Course Name: Design of Electric Motors

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Title: Heat Flow in Electrical Machines

Greetings to all, in the last lecture we have discussed the heat transfer methods right like conduction, convection, radiation. In this lecture, we will identify the different thermal nodes and how the heat is transferred from one node to other node like stator winding to different parts of machine like stator winding to end region or stator winding to core like that we can see here this machine. So, first we will identify the different parts of thermal sources or with respect to the losses what are the heat sources and based upon the heat sources how the heat is transferred let us say from winding to end winding here we can see this is the inside the core and in the slots the windings are placed. So, from the slot region of the winding to end winding then end winding to shielding through the radiation. So, we will identify different nodes with respect to the thermal aspect and we will analyze the how heat flow is happening either it is conduction or convection or radiation. First we will discuss the heat sources.

So, the main heat sources are nothing, but loss components right. So, the stator copper loss and stator core loss, rotor copper loss and rotor core loss. Copper loss with respect to the stator and rotor it will be I square R losses and core losses will be hysteresis and eddy current losses and mechanical losses are nothing, but friction and windage losses. We can see the stator copper loss with respect to the stator winding, stator core loss with respect to the stator core and rotor core loss with respect to the rotor core and rotor windings either it may be squirrel cage bars or windings on the rotor and mechanical losses with respect to the bearing portion and end region portion or end air with respect to the rotation of the rotor how windage losses are happening that are the mechanical losses.

Now, we will identify the thermal nodes. So, we have observed the heat sources one is at here copper losses, stator core losses and rotor core losses, rotor copper losses and mechanical losses with respect to the friction and windages. So, these are the sources. Now, to make the heat transfer from one point to other point we will define the or we will

divide the machine surface into different thermal nodes. In this image I have shown the quarter section of the machine and this image I have taken from the Lippo text book and the different thermal nodes we can see here and thermal node one represent the stator windings and thermal node two represent the stator end winding.

This is stator end winding we can see here this is the stator winding node one stator end winding node two and stator teeth is node three and stator core is node five. So, stator part is divided into four nodes stator winding stator end winding stator teeth that is three and stator core is nothing, but four. Same way five, six, seven, eight are representing rotor winding that is five and rotor end winding that is six and rotor teeth is seven and rotor core is eighth node and air gap represents the node number ten and eighteen represents the radial duct and nine represents the frame machine frame that is this one this is nothing, but frame and enclosures we will see at the both sides of the machine that are nothing, but fourteen and bearings are represented with thirteenth node and shaft is represented with twelfth node and eleventh is nothing, but air gap space at the end ring portion. We can see here some portion is there right I am showing with laser pointer here this end ring region the air gap region is nothing, but thermal node eleven and ambient is represented with fifteen and stator end support is nothing, but sixteen the stator core to frame connection. These are the different nodes with respect to the machine induction machine and how the heat is transferring from one node to other node we will see now.

So, total eighteen nodes we have divided the machine and we can divide or we can decide this thermal nodes depends upon the analysis whether it can be eighteen or whether it can be five or whether it can be twenty to make the more accurate thermal modeling we have to select the higher number of thermal nodes. First we will discuss with respect to the stator winding. So, this is the stator winding we can see here. So, from the stator winding the heat is generated with respect to the losses and it is transferred to the stator end winding. So, the end winding is directly in contact right through the conduction the end winding is happening red color line means conduction end winding region it is going the conductors which are placed in the slot portion to the end winding portion.

Then stator winding to the stator core or teeth portion we can see here through the radiation and small portion of conduction because thermal conductivity of slot liners we can see in this image that white color insulating papers. The insulating paper thermal conductivity is small, but the conduction is happening slight conduction that is red color line and purple line is representing the radiation. Through convection it is heat is transferred to the air gap and through radiation also heat is transferring to the air gap. So, from stator winding to the air gap heat is transferred through the convection as well as radiation. These are the different paths or different heat transfer methods from stator winding to stator end winding stator core and air gap.

Same way if I will consider the stator core or teeth from stator core with respect to the core losses the heat is dissipating and some part of heat can be come from the radiation as well as conduction from the winding because winding temperature is very high and core temperature is slightly less as compared to the winding temperature. So, from stator core to teeth to frame through the conduction as well as radiation it is dissipating the heat or transferring the heat core to frame and core to stator end surface through conduction because it is a physical contact is there between stator core and stator end surface. That is why there is a conduction with respect to the physical surface or physical contact. Then radial ducts if there are any radial ducts are there here radial means in this direction axial means in parallel with the shaft perpendicular to the shaft will be radial direction. So, the radial duct heat is transferred through the convection manner green color and to the air gap also with respect to the convection the heat is transferred because there is no contact from teeth to air gap right only air is there.

So, with respect to the convection heat is transferred to the air gap from the core. This rotor winding also same with respect to the copper loss involved in the rotor winding then heat is transferred to the rotor core or teeth with respect to the insulating material. Generally there is no insulating material which separate the rotor slots as well as aluminum bars. Since it is a squirrel cage no need of insulating material with respect to the slot liner directly through the conduction heat will transfer and then rotor winding to rotor end winding it will be through convection and radiation as well as conduction also will come because these two are in directly in contact right. So, there will be a conduction part also from the end winding to the rotor end region.

Rotor end winding and rotor windings are directly connected right. So, through the conduction we can see the heat transfer. Next rotor end winding to the surface rotor end surface also through a physical contact will be the conduction. Next rotor core or teeth and rotor core there will be a losses with respect to the hysteresis and eddy currents and these losses are dissipated in the form of heat and this heat will transfer to the air gap through the convection and to the rotor end winding it will be to the convection only and again rotor end winding to the rotor end surface it will be the conduction. Then rotor core to core and teeth to stator core and teeth through the radiation manner because there is no connection between rotor core and stator core with respect to the air gap through the radiation it will transfer the heat.

Since the rotor core is at the middle of the machine after that windings are coming that is why the end winding is conduction sorry convection I have mentioned here. If the rotor end winding temperature is high as compared to the core then heat will not transfer from the rotor core to teeth. This will not come if the temperature of this thing is greater than temperature of this thing. If this part temperature is greater than rotor core temperature then this heat transfer will not happen as per the thermodynamics second law principle.

And now we will see the complete heat flow diagram with respect to the induction machine.

First we can see the different thermal nodes stator winding or slot portion and stator end winding and stator core or teeth and frame stator end surface overhang region and air gaps end shield radial duct and axial duct and rotor winding and rotor core and rotor end surface and bearings and rotor end winding. These are the different thermal nodes we have considered. Now we will see how the heat is transferring is happening. So, the red color line represents the conduction. So, the stator winding portion to the stator core and core to frame or core to end surface and finally, everything is related to the ambient heat is transferred to the ambient.

Next with respect to the convection we can see the green color lines here stator winding to the air gap stator core to the air gap whatever we have discussed one by one all things I am clubbing here the heat flow and the purple line represents the radiation. We can see here from the frame to the ambient the heat is dissipated or heat is transferred through the conduction convection and radiation all three manner the heat is transferred to the ambient same way from the end shield. End shield is nothing, but the supports at the both sides of the machine. We can see here this is the end shield this is the one end shield or end cap. So, from the end cap to ambient also through the convection and radiation the heat is transferred.

Next, we can see the rotor winding to core portion and then rotor end surface and bearings to the ambient how the heat is transferred and same way with respect to the all aspects or all thermal node the complete thermal heat flow diagram for any mission. This is the picture I have shown for induction machine, but any mission we can realize in this fashion the heat flow diagram the yellow color line representing the air or coolant flow the coolant is flowing through the radial duct as well as axial duct. We can see here then axial duct to the air gap region then the air gap region to the overhang region then from the axial duct to overhang region again then overhang region to back to ambient. This is with respect to the axial and radial duct directly it will go to the air gap region then overhang region and from the overhang region it is coming out to the ambient again. Similarly, we can see the different nodes how the heat transfer with this I am concluding this lecture.

In this lecture, we have discussed the heat transfer with respect to the different nodes of a electrical machine especially induction machine we have discussed. Thank you.