Course Name: Design of Electric Motors

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Title: Magnetic Fields-1

Greetings to all of you. In the last class, we have discussed about electric fields. In this class, we will discuss about basic principles of magnetic fields. The magnetic fields are created by moving charges or electrical currents is invented by Orsted in 19th century. He also concluded that magnetic fields are always dipoles and there is no monopoles, but whereas, electric fields are monopoles. So, in this class, first we will discuss about the magnetic field sources.

So, in this class, first we will discuss about the magnetic field sources. What are the magnetic field sources are available and how we can utilize it to design the magnetic circuits? The first source of magnetic field is nothing, but earth. in 16th century, Gilbert invented that earth also exhibits the magnetic phenomenon. So, if we will take the earth in this manner, here north and south, so the magnetic flux lines will flow from the north to south and the magnetic flux lines will flow from north to south and the magnetic field lines will not intersect each other.

So, this is the magnetic field source 1. After that, Orsted invented that electric currents produced by the magnetic fields, electric currents produces the magnetic fields. So, he did the experiment with the current carrying conductor. If I will consider a current carrying conductor, this is the conductor and current flowing through the conductor is in this direction. Then as per thumb rule, we can see the magnetic flux lines in this direction.

We can apply a thumb rule like current is flowing in this direction and with respect to the current perpendicular direction, we will see the flux lines. So, this is a source of magnetic field 2. So, here magnetic field is going in and here magnetic field coming out, going in and coming out. This is the B fields, not the currents. B field is going in and coming out and this is the current.

So, Arstert invented this kind of analysis and it is a magnetic field source 2, current carrying conductor. So, how to find the flux direction is we can apply a thumb rule. The thumb represents the current and fingers represents the flux lines. If you will represent the current with fingers, then we have to consider the thumb is nothing, but flux. Now, how to find or what is the magnetic flux with respect to the electric flux? What is the magnetic flux? Gauss law of magnetic flux, we will discuss now.

Gauss law of magnetic flux will give the relation with respect to the magnetic fields and magnetic flux. The magnetic field is nothing, but B. The relation between B and phi, we will get with respect to the Gauss law. In order to find the relation between the B and phi, we will consider the magnetic flux lines are flowing in this manner and consider an arbitrary surface or any closed area. We can take in this manner from here.

I am taking a small portion d A and B fields are in the same direction and I am considering a unit normal that is n cap. The angle between B and n cap is nothing, but theta. The change in flux is equals to B dot n cap into d A. Generally, n cap into d A represented as d A bar. It is also a vector B dot d A.

If you want to find the flux, then you have to integrate it with respect to the entire area. We have to integrate it d phi B equals to integral of B dot d A. As per the Gauss law, with respect to the closed surface, the flux is equal to the total flux entering and leaving from the closed surface are equal and the flux inside the closed surface is equals to 0. This is because there is no magnetic monopoles. Why the average or total flux inside the closed surface is 0 means no monopoles of magnetic fields.

Inside this surface area, inside this area, this surface area, there is no source or there is no sink for magnetic field, no source or sink of magnetic field inside the surface area. So, this is the reason. Because of these reasons, as per the Gauss law, we can say that the flux inside a closed surface is equals to 0. Now, we have seen that flux, what is the magnitude and we have discussed the source 1 and source 2 of the magnetic fields. Next, we will discuss about the current carrying a loop or wire.

We have seen only one kind of single conductor. If current is going in, then the magnetic field lines will be in this manner. As per the thumb rule, if it is going in, then it will be clockwise direction and if current is coming out, it is opposite direction. So, this is the current carrying loop. Anticlockwise direction, we can see in this manner.

Now, the source 3, we will discuss with respect to the current carrying loop or single-turn coil. So, this is the single turn coil or we can generally, with respect to the electrical missions, we can see the coil in this manner. So, how the magnetic field looks like? So, the current is flowing in this direction and coming out like this manner and here also same. So, apply a thumb rule and identify the current carrying loop. How the flux lines are flowing? With respect to this portion, here flux lines are going in and here coming out and here also going in.

All flux lines are going in into the coil from the outside. Outside flux lines are dot. We can say that now, flux lines if I draw, then all flux lines are in this manner. Here, the loop will be in this direction. Here, current is entering.

We can relate with respect to this one. Current is entering at the left side and current is leaving at the right side. Similarly, top and bottom, we can relate it. So, flux is entering into the coil.

Here also same. Just apply a thumb rule and identify that how the flux lines are flowing. So, this side I can say that these are the flux lines are flowing in this manner. So, this side north pole and this side south pole. Generally, in a medium like if I will consider outside from the system, the magnetic flux lines will flow north to south. If I consider either this is permanent magnet or any coil, anything, the flux lines will flow from north to south.

Inside the medium, inside this block box, inside this thing, flux lines are flowing from south to north. Here, flux lines are coming in this direction. This is the source three single turn coil. How the flux lines will form? How the poles will form? The next we will discuss about the solenoid solenoid. Solenoid is invented by the ampere and instead of a single turn coil, let us consider the solenoid in this manner.

We are exciting this coil with a current I. Current is going in and coming out. Apply a thumb rule and assume that current is going and I am representing the current with fingers now and flux is in the with respect to the thumb. So, the flux is coming in this direction and current is going in and coming out. So, current is going in and coming out.

You just assume that current is going in and coming out and thumb represents the B fields. So, if I will consider the current direction, current is going at this point, current is entering and current is leaving, coming out at this point. So, like this if I will represent all corners of the coil, how the flux lines will be in for this plot? So, here with respect to this one and this one, we can draw the flux line plot. So, for the cross clockwise direction, for dot anticlockwise direction, so here clockwise all crosses are clockwise and all dots are anticlockwise and the resultant flux lines also will flow in this manner.

So, this is B. So, B fields are in this direction and if current is flowing in and out in this manner. So, this is the flux lines plot with respect to the solenoid and this is magnetic field source 4. This is the one invented by Ampere. What is Ampere's law states that the magnetic field in a space around a current carrying conductor is proportional to the source of it like current. The magnetic field surrounded by the current carrying conductor, assume that this is the current carrying conductor.

Here, current is flowing in this direction and magnetic field like this, clockwise current is going in. So, clockwise this is the B field. So, the magnetic field in a space around a current carrying conductor is proportional to the electric current which serves as its source. So, consider an electric conductor which is carrying a current where it is current is going into the board and the magnetic field is surrounded by that one is in the direction of clockwise direction. This is I and at a distance r, we are seeing the magnetic field B that is the radius of magnetic field circle.

Consider a small length dl on this loop. Consider a small length d l and tangent to that particular portion is nothing but B fields and the tangent in on this circle anywhere you will see the B fields. Now, the closed integral of B dot d l with respect to that particular small element is equals to mu naught into I enclosed. Here, I enclosed is nothing but the current which is acting as a source for the magnetic field.

Now, B dot dl equals to I. I am bringing mu naught this side and B by mu naught we can replace with magnetic field intensity I. So, this is the magnetic field intensity H dot dl equals to I. This is for single turn if n equals to 1 or number of turns per unit length equals to 1, then it will be this equation. If the number of turns are more, here we have considered a single conductor. If the number of turns are more, then n into I we have to consider that is H dot dl equals to N into I.

Here, MMF is nothing but N into I. The MMF is a dual of electromotive force or I can say voltage in the electrical circuit. This is the source for the magnetic field N into I. So, as per the Ampere's law, B equals to mu naught I into N. So, this is the source for the magnetic field N.

I am representing here. Here, N is equals to number of turns per unit length mu naught I into n divided by l. So, here mu naught is the permeability of free space. That is equals to 4 pi into 10 power minus 7 7 Henry per meter. So, let us consider we want to generate a 0.1 Tesla. Consider an SUB_TEXT example. We want to create a 0.1 Tesla with solenoid. So, as per the Ampere's law, what we have concluded? B equals to mu naught n into I divided by l or mu naught n I. n is nothing but number of turns per unit length.

Earlier also, we did the same. Here also, mu naught I into n because already we have considered the n equals to number of turns per unit length mu naught n I directly. So, here B equals to mu naught n I. So, mu equals to what? 4 pi into 10 power minus 7 into n is the number of turns per unit length. So, turns per unit length and current.

So, current is not given. Consider a 10 Ampere is the current rating and flux we require 0.1 magnetic field.

We require 0.1 Tesla. So, this side 0.1 Tesla and this side current is 10 Ampere. So, here n equals to what? 0.1 divided by So, this is equals to almost 8000 turns required per unit length, which is practically impossible. In other way, in order to generate the 0.1 Tesla, we have options with respect to n and with respect to current I.

So, we can increase either numberof turns or we can increase current. So, both are not feasible with respect to the practical limitations. So, what to do? So, in order to avoid this situation, William Sturgeon invented the electromagnet. What he did in a smart way is, in order to increase the magnetic flux density, he decreased the reluctance or he decreased the resistance with respect to the magnetic fields, that is, mu r. So, b equals to, as per the Ampere's law, mu naught mu r into n into I, he considered.

So, here mu r is the relative permeability of the core. So, he introduced a core such that it will enhance the flux density. So, that is the magnetic field source 5. So, this is the solenoid, what we have discussed and he introduced a core here, iron core. So, because of this iron core, the flux, the magnetic field density is increased or other way I can say that the resistance in the circuit is reduced, that means, the flux will increase in a magnetic circuit.

The magnetic resistance we are reducing. So, automatically the magnetic flux will increase. So, the magnetic field lines will be in this manner. So, because current is flowing into the coil and I am considering in this manner. So, current I am representing with the again fingers and field will be upward. So, the b fields will be direction in this manner b and current is in this direction.

Here, we can say that the magnetic field lines are flowing north to south outside the core and inside the core south to north it is flowing. Now, I will consider the same example. So, why we want to generate the 0.1 tesla and current is 10 ampere and mu r I am considering, iron core I am considering, iron relative permeability is 5000.

Now, we will find the what is the number of turns value. So, b 0.1 tesla equals to 10 ampere into mu naught is into n. So, n equals to here we will get it approximately 2 tons. So, without increasing the current value, without increasing the number of tons, we are not increasing the current, we are not increasing the number of tons, but we are getting the 0.1 tesla the required magnetic field. We are achieving the required magnetic field with the known number of tons and lesser magnitude of current. This is the advantage of electromagnets by incorporating the core. This is source 5 and source 6 is nothing, but permanent magnet. Permanent magnets also the source of magnetic fields. So, if I will consider a magnet in this manner, this side north and this side south, so the magnetic field lines will flow in this manner, same as the electromagnet.

So, north to south the magnetic flux lines will flow inside the medium either it is a core or either it is a permanent magnet, the flux lines will flow south to north. Generally, outside the medium we will see north to south flux lines are flowing and relative permeability values with respect to different materials we will see now. So, as of now we have discussed about the magnetic field sources. So, what is the relative permeability values for different cores? We will see here it is 1 and iron it is 5000 and for steel it is 2000 and cobalt steel it is 100, for nickel it is 100 to 600. So, now we will discuss about the relation between the magnetic fields and electric fields.

As of now we have discussed about electric fields and magnetic fields. Now, we will see the interaction between the magnetic fields and electric fields. The interaction of magnetic fields and electric fields is invented by Michael Faraday and he presented the Faraday's laws. The first law of Faraday's is, Faraday's first law is the change in flux or change in magnetic field will induce a EMF in a coil or if it is a closed coil the current will induce in the coil.

So, we will take a simple example. This is the primary coil and secondary side one more coil is there. So, I am considering a DC power supply here source, this number of tons N 1 and number of tons N 2. Here the induced EMF is E 2. So, if I will give the DC voltage the induced EMF is 0 because there is no change in flux, no change in flux d phi equals to d phi by dt equals to 0 because of that reason we will not see any induced EMF.

The next case what I will do is, I will add a simple switch here. If I will add a simple switch here, what kind of waveform we are generating here constant DC we are giving. Here instead of constant DC with switch we are giving this pulsating square wave. So, this is case one, this is case two. In case two we are changing the voltage. So, automatically we will see the change in flux also and here we will see the EMF value which is not equals to 0.

Similarly, third case I am taking square wave in this manner case three. Here also d phi by dt is not equals to 0 that implies induced EMF will be there not equals to 0. So, as per the faraday's law we have seen that there the change in magnetic field will induces the EMF in the coil. If it is a closed then current will be induced. Now, what is the magnitude of EMF? What is the magnitude of induced EMF? That is proportional to the change in magnetic field that is d b by dt and also proportional to the area and also proportional to the number of tons.

So, that finally, we can say that induced EMF is equals to n into area into d b by dt. Here area is nothing, but the area which is linked to the secondary coil or if it is a system with a core the cross sectional area with respect to that particular system. So, here area with respect to the secondary coil which is linking I am considering n a d b by dt here b into a is nothing, but flux n into d phi by dt is nothing, but the magnitude of induced EMF. The faraday's second law gives this one the mutual induction the induced EMF is equals to the rate of change of flux linkages.

Now, this induced EMF equation consists of a negative sign. Why this negative sign is the Lenz's law defines the sign. Let us consider a simple example like this is the magnet and we are bringing in and out from a electric circuit consider this is north and this side is south we are bringing in. So, automatically the current will induced in a closed coil right the current will induce in this direction. The induced B fields with respect to the induced currents is always opposite to the applied magnetic field. So, this is the applied one and this is the induced one both are in opposite direction that is what Lenz's law will explain and the same thing we can consider here negative sign the induced EMF is always in the opposite direction with respect to its source.

The source of induced EMF is nothing, but the source voltage right what we have applied that is the faraday's laws. With this I am concluding this class. Thank you.