Project

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clc; clear; close all;
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You are told that the design should have a **rated speed of 10,000 RPM**, have a **rated power of 50 kW**, have an **electric frequency under 600 Hz**, have **three phases**, use **surface mounted permanent magnets** on the rotor, and use forced air cooling. You need to determine the number of slots, poles, the winding layout, and various dimensions of the machine.

Question 1

Propose **a number of slots and poles** that you wish to use in your design which satisfies the **electric frequency** and **symmetry requirements**. Submit this in Canvas as your first deliverable in the form of a ranked list of 3 slot / pole combinations you are interested in.

Answer:

First, I want to mention that I am choosing the number of slots and poles for a double-layer slot winding. The number of poles of the machine is related to the number of poles by the following formula:

$$f = \frac{P \cdot N}{120},$$

where f is the electrical frequency, P is the number of poles (**NOT** pole pairs), and N is the synchronous speed in RPM.

Rearranging the equation to make P the subject gives us:

$$P = \frac{120 \cdot f}{N}$$

But since the frequency has to be less than 600 Hz, the number of poles is bound by this equation:

$$P < \frac{120 \cdot f}{N}$$

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f = 600; % Frequency in Hertz
N = 10e3; % Speed in RPM

P_max = (120*f)/N;
```

The maximum number of poles is:

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disp(round(P_max))
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7
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Considering that I have to have an even number of poles, the options available are 2,4, and 6 poles.

Some background *(Pyrhönen, J., Jokinen, T., & Hrabovcová, V. (2014). Design of rotating electrical machines (2nd ed.). Wiley.)*:

(a) **The first condition of symmetry**: Normally, the number of coils per phase winding has to be an integer:

$$\text{for single-layer windings}: \frac{Q}{2m} = pq \in \mathrm{N}, \tag{2.72}$$

$$\text{for double-layer windings}: \frac{Q}{m} = 2pq \in \mathrm{N}. \tag{2.73}$$

The first condition is met easier by double-layer windings than by single-layer windings, thanks to a wider range of alternative constructions.

(b) **The second condition of symmetry**: In poly-phase machines, the angle α_{ph} between the phase windings has to be an integral multiple of the angle α_z. Therefore for normal systems, we can write

$$\frac{\alpha_{\mathrm{ph}}}{\alpha_z} = \frac{2\pi Q}{m2\pi t} = \frac{Q}{mt} \in \mathbf{N} \tag{2.74}$$

and for reduced systems

$$\frac{\alpha_{\mathrm{ph}}}{\alpha_z} = \frac{\pi Q}{m2\pi t} = \frac{Q}{2mt} \in \mathbf{N}. \tag{2.75}$$

I have to check if my slot-pole combination meets the symmetry conditions for a normal system (3-phase system) with double-layer winding.

Combination 1 (Rank 3):

$P = 2$ or $p = 1$; the number of pole pairs.

$m = 3$ is given as one of the requirements.

Now I need to make sure that I have a symmetric winding. So I will use the rules for symmetry as constraints.

$\frac{Q}{m} \in N$ and $\frac{Q}{mt} \in N$, where $t = GCD(Q, p)$.

Since $p = 1$, the t will also always be 1 in this case. Therefore, the two constraints are the same for this option.

$\frac{Q}{3} \in N$

Q must be a multiple of 3 for this machine to have a symmetric winding.

I will pick $Q = 12$ as I am familiar with this slot-pole combination and I know that the magnitude of the winding factor of the first harmonic is equal to 0.966. Refer to lecture 10-3 for the winding factor of this combination.

$q = \frac{Q}{2pm} = \frac{12}{2(1)(3)} = 2 \in N$, which means this an integer slot winding.

The combination:

$$Q = 12, P = 2$$

Combination 2 (Rank 2):

$P = 4$ or $p = 2$, and $m = 3$

Q still has to be a multiple of 3.

$t = GCD(Q, 2)$, if Q is an odd number, then $t = 1$.

I will pick $Q = 27$ this time around to reduce torque ripple.

Both symmetry conditions are met!

$q = \frac{Q}{2pm} = \frac{27}{2(2)(3)} = \frac{9}{4} \notin N$, which means this a fractional slot winding.

The combination:

$$Q = 27, P = 4$$

Combination 3 (Rank 1):

$P = 6$ or $p = 3$, and $m = 3$

I will pick $Q = 36$, which will make $t = GCD(36, 3) = 3$.

The winding is symmetric as both conditions are met.

After googling a little bit, I found that this is a machine available in the market, so it must have some benefits.

$q = \frac{Q}{2pm} = \frac{36}{2(3)(3)} = 2 \in N$, which means this an integer slot winding.

The combination:

$$Q = 36, P = 6$$