Course Name: Design of Electric Motors

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Title: Design of Induction Machine- Stator Design -2 (Stator Winding Design)

Greetings to all, in the last lecture we have discussed the induction machine design with respect to the stator core right. In this lecture also we will discuss and we will continue the design of stator core as well as rotor core. So, we have stopped at winding factor right where the winding factor equals to Kw is nothing, but Kp into Kd after substituting Kp and Kd in the voltage equation, then we can find the number of turns per phase. Once the number of turns per phase calculated, then we can select the what type of core or sorry what type of coil with respect to the SWG data and what is the area of cross section and different copper weight and copper volume and resistance of the coil all those things we will calculate it. Before going to that we will discuss some example with respect to the winding factor Kw. Let us consider a 3 phase induction machine and 4 pole winding and 36 slots and short pitch winding, distributed type, distributed short pitch winding and the short pitch is one slot.

Find the winding factors for fundamental and third harmonic. First we will calculate the q value slots per pole per phase. Number of slots is equal to 36 poles 4 phases 3 q equals to 3 slots per pole per phase, then slots per pole is equals to 9. Coil pitch is equals to 9 means full pitch winding.

Here one slot the short pitch is the given in the problem statement that means coil pitch is equals to 8 slots. Then what is alpha with respect to the one slot pitch a short pitch is nothing but full pitch is nothing but 9 slots 9 slots equals to 180 degrees that is one pole pitch and 8 slots is the present coil pitch is equals to 180 into 8 divided by 9 right it is equals to 160 degree. Now the coil pitch the updated coil pitch for this winding type is 160 degrees. Here alpha is nothing but 180 minus 160 then 20 degrees is the alpha. Now we will calculate the slot angle beta is equals to 360 by Q s into P by 2 360 by 36 slots into number of poles is equals to 2 by 2 it will give 20 degrees is the beta value.

Now we know the alpha value and we know the beta value substitute the alpha beta values in the winding factor equation. The winding factor for nth harmonic for fundamental means n equals to 1 for nth harmonic means with respect to that particular harmonic we have to calculate it.

First one is with respect to fundamental right for fundamental n equals to 1 that is K w 1 cos n is 1 alpha is nothing but 20 by 2 into sin n is 1 for fundamental q is nothing but 3 slots per pole per phase equals to 3 right. So, 3 into 20 degrees is the beta by 2 divided by beta q is nothing but 3 sin n is nothing but 1 20 divided by 2. After calculating this thing we will see K w 1 is nothing but 9452 this is winding factor with respect to the fundamental.

Similarly, winding factor with respect to the third harmonic if you will calculate cos n alpha by 2 means 3 into 20 degrees by 2 into sin 3 into q into beta by 2 divided by 3 is q into sin n beta by 2 n is nothing but 3 third harmonic beta is 20 degrees by 2. So, this number if you will calculate winding factor for third harmonic is 0.5774. So, now with respect to the fundamental we can calculate the number of turns n phase by substituting the K w 1 in the voltage equation. This is how we can calculate the winding factors.

For example, another example I will consider how to decide the short pitch angle to eliminate the fifth harmonic. I am considering one more example to eliminate the fifth harmonic. So, K p is nothing but cos n alpha by 2 for fifth harmonic cos 5 alpha by 2 in order to eliminate fifth harmonic means K p should be equals to 0 that means 5 alpha by 2 equals to pi by 2 alpha is equals to pi by 5. So, if we will make the short pitch angle pi by 5 then we can eliminate the fifth harmonic from the MMF wave with respect to the induced EMF fifth harmonic we can eliminate it. MMF is MMF with respect to the distributed winding with respect to the short pitch winding only we can reduce the harmonics with respect to the induced EMF 1.

Next we will discuss about the wire selection or SWG thing how to select the SWG to make the winding next step. In order to select the SWG or in order to calculate the area of cross section first we have to calculate the RMS current what is I phase RMS current. We have to calculate the RMS current from the power equation input power divided by m into V phase RMS into cos 5 this is equation number 5. So, from this equation power factor is known V phase RMS is known and number of phases also known variable and p in also known variable if we will consider efficiency equals to some number let us say 90 percent then P in we can calculate it we know the P naught right then P in is equals to P naught by efficiency. Once we know the I phase RMS we can find the area of cross section with respect to the current density.

Current density J is equals to I phase RMS by area of cross section of each conductor this is equation number 6 here current density is equals to for copper we can select 3 2 5 3 into 10 power 6 2 5 into 10 power 6 ampere per meter square or we can say 3 2 5 ampere per meter mm square mm square. So, depends upon the material we have to select the current density and we know the I phase RMS and calculate the AC value cross sectional area of each conductor then we can based upon this area from the SWG data we can find the which SWG is suitable for that particular current. Once we have selected the SWG from the data SWG data sheet we have to calculate the copper area. This is the slot here n number of conductors are placed.

So, copper area Acu is nothing, but cross sectional area of each conductor into number of conductors per slot here number of conductors per slot is nothing, but 2 into m into N phase by Q s, number of turns per phase into number of phases into each turn has 2 conductors 2 divided by Q s this is the total copper area with respect to a single slot.

Now, we will calculate the length of a coil we are going in detail with respect to the winding structure. So, copper area we have calculated and area of each conductor also we have calculated and current rating or we can say SWG data also we have calculated. Next thing is length of each coil. So, in order to find the length of each coil we can see here the stator core what we have to know is the length of the stator core. We can see here this is the stator core we have to place the coils right we have done the how many number of slots required what type of winding and each coil consist of how many number of turns and SWG data for each conductor also we have calculated.

The remaining thing is how to calculate the length of coil and resistance of the coil and volume of the copper and weight of the copper ok. So, in order to calculate the resistance of a coil we require first length of the coil. We can see here the coil is placed in the slots 2 slots it is placed and the length of each coil is nothing, but 2 times the core length here we can see this is the core length ok. This one is the core length and then some extra end winding also required and then end ring length ok. We can see here I am drawing these are the 2 conductors we are placing in the slots ok.

We can see here these are the 2 conductors we are placing in the slots and other thing is end winding this is the end winding this portion. This is the end winding portion on both sides and in between there will be some straight conductor portion for making the proper winding arrangement or ending. We can see here this portion is nothing, but end ring circular based end ring and this portion it is in a straight line with respect to the core that portion is nothing, but coil length with respect to the end ring side that is I am representing with x on all 4 sides and this length is le that is core length including the air ducts and other things and this is the end ring ok. This also end ring this is length of 1 single turn right like this n number of turns we are placing inside the slot. So, in order to calculate the length of a single turn l single turn is equals to 2 times length of a core plus 4 x is nothing, but this portion where the coil came out of the core, but it is a straight portion end ring will be this portion the bended circular portion, but out of the core the iron part some straight conductor portion also there that I am representing with x plus 2 times the end rings end ring width.

So, here 2 times l e we know length of the core we know already and 4 times x I am considering 30 percent of l e 4 x together I am considering 30 percent of the length of a core plus end ring from this point to this point if I will consider the semicircle we know the radius that is D I s by 2 then we can find the perimeter right like 2 times the pole pitch is nothing, but pi into D I s by p this is the pole pitch or this semicircle radius or perimeter of this semicircle is nothing, but pi D by p into 2 will come because this side 1 semicircle and this side 1 semicircle or arc is there that arc length is pi Dis by p.

So, this is length of a single coil sorry single turn for example, each coil has n number of turns n phase is the total number of turns per coil with respect to each and every phase per phase this many number of turns are there then length of a total coil is nothing, but N phase into length of single turn that is equals to n phase into length of single turn is 2 times l e plus 30 percent of l e plus 2 times pi D I s by P this is the total length of a coil per phase length of a coil per phase is nothing, but this one generally for small missions this portion will be 20 to 40 percent and for large missions where length of core is very high during that time we have to consider 20 to 30 percent to make the extra portion of the straight conductor length outside the stator core. If l e is small we can consider that straight portion of the conductor to make the symmetrical winding 20 to 40 percent this is the length of coil per phase with respect to the full pitch winding next we will discuss length of a coil with respect to the short pitch winding the equation and everything will be same N phase 2 times length of the core plus 30 percent of length of the core plus 2 into pi D I s by P into some short pitch constant that is alpha s e I am considering here because once we may we will do the short pitch winding the length of a coil or arc length will come down.

Similarly the arc length with respect to the full pitch winding let us consider here 9 slots are there and then if we will reduce the distance between 2 conductors let us say 7 slots then the arc length also will come down this portion here arc length is pi D I s by p that is pole pitch in mm here pi D I s by P into how many number of slots we are short pitching depends upon that we have to select the short pitch factor. Let us say if we are short pitching by an angle alpha then pi minus alpha by pi is the short pitch factor this one is nothing, but short pitch factor if let us say 1 slot we are short pitching or 30 degrees we are short pitching then pi D I s by P into pi minus 30 degrees means pi minus pi by 6 divided by pi this is the nothing, but 5 by 6 into pi D I s by P this we have to substitute here alpha s e is nothing, but 5 by 6 for example, 1 slot is short pitched.

So, like that length of a coil is coming down for short pitch winding this equation is for short pitch winding. So, from this analysis length of coil is coming down means resistance also will come down then losses also will come down some advantages with respect to the short pitch winding we have discussed already from this equation we can it will be clear with respect to the length resistance is coming down and losses will come down and efficiency will be improved. Once the length is calculated next we have to calculate the resistance phase resistance R phase is equals to rho l coil per phase by area of cross section of each conductor the resistivity of the copper will be 1.72 into 10 power minus 6 ohm meter. Similarly, for different materials it will be different resistivity will be there here length we know and area of cross section of each conductor also we know we can calculate the resistance per phase resistivity also known value only resistance is the unknown one.

Next thing once the resistance also done what is the volume of copper volume of copper with respect to each coil is nothing, but area of copper coil into length of a coil. So, we are calculating length of a coil with respect to each phase into conductor cross sectional area is nothing, but volume of a coil per phase for 3 phase machine total volume of the copper is equals to 3 times area of area of cross section with respect to each conductor into length of total phase coil like length of a coil with respect to total phase.

If we will do then this is the volume equation that is equation number 11 this is equation number 10 and this is equation number 9 equation number 8 equation number 7 I give the numbers to all equation this is the volume of a copper. Then once we know the volume we can find the weight of a copper winding at the end we have to see the torque to weight ratio power to weight ratio and everything. So, first we have to see the what is weight of the copper winding next weight of a core stator core then weight of the rotor core iron material and weight of the rotor winding all those things we have to add then that is the total weight of the complete machine.

Now, weight of the coil is equals to density of the material copper material into volume of the total copper winding this is equation number 12 here volume will be in a meter cube and density will be kg per meter cube then we will get weight in the in terms of kg. After calculating the weight of the copper with respect to the stator winding type we have done the analysis.

Next we can discuss the slot shapes what kind of slot shape we have to select and then slot geometry. So, with this I am concluding this lecture. In this lecture we have calculated the how many number of tons required and what kind of pitch factors and distribution factors we have to select depends upon the winding type and resistance of the each coil and length of the each coil and volume of the copper and weight of the copper we have discussed. Thank you.