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: 12

Lecture: 64

Title: Cooling Methods and Standards for Electrical Machines

Greetings to all of you. In this lecture, we will discuss the types of cooling methods for electrical machines, whether it is natural cooling method or forced cooling methods and different type of standards as per NEMA standards and IEEE standards, what are the different type of cooling methods are there. If we will see here, the specification with respect to the cooling method. In any machine data sheets, we will see the specifications for the type of cooling method or this specification will give the type of cooling method for any electrical machine. We can see here, first two positions that is 1 and 2 letters IC. IC represents the international cooling standard and then third position, we have an integer that is 8.

This integer represents the circuit arrangement with respect to the machine structure and arrangement how the cooling or coolant flow will happen. Fourth position, we have a letter that is A, which represents the type of primary coolant, whether it is air or whether it is liquid or anything else. So, fourth place, we have a letter that represents the primary coolant. Fifth position, we have another integer that integer represents the moment of primary coolant like what is the cause for the flow of coolant, whether it is in natural cooling or free circulation means with respect to the temperature difference, the coolant will flow.

In forced cooling with respect to the pressure created with respect to the external source, the coolant will flow. In the sixth position, we have again letter that is W. W represents the water type of coolant that is secondary coolant and seventh position, we have another digit or number that number represents the moment of secondary coolant. Let us say water is there. How water is flowing to bring the temperature down of a machine? For example, IC 4 double 1, I am considering one standard of cooling method for induction machines.

IC 4 double 1 or IC 4 A 1 A 1, we can see. So, IC 4 A 1 A 1, we can see the example. A and A represents the air is the primary coolant as well as secondary coolant and the digit

1 represents the moment of coolant that is self circulation where fan is mounted on the rotor and 4 represents the frame surface cooled machine. That means, the air is circulated through the or on top of the frame to reduce the temperature of a machine and the characteristic letter, how we have to represent with respect to the different type of coolants means the letter A represents the air as a coolant. Letter F represents the refrigerant as a coolant.

Same way, hydrogen with H, nitrogen with N and carbon dioxide with C and water with W and oil with U and any type of other coolant, we can represent with S and coolant which is not yet selected or undefined one, we can select Y letter. So, these are the different letters representation which will give the different type of coolants as per the NEMA standards. The reference we can see here. First we will discuss the natural cooling or free convention method of cooling. In this method, there is no external fan or there is no any external source for coolant flow.

The coolant is circulated due to the temperature difference like the air is freely moving through the fins on top of a machine to reduce the temperature. We can see here one type of machine for free and natural cooling. This is a simple induction machine. This is IC double 0 type of cooling. There is no fins on top of the machine, but due to the temperature difference, the air will flow through or across the machine surface.

Then, it will reduce the temperature and in IC 4 1 0 and IC 4 A 1 A 0 standards, the fins will be there on top of this machine. There will be a fins for cooling purpose that we can see in this image in the PPT. So, through the fins, the air will flow naturally with respect to the temperature difference and the temperature of a machine will come down. Next one is self cooling or self circulation. The name itself indicates that self cooling or self circulation, where the fan is mounted on the back side of rotor with respect to the rotation of the rotor.

The circulation of coolant will happen. So, the fan we can see here, red color highlighted in this image, red color one at the back side of the rotor. If the rotor is rotating, automatically fan also rotating and with respect to the pressure difference, air will flow through the fins. We can see here, the fan is rotating and air is flowing through the fins. This is nothing, but self cooling or self circulation method.

Here, fan will be there and air is coming from this side and leaving through the fins. So, air is coming in here and going out through the fins. This is a part of self cooling. The standards are IC411 and IC4A1A1. The type of coolant, if it is air, generally they will not represent.

Next, also self cooling or self circulation methods that is IC01 standard, IC11 or IC21 or IC31. Here, 0123 like some digit is there, third digit. This third digit is representing type of circuit arrangement. We can see here, if it is IC01, there is no inlet duct or outlet duct.

In this portion, there is no duct, but whereas, in IC11, the outlet duct is there, inlet duct is there.

The air is coming through the inlet duct and air is flowing out from the outlet. There is no duct here, whereas, in the IC21, outlet has the duct. Inlet does not have any duct. In IC31, both sides for inlet as well as outlet, a separate duct will be there for circulation of coolant. Here also, the moment of coolant will happen due to the rotation of rotor.

For rotor, there is a fan is attached. Next method is forced cooling with machine mounted independent component. So, the machine, a separate and independent machine is mounted on top of the machine to circulate the coolant. Here, coolant is air. So, with respect to the independent machine, the pressure is created and it is not dependent on the speed of the actual machine.

This is the actual machine. So, it is not depending upon the speed of actual machine. With respect to the independent machine speed, the pressure will be created and air is coming in here and going out from the vent, outlet vents that we can see here. From this side, air is coming in with respect to the independent machine mounted on the main machine and outlet ducts, we can see here. Outlet vents, there is no duct, but vent is there.

Vent means holes. So, air is coming out from here. Same way, other type of machine from Siemens, we can see here. These are the outlet vents and these are the inlet vents where air is coming in and here air is going out. This is the method with respect to the forced cooling where the circulation of coolant is happening with respect to the machine mounted independent component. The standards are IC06 and IC0A6 and this type of cooling methods, we will utilize in low and medium voltage application.

Earlier methods like self cooling or self circulation and natural cooling also, we will utilize for low voltage and low power applications. Similarly, here we can see the difference. IC06 means the inlet side as well as outlet side, there is no duct in here, whereas in IC16 standard, inlet side we have a duct. We can observe here. This is the inlet duct, whereas in IC26 standard, outlet has duct, but there is no inlet duct.

IC36 standard represents the inlet duct as well as outlet duct. Both ducts are there. Both sides we have a duct for coolant flow. The circulation of coolant will happen with respect to the independent machine mounted on the machine with a fan. Same type of machine, assume that here one inlet duct will be there.

Then, it will be IC16 type of cooling standard. If outlet duct also there, both ducts are there means, then it will be IC36 cooling standard. Same way, if the machine is mounted axially on top of the rotor, we can see here on top of the rotor, the machine is mounted. This machine is independently controlled and this speed is not related to the mine

machine and it is not mounted on the rotor. It is mounted back side of the machine and separate machine is mounted in the axial direction.

We can see that thing here. In this portion, separate machine will be there to make the circulation of coolant. The terminal box for the cooling fan or mounted machine and terminal box for the main machine, we can see the two terminal box here. So, this is the machine. So, this side we have the machine which will make the circulation of coolant and this is the main machine where the mounted machine for cooling purpose is placed axially. Next, forced cooling with relative displacement.

Here the circulation of coolant will happen with respect to the relative displacement between machine and coolant. Here either machine is moving in the air stream or machine is constant and air is flowing in both ways. Either machine is moving in air or air is moving on top of the air that is the totally enclosed air over cooling. The standard is IC418 and second method is IC71W. We can see here W represents the water cooled standard and water as a coolant.

So, 71W, IC71W here air is the primary coolant and water is the secondary coolant and this is the water inlet and this is the water outlet. So, two vents are there. One is inlet, other is outlet with respect to the water cooled thermal or cooling method where the jacket will be there and through this jacket, this coolant is circulated. Next method is forced cooling with separate and independent component. As of now, we have seen that the motor is whether it is fixed on axially or on top of the machine with mount type of motor.

We can see here this is the axial type of coolant where the machine is mounted with respect to the axial portion of the rotor and here machine is mounted on top of the machine. Now, assume that this cooling circuit or pressure creating circuit is done externally and there is no connection with the pressure creating circuit. Here, it is the inlet of the coolant and outlet of the coolant will be vents and we are creating with separate electrical plus mechanical unit. The circulation of the coolant will happen with respect to the pressure created by this separate unit. This is the separate unit which is externally we are creating the cooling system.

This cooling system will create the pressure and makes the flow of coolant through the machine. Here, inlet duct will be there and vents are there at the outside. This type of machine we will utilize it for low voltage and medium voltage applications. Examples we can see some water distribution supply how the pressure is created externally and at the end user will see or will get the water depends upon the tap pressure created with respect to the tap. Here, we can see another type of standard IC37.

Here, IC17 and IC37 means both inlet as well as outlet as a separate duct. This is the duct whereas, IC17 has only inlet duct and outlet has vents. Next one is IC611 standard. In IC611 standard, the cooling circuit or heat exchanger is placed on the motor shaft.

We can see this portion. This blue color portion is the heat exchanger and a fan is mounted at the back side of the rotor. When rotor is rotating, automatically fan also rotating and depends upon this rotation of the fan. Heat exchanger will be there for cooling the machine. Whereas, in IC511 standard, only air pipes will be there. Here, there is no separate exchanger and air pipes are installed on top of the stator core.

We can see some pipes here. These are the pipes for coolant flow and here, the circulation of coolant will happen by with the rotation of fan, which is placed on the back side of rotor. Here also, the circulation of air will happen with respect to the rotation of the rotor and it is flowing through the air pipes. We can see the air pipes here in this method. Whereas, in this method, heat exchanger will be there. Next heat exchanger is placed and motor mounted on the heat exchanger for coolant flow.

Air is coming in from this side and air is going out from this side. Here, circulation of coolant is created with respect to the independent machine mounted on the main machine. Here, the multiple machines are mounted. The standards are IC666. There is no letter mentioned 6 W 6 like that, if W is mentioned means it is water cooled system.

Otherwise, it is air cooled system only. If all after IC, if all are digits means it is air cooled type of method only. Next one is IC516. IC516 is nothing but externally mounted machine will be there and heat flow like heat flow or a coolant will flow through the air pipes. We can see air pipes here and here coolant air is flowing with respect to the pressure created from the externally mounted machine axially on top of the machine with respect to IC516. This type of cooling method we will utilize in medium and high voltage motors.

Same way, IC81W we can see here. W represents the water cooling method. Water is coming in from this side and going out from this side. Water cooled heat exchanger is placed on top of the machine and with respect to the heat exchanger, this water is flowing and red color line is representing the air flow primary coolant in this image. In the IC86W, the air cooling and forced ventilation inside the stator and water cooled heat exchanger. Here, exchanger is there and water cooled and the pressure is created with respect to the externally mounted machines.

That is the standard IC86W. So, these are the few different standards which we will use generally. IC411, IC410, 416 and 418. IC411 represents the totally enclosed fan cooled machine that is used for low voltage drives like pumps, fans and hydraulic applications. IC410, totally enclosed non ventilated. Only finned casing will be there without any fan

and generally, we will utilize in cranes and other applications which will operate only to meet the constant load for a shorter duration.

IC416 type of cooling method are used in totally enclosed forced ventilated machines. The motor is totally enclosed with finned casing and cooled by externally mounted motorized axial or radial fans. Generally, used in variable frequency drives, controlled motors and to operate at variable speeds and torques and totally enclosed air over type of cooling is IC418. Here, either machine is moving in the air or air stream is flowing on top of the motor. So, this number whatever with respect to the IC411 or IC some numbers, it is representing the type of cooling method for any type of electrical machine.

Now, we will see the existing cooling methods like fan mounted machine with respect to the forced cooling or self circulation where the fan is mounted on backside of the rotor and different type of fans. We can see here fan arrangements and with respect to the different fan arrangements, the coolant flow will vary in the machine and how coolant is flowing in the machine with the fan. We can see here the air is entering from this point incoming air and with respect to the fan, the outgoing air is flowing through the fins. This is the portion for the fins top side and bottom side and inside the machine even though the fan is not circulating the air inside the machine, but with respect to the temperature difference, the air in the end regions will circulate in this manner. This thing and this thing and the end ring air is also flowing through the air gaps also.

These bigger arrows represent the air gap regions. How the hot air with respect to the air flow with respect to the temperature difference from the end regions to the air gap and end regions, one end region to the other end regions. Some external air cooling methods we can see the fan machine mounted type of cooling we have discussed and here axial ducts will be there. Here axial duct we can see this blue color is representing the axial duct for air flow. This is the axial duct and pressure will be created with respect to the external source.

Here, this is the air inlet and this is the air outlet. Air is flowing from inlet to outlet to bring down the temperature of a machine and in detail analysis, we can see in this reference with respect to this axial ducts type of cooling methods. Same way for high power density machines, nowadays we are utilizing the high power density machines in electric reaction application, where the power or torque per unit kg or per unit volume is keep on increasing. So, the size of the machine is coming down, but losses inside the machine will vary with respect to the power rating in order to make the thermal design. For this high power density machines, we have to go with liquid cooling methods because this liquid cooling method will give the better thermal conductivity. Here, we can see the electric motor transmachine system and power electronic system completely thermal design with respect to the water cooling.

Here we can see the water cooling for all three systems that is transmachine, electric motor and power converters. Here, stator winding cooling we can see the pink color one and power electronics cooling with blue color and red color with respect to the rotor windings. This is some BLDC machine water cooled drive, where inlet will be there and outlet will be there. We can make the external source to create the coolant flow. One will be inlet and other will be outlet from these two terminals.

In order to design the high power density machines, we have to design the appropriate cooling method. So, liquid cooling will help you for designing the machines with high power density and other liquid cooling methods with jockeyed liquid cooled jockeyed. We can see where jockeyed is placed around the stator core and with respect to the external source, we can create the water circulation or coolant circulation. The details are given in this reference with respect to this liquid type of cooling. Same way for large machine like a megawatt drives and where the length of the machine as well as diameter of the machine is very big, in that situation, we will utilize the radial ducts.

In this image, we can see the radial ducts. These are the radial ducts. Radial ducts we can see here and axial ducts of the machine we can see here. So, with respect to the radial ducts and axial ducts, we can make the coolant circulation such that the temperature of the machine can come down quickly. So, if we will make the coolant system for this thing, the coolant will circulate through this radial ducts as well as axial ducts and natural cooling with fan cooled and fan cooled machines, we can see without any fan, we can see here. So, naturally the air will flow through the fins with respect to the temperature difference and here fan is mounted on the rotor and air will flow through the fins with respect to the rotational speed of the rotor.

We can see here the general standards which are applying to the different all machines. As of now, we have seen few standards, IC416, IC516 and some other standards, but n number of methods are available with respect to the NEMA standards. So, primary coolant and secondary coolant we can see here with respect to this document and specification with respect to the cooling method we have discussed and different type of cooling. Here we can see the characteristic number with respect to the circuit arrangement, whether it is free circulation or inlet pipe or inlet duct is circulated and outlet pipe or outlet duct is circulated.

So, different type of circuit arrangements we can see. So, 0, 1, 2, 3 like that different numbers will represent the different circuit characteristic combination. Same way the coolant characteristic letter also we have discussed and with respect to the method of movement is nothing but how coolant is circulated in a machine. So, the coolant with respect to the 0, 1 we have discussed free convention and self circulation and 5, 6, 7, 8 represents the forced cooling by utilizing the integral or machine mounted with separate machines like independent machine will be there to create the flow. So, these are the

different examples and different standards for the machine. So, with respect to the free circulation circuit arrangement IC00 and IC0A0 standard and free convention or free circulation is the movement of coolant same way self circulation means with respect to the fan mounted on the rotor.

So, the difference we can see here IC01, IC11 means one duct will be there with respect to the input and IC21 means one duct will be there for outlet and both ducts are there for inlet as well as outlet with respect to the coolant that is IC31. Same way different methods with respect to the different cooling arrangements or cooling circulation coolant circulation methods we can see here those who are interested they can go through these standards and the examples for primary circuits are closed and secondary circuits are open and for using the surrounding medium and heat exchangers IC511, IC611 we have discussed and the different type of water cooling methods and standards we can see here IC70W, IC71W, IC81W, IC76W. So, different type of cooling methods with respect to the different coolants is presented in this document. The document is NEMA standards, MG1 motors this is the standards with respect to the all machines and different type of cooling methods.

With this I am concluding this lecture. In this lecture, we have discussed the different type of cooling methods and standards with respect to the cooling methods for forced cooling as well as natural cooling. Thank you.