Course Name: Design of Electric Motors

Professor Name: Dr. Prathap Reddy B

Department Name: Electronic Systems Engineering

Institute Name: Indian Institute of Science Bengaluru

Week: 11

Lecture: 62

Title: Heat Transfer Methods and Basic Equations for Thermal Resistance

Greetings to all of you. In this lecture, we will discuss the heat transfer method methods like conduction, convection, radiation. The loss component in the electrical machine results in heat dissipation, right. These losses are dissipated in the form of heat and this heat will flow from high temperature region to low temperature region as per the principles of thermodynamics and how it is flowing with respect to the different heat transfer methods. In all methods, it will flow from high temperature to low temperature region, but different methods are there. One is conduction, convection and radiation.

We will discuss related to these three methods, how heat is transferring or heat is flowing from high temperature to low temperature region. First, we will discuss the conduction method. In conduction method, the heat is transferred through a solid body or physical contact. Let us consider a stator core.

Stator core is directly connected to the frame, right. Assume that this is the frame. So, with respect to the losses in the core, that is core losses, heat will be generated. That heat is transferred to the frame through the physical contact or we can call it as a conduction, where the core is high temperature object and frame is low temperature object. So, heat is transferred through the physical contact or through a solid object or medium from high temperature to low temperature.

We can see some examples like touching the hot object or holding the ice cube, some general examples for the conduction method. Let us consider this is temperature 1 and this is temperature 2. The temperature with respect to the core and temperature with respect to the frame. In between, we can model the material or the structure as thermal resistance. We can represent the temperature difference and heat flow through a medium as the thermal resistance that is r theta.

So, here thermal resistance r theta with respect to the conduction is nothing but l by lambda into A. l is nothing but length of the object. If we will consider this is the an object, this is the length and thermal conductivity for the heat transfer is lambda and cross sectional area, this portion is Ac. The cross sectional area with respect to the heat flow is Ac and this is thermal conductivity. Similar to the electrical resistance, here also we can represent the thermal resistance with respect to the conduction.

Generally, the resistance with respect to the electrical circuit resistance equals to rho l by A. We will define. So, 1 by rho is nothing but electrical conductivity that is sigma into A. So, in the same fashion, we can write the thermal conduct, thermal resistance equation in terms of length of the object that is l and thermal conductivity is nothing but lambda and area of cross section is A. The units are for A, it will be meter square.

For lambda, the units are watt per degree Celsius per meter and the thermal resistance units are Kelvin per watt or degree Celsius per watt and length in meters area is in meter square. This is the thermal resistance with respect to the conduction and we can see here different thermal resistance values for a different material. Thermal conductivity of the metals which are used in electrical machines like copper thermal conductivity is 360 watt per meter into Kelvin. Copper and aluminum, we can see here 200 to 220 and M 27 lamination M 43 laminations, we can see 24 and 34 watt per meter into Kelvin and for stainless steel and cast iron and ferrite magnet and neodymium magnets, we can see here different thermal conductivity values. Generally, we will see the copper and aluminum for windings that is copper windings are 360 and aluminum windings are 220 watt per meter Kelvin and similarly, we can see the thermal conductivity for insulators for glass or fiber.

It is 0.8 to 1.2 watt per meter into Kelvin. Similarly, for water paper, we can see here mica sheets which are we are utilizing for slot liners. This is the slot right. So, in order to isolate the conductors from the core, we will use the slot liner and some closures.

So, the material of this slot liner that is insulating paper is nothing but mica paper that is 0.2 to 0.3. We can see here thermal conductivity value is very less because of this reason in order to bring down the temperature with respect to the conductors placed in a slot. These are the high temperature operating region with respect to the conductors in order to bring down the temperature at this particular region.

It is a challenging task because there is no conduction path from the windings to core because in between some insulation material that is green color one slot liner is there. For hydrogen and air, we can see here the thermal conductivity for different materials. The typical heat flow densities in watt per centimeter square in different portions of electrical machines, we can see here indirectly cooled windings in slots will be 0.15 watt per centimeter square. Iron laminations it is 0.4 and solid iron pieces it is 2.5. Heat flow densities I am talking and direct air cooled mission it is 4.4 and water cooled mission we can see 9. So, if we will design a water cooled system, then heat flow density watt per centimeter square is 9.

So, for high power density machines, we have to design the thermal system by with the direct water cooling or liquid cooling systems. Next we will discuss the heat transfer with convection method. In convection method, the heat is transferred between the solid and a fluid or medium, whether it can be air or liquid. The heat is transferred through the air or liquid medium, where we can see either it is forced cooling or natural cooling. In natural cooling, air or coolant is flowing with respect to the temperature difference, whereas in the forced cooling, the pressure is created with respect to the external source like fan or pumps etcetera.

In the forced cooling, the coolant movement is depends upon the pressure created with respect to the external sources like fans and pumps. In the natural convection based upon the temperature difference, the coolant will flow. Let us consider the stator structure. This is the stator structure on top of that the finned stator frame will be there or mission frame will be there. With respect to the temperature difference, the air will flow from one direction to other direction and it will cools down the temperature of the stator core.

Let us consider in this fashion. Here, this is the hotter object and here heat is dissipated with respect to the convection natural cooling method, where with respect to the temperature difference, the heat is dissipating. We can see the arrow directions, examples coolers and exhaust fans we can see. The thermal resistance with respect to the convection or theta convection is nothing but 1 by h c into area of with respect to the convection. Here, h c is nothing but heat convection coefficient and the units are watt per meter square into Kelvin or we can write watt meter power minus 2 and Kelvin power minus 1 and area with respect to the convection is nothing but cross sectional area in meter square.

So, this is the thermal resistance with respect to the convection. So, we have to identify the different parts of the machine and different heat sources in the machine and how the heat is transferred with respect to either it is convection or conduction and then we have to calculate the resistances with respect to the following method whether it is conduction means conduction based thermal resistance, convection means convection based thermal resistance and radiation final method. In radiation, the heat is transferred through the electromagnetic waves. This is the hot object. So, with respect to the electromagnetic waves, the heat is transferred.

Examples we can consider the how we are receiving the sunlight or heat energy from sun to earth and fireworks at the room, the general examples and in electrical machines, end winding space, the air will be there and then end surface that is nothing but end cap with respect to the machines, end cap on the both sides. This is the air region with respect to the end windings. So, from this point air region to outside in the form of radiation, it will transfer the heat. The thermal resistance with respect to the radiation is equals to 1 by radiation thermal coefficient h r into area with respect to the perpendicular area to the radiated direction. The area in terms of meter square and thermal coefficient with respect to the radiation is watt per meter square into Kelvin and here the radiation thermal coefficient depends upon the equation.

The empirical equation is equals to 4 into sigma epsilon effective into 1 minus 5 into T 1 plus T 2 divided by 2 whole cube. Here, T 1 and T 2 are the temperature of the two different objects and sigma is nothing but Boltzmann constant 5.67 into 10 power minus 8 watt per meter square per Kelvin power 4 and epsilon effective is nothing but emittance with respect to the different materials. Efficient emittance is nothing but epsilon effective and phi is nothing but shielding factor. This shielding factor gives the measure of shading of radiated heat transfer from the hot body, how the heat is transferred in the form of radiations.

For single plate and two parallel plates, the shielding factor phi is equals to 0. If through single plate or through two parallel plates, the heat is transferred through the radiation, then the shielding factor is equals to 0. We can consider the emittance value depends upon the different type of materials that values. We can see here the emissivity values with respect to the materials used in electrical machines.

The polished aluminum, it is 0.04 and polished copper it is 0.025 and mild steel it is 0.02, 0.03. It is a unit less quantity and cast iron it is 0.3 and black paint we can see it is a good absorber as well as radiator right black body. So, emittance value is always equals to almost 1. We can see here 0.92, 0.95 for black paint for black object or black body the emittance value is approximately equals to 1.

So, based upon different emittance value, we have to calculate the thermal resistance with respect to the radiation. Now, we have discussed the different type of methods of heat transfer right. So, we have to identify. Let us consider this is a machine. So, we have to identify the different thermal nodes.

So, based upon the thermal nodes how the heat is transferring let us say this is node 1, node 2, node 3, node 4, node 5, node 6 like that with respect to the different heat sources. How the heat is transferred from one node to other node? Let us say stator winding is first node, stator core is second node. So, stator winding to stator core how heat is transferring whether it is conduction or convection. If it is conduction from stator core to frame, I am considering as a conduction. Then the thermal resistance with respect to the conduction we have to calculate while realizing the thermal equivalent circuit or while designing the thermal design.

Similarly, from frame to ambient, it will be some kind of radiation right. Thermal resistance with respect to the radiation we have to analyze by utilizing these basic formulas. We will discuss in detail while discussing the thermal equivalent circuit. So, with this I am concluding this lecture. In this lecture, we have discussed the different methods of heat transferring like conduction, convection and radiation. Thank you.