Course Name: Design of Electric Motors

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Title: Example Problems on Output Power Equation in terms of D^3L Product

Greetings to all, in the last lecture we have discussed the sizing equations with respect to the D cube l product, right, for a an electrical machines with respect to the AC systems. For DC machines we have to derive the D square l or D cube l equations based upon the power equations. The equation what we have derived for AC machines, we can see here the output power.

Now, we will solve one example, how to select the dimensions of an electrical machine for a given specifications. Let us consider the induction machine, squirrel cage type and power rating is 30 kilo watt, voltage is 690 volts and 50 hertz frequency and 3 phase and 1410 rpm, the speed of the rotor and it is torque connected, this is the given data. How to find the dimensions of the stator as well as length of a machine? The dimensions with respect to the inner diameter of the stator, outer diameter of the stator and then length of the core.

We can find these three quantities by utilizing this equation. Whereas, in the D square l equation we can find only inner diameter of the stator and length of a core. In this equation we can find outer diameter of the stator also, we can find complete volume of the stator. So, our objective is to find the inner diameter of the stator, outer diameter of the stator and length of a machine or length of a core.

First I will consider the different parameters to start the analysis. First I will assume the efficiencies, same to the earlier example, efficiency will be 0.9 and power factor cos 5g, I am considering 0.9 and winding factor is equals to 0.955 and copper fill factor 0.7, I am considering and current density Jl is equals to 3 into 10 power 6 ampere per meter square. We have discussed how to select the current densities for different materials. So, for copper winding I am considering 3 into 10 power 6 ampere per meter square. If we take higher current density values, we have to design the thermal or cooling system appropriately. And then synchronous speed, the actual speed is given in the problem statement that is 1410 rpm.

With respect to the 50 hertz 50 hertz machine, the nearest synchronous speed will be 1500 rpm, where the 90 rpm is the slip speed. What else is missing means to solve the power equation, what is the Bt value and Bg value and Bc value. Bt is the flux density is at the teeth and Bg is the flux density at the air gap, Bc is nothing but flux density at the core, we can see here. So, these are the three values we have to select it. Here, I am considering Bt value is equals to 2.1 tesla, this all three are the peak values, Bg value is 1.57 tesla, which we have considered for the earlier example to calculate the D square l sizing equations and dimensions and Bc is nothing but 1.8 tesla. From here, we can find what is the ratios to calculate the f of lambda function. In the power equation, we can see this one is the constant, efficiency we have assumed, power factor also assumed, copper fill factor we have considered and winding factor also we assumed and Bg current density, we have considered as per the standards as well as material, depends upon the material we have considered and synchronous speed also we know.

The remaining thing what we have to calculate in order to find the D cube l product means f of lambda or f naught of lambda output function. Here I am neglecting this term for the easy calculation, otherwise we have to consider the delta value as well as D naught s value also because D naught s is unknown. So, we have to consider this also one more unknown variable and this also unknown variable. Two unknown variables we have to consider and it will be a complex task. For that reason, I am neglecting this term because this delta consists of only d naught r 1 and r 2 terms.

Here d naught is nothing but the slot opening this portion and r 1 is nothing but this radius, r 2 is nothing but this radius. So, I am neglecting that thing and I am making the approximate design. So, Bg by Bt constant we have to calculate first and then Bg by Bc we have to calculate next and if requires Bc by Bt also. Bg by Bt is nothing but we know the Bg value that is flux density at the air gap and flux density at the teeth also we know 1.57 by 2.1 and Bg is nothing but 1.57 divided by 1.8 divided by 2.1. Now, we know the different ratios.

In the last lecture, we have analyzed the curves with respect to the different poles and different values of the Gc and Gt values. So, here we can see whatever the flux density values we have considered. I am presenting here Bg 1.57, Bt 2.1 and Bc is nothing but 1.8 and same values I am considering here. We will find the what is maximum value of output function F naught of lambda with respect to the lambda. These are the curves with respect to the different values of a and b. For our case Bc by Bt value is 0.85 and Gt value is 0.74. The nearest operating curve will be this one. If we will consider 0.8 is the B C by B T value and 0.75 is the Gt value. We can observe here Gt is the 0.75 is there. So, nearest equivalent operating curve will be this one where a equals to 1.42 and b equals to 1.21. 1.42 is this one and 1.21 is this one. So, this is the operating curve with respect to the respective a and b values. a is 1.42 we can see here 1.42 and b is 1.21. The associated curve is this ash color one. With respect to this curve, we have to find the what is f of f naught of lambda value with respect to a given lambda. See here the maximum operating point with respect to the output function is happening at this particular point where lambda is equals to 0.29. That means, D I s value and D naught s value if we will compare this diameter is very high.

We can see here D I s value is nothing, but inner diameter of the stator and D naught s is nothing, but outer diameter of the stator. If the lambda value is very small, then D I s value is coming inside. D I s value is coming inside means there is no space for rotor. Because of that reason, the feasible values with respect to the lambda are 0.4 to 0.75. That is what we have concluded in the last lecture. So, I will consider 0.55. I am considering randomly. We can take it in a trial and error procedure also.

I am considering lambda is 0.55 with respect to 0.55. What is the output function? We have to note it down f naught of lambda value. So, for that f naught of lambda value is 0.08 and lambda value is 0.55. I consider with respect to the practical solutions where 0.4 to 0.75 we can consider. So, lambda I am considering 0.55 based on that f naught of lambda. We can see that particular value. So, that particular value from the curve I have considered 0.08 and lambda value is 0.55. Now, we know all values in the power equation. We have to substitute all numbers in the power equation.

Then, we can solve the D cube l product. So, power 30 kilowatt is equals to output function that is 0.08 into pi square by 240 root 2 is a constant and then efficiency power factor and then copper fill factor, winding factor into flux density at the air gap and current density into D cube l product into synchronous speed. Then, solve for D cube l product.

Then, we will get 0.0034 meter power 4. Here, D also in meters and l also in meters. So, meter power 4 is the units. Now, we have to consider the aspect ratio here. For aspect ratio, l by tau p is equals to 1.5. I am considering here. Otherwise, l by D I s ratio with respect to the approximate equation cube root of pole pairs also we can calculate it. Here, I am assuming aspect ratio will be 1.5. Based on this thing, l e is equals to 1.5 into pi into D I s by 4. 4 is the number of poles. Then, we can get l e is equals to 1.18 into D I s here. This is the length of a core in terms of inner diameter of the stator, but lambda is equals to D I s by D naught s, the ratio between inner diameter of the stator to outer diameter of the rotor. So, if I will substitute lambda in the core length equation, l e is equals to lambda equals to 0.55. So, D I s is equals to 0.55 into D naught s. Substitute in the core length equation 1.18 into 0.55 D naught s. We are representing the core length in terms of D naught s.

Now, l e is equals to 0.649 D naught s. This is the core length equation in terms of outer diameter of the stator. This is equation number 1 and this is equation number 2. Substitute equation 2 in 1. Then, D cube into in place of l e 0.649 into D naught s is equals to

0.034. Then, d naught s is equals to outer diameter of the stator is equals to fourth root of 0.034 divided by 0.649. It will give 269 mm outer diameter of the stator.

Once we know the outer diameter, then inner diameter of the stator is equals to lambda into D naught s. That is 0.55 into 269 will give 148 mm. This is inner diameter of the stator. Next, length is equals to 1.18 into D I s, inner diameter of the stator. That will give 175 mm. So, the main dimensions with respect to the inner diameter of the stator and outer diameter of the stator and then, length of a core by utilizing the D cube l product equation.

That we can summarize it here. 269 mm is the outer diameter of the stator, inner diameter is 148, outer diameter is 269 and length of a core is equals to 175 mm by utilizing the D cube l sizing equation. With the same ratings, we have solved one example in the last lectures. The D I s, inner diameter of the stator is 178 mm and outer diameter of the stator, we have not calculated. Only length of a core is 210 mm with DIs square l e, volume product equation. This is power equation with respect to the d cube l and power equation with respect to the d square l.

We can see here for the same power rating, we have calculated the main dimensions. The difference is there with respect to the different analysis. Here, the analysis is different and here, the analysis is different, but the values like efficiency, power factor and everything we kept same, but the lambda value and f naught of lambda value, how we are maximizing and what kind of values we are taking based upon that this inner diameter, outer diameter and length will change. If we will do the iterative procedure, then these two numbers will match, but the numbers whatever we have arrived, these dimensions also valid for a given lambda value and f naught of lambda. We can do the iterative process to tune the performance of an electrical machine.

This is the example for how to solve the main dimensions with respect to the D cube l product equation. Now, if you will observe the power equation with respect to the D square l and power equation with respect to the D cube l products. In these two equations, we have not considered the rotor geometry. Here, we can see this is the rotor lamination and this is the stator lamination. As of now, we have derived the equations with respect to the stator geometry.

We have considered the flux densities at the different parts of iron and flux densities at the different parts of the teeth and those things, but we have not considered the rotor geometry like what kind of rotor we are taking and how the slots will be there and flux densities at different parts of the iron. We have not considered that. We can derive it in the next class. Thank you.