Course Name: Design of Electric Motors

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Title: Importance of Motor Design and Standards of Electric Motors

Greetings to all of you. In this lecture, we will discuss about the principles of design with respect to electrical machines. We will discuss in terms of why we require the design and what is the importance with respect to different applications, we will see. For example, if we will consider for the water pump applications and adjustable speed drives and electric traction and industrial motors and like household applicants applications and medical applications, all these applications one or another way we are utilizing the electrical machines. If we will see how to design it, the design is an iterative process and there is no unique solution due to the multiple constraints and multiple number of variables. For example, if we are designing a motor for attaining the higher efficiency at the end of our design, we should meet the particular efficiency, whether efficiency is matching or not.

We should not consider about the other parameters and design of a machine is an art, science and engineering it involves. It involves the multiple variables and factors. So, it is impossible to work along with the rigid lines. There is no unique procedure or unique solution.

We have to do in an iterative manner and we have to compromise between large number of conflict of requirements. For example, if you want to design the machine for higher efficiency, higher torque density and higher power density and better thermal cooling like this if multiple requirements if will present, then the design procedure and design solution will be complex. So, for that we have to compromise between some requirements. Let us say only higher efficiency and higher torque density required, then the remaining requirements we have to compromise, then we will get some solution. So, if we will consider all requirements, then it will be a complex job and similarly design of a machine for the same specification with respect to the different manufacturers, it will be different.

The emphasis with respect to the one manufacturer may be depends upon the higher efficiency and other manufacturer may be higher torque density. So, for the same specifications also there will be no similar solution and the purpose of design is to estimate the optimal dimensions of the machine to satisfy the given requirements with respect to the rated power and speed, torque and temperature, rise and term conditions of service. And why design is important means to achieve the optimal solutions as well as efficient performance. If we will see the different applications with respect to the medium power and high power applications like sustainable systems, electric vehicle, aircraft, traction, ship propulsion and wind energy systems, marine and ocean energy systems, hydropower systems, the power level is 1 kilowatt to megawatt level we are utilizing. Similarly, low power and industrial systems also from the right from the tens of watt level to megawatt level we are utilizing the electrical machines.

The design procedure or design equations will be same, but there is no unique solution or there is no proper approach. We have to follow with respect to the design equations by iterative manner we can get the solutions for that particular application. And what are the factors to be considered in a design means first one is the cost and second one is the size and volume and third one is we have to follow with respect to certain standards in terms of voltage, in terms of power densities and torque densities and footprints and volume etcetera. And materials what type of material we are utilizing for copper like electric loading as well as magnetic loading and factors with respect to the applications like reliability, noise, higher speeds or torques and higher efficiency etcetera. And theoretical factors with respect to the electrical aspect, mechanical, dielectrics and thermal and magnetic aspects we have to consider while designing the machine.

How to design the machine means the basic steps will be like this. First we have to identify the volume with respect to the power and MMF requirements and flux density with respect to the power MMF and flux densities we have to find the volume. Once we know the volume then we have to estimate the amount of copper and magnetic materials requirement. After that for a given torque rate, torque density and for a given power density we are matching or not with the calculated amount of copper and magnetic materials we have to verify. After that stator and rotor design and shaft dimensions with respect to higher speeds or higher torque and factors with respect to the applications and theoretical factors we have to see.

And at the end we have to do the iterative process whether the requirements or specifications are meeting or not. If the specifications we are unable to meet again we have to do the iterative process. The standards with respect to the electrical machines whether it may be motors or generators we have to follow these standards. The key standards are IEEE standards IEEE 112 and 115 and 841 these are the standards for different electrical machines. And IEC standards IEC 60034 and IEC 60072 are the key standards to design the electrical machines.

And NEMA standards National Electrical Manufacturers Association MG 1 Motors and Generator this is the another standard to design the electrical machines. Why we have to follow these standards means with respect to the available voltage ratings like 440 volts or 230 volts single phase supply with respect to 230 volts and for 3 phase supply with respect to 440 volts and 11 kV or 33 kV depends upon the utility grid side what kind of voltage ratings we can do it and power ratings and footprints are dimensions like terminal notations and efficiency class and torque densities. So, the standards will give the generalized or similar approach for all type of manufacturers such that the maintenance as well as analysis will be easy for all type of machines. And the standards will be with respect to the NEMA standards MG 12009 we can see here for the year 2009 and for the year 2018 revised version and approval date in June 15, 2021 NEMA standards we can see here and with respect to the some manufacturers the NEMA standards we can see here. For example, if we will consider the efficiency classes with respect to the different machines the IE4 standard represents the very high efficiency and IE3 standard represents the premium efficiency that means slightly less than the IE4 standard and IE2 represents the higher efficiency, but lesser than the IE4 and IE3 and IE1 represents the standard efficiency which is having the lesser efficiency as compared to the other 3 classes with respect to the IEC standards and NEMA standards there are 2 classes are there NEMA premium, IEISA 2007 and NEMA energy efficient EPACT.

From the right side image we can observe that with respect to one particular power let us consider 3 kilowatt rating here with respect to 3 kilowatt rating at this particular point IE1 standard machine consist of efficiency of 80 percent IE2 standard machine consist of efficiency 85 percent and IEC standard consist of efficiency 85 to 90 percent and IE4 standards consist of greater than 90 percent efficiency. So, with respect to different power level and how the efficiency is varying with respect to different standards we can observe from this figure. If you want to design a machine let us say IE4 standard we are designing means the efficiency should be higher than the 90 percent with respect to the power level. For example 500 HP machine if you want to design the efficiency should be greater than 95 percent we can observe here with respect to 500 kilowatt. Similarly with respect to the different power ratings what is the efficiency level and what type of class of motor we are designing we have to see.

And next thing different type of classes based upon the percentage of full load torque we can see here class A, class B, class C, class D different type of electrical machines with respect to induction type. So, the class A has different torque speed characteristics and class B has different torque speed and class C has different and class D has different. So, with respect to the torque requirements we have to design for that particular class type of machine. For example here class D is giving higher starting torque. So, if you want to design a higher starting torque machine we have to go ahead with the class D type of design.

So, for class B the torque versus speed waveforms we can see in this right side image with respect to the breakdown torque and pull up torque and starting torque. Breakdown torque is the maximum torque and pull up torque is the where the minimum torque will happen while speed is building up and starting torque is nothing, but the torque which is machine is capable to generate at the time of starting. With respect to the percentage of synchronous speed and percentage of full load torque we can see here. For example, if we will consider the 5 HP machine the torque will be 230 percent of the full load torque breakdown torque and the pull up torque is 120 percent of the full load torque and starting torque is 180 percent of the full load torque. We can see just follow with respect to one waveform this one 5 HP curve and identify the what is maximum torque or full of pull up torque and starting torques with respect to different power ratings.

And similarly power factors with respect to the different power rating we can observe here. For example, 40 kilowatt machine for 40 HP rated machine we are taking for 600 RPM the available or the power factor rating for 600 RPM machine with respect to 40 kilowatt is 79 or 80 percent that is 0.8 power factor we can attain for a 40 kilowatt machine if you are operating at 600 RPM. If you will operate the same machine at 900 RPM the power factor will be 0.

86 for 40 HP machine. If we will see the efficiencies versus horsepower ratings or HP rating with respect to different power ratings and different efficiencies we can observe in this image. For the NEMA class B standards all waveforms are NEMA class B standards this waveform represents the power factor with respect to the HP rating and this waveform represents the efficiency with respect to the HP rating. And if you will see the typical starting torque values per unit with respect to the rated torque NEMA class A and class B for different poles and different HP ratings we can find here. These numbers has taken from the NEMA standards or IEEE standards or IEC standards only are summarized here with respect to the this particular reference. And recommended voltage with respect to the electrical machines and power ratings we can see here the HP ratings are up to the 25000 HP and the voltage ratings are up to 13 kV 230 volts and 460 volts and 2300 4 kV 6.

6 kV and 1133 sorry 13 kV like that different rated voltages are there and associated recommended power ratings also we can see here. Now, we will see how the standards of the electrical machines will be there. These are the standards with respect to the 3 phase induction machines we will see in this PDF file. So, here product range we can see low voltage general purpose induction machines the ratings from 0.04 kilowatt to 2200 kilowatt and high voltage machines up to 11 kV and traction motors up to 1500 kilowatt we can see different type of applications and different type of power ratings as per the standards we can see here.

Here we can see the efficiency class with respect to the efficiency and IEC standards and NEMA standards for a given voltage and the rating of the power will be up to 500 HP and the poles will be 2 poles, 4 poles, 6 poles like that. So, IEC standards 60034 and NEMA standard MG1 with respect to that we can define the efficiency classes here IE1, IE2, IE3 and IE4 and these are the NEMA standards and the tolerances with respect to the supply voltage and frequencies also defined with respect to the standards 10 percent with respect to the rated frequency and 5 percent with respect to the rated voltage. And insulation classification with respect to the applied voltage as well as with respect to the operating temperature we have to select the insulation class. So, class A type, class B, class C, class F and class H the operating temperatures will be summarized here. Class A operating temperature with respect to the ambient temperature of 40 degree Celsius is nothing but 105 and class B type of insulation will withstand up to 130 degree Celsius and class F and class H also we can see here.

So, we have to select the insulation type of class with respect to the operating temperature. And next materials for housing and end shields what type of materials we have to utilize we can observe here and then type of cooling mechanism, IEC code or standard which type of cooling mechanism we are utilizing for example IC01 open machine and fan mounted on the shaft backside of the shaft we are mounting the fan. For example, here we can see the backside of the shaft we will place the fan just look at this machine here we can see the fan for this motor the fan is not available for larger and higher power rating machine backside we will see the fan which is mounting on the shaft that is the IC01 standard. And similarly other standards IC410, IC411 different type of standards for cooling purpose. And terminal box like how to represent the terminals with respect to the induction machine is presented here maybe I will zoom it out.

So, these are the different terminals how to represent the terminals, terminal 1, terminal 2, terminal 3 and multiple coils are there type 1, type 4. So, we have to follow the unique procedure in order to represent the terminal notation. These are the terminal rotation with respect to star and delta for delta it will be like this manner for star it will be in this manner. For star connection how to represent the terminal notation for delta connection how to represent the terminal notation we can observe in this image. And then frame letters which type of frames we are utilizing we can see here for industrial direct DC machine the letter will be A and for carbonator pump motors we can see the letter will be B.

So, different type of machines will be represented with different letters as per the NEMA standards and design we can see here. We have discussed the different type of classes with respect to the torque versus speed right. So, here we can observe that the torque versus speed with respect to the different classes. So, NEMA design A the locked rotor torque and full pull up torque and breakdown torques will be in terms of full load torques are presented here. So, locked rotor torque at the starting at 0 speed 70 to 275 percent and pull up torque is 65 to 190 percent and breakdown torque is 175 to 300 percent of the rated torque.

And sleep and different type of applications where we are utilizing the NEMA design A and design B and design C and design D we can observe here. Typical applications fans, blowers, centrifugal pumps, compressors and magnet motor generator sets motor generator sets etcetera and design D has higher having the high torques right we can observe here. Design D has the higher starting torques right. So, that is what reflected here high peak loads with without with or without flywheel such as punch presses and shears elevators hoist and oil well pumping and wire drawing motors etcetera wherever the peak torque starting torque requirement is high there we are utilizing the NEMA design D type of machines. Similarly, we can see that permissible shaft and end loads with respect to different sizes how to select it depends upon the torques and speeds and bearing types and bearing nodes also we can observe we can see here the frame size and number of poles and bearing bearing notation and frame size here and bearing lubrication on run.

Whether lubrication is required or not for that particular machine with respect to the frame size and number of poles and bearing structures we can see here. So, the first two cases there is no requirement of bearing lubrication, but in the other seven other six cases for example, frame size 404 and 405 the number of poles and bearing structure here the lubrication is required. We can see here. So, some applications with respect to the different frame size and different type of bearings we require the lubrication also and overall mounting dimensions or footprints we can see here with respect to the motor types. So, mounting footprints will be described with respect to the different letters and different dimensions we can observe here with respect to the footprints.

And similarly list of motor parts we can observe here different parts of the machine like end shield like stator structure and then terminal box here and then rotor and bearings and enclosures and if any fan is there fan type of cooling and all these parts we can identify here. And similarly if we will see the standards for all type of electrical machines it is presented in this standard NEMA standard MG 2009 we can go through these standards the latest one are the paid versions. So, if who are manufacturing the electrical machines they have to purchase these standards and they have to design with respect to that particular standards and with respect to the standards IEEE standards and IEC standards and NEMA standards we have to follow and then classification according to size small size and mediums medium size of the machines or power rating of the machines and high power machines and AC machines with respect to the medium power rating up to 500 HP and speeds also we can see here in this table and generators at kilowatt at 0.8 power factors ratings will be up to 400 kilowatt and similarly classification according to application also we can see. Electrical type and design letters for poly phase squirrel cage medium motors design A design B design C and design D the one what we have discussed as of now and similarly generalized general standards with respect to the terminal markings we can see here for DC machines how the terminal markings for here we can see separately excited series and parallel dual voltage field winding terminal notations we can see here and similarly shunt motors how the terminal notations.

So, like this way for each and every aspect there are a certain standards we have to follow according to the standards we cannot design the electrical machine for example, voltage randomly 500 voltage AC thing then we do not have any 500 volts RMS AC supply. Similarly, if frequency if I will make it 70 hertz frequency it is not possible with respect to the standards, but we can design the machine for 70 hertz frequency also there we have to utilize the power converters to drive that particular motors. These are the terminal markings and dimensions we can see here different dimensions and letter symbols. So, these are the different footprints what we have seen just now. So, with respect to the different machines.

So, different type of footprints will be there. So, according to that particular footprints and that particular frame sizes we have to design the motor. So, these are the machine assemblies with respect to the floor mount how the footprint will be there and with respect to the wall mount how the footprints are there these are the four with respect to the wall mount and with respect to the ceiling mount these are the three. So, different type of footprints are available with respect to the application we have to select it. So, these are the standards what we have to follow in order to design a electrical machine.

With this I am concluding this lecture. In this lecture we have seen what are the steps we have to follow the to design a electrical machines and what are the standards with respect to the voltage with respect to the power densities with respect to the footprints with respect to the terminal notations and etcetera we have discussed. Thank you.