Course Name: Design of Electric Motors

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Title: Magnetic Fields in AC Machines-3

Greetings to all, in the last lecture we have seen the symmetrical rotating magnetic fields in a two phase machine or with two coils are displaced with 90 degrees we have discussed right. In this lecture we will see by considering an example where there is no mechanical displacement or there is no symmetrical electrical displacement, what kind of magnetic fields will establish inside the electrical machine we will discuss. Let us consider the example before going to that the summary with respect to the last class we can see here the symmetrical rotating magnetic fields with respect to the conductors placement this is B, B dash and A, A dash mechanically displaced by 90 degrees and electrically displaced by 90 degrees or I can say electrically excited with 90 degree phase shifted currents. This is A and this is B coil currents. Now I will change the electrical displacement by considering the an example where 45 degree displacement only there with respect to the both coils this kind of coils what kind of magnetic fields will be there we will see now. Same analysis we can do with by considering the different mechanical displacement also.

Let us consider the same coil arrangement where A, A dash, B, B dash these are the two coils mechanically displaced by these two coils are mechanically displaced by 90 degrees, but electrically we are not exciting with 90 degrees displacement. Now, we will see the excitation currents. This is 2 pi pi and 0 degrees and now the other current is displaced by 45 degrees. This is B, B dash coil current and this is A, A dash coil current blue color one.

Here I A equals to I m sin omega t and I B, B dash coil current earlier one also A, A dash we can consider or I A also fine I m sin omega t plus 45 degrees. That is leading right. So, that is why plus 45 I considered.

Now, we will analyze what kind of magnetic fields will be there. At omega t equals to 0 I will start before going to that I will define the segments this is pi by 4 and pi by 2 and this is 3 pi by 4 and same way this is 5 pi by 4 and at this point 6 pi by 4 and this is the instant 7 pi by 4.

So, at omega t equals to 0 current with respect to the coil A, A dash is 0 B, B dash positive current is there that is I m sin 45 since omega t equals to 0 right. This is the current magnitude positive current is there. So, how the magnetic fields will be there with respect to the coil placement this is B and B dash and A, A dash there is no current. So, here B side current is entering and B dash side current is leaving because of the positive current and the flux loops analysis it will be same for cross it is clockwise for dot it is anticlockwise then the resultant flux is in this direction. Here the resultant flux phi r is equals to phi B here phi B magnitude is nothing, but phi m sin omega t plus 45 omega t is 0.

So, phi m by root 2 is the magnitude

we will see the next condition omega t equals to pi by 4 or 45 degrees what kind of magnetic fields are there we will see now. The current with respect to this condition I for A, A dash coil is positive and B, B dash coil is negative sorry B, B dash coil also positive. So, conductor placements will be same this is B and B dash this is A and A dash. So, draw the flux loops for B it is a cross for B dash dot for A it is cross for A dash it is dot and the direction will be for cross clockwise for dot it is anticlockwise. So, the resultant flux loop with respect to the both dots we can observe like this manner and with respect to the other 2 loops also in this manner.

So, the resultant vector phi r is in this direction that we will see. Now, we have to find the resultant flux vector magnitude at pi by 4 what is the resultant vector magnitude. So, from our vector analysis phi B is in this direction and phi A is in this direction reference vectors where current is positive. At omega t equals to 45 degrees both currents are positive then this is phi A and this is phi B. So, the resultant vector is in this direction that is phi r the same thing we have analyzed now from this case.

In these 2 cases we can see that this is with respect to the flux loop analysis and this is with respect to the vector analysis both cases we are seeing the same resultant flux vector direction. Here phi r magnitude is nothing, but phi A vector plus phi B vector addition we have to do phi A is nothing, but phi m sin 45 degrees plus phi B is nothing, but sin 45 plus another 45 degrees then take the square roots square and then square root. This will result phi m square into 1 by 2 plus phi m square into 1 square root. So, total the resultant thing will be square root of 3 by 2 into phi m. So, this is the resultant vector magnitude at 45 degrees.

I will make the summary at 0 omega t equals to 0 we can we are seeing the flux vector magnitude is phi m by root 2 at 45 degrees it is phi m into square root of 3 by 2. Next we will analyze at omega t equals to 90 degrees at omega t equals to 90 degrees the current how it looks like we will bring it. So, currents are in this fashion. So, at 90 degrees current in A A dash as well as B B dash coils it is positive only I A is nothing, but I m sin 90 I B B dash here A A dash and B B dash is nothing, but I m sin 135 90 plus 45. So, the flux vector analysis phi A is same direction phi B also same direction because of the positive currents and the resultant vector will be in this direction, but phi A magnitude is nothing, but maximum right.

So, resultant vector direction is here as per the instant omega t equals to 90 degrees phi A vector magnitude is nothing, but phi m and phi B vector magnitude is phi B equals to phi m into 1 by root 2 right because phi A equals to phi m sin 90 phi B equals to phi m sin 135 degrees or 3 pi by 4 it is equals to phi m by root 2. So, this phi A and phi B values I am considering with respect to the currents then the resultant vector with respect to this kind of magnitudes it will be in this manner this is the phi r magnitude. So, here phi r magnitude is nothing, but phi m square plus phi m by root 2 square take the square root then it will results in 3 by 2 square root into phi m at omega t equals to 90 degrees also square root of 3 by 2 phi m, but resultant vector direction is different at 45 degrees also the resultant vector direction we can see with respect to the different magnitudes phi A phi B magnitude is more and phi A magnitude is less right. We can see the resultant vector like this way phi A is small then the resultant vector is here the magnitude will not change. So, at 90 degrees also phi m square root of 3 by 2.

Now, we will see at omega t equals to 145 degrees or 135 degrees what it will be or 3 pi by 4 at 90 degrees we have discussed as of now at 135 degrees what kind of magnetic fields will be there we will see. At 135 degrees what is the current? So, this is the current waveform at 3 pi by 4 current in B B dash coil is 0 A A dash coil is positive. So, the with respect to our reference phi A vector this is the phi A then the resultant flux vector also is in the same direction that is phi r that magnitude is nothing, but phi m sin 135 degrees then phi m sin 90 plus 45 we can say that is again 1 by root 2 here the phi B value is 0 that is why I am I consider directly phi A equals to phi r resultant vector magnitude. In same thing I will summarize at the this point at 135 degrees phi m square root of 1 by 2 or we can say phi m by root 2.

Next we will discuss at omega t equals to 180 degrees what it will happen.

At omega t equals to 180 degrees current with respect to the A A dash coil and current with respect to the B B dash coil we will see A A dash coil current is 0 and B B dash coil current is negative in opposite direction that is what we can observe here for phi instant at pi. Here phi A equals to 0 and phi B equals to phi m sin 180 plus 45 this is minus phi m into 1 by root 2.

So, phi B our reference direction with respect to phi A and phi B are in this manner and now the phi B direction has to be reversed because of the currents. So, this is phi B the new phi B and the resultant vector also is in the same direction phi m by root 2 if I will consider the only magnitude. The same thing we can identify with respect to the flux loop analysis also.

Then at omega t equals to phi pi by 4 or 225 degrees at omega t equals to 225 degrees current in a coil A A dash is negative and B B dash also negative. Then with respect to our reference vector analysis that is this one. So, with respect to that thing phi A should be reversed and phi B also should be reversed. So, the resultant vector is in this manner before seeing the resultant vector what is the phi A magnitude here phi A magnitude is nothing, but phi m sin phi pi by 4 or 225 that is nothing, but phi m by root 2 and phi B is nothing, but phi m sin 270 45 plus 225 then it will results in minus phi m. So, phi B magnitude is more then we have to consider phi B is more and phi A is small the resultant vector is lying at this direction phi r this phi r magnitude will be square root of phi m square plus phi m square by 2.

So, take the square and then take the square root of those two terms then phi m into square root of 3 by 2 will come. So, the resultant flux vector magnitudes will summarize with respect to the omega t is equals to 135 degrees 180 and 225. So, here we can see for 135 it is phi m by root 2 and for 180 it is 135. For 180 degrees it is phi m by root 2 for 225 it is phi m into square root of 3 by 2. Similarly we will see for 270, 325 and 360, 360 anyhow same as 0 that is phi m by root 2.

At omega t equals to 270 degrees before saying that thing first we have to see the currents right. So, the current can get it from this waveform at 270 degrees that is phi pi by 4 at this particular instant we can see the current with respect to the A A dash is maximum at this particular instant and B B dash is smaller. So, current in A A dash coil is maximum because I A or I m sin 270 degrees and B B dash coil is I m sin 325 degrees both are negative only. The flux vector with respect to the A is maximum in a opposite direction the flux vector with respect to the B B dash coil is in a opposite and the magnitude is smaller as compared to the A A dash from these two current magnitudes we can get that thing and the resultant vector will be in this direction that is phi r. Here if you will solve the resultant flux vector magnitude then again it will results to phi m square root of 3 by 2.

At omega t equals to 325 degrees we will see the flux line analysis this is the last instant. So, I will consider the both vector analysis as well as the flux loop analysis current at 325 degrees for A A dash coil I m sin 325 the positive current is there negative current is there sorry here negative current is there with respect to the A A dash and B B dash coil I m sin 360 current is equals to 0 there is no current in B B dash coil. So, with respect to our vector reference analysis this is phi A and this is phi B right. So, the phi B is nothing, but 0 this phi B value is 0 only phi A is there then the resultant phi A value or phi A vector is in a opposite direction because of the negative current. So, this is the resultant vector that magnitude is nothing, but phi m sin 325 sin 360 minus 45 we can consider minus phi m into 1 by root 2 if we will consider only magnitude then it will be phi m into 1 by root 2 and for 270 degrees it is phi m into square root of 3 by 2 based on this analysis we will see the resultant flux vector plot.

Now, if we will draw the resultant flux vector. So, if we draw the resultant vector magnitudes on a x y plane then we will see what kind of magnetic fields are there in a machine x and y plane and at 0 degrees we know the magnitude, but in order to find the direction we have to see the vector resultant vector direction right. At 0 degrees where is the resultant vector? Resultant vector from between the second and third quadrant that we can observe in this figure. The resultant vector is in the second and third quadrant x axis negative side then at 45 degrees it is clockwise manner it is varying it is rotating in a clockwise direction based on that analysis. At 0 degrees we are seeing phi r is lying with respect to the second and third quadrant negative axis of the x axis 1 x axis plane.

So, this is phi r resultant vector at 0 degrees the magnitude is phi m by root 2 and then at 45 degrees we are seeing root 3 by 2 phi m. So, here root 3 by 2 phi m the resultant vector and then at 90 degrees also we are seeing same kind of magnitude and phase shift is in this manner that is what we have analyzed right. If requires I will show you again at 90 degrees we can see the resultant vector direction we can find here. Similarly at 135 degrees and 180 degrees these things we can observe from the analysis. Then at 135 degrees we will see again in this direction then at 180 degrees the resultant flux vector in this direction and then this is at 225 at 2 3 at 270 degrees the resultant vector is here and then at 325 degrees the resultant vector on this axis that is phi m by root 2.

So, we can observe in this plot the resultant vector magnitude is different with respect to these two things the magnitude is root 3 by 2 phi m and with respect to the other vectors that is 1 by root 2 phi m. So, the resultant vector magnitudes are different completely and there is no vector in this zone as well as in this zone there is no symmetrical rotation. With respect to this unsymmetrical rotating magnetic field this is a rotating magnetic field, but it is not symmetrical and the magnitudes are different. If this kind of magnetic fields are existed in the mission then we can see the vibrations and noise and torque pulsations and then losses also stress on some conductors and because of the losses there is a temperature rise and difficult to manage the thermal aspect difficult to manage the cooling. So, from this analysis we can conclude that if there is no mechanical displacement or there is no electrical displacement symmetrical thing I am talking then we will see the uneven or unsymmetrical rotating magnetic field with unequal magnitudes.

To avoid this kind of situation the windings or coils should be displaced symmetrically in mechanical aspect and electrical aspect also. With respect to the mechanical thing the coils for example, in a two phase system the coil should be displaced in a 90 degrees for a two phase system. For a three phase system the coil should be displaced 360 by 3 into pole pairs. Here P is the pole pairs small p or we can say P by 2 number of poles by 2. The electrical angle theta E is equals to theta M into pole pairs.

Because of this thing we have to consider here for three phase 360 by 3 into pole pairs for n phase 360 by n into number of pole pairs. How many number of pole pairs are there based on that we have to consider the mechanical displacement. Similarly, with respect to the electrical side for a two phase we require the 90 degree excitation. For three phase we require 360 by 3 degree 360 by 3 degrees that is 120 degree symmetrical displacement is there required for n phase 360 by n degree displacement is required. For example, for nine phase system in order to make the symmetrical rotating magnetic field it is a vector and rotating we can call it as a phasor also.

For nine phase 360 by 9 it is equals to 40 degree displacement is required electrical displacement in order to get the symmetrical rotating magnetic field. If we will change the mechanical displacement or electrical excitations displacement phase shift I can say anything if we will change then we can see the unsymmetrical type of rotating magnetic fields in this manner the vector magnitudes are different then we cannot create the symmetrical magnetic fields. So, the same analysis we can consider for three phase missions also three phase rotating magnetic fields we can analyze that I will give the brief explanation for three phase rotating magnetic fields, but the analysis and explanation everything will be same. Let us consider the three phase mission and consist of a three coils that is 1, 2, 3, 4, 5, 6 this is a a dash then b at 120 degrees b b dash c this is c and this is c dash. So, at 0 degrees we are placing the a phase at 120 degrees we are placing the b phase at 240 degrees we are placing the c phase start terminal of all three conductors these are the mechanical displacement is existed now symmetrically.

Now electrical displacement consider the three phase currents displaced by 120 degrees. This is a then b and then c current i omega t this is pi then 2 pi all three phase currents are displaced by 120 degrees I a equals to I m sin omega t I b equals to I m sin omega t minus 120 degrees I c is equals to I m sin omega t minus 240 degrees. Now we are giving the symmetrical electrical excitation as well as symmetrical mechanical displacement symmetrical mechanical displacement and electrical currents. Analyze the this kind of conductor arrangement and with this currents with respect to the two phase missions. We can conclude that the same kind of rotating magnetic fields will be there in a three phase mission also I will consider one or two cases at omega t equals to 0 degrees I will consider first and then at omega t equals to 30 degrees I will consider one more instant after that you can analyze the remaining instants and then we can see the rotating magnetic fields in a three phase mission also because we have given the mechanical mechanical displacement symmetrically and electrical excitation also symmetrically.

At omega t equals to 0 what it will happen current to the a phase is 0 a a dash coil and b b dash coil is negative and c c dash coil is positive then with respect to this thing consider the same conductor placements this is a a dash b b dash c c dash then in a a dash there is no current and then b b dash negative current means b dash b dash should be cross and b should be dot and c c dash positive current then c will be cross and c dash will be dot. Here n number of loops will be there I have drawn only one loop with respect to the dot it is anticlockwise direction here also anticlockwise direction and then with respect to the cross it will be clockwise direction sorry here I think this conductor is the c and this conductor is c dash right with respect to the 240 degree displacement. So, this is c and this is c dash right. So, c dash should be dot and c a should be cross in that case here with respect to the cross we will see the clockwise direction of magnetic fields and with respect to the dot anticlockwise then the resultant flux loop in this direction this is the resultant flux vector. If we will draw the vector analysis also same thing will come this is the phi r and calculate the resultant flux vector either vector addition manner or with respect to the phi a and phi a magnitudes the phi r magnitude will come 3 by 2 phi m and then at omega t equals to 30 degrees the current with respect to the a a dash coil is positive and b b dash coil is negative and c c dash coil is positive right.

So, consider the same conductor arrangement a a dash then here b b dash this is c dash and this is c a a dash positive current means at a it is entering and dot it is leaving and b b dash negative current means at b dash current is entering and at b current is leaving and c c dash coil having the current positive. So, at c it is entering and c dash it is leaving. So, apply thumb rule and draw the flux loops for this kind of arrangement. So, here we will see the flux loops in this manner I have drawn the 1 flux loop, but there is a n number of flux loops and with respect to the thumb rule all crosses will be in a clockwise direction and all dots will be in anticlockwise direction. So, with respect to these 3 dot loops the flux will be in additive manner these 3 flux loops will be additive and this side these 3 flux loops the current carrying with respect to these 3 conductors is same these 3 flux loops also in additive manner the resultant flux vector is in this direction.

So, if you want to someone want to analyze the this kind of magnetic fields with respect to the vector analysis first consider the reference vectors with respect to phi a phi like a phase conductors b phase conductors and c phase conductors with respect to the a phase conductors this is a and a dash and then with respect to the b phase conductors and with respect to the c phase conductors. Consider the positive currents for a reference then a a dash and then for b b dash here cross and here dot and c c dash here cross and here dot then analyze the flux loops for cross it is clockwise direction for dot it is anticlockwise then the resultant flux vector is in this direction for phi a and with respect to the b conductors b phase coil for cross it is anticlockwise direction the flux loops flux here it is in a clockwise manner for cross for dot it is in a anticlockwise direction. So, this is phi b and similarly for phi c also we can identify this is phi c. So, the resultant vector diagram with respect to these three reference things phi a is in the direction of left to right this is phi a and then this is phi b and then this is phi c. So, from this reference vectors we can analyze the remaining things for omega equals to 30 degrees we can see that a a dash is positive and b b dash is negative this is phi a and b b dash is negative means we have to reverse it this is phi b and phi c is in the same direction because of the positive current.

So, make the addition of do the addition of these three vectors then you will get the phi r equals to 3 by 2 phi m here also phi a equals to phi m sin omega t and phi b equals to phi m sin omega t minus 120 degrees phi c equals to phi m sin omega t minus 240 degrees.

And similarly you can analyze with respect to the other instance and finally, you will see the rotating magnetic fields on a x y plane the rotating magnetic field vector at 0 degrees we are seeing the vector here at 30 degrees we are seeing the vector in this manner this is the resultant vector phi r these two we can impose it to the phi b axis then we can get the resultant vector in the same direction with respect to the phi b that is at 120 degree opposite to the actual phi b. Then similar way we can see the remaining vectors at different angles here all vectors magnitude is same 30, 60, 90 and so on it is 120, 150, 180 for a three phase thing also we can see we can observe there is a rotating magnetic field because of the symmetrical electrical displacement as well as symmetrical mechanical displacement that is what we have considered here. If we will change the mechanical displacement or electrical displacement we cannot see the symmetrical rotating magnetic field with this I am concluding this class. So, in order to generate the rotating magnetic field or in order to make the ah machine operating or machine operation we have to give the mechanical displacement symmetrically as well as electrical displacement also symmetrically with respect to excitation. Thank you.