Accordingly there is a change in the Young's modulus which is the property of material and the sound velocity or the velocity of mechanical waves is given by V equal to under root Y upon rho. Rho is the density of the material which we assume remain fixed or remains constant. Then delta V upon V delta V is the percentage change in velocity is equal to under root delta Y upon Y which is the change in the Young's modulus of the material. And typically in the alloys what we mentioned here typically a change of 10% we can achieve easily at room temperature when we apply these magnetic fields.

So this is the delay line sensor. Let us now discuss the force or the torque or the pressure sensors. Torque or force sensor using magnetic materials and the very common example is the yoke coil sensor is used for torque measurement. So in this yoke coil sensor we have a U shaped magnetic pole. magnetic pole pieces are mounted in a crossed fashion.

facing the sharp surface to provide narrow gap. One of these U branches used as primary. with two coils P1 and P2 excited by NAC supply. And the other U branch or the second U branch is mounted at right angle. So two secondary coils let us say S1 and S2. So in this torque or force sensor we use a yoke coil based sensor. In yoke coil sensor what we have we have two U shaped coils one U shaped coil it has two coils actually one on one side and one on the other side. These two P1 or P2 they act as a primary coil we excite both of them using some AC signal and we have a second U shaped branch which is placed perpendicular to this primary. So primary let us say it aligns in the Y direction then secondary is aligned in the X direction. Secondary also has two coils one S1 one S2. So this secondary coil will pick up the flux generated by the primaries P1 and P2. So it looks something like this. This is one primary and on this primary we have two coils which is bounded on one side here and one on the other side here and we excite them using external electrical signal. These are connected here. This is the primary and we let us name it P1 and P2 and we have a secondary U shaped curve which is let us say perpendicular to this. This is secondary winding. This will pick up the flux generated by the primary which we can measure using some voltmeter or so and these secondary windings are let us say S1 and S2 and these are S1 and S2 are perpendicular to P1 and P2.

This assembly is called yoke coil and we put it in very close proximity with the moving shaft. This is the shaft which is applied some torque in this direction. So now if we see all these primary and secondary coils and plot the flux generated by primary and received by secondary, these are our primaries let us say P1 and P2. When we do not apply any torque to the shaft, there is a uniform field distribution generated by this P1 and P2. And here we have our secondary placed here and here perpendicular to P1 and P2. So in this diagram, this is the flux diagram we see P1 and P2 are generating the flux in the shaft. Shaft is coated with some magnetic material. And P1 and P2 when they are generating this flux, this flux is uniform and it reaches S1 and S2 at the same time. P1 generating flux and that also reaches at the same time when the flux generated by P2 reaches the secondary. So because of the symmetry we can see S1 and S2 receives the flux at the same time generated by P1 as well as P2. This is the condition which happens when there is no torque applied on the shaft. There is no kind of field or the change in the magnetic properties of material of the shaft or something is coated on the shaft. When there is a torque applied because of the magnetostriction, when we apply a mechanical stress on the shaft, the magnetic property of this material, the shaft that it changes and because of the change in the magnetic field or the magnetic properties, the flux what we have shown here which is uniform for time being, this uniformity will disturb and because of the application of torque, if we apply more torque, the more change will be there in the magnetic property and more disturbance will be there in this flux.

So if we draw the same diagram, when we apply the flux, it will look slightly different, it will not be uniform and this non-uniformity which will be picked up by S1 and S2.

Accordingly, we can see that how much is the flux change compared to the normal condition that change in the flux or change in the secondary voltage that is proportional to the torque applied on the shaft. So if we plot the flux in case of applied strain, so this is the one without mechanical stress or without torque. And now we plot flux with torque. These are P1 and P2 primaries. This is the neutral axis where we have these secondaries S1 and S2. Now because of the change in the magnetic property of material, this flux let's say linked more towards S1 compared to S2. So we see there is a more flux picked up by S1 compared to S2 and vice versa. So this change in S1 and S2 voltage because this flux will lead to some potential buildup across secondary windings S1 and S2. This magnitude of this secondary voltage gives us the reading of how much the torque is applied actually on the shaft. One point to note here in case of yoke coils because we are relying on the magnetic property change of the shaft. So the yoke coil which we are using here, this need to be placed in very much proximity of the shaft so that the change in the magnetic property of the shaft affects significantly on the flux linkage of primary and secondary. So we need to have a very close closely placed yoke coil with the shaft for accurate measurements.

So depending upon the material the sensitivity of this transducer system changes. For example, a more branch type design sensitivity varies from 1 milli volt per Newton meter to about 2.5 milli volt per Newton meter when material is C15 steel or chrome MOB steel. In general, the torque sensitivity increases with increasing hardness of ferromagnetic material. Other parameters governing the sensitivity are excitation frequency, etc. And these can be chosen based on the following basis. For example, transient requirements, shaft speed, shaft material, and shaft speed. So, in this yoke coil based sensor, depending upon the material, the sensitivity actually changes and for C15 steel, the sensitivity actually varies from 1 milli volt per Newton meter to 2.5 milli volt per Newton meter. And this generally the sensitivity decreases for the hardness of ferromagnetic material. The more the harder the material is, the sensitivity goes down. And there are multiple parameters which we can use for improving the sensitivity. For example, excitation frequency or the frequency at which this AC signal is applied, that can be used as one parameter. And we choose all these factors based on multiple requirements. For example, transient requirements, shaft speed, how much is the shaft speed, shaft material, and the output signals. These are some parameters on which we decide which frequency and what parameters we need to use to make this torque sensor.

So, this is all for today.

Thank you.