Course Name: Design of Electric Motors

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Title: Loss Calculation of Induction Machine -2 and Performance Parameters of Induction Motor

Greetings to all, in this lecture we will continue the loss calculations of an induction machine. So, we will calculate the mechanical loss of an induction machine with respect to the bearing and friction and windage losses. So, here mechanical losses are a consequences of bearing friction losses and windage losses of the rotating rotor. The total mechanical loss we can divide into three parts, first one is with respect to the bearing loss, second one is with respect to the windage losses with respect to the air gap and third component windage losses with respect to the ends of the rotor. So, the bearing loss depends upon the shaft speed, bearing type and properties of lubricants and how much load it is acting on the bearing. Then windage losses are a consequences of friction between the rotating surface and the surrounding air.

So, these windage losses are divided into two parts, one part is with respect to the loss with respect to the air gap. So, we can see here the windage losses with respect to the loss which are inside the machine and second one the windage loss with respect to the ends of the rotor. At the ends of the rotor we can see the windage loss component two, inside the air gap what is the and what are the losses that is nothing but part one of the windage loss. So, first we will discuss the bearing losses.

So, bearing losses we can calculate based upon this equation, the proof for this equation we can see this text book. This equation is derived with some assumptions and some empirical relations. So, bearing losses are equals to 0.5 into angular speed of the shaft supported by the bearing, we can see here in this image and then mu friction is nothing but frictional coefficient that is 0.08 to 0.20 for steel on steel sliding contact surface combination. And F is nothing but force acting on the bearing and D is the inner diameter of the bearing we can see here this is the inner diameter of the bearing. So, by knowing the inner diameter of the bearing and force acting on the bearing and frictional coefficient and rotating angular frequency of the shaft we can calculate the bearing losses.

The next component is windage losses, the windage losses are more significant if we are increasing the speed, if more speed is there more friction will be there with respect to the air presented inside the machine. These losses are the friction between the rotating surfaces and air and windage losses with respect to the air gap we will see now.

The with respect to the air gap again some equation that is 1 by 32 into roughness factor or roughness coefficient for smooth surfaces it will be 1 and for other we can consider 1 to 1.4 into torque coefficient that is Cm and pi into density of the coolant into angular frequency of the shaft and rotor outer diameter power 4 into length of the rotor that is ler we can consider it is le. If different rotor length and different stator lengths are there then effective length of a core we can calculate it with empirical formulas, but here ler we can consider same as le where the case is both stator length and rotor lengths are same. So, by utilizing this equation we can find the windage losses at the air gap. The proof is given in this text book in the references.

So, here the torque depends upon the torque coefficient Cm value we have to calculate the windage losses. The torque coefficient depends upon the Reynolds number like flow variable that is Reynolds number means Re delta is equals to coolant density into angular frequency of the shaft supported by the bearing and outer diameter of the rotor into length of the air gap divided by 2 into dynamic viscosity of the coolant depends upon this variables.

Next we have to calculate the Couette Reynolds number based upon that thing we can calculate the torque coefficients with this 4 empirical formulas. So, after knowing the torque coefficient depends upon the Reynolds number with respect to the different range we have to substitute the torque coefficient here then we will get the windage losses at the air gap of a induction machine.

Then windage losses at the ends of the rotor we can get it with this formula again it is a based upon assumptions and some empirical formulas like partial proof we can get it in this reference and this windage losses at the ends of the rotor depends upon the torque coefficient value again.

The torque coefficient depends upon the tip Reynolds number it is a different variable as compared to the Coat Reynolds number what we have discussed in the earlier slide that is this one this is the Coutte Reynolds number this is the tip Reynolds number. This also depends upon the coolant density and angular frequency of the shaft supported by the bearing and outer diameter of the rotor square divided by 4 into dynamic viscosity of the coolant. So, after selecting the Reynolds number with respect to the tip we can based upon the range we can calculate the torque coefficient. Once if you will substitute the torque coefficient value and density of the coolant and angular frequency of the shaft supported by the bearings and in a outer diameter value and inner diameter value of the rotor based on all these aspects we can calculate the windage losses at the ends of the rotor. Here in the machines air is the medium inside the machines.

So, the coolant density with respect to the air is 1.18 kg per meter cube and dynamic viscosity of the air is nothing, but 18.3 into 10 power minus 6 Pascal seconds. Then stray load losses are the losses which are not considered with respect to the stator copper losses and core losses and mechanical losses. So, the losses with respect to the load currents and its spatial harmonics caused in the windings or laminations or frame and other constructional parts which are not considered during the other loss component calculations.

These losses are caused by some part of the time harmonics with respect to the supply voltage also and these losses has to be considered with respect to the IEC standards. Some empirical formula we can see here stray load losses are equals to 2.5 percent of input power if the rating of the machine is less than 1 kilowatt for an induction machine. If it is greater than 1 kilowatt and in the range of 10,000 kilowatt, we have to consider this equation number 2 that is 0.025 minus 0.005 into log base 10 of P out divided by 1 kilowatt output power per unit with respect to 1 kilowatt. If output power is greater than 10,000 kilowatt, we can consider 0.5 percent of input. So, PLL represents the stray load loss and input power is nothing but P in and output power is P out. With respect to different machines, what is the loss percentage with respect to the stray load losses? For a squirrel cage induction machine, it is 0.3 to 2 percent and we can consider up to 5 percent depends upon the rating of the machine and slip ring induction machine, it will be 0.5 percent and salient pole induction machine up to 0.2 percent, non salient pole and DC machine without compensated winding and with compensated winding, we can see the different numbers with respect to the stray load losses in detail is given in this particular reference that is Juha pyrhonen design of rotating machines. So, after calculating all these losses, we have to find the efficiency that efficiency should fall in the standards and classifications as per the IEC 60034 standard. I E 4, I E 3, I E 2 or I E 1 with respect to the standards, we have to make the design and these are the standards we have discussed already.

These are the NEMA standards, these are the I E standards. Next how to calculate the no load current per phase with respect to the equivalent circuit? Once we know the core loss component plus mechanical losses, then we can calculate the core loss component that is power divided by 3 into voltage because 3 phases are there into phase voltage RMS will give the core loss component. Here mechanical loss also considered because these mechanical losses will be there during no load condition also. The magnetizing current we can calculate based upon the fundamental stator MMF and the number of turns and number of poles and winding factors relation. This equation already we have derived.

Once we know the core loss component current and magnetizing current, then no load current we can calculate it the current which is flowing through this branch IM we know and core loss current also we know. Then no load power factor is equation is equals to cos phi naught is equals to IC core loss component divided by I naught no load component from the vector diagram of an induction machine we can get this relation.

After knowing the loss copper loss with respect to stator and rotor and core loss with respect to stator and rotor and mechanical losses and stray load losses we can find the output power. Once we know the output power and losses output divided by output plus losses gives the efficiency. This is the actual efficiency of the machine.

The input power is nothing, but P out plus P losses. Then from the copper loss of the machine we can calculate the what is exact output of a machine P out. So, P out is equals to P copper loss into 1 by s minus 1. Then from this equation mechanical output power equation in terms of speed and torque that is 2 pi nt by 60 we can calculate the torque developed by a machine te is equals to 6 into 60 into P power output divided by 2 pi into actual speed of the machine. This equation will give the torque developed by the machine.

Once we know the power and torque developed by the machine we can calculate the densities as well as maximum and full load torques with respect to the different equivalent circuits. The equivalent circuit with respect to the IEEE standards by neglecting the core loss component will be this thing. With this equivalent circuit we have to find the full load torque equation and this is the equivalent circuit with respect to the Thevenin's model where the magnetizing inductance also neglected. Here Rth and Xth and other variables we can calculate it based upon this thing Zth is nothing, but J xm parallel to Zs stator impedance parallel to the magnetizing inductance. So, that is nothing, but Rth plus J xth and Vth is nothing, but Thevenin's voltage as per the voltage division rule we can find the Thevenin's equivalent voltage here.

Here the xm variable is considered in terms of Rth plus jXth itself. Even though with respect to the shunt branch it is neglected, but it is effect is considered in the series branch itself. So, the electromagnetic torque developed by the induction machine with respect to the equivalent circuit 1 that is this one equivalent circuit 1. Then maximum torque developed by the induction machine with respect to the Thevenin's equivalent circuit will be this thing. So, that is 3 by angular speed into Thevenin's voltage square divided by Rth square plus R2 dash by s plus Xth plus X2 dash square by X2 dash square into R2 dash by s.

This is the T full load torque equation and this is maximum torque equation based upon these two torques we can find the ratio between maximum torque to full load torque ratio. Then once we know the torque developed by the machine and power developed by the machine we can calculate the density of a machine with respect to the volume as well as with respect to the mass of the machine. The total mass of a machine we can calculate it by considering the actual weight of the stator winding, rotor winding and stator teeth at the stator side and core weight at the stator side teeth weight at the rotor side and core weight at the rotor and frame weight and bearings weight and other weights with respect to the lubricants and terminals extra conductor length from slot to terminal box and terminal box weight and etcetera. So, by combining all these weights we will get the total weight of the machine then mass is equal to density into volume. From here we can get the volume of the machine also complete volume or we can calculate the volume of the machine by considering the outer diameter of the stator also approximately.

We with respect to the outer diameter of the stator will be pi D naught s square divided by p into L e area into length sorry directly D naught square s square into L e is the volume of the machine with respect to the outer diameter. Then torque and power density of the machine P is equals to density power density with respect to the mass will be actual output power developed by the machine with respect to the total weight of the machine. The torque density is equals to actual torque developed by the machine divided by weight of the machine. Then density terms with respect to the volume then power density with respect to the volume is power per unit volume torque density with respect to the volume is torque per unit volume.

With this I am concluding this lecture.

In this lecture we have discussed the last calculations as well as power density and torque density of an induction machine. Thank you.