Course Name: Design of Electric Motors

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Title: Magnetic Fields in DC Machines-1

Greetings to all. In the last lecture, we have discussed the realization of electrical machines from the basic principles of magnetic fields and winding structures with respect to different machines. In this lecture, we will see what kind of magnetic fields are there in the electrical machines. For example, in DC machine, what kind of magnetic fields are there? In AC machine, what kind of magnetic fields are there? Like rotating magnetic fields, why we are calling it as a rotating magnetic field or why not static field? Why only rotating magnetic fields are there in AC machines? Why not in DC machines? Like the discussion, we will see with respect to all type of machines. First, I will start with the DC machine. In a DC machine, we have a field winding at the stator side.

These poles are formed because of the windings at the stator side and fields are in this direction, magnetic fields. These magnetic fields are constant and we are not changing any excitation to the windings, such that there is no change in magnetic fields. Always, it is in the same direction and it is static fields, but inside rotor, what kind of magnetic fields are there? Let us consider the single conductor at the armature side, this side cross and this side dot. I am considering here, north and here, south.

So, with respect to one particular conductor, we will see the current is entering at the cross side and leaving at the dot side. First, we will see what kind of current we are giving. This is the current what we are giving from the supply, DC current. If we will see at the coil side, after the brushes, at 90 degree, we have to reverse the current direction and after 270 degrees, again we have to reverse the current to get the continuous torque. That is what we have discussed in the last lecture.

This is 2 pi, 2 conductors with 2 commutator rings and 2 brushes. So, with respect to the dot, we will see the magnetic fields in this manner. With respect to the dot means, anticlockwise with respect to the cross, clockwise direction. So, flux is in this direction. The resultant flux will be in this direction at 0 degree.

At 90 degrees, we are changing the current direction. From 0 to 90 degree, what is happening? We will see the rotor side conductor also moving. That means, the flux also moving along with the conductors, even though these conductors are sitting on the rotor, which is rotating. That means, flux also moving in with respect to the same. So, the rotor is rotating in this manner.

That means, conductor as well as resultant flux also moving from this point to this point. Magnitude is not changing because the current magnitude is same. Here, the current magnitude is I. That magnitude is not changing. That means, flux vector magnitude will not change, but angle is changing with respect to the rotor.

With respect to the position, it is rotating in this manner. At exactly at 90 degrees, what will happen? We are changing the excitation. Current direction, we are changing. The coil will be in this manner earlier, dot and cross before changing the current. Here, dot and here, cross.

The flux is in this direction. We can find that thing with thumb rule. Dot means anticlockwise, cross means clockwise direction. But, at this particular point, we are changing the current direction. That means, this side cross and this side dot.

Here, the magnetic field lines, cross means clockwise, dot means anticlockwise. So, the resultant flux is in this direction. It is reversed. If we draw the resultant flux plot, I am drawing here in an x y plane. At 0 degree, the flux vector is at this particular point.

Then, from 0 to less than 90, what is happening? It is rotating with respect to the rotor structure. The conductor is also rotating. That means, flux vector is also rotating like this way up to this point. But, at 90 degrees, there is no flux vector. It is there in an opposite manner.

This is at 90 degree. This is 0 degrees. Now, we will see at 180 degree, what is happening. At 180 degrees, conductor is seeing what type of current, negative current. It is in the same direction.

Conductor will move by 90 degrees. If displacement is 90 degrees from 90 to 180, then conductor also rotated 90 degree. That means, in this manner, it is exactly same as the 0 degree condition, where the resultant flux is in this direction. With respect to the dot, it is anticlockwise direction and with respect to the cross, it is clockwise direction. I am simply applying a thumb rule, nothing else to find the resultant flux.

Here, dot means anticlockwise and cross means clockwise direction. We have to visualize the flux lines. From 0 to 90 degrees to 180 degrees, what is happening? The conductor is rotating along with the rotor. We can see here. So, conductor is rotating means automatically, flux vector also rotating along with the current carrying conductor.

So, at 180 degree, we are not changing any current. That means, it will not go in an opposite direction. It is coming in a same direction. So, here, flux is in the same direction at 180 degrees.

This is at 90 degree. The conductor is rotating in a clockwise direction. That means, flux vector also rotates in this manner. So, in the resultant plot, if we plot, it will be in this manner, flux vector from 90 to 180 degrees. Now, we will see at 270 degree, what kind of magnetic fields are there? At 270 degrees, the conductor is rotated 90 degree clockwise direction. This side dot and this side cross, the magnetic fields will be in this manner.

With respect to the dot, we can observe that current is coming out anticlockwise. With respect to the cross, it is in a clockwise direction. That means, flux is in this direction, In order to get the symmetrical torque, we have to change the current direction at 270 degrees because the rotor is rotating in an opposite direction. Now, that is what we can see from the current thing. At 3 pi by 2, we have to change the current excitation.

So, if we will change the excitation at this particular point, then flux will be exactly in opposite direction. So, if I plot the same thing on this plot, from 180 to 270, it is same as the 0 to 90 degrees. It is rotating in this manner, but at exactly at 270 degree, the flux vector is in this direction. Next, at 360 degrees, it is equivalent of 0 degrees. So, it will be in the same direction and 180 degrees also in the same direction.

At 0 degree, 180 degree and 360 degree, we are seeing the flux in this direction and 90 degree and 270 degree, we are seeing flux in this direction. This is the resultant flux plot. If we will see the resultant flux, it is rotating 180 degree duration. It is rotating from here to here and then coming back from here to here and again from here to here, it is rotating left to right and right to left. Like that manner, it is rotating.

It is not rotating complete 360 degree. Within the 180 degree span, it is rotating. So, in a DC machine, so final conclusion, in a DC machine also, we are seeing the rotating magnetic field, but it is not symmetrical with respect to 360 degree rotation. We can call it as a rotating magnetic field, but it is not symmetrical with respect to the circular rotation. It is just varying from 90 degrees to 180 like 90 to 270, 270 to 90 or I can say 0 to 180 degree duration only from this point to this point and then again from that point to back to this point.

This is with respect to single conductor. respect to multiple conductor also results in a same manner. If we will take the two conductors example for a DC machine, this is 1, 1 dash, 2, 2 dash. Consider a current here, cross here, dot here, cross and here, dot. What kind of currents we are giving here? At 90 degree, commutator rings are 90 degree span.

With respect to the A phase, the current will change after 45 degree and from 45 to next 90 degree, it will be 0. Then, again 45 degree duration, we are giving the current. This is the 1, 1 dash current after the commutators. From the supply, we will see the constant current and 2, 2 dash current will be in this manner. From 45 to next 45 degrees, we will see this current.

Then, it will be 0. Next 45 degrees, we will see this current. Next 90 degrees, it is 135 degrees and then, next 90 degrees, we will see the 1, 1 dash current and after that, this is 90 degree duration. Here, A phase current will be there. Why I mentioned 45 degrees means half of the commutator angle, we are changing the currents. With respect to the 180 degree commutator rings, we are changing at 90 degree to get the continuous torque.

With respect to the 90 degree commutator rings, we are changing a current at 45 degree span to get the continuous torque. That is what we have discussed in the last lecture. So, I will consider this kind of current and we will analyze how the magnetic fields look like. So, at 0 degrees, what kind of magnetic fields will be there? We will see now. At 0 degrees, only 1, 1 dash current is there in the circuit.

That means this side cross and this side dot is there. So, the magnetic fields will be in this manner. Apply a simple thumb rule. With respect to the dot, we will see anticlockwise. With respect to the cross, we will see the clockwise direction.

Just simple thumb rule, I am applying to visualize the magnetic fields. So, the resultant fields will be in this direction. The resultant fields are in this direction at 0 degrees. Only 1, 1 dash excited and 2, 2 dash current is 0. At 90 degrees, what we are doing? We are exciting 2, 2 dash conductor or 2, 2 dash coil and we are removing the current in the 1, 1 dash coil.

Then, what will happen? This also rotated 90 degrees. This will rotate 90 degrees. Conductors also will rotate. Now, at this position, 2, 2 dash are there. Then, again it will result to the same magnetic field, upward direction only.

It is same as the earlier version, but currents and conductors are changed. In the 2, 2 dash conductor current, we are giving and in 1, 1 dash coil, we are not giving any current at 45 degrees. We are seeing the same kind of resultant flux vector 0 to 45. Where is the resultant flux vector? It is from this point to 1, 1 dash conductor is like this manner.

So, it is rotating. After 45, only we are removing the current in this 1, 1 dash and we are exciting 2, 2 dash. That means, 1, 1 dash reached to this point and 2, 2 dash will be at this particular point. So, from this point to this point along with the rotor rotation, the flux vector will rotate at 45 degrees. What is happening? The 2, 2 dash coil come into this place after 45 degrees rotation. For clear visualization, I will draw in a bigger manner here.

Rotor is rotating in this direction at 2, 2 dash sorry at 45 degrees. This is the 0 degree reference and once the 45 degree is rotated, then 1, 1 dash reached to this point. This is 1, 1 dash. This is 2, 2 dash.

So, we are exciting 2, 2 dash at 45 degrees. 2, 2 dash is sitting at this particular location. So, here this side positive current we are giving right at 45 degrees. So, this side cross and this side dot. So, with respect to the cross, we will see the magnetic fields in a clockwise direction with respect to the dot in a anti-clockwise direction. The resultant flux is in this direction now less than 45 degrees.

We have seen the resultant flux is moving along with the rotor direction in this fashion, but at 45 degrees, the resultant flux vector is in this direction. If I will draw in a x y plane, I am considering the x y plane in this manner. Initially, at 0 degrees, the coil 1 is excited. Flux is in this direction from 0 to 45.

The rotor is rotating in this manner. In all cases, rotor is rotating in a clockwise direction. That means flux vector also will move in this manner at 45. After rotating the 45 degrees duration, the rotor flux vector will be in this fashion because of the 2, 2 dash current. This is 45 degree displacement.

Next, at 90 degrees, what will happen? We will see. So, the initial conductors are in this manner 1, 1, 1 dash, 2, 2 dash. This is 2 and this is 2 dash. Once the rotor is rotated 90 degrees means here 2 came, here 2 dash and here 1 dash and here 1. Now, 2 we are exciting with. Second 2, 2 dash conductors are there like this manner and second conductor positive current at 90 degrees here dot, here cross and here dot.

So, the magnetic fields will be again apply a thumb rule. So, with respect to the cross, we will see the clockwise direction with respect to the dot anticlockwise direction. This direction means in this manner. So, the resultant flux in this direction, again it reach to the same state. At 90 degrees, we are giving the same current to the second coil.

That means current is not changed. Flux is in the upward direction for 0 degrees as well as 90 degrees. We are seeing flux is in the same direction resultant flux vector. From 0 to sorry from 45 degrees to 90 degrees, what it is happening? The rotor is rotating in a clockwise direction means flux vector also rotate in a clockwise direction. So, at 45 degrees flux vector at this particular location. So, with respect to the clockwise direction, the flux vector is rotating in this manner and reached to the y axis position at 90 degree duration.

In this manner, it is rotating. Then, resultant vectors we can draw in this manner. This is from 0 to 45 and then from here 45 to 90 degrees. Then at 90 degrees, it reached to the same position or same location it reached this one, yellow color one, middle one. Now, we will see the flux vector with respect to the 135 degrees 3 pi by 4. At 3 pi by 4, what we are doing? We are removing the excitation with respect to the coil 2 and we are giving the excitation to coil 1 in a opposite direction.

Why we are giving that in a opposite direction? We will see why it is required. Already we have discussed many times and again I am repeating this is the basic to realize the magnetic fields. So, this blue color one here is the initial position of the rotor, right. After 135 degree rotation, this is the 0. After 135 degree rotation means at this particular location with respect to this reference, this is 135 degrees rotation.

So, 2 to 1 dash we are exciting that means 1 dash, this is 1 dash and this is 1, right. So, here the current if will give the positive manner, if will not reverse the current, then here we are seeing the cross here it is dot. So, with respect to the cross, the magnetic fields will be in a clockwise direction and with respect to the dot, it is in a anticlockwise direction, right. Anticlockwise direction means in this direction.

So, the resultant flux is in this manner. So, if we are rotating in a clockwise direction, but resultant field is coming in a opposite direction that means rotor will rotate in a opposite manner. Earlier at 90 degrees, the flux vector was at this particular location and it is rotating in a opposite manner. So, it is not valid situation. To avoid this thing or to make the symmetrical rotation, we have to reverse the current direction here instead of dot cross and here dot is there. So, with respect to the cross, clockwise direction of the magnetic fields with respect to the dot, anticlockwise direction of the magnetic fields.

So, the resultant flux vector is in this direction that means at 45 degrees as well as 135 degrees, the flux vector is sitting at this particular location only and then from 90 degrees to 145 degrees duration, it is varying in a same direction in this manner and at 180 degrees, what will happen? Next condition I am taking at angle pi or 180 degrees. At 180 degrees rotation with respect to this thing exactly flipped right, 1 1 dash came this side, 1 1 dash, this side 1 and that side 1 dash, this is the initial position 1 dash. So, exactly reversed this will be 1 and this will be 1 dash and here this is 2 and this is 2 dash. So, we are exciting only coil 1 right with respect to the currents at 180 degrees, we are exciting coil 1. Coil 1 means here we can see current is reversed, same polarity will be continued, this is dot and this is cross and the magnetic field will be upward direction, it is same as the earlier case.

2 2 dash we are not exciting that means resultant flux is in this direction. So, for 0, 90 and 180 degree duration, it is in the same direction from this point to this point, it is varying. From again 180 to 225, it will vary in a same direction in this manner. From 225 to at 225, we will see a flux vector here, just analyze with respect to the thumb rule at 225, again it will be here. From 225 to 270 degrees, again it will move in this direction. From 275 sorry 270, it is 270 to 325 degrees, it will rotate in the clockwise direction

along with the rotor and now from 325 degrees to 360 degrees or 0 degrees, it is rotate in this manner.

So, the flux vector is rotating in the span of 90 degrees. So, we can conclude that with respect to the 2 conductors, the flux vector is rotating in a span of 90 degrees. This is the flux vector plot, it is a rotating magnetic field, but for a duration 90 degrees, no symmetrical rotation. So, with this, the magnetic fields with respect to the DC missions is done. Now, we will see magnetic fields with respect to the AC missions or we are giving the AC supply directly, what it will happen. Let us consider the induction motor or induction mission or we can consider the synchronous mission also.

We will see the fields with respect to the stator side. Stator side, we have the distributed winding here in the induction motor as well as the synchronous motor. Stator side, we have a distributed winding, but rotor side what we have here squirrel cage or closed coil. In the synchronous motor, it is a distributed winding at a stator side. At rotor side, just field winding we have.

Field winding means there is a static field, it is not a rotating magnetic field. It is just simply a field poles, the magnetic field or flux vector is constant here, it is not rotating, but with respect to the distributed windings, we will see how the magnetic fields are there. The analysis for the induction motor and synchronous motor, stator side it is same if you are giving the AC currents. Consider a single conductor, we are giving the AC supply. The current will be in this manner 0, 90 degrees, 180, 270, 360 or we can represent with pi by 2 pi, 3 pi by 2 and 2 pi.

This is 1, 1 dash, 2 conductors I am considering. Stator rotor side, we have some poles. This is the stator structure. Apply a thumb rule and find the magnetic field direction. This is the stator side right now. At 0 degrees, since it is a stationary object or stationary body, there is no rotation of conductors.

Conductor is fixed. The current magnitude is varying with respect to the current waveform. Here, one is cross and one dash is dot. With respect to this cross current, we are seeing the magnetic fields. Apply a thumb rule and magnetic fields are in a clockwise direction.

With respect to the dot, it is in a anticlockwise direction. So, the resultant flux is in this manner at 90 degrees, but what will happen at 0 degrees? The current magnitude is 0, right? I equals to 0. Then, what happens to the flux thing? It is 0. This one is equals to 0. No need to do anything, but we assume that what kind of flux will be there with respect to the 0 degrees I have drawn here, but the current magnitude is 0.

That means, flux also 0. At 90 degrees, current is maximum. That means, flux also, we will see the maximum flux. Here, flux is 0 and here, maximum flux we will see what is the direction also we will find. The direction will be, it is same, right? Just current magnitude is changing. That means, flux direction also same manner.

It is in the same direction, but the magnitude will reach to the phi max. From 0 to 90, just the magnitude of the vector is increasing. If I draw the plot x y plot, initially 0, then it will increase. Then, further it will increase, like this manner and it will reach to the peak value at 90 degrees.

This is the flux vector 0 to 90 degrees. It is varying here. At 180 degrees, what will happen? Current is 0, flux also 0. Again, it will come back to the 0 position. Current is positive, right? So, the flux vector also positive. It will come back to the same state.

From this point to this point, it will come back and again, it will reach to the 0. Then, from 180 to 270 degrees, at 270 degrees, what is happening? Current is maximum at the other direction. That means, current in a coil is reversed. This side cross and this side dot, this is 1 1 and 1 dash. Earlier, 1 is getting cross and 1 dash is getting dot.

Now, 1 is getting dot and 1 dash is getting cross thing. With respect to the cross, we are seeing the flux in the clockwise direction with respect to the dot in a anticlockwise direction. So, the resultant flux is in this direction at 270 degrees. That means, from 180 to 270, current is increasing. That means, flux also will increase in the opposite direction like this fashion.

At 270 degrees, it will reach to the maximum. This is the flux vector. Is it fine? Now, from 270 to 360 degrees, current is in a decreasing fashion in a same direction. So, current is not changing. It is in a decreasing fashion. So, the flux vector also in the same direction, but it will decrease and it will reach to the from this point to this point.

So, at the end, if we will see the resultant flux vector, it is starting from 0. It is starting from 0 and at 90 degrees, it reached to the maximum because the current is maximum. At 180 degree, current will reach to the 0. That means, flux vector or magnitude also will come down to 0 and from 180 to 270, flux vector is increasing in a opposite direction and magnitude also increasing along with the current. Then, it reached to the maximum at the negative side. From 270 to 360 degrees, flux vector is increasing in a opposite like in a positive manner and it reached to the 0.

So, this kind of flux resultant flux vector, when we call it as a rotating magnetic field means, it is no rotating magnetic field. It is just increasing and decreasing flux vector magnitude. So, in order to get the rotating magnetic field or to make the machine functional, what to do and what kind of magnetic fields will be there with multiple conductors like with single conductor I placed and single phase AC, we are giving. Then, this kind of magnetic fields will induce.

So, with this kind of magnetic fields, we cannot generate or we cannot create any type of machine. That is what we have seen in the last lecture also. We require the multiple conductors with variable fields. Here, field is varying just in a vertical direction, one direction.

It is increasing and decreasing. That is it. So, how to make the rotating magnetic field or induction motor functional, we will see in the next lecture. Thank you.