Course Name: Design of Electric Motors

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Title: Design of Induction Machine- Rotor Design -1 (Rotor Slots Selection)

Greetings to all, in this lecture we will discuss about the rotor core design for an induction machine. In the last lecture we have discussed the stator core design right, in this lecture we will discuss related to the rotor core design. The first step with respect to the rotor core design, what is the air gap length? The air gap length, how to select means there is no straight forward equation, but the factors we have to consider while selecting the air gap length are, peripheral speed and magnetizing current I m and power factor cos phi and reluctance theme and harmonics and cooling or thermal management at the end overload capability with respect to the torque. These are the constraints we have to select while choosing the proper air gap length. So, peripheral speed and magnetizing current and power factor reluctance variations harmonics and cooling or thermal management and overload capability we have to select, based on this we have to select the air gap length. The approximate air gap length equation l g is equals to 3 into 10 power minus 3 into square root of P by 2 pole pitch into pole pitch, this is equation number 27.

Here P is equals to poles, tau p is equals to pi DI s by P pole pitch. So, based on this equation we can find the approximate air gap length. In general, the air gap length will be lg is equals to 0.2521 mm depends upon the power rating of the machine.

And other equation to find the air gap length either this one we can utilize it or lg is equals to 1.6 into 0.18 plus 0006 P power 0.4 in mm and here also length of air gap will be in mm for pole pitch greater than 1. These two equation there is no straight forward derivation based upon the different studies, this lg well lg equation is defined.

In order to select based upon the graphical approach with respect to the studies, we can see the air gap variation for different power ratings. For 3 HP and 5 HP up to 200 HP machines, the air gap length is given in terms of mm and in terms of inches also given. The thicker line with respect to the square blocks this one, square blocks representing the standard efficiency and the circular blocks representing the premium efficiency. For example, 100 HP 100 HP machine the air gap length will be 1.1 mm from this waveform, we can select directly also based upon this waveform.

This waveform is derived based upon the different literatures and different standards or we can go ahead with the approximate equation. Similarly, for 50 HP machine the air gap length will be 0.75 mm for premium efficiency and 0.8 mm for standard efficiency. So, from this waveform we can find the different air gap lengths.

So, after knowing the air gap length, we can find the rotor outer diameter. The rotor outer diameter is equals to stator inner diameter minus 2 times the length of air gap. This is nothing, but equation number 28 from here we can find the outer diameter of the rotor. First in order to make the rotor core design, this is the rotor lamination. First we have to select the how many number of slots required and what is its shape.

Similar to the stator core, we have to find the number of slots first, then what type of winding we have to place and what type of stator slot we have slot shape we have to select it. In order to select the rotor number of slots, here also there is no straight forward equation for selecting the rotor slots depends upon the cogging effects, crawling effects and noise or vibration things and synchronous cusps. To avoid this kind of aspects or this kind of crawling effect, cogging effect and noise and vibrations and synchronous cusps and etcetera, we have to select the rotors number of slots appropriately. The rotor number of slots represented with Qr are in order to avoid the cogging certain number of combination of rotor slots we have to avoid. Similarly for cogging and similarly for different aspects, different equations we have to follow.

First we will discuss about the crawling. In order to avoid the crawling, the number of slots with respect to the rotor and stator, the equation should not be equals to 0 and should not be equals to n times the number of poles. Here n is equals to integer. In order to avoid the crawling effect, we have to select the rotor number of slots with respect to this particular equation, where the difference between the stator slots and rotor slots should not be equals to the 0 and it should not be equals to n times the poles, n is the integer. Now, we will discuss what do you mean by crawling.

The MMF waveform at the air gap is not the sinusoidal. For infinitely distributed windings and sinusoidally excited machines, we can consider MMF waveform will be sinusoidal, but in practical machines the MMF waveform will be not sinusoidal. It consists of fundamental and 6 n plus or minus 1 harmonics. 6 n plus 1 harmonic will rotate in forward direction, that is seventh harmonic, n equals to 1 and 6 n minus 1 harmonic field will rotate in backward direction, that is fifth harmonic. If we will see the torque speed characteristics with respect to the fundamental, that is n s and seventh harmonic, that is n s by 7 and fifth harmonic, that is n s by 5.

With respect to this synchronous speeds, if we will draw the torque speed characteristics, for seventh harmonic it is in forward direction, then the torque speed characteristics will be in this manner at n s by 7. This is n s. So, for fundamental one, it will be in this manner and for fifth harmonic, it is in a backward direction, magnitude will be slightly less, it will be here. If the resultant torque will be cumulative with respect to all these three harmonics, fundamental and seventh harmonics and fifth harmonic, if we will draw the resultant torque speed curve, then it will be in this manner. This blue color one is the resultant torque.

Here if we will draw a load line, let us consider the load line in this manner. This is A, B and C. Here the rated stable operating point will be c with respect to the load line. Now, because of the seventh harmonic, because of the fifth harmonic, what it will happen? We will see. If the load torque is equals to constant and the generated electromagnetic torque is slightly less than the load torque, then the motor will be operated at the particular point a and it will be stable at that particular point.

It will rotate at that particular n s by 7 synchronous speed and it is matching with respect to the load torque and it will not go back to the stable point c. Speed will not increase and torque with respect to the load it is matching, then the motor will settle at point a. That point a we used to call it as a crawling point or crawling torque with respect to the n s by 7. The machine is seeing the crawling torque and motor is stable at point a, which is unwanted operating point because of the seventh and fifth harmonic, the motor is operating at point A. So, this thing is not desirable to avoid this thing.

We have to select the number of slots Q s minus Q r should not be equals to 0 and Q s minus Q r should not be equals to n into p. The next parameter is cogging. Cogging is nothing but magnetic locking or stalling. If we will consider the stator side slots as well as rotor slide slots in this fashion, exactly the pole shoes are matching and the magnetic field lines are flowing in this manner. Here we can see the magnetic locking is happening, which is depends upon the reluctance.

This magnetic locking is happening because of the low value of reluctance in an induction machine. If magnetic locking is happening means there is no torque and there is no interaction between the current carrying conductor and rotating magnetic field. In this condition, torque will be equals to 0 or unwanted torques will happen. If it is exactly aligned, then torque should be 0. Otherwise, some unwanted cogging torques will come into the picture.

Because of this cogging torques, there may be higher losses as well as vibrations and noise and efficiency may come down. To avoid this thing, the number of slots at the stator side and number of slots at the rotor side should not be same and it should not be equals to p also. The difference between the two things should not be equals to P also.

This is the condition to avoid the cogging. Similarly, slot harmonics or synchronous curves is nothing but the slot harmonics will generally will occur in the machine because of the variation in reluctance.

Huge variation in the reluctance similar to the stator side slot harmonics, there will be a rotor slide slot harmonics also. To avoid the slot harmonics because of the variation in the reluctance, Q s minus Q r should not be equals to plus or minus p number of pole pairs and minus 2 p and minus 5 p. We should avoid this combination. The difference between the stator slots and rotor slot should not be equals to plus or minus p and minus 2 p and minus 5 p to avoid the slot harmonics. The order of slot harmonics q slot harmonics with respect to the rotor slot harmonics is nothing but Shr is equals to 2 into A m into q plus or minus 1.

Here A is nothing but integer and q is slots per pole per phase and m is the number of phases. Next thing is noise and vibrations. Usually this noise and vibrations will happen because of the harmonics with respect to the induced EMF and MMF waveforms. The harmonics with respect to the MMF and harmonics with respect to the EMF are the responsible for the noise and vibrations, especially spatial harmonics are the dominant variation and these harmonics will result in torque pulsations or ripples. This torque pulsations or ripples will result in noise and vibrations and other side the rapid variations are the dominant changes in reluctance will result in the B fields rapid variation.

This variations in B fields will results in some vibrations. If the reluctance variation is dominant or unwanted variation is reluctance variation is happening for example, magnetic pull where the air gap symmetry with respect to the rotor is not uniform. There is a slight bend at the middle of the rotor where the air gap is not symmetrical. Here air gap will be at the top side it will be more at the bottom side it will be less like you can consider that there is sag kind of structure came into the rotor side. During that condition the air gap will not be symmetrical with respect to the rotor structure.

During that condition also reluctance variation will be very high and B fields also will be different with respect to one side wherever the sag is there at that particular position the magnetic fields will be high and wherever the sag is not there the magnetic fields will be different. Because of that variation in magnetic fields we will see some vibrations to in order to avoid the noise and vibrations the difference in slots with respect to stator and rotor should not be equals to plus or minus 1 plus or minus 2 and plus or minus p plus or minus 1 and plus or minus p plus or minus 2. These are the generalized guidelines to select the number of rotor slots.

The summary with respect to the rotor slots the difference should not be equals to 0 and it should not be equals to n into p where n is nothing but integer and it should not to plus or minus p minus 2 p minus 5 p and plus or minus1 plus or minus 2 plus or minus p plus

1 p plus or minus 1 plus or minus p plus or minus 2. These are the combinations the difference between the stator slots and rotor slots should not be equals to these are all possibilities.

Then we can select the number of rotor slots this is equation number 29. If you want to select the rotor slots directly without thinking about all this aspect one solution will be Qr equals to Qs plus or minus 20 to 30 percent of stator slots. For example, Qs equals to 36 means Qr is equals to 36 plus or minus 20 percent of Qs. So, 36 plus 0.2 into 36 or 36 minus 0.2 into 36 this will gives 43.2 approximately we can take 43 this will give 28.8 we can take it 29. For 4 pole mission if we will assume then whatever the numbers we got here the rotor number of slots it should match the equation number 29. In most of the cases if we will follow this expression all these conditions will be matched with respect to equation number 29 based on this equation we can have to select the rotor number of slots.

And other way is we have to skew the rotor whatever the number of rotor slots we can select it and skewing the rotor will minimize the crawling, cogging and synchronous cusp and noise and vibrations and other effects. So, with this way we can find the number of rotor slots. So, with this I am concluding this lecture. In this lecture we have discussed the how to find the rotor number of slots. This is the equation to find the number of slots and also we have discussed the how to find the air gap length also. Thank you.