Course Name: Design of Electric Motors

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Lecture: 42

Title: Design of Induction Machine- Rotor Design -3 (Rotor Slot Geometry)

Greetings to all, in the last lecture we have started doing the rotor core design equations right with respect to the number of slots, with respect to the bar currents and bar length etcetera. In this lecture, we will discuss rotor slot geometry equations like what is the slot depth, slot width and slot height and etcetera. We can see here this rotor slot geometry, this one rotor slot lamination we can see here. So, we have to find the what is the slot depth and back iron width and slot width and slot opening and etcetera. Let us consider the rotor slots, two rotor slots I have considered here. The slot width at the bottom side is w2r and slot width at the top side of the slot is w1r.

We can see here, t r is the teeth width of the rotor and d cr is the back iron width and r2r is the radius at the bottom side of the rotor slot and d sr is nothing but slot depth and r1r is rotor slot radius at the top side of the slot and d naught r is the height of the slot opening and one more variable b naught r, b naught r is nothing but slot opening width. So, with respect to this slot shape not only this slot any type of or any type of slot shape, we can have to find the slot dimensions. How to find the slot dimensions we will discuss. First b naught r the slot opening and r1r radius at the top side of the rotor slot and r2r and d naught r.

These are the four parameters we have to assume as a designer choice. And the approximate equation for r2r we can find. If you do not want to assume r2r approximate equation also we can find the radius of the slot at the bottom side of the rotor slot. If we will consider the midpoint, let us consider this is the midpoint center point of the machine and if I will draw a line with respect to this point mid of the rotor slot to other slot midpoint or half cross section, then this angle is alpha that is slot angle with respect to the rotor. And half of this thing will be alpha by 2 right.

This period we know this width of the stator teeth we know. If we will see here the width of this portion is nothing but t by 2 and width of this portion is w2r by 2 and height of this triangle we can consider it as a right angle triangle. This triangle is alpha by 2 and this opposite side is w2r plus t r by 2 and this height will be from this point to this point is nothing but d Ir by 2 up to this point and after that d c r and then r2r. If I will write the sine angle with respect to this right angle triangle sine of alpha by 2 is equals to w2r that is width of the rotor slot at the bottom side of the slot and teeth width tr by 2 opposite by diagonal right. Diagonal width is d Ir by 2 that is inner diameter of the rotor by 2 plus back iron width of the rotor plus r2r.

So, here we know the value of alpha, we know the value of w2r and tr and d cr how to calculate we will discuss the equations. Once we know these values and we can calculate the r2r this is one way of doing to find the radius of the rotor slot at the bottom side. Otherwise we can directly assume these four parameters as a designer choice initially itself. Next in order to find the width of the rotor slots w1r and w2r and teeth width tr back iron width d cr and slot depth d s r. To calculate these parameters we have to analyze the flux densities at the different parts of the iron flux density at the back iron that is B cr flux density at the teeth that is Btr and flux density at the air gap is Bg.

First we will start with flux density at the air gap. To find the flux density at the air gap let us consider the equation with respect to the flux per pole phi g average is equals to 2 by pi into phi g peak for the sinusoidal quantities that is equals to 2 by pi flux peak value is nothing, but B g peak value into area right A g. Here area of cross section with respect to the air gap we have to consider the rotor outer diameter in terms of D naught r we have to represent. X axis length will be pi D naught r divided by P and y axis length is nothing, but le B g peak will be there as it is. This is the phi g average flux per pole from here we can calculate the Bgr peak that is equals to phi g average divided by 2 into D naught r that is outer diameter of the rotor into length of the effective length of the rotor core B g value in Tesla or Weber per meter square.

This equation is 34. Similarly, we have to calculate the flux densities at the teeth and back iron. Flux density at the teeth will be the flux lines are flowing in this manner and we have to find the cross sectional area with respect to this portion. So, here B t r we have to calculate for that first we have to consider the flux at the teeth average with respect to pole is equals to 2 by pi phi t peak 2 by pi phi t peak is nothing, but B into At is nothing, but flux density at the teeth peak value into area is nothing, but A t x axis will be Qr into tr by P that means, number of slots into number of teeth by P that is flux per pole we are calculating right into x axis y axis length will be l e is the effective length of the core into k s is the stacking factor steel stacking factor. So, from here we can calculate the B t peak is equals to pi by 2 into phi t average divided by tr into Qr into l e k s and the number of poles this is equation number 35.

Next flux density at the back iron if we will see here the flux lines or flux per pole is dividing into two parts in the back iron this side phi by 2 and this side phi by 2. So, to find the flux at the back iron phi c average by 2 is equals to directly we can represent in terms of B c peak into area is nothing, but d cr into l e into k s this is y axis and d cr is nothing, but depth of the back iron is d c r from here B c peak value is equals to phi c average by 2 into d cr into length of effective length of the core into stacking factor this is equation number 36. Here the maximum flux with respect to the teeth whatever it is coming towards the back iron is splitting into two parts the flux per pole is splitting into two parts and flowing through the back iron that is why phi c by 2 I have considered here that is B c peak value is equals to this one.

Once after knowing the flux density values at the different parts of iron we can calculate the teeth width by doing the equation number 30 in order to calculate the tr equation number 34 by 35 from the equation number 34 by equation number 35 then we will get the tr value that is teeth width or tooth width is equals to pi into D naught r outer diameter of the rotor divided by stacking factor into number of slots into Bgr divided by B tr this equations we have already derived with respect to the stator same way we can derive it for rotor also this is equation number 37. In order to find the depth of the back iron we have to utilize the equation number 34 and equation number 36 d cr is equals to depth of the back iron rotor outer diameter divided by number of poles into stacking factor into B gr divided by Bcr this is equation number 38.

So, from the equation number 37 and 38 we can find the tooth width and depth of the back iron and the remaining things will be what is the width of the rotor slots at the top and bottom in order to find the widths w1 and w2 we have to analyze the perimeter. If we will see the perimeter with respect to the w2r here w2r plus tr into Qr is nothing, but the perimeter Qr number of slots into w2r is the width of the rotor slots at the bottom side and tooth width is nothing, but tr this is the perimeter with respect to the bottom side of the rotor slot that is equals to pi into D naught r pi into in terms of Dir we will write because w2 is near to the with respect to the inner diameter of the rotor right Dir plus 2 into d cr that is depth of the back iron plus r2r. So, from this equation we can find the value w2r in mm here we know the value of tr we know the value of Dir that is inner diameter of the rotor and d cr also we know and r2r also we have assumed already then we can find the w2r.

If we are deriving the w2r value then we have to find the r2r value first then only we have to find the w2r value. Next thing for w1 same way the number of slots at the rotor side into w1r plus tr is equals to the perimeter of the rotor at the top side of the rotor slot that is equals to pi into D naught r minus 2 into D naught r plus r1r.

Here we know the tr value D naught r that is outer diameter of the rotor and small d naught r is nothing but height of the slot opening and r1r is nothing but radius at the top side of the rotor slot. What we have done here is we have calculated the perimeter with respect to the different portion of the rotor slot. So, we can find the perimeter in terms of with respect to this portion as well as this portion w1 plus tr and w2r plus tr in terms of pi D we have to represent then we will get the equation we will get the equation number 39 and 40 this is 39 and this is equation number 40. So, the remaining thing is slot depth that is d sr. So, from equation number 39 and 40 we can find the difference between w1r minus w2r into Qr is equals to pi into 2 d sr will come.

Here pi into D naught r minus 2 into slot opening height plus r2r minus inner diameter of the rotor minus 2 into back iron width plus radius at the bottom side of the slot. This will eventually results in 2 into d sr or this complete value in the bracket is equals to 2 into d sr that is slot depth. So, from this equation we can find the d sr value this is equation for d sr it is 41. So, we have calculated the all dimensions of the stators rotor slot. Now, we will find the rotor slot area.

Let us consider this is the rotor slot here r1r d sr r2r and d cr and this is d naught r this is b naught that is slot opening. So, we have to find the slot area. Similar to the stator side slot area equation we can calculate the rotor slot area that is Ar is equals to w1r plus w2r by 2 into slot height that is d sr plus r1r into w1 minus c 1 into r1r plus r2r into w2 minus c 1 into r2r. This is the slot area equation in mm square equation number 42. Here c 1 is a constant that is equals to 2 minus pi by 2 similar to the stator side slot area c 1 is equals to some constant.

Now, we will find the slot area with respect to the copper function. I have not derived the output function and power equation in terms of rotor side copper function as well as rotor dimensions. If we will derive the copper function and output power equation in terms of output function with respect to the rotor dimension, then we can find the equation Ar into Qr that is slot area into number of rotor slots is equals to pi into D naught r square by 4 into copper function with respect to the rotor f lambda 2 f of lambda 2 function minus constant del 2 divided by D naught r square. We can neglect this term and we can find the slot area by knowing the number of slots and outer diameter of the rotor and copper function Ar from this equation also we can find. Otherwise, we can go ahead with the equation number 42.

This equation will come if we will write the power equation in terms of some constant into D naught r cube le term with respect to the rotor volume if you will find the power equation, then we will get this kind of equation. As of now, we have discussed the rotor slot geometry and respective equations. So, if anyone is interested to derive the power equations in terms of rotors geometry, they can go through this reference paper sizing equations for the electrical machinery. From this reference only we have derived the power equations with respect to the stator slot geometry that is D cube l sizing equation we have derived from the similar to this reference. I have not derived the power equations with respect to the rotor slot geometry.

If anyone is interested, they can go through this reference paper and they can find the output power equation in terms of rotor slot geometry. We can see here the final output power in terms of rotor slot geometry here D power 2.5 l and D cube le equation also we can see here. Here this is D square l product with respect to the rotor and D cube l product with respect to the stator. We can consider it as it is and we can find the output equations like D square l product equation as well as D cube l product equations in terms of rotor slot geometry.

So, here rotor slot geometry we can see here this kind of rotor slot is considered the slot dimensions ds, dc, w2, w1 and d0 and r1 all those things are considered. Here this is the closed type of rotor slot where slot opening b0 may not required for closed slot. For open type of slots only we require the b0 value and different perimeter equations and this is the copper function what I have discussed. You have to go through this equation number 22 to find the copper function such that inner diameter and outer diameter we can find. Generally, the slot opening b0 r value is equals to 0 for closed type of slots like squirrel cage rotors and b0 r value is equals to 2 to 5 times the conductor cross sectional area that is AC for open type of slots.

So, with this I am concluding this lecture. In this lecture we have discussed the rotor slot dimensions with respect to the slot depth, slot height and slot width and back iron width etc. Thank you.

Ref:

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SIZING EQUATIONS FOR ELECTRICAL MACHINERY

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