EE 568 SELECTED TOPICS ON ELECTRICAL MACHINES: PROJECT 2

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Introduction

Integral-Slot Winding Design

The given machine has 20 pole, 120 slots 3-phase machine. The winding diagram of the machine is given in Table 1. Short pitch is used. The slot per pole per phase calculated as 2.

Table 1. The winding diagram of the given machine

A1	A2	-C1	-C2	B1	B2	-A3	-A4	C3	C4	-B3	-B4
-C3	-C4	B3	B4	-A1	-A2	C1	C2	-B1	-B2	A3	A4

Electrical angle between two slots calculated as (1). p denotes the pole number and s donates the number of slots.

$$\lambda_{slot} = \frac{p\ 180^{\circ}}{s} = 30^{\circ} \tag{1}$$

Coil span calculated as;

$$\lambda = 120^{\circ} \tag{2}$$

The formulation for pitch factor (considering fundamental MMF) is following;

$$k_p = sin(\frac{\lambda}{2}) = \frac{\sqrt{3}}{2} = 0.866 \tag{3}$$

where λ denoted as coil-pitch in electrical degrees.

The formula for the distribution factor (considering the fundamental MMF) is following;

$$k_d = \frac{sin(q\frac{\alpha}{2})}{qsin(\frac{\alpha}{2})},\ \alpha = 60^{\circ},\ q = 2 \tag{4}$$

where q denotes the slots per pole per phase.

$$k_d = 0.966 \tag{5}$$

The formulation for winding factor (considering the fundamental MMF) is following;

$$k_w = k_d k_p = 0.8365 \tag{6}$$

The formulation for pitch factor, distribution factor and winding factor for nth order MMF harmonics are;

$$k_p = sin(\frac{n\lambda}{2}),\ k_d = \frac{nq\frac{\alpha}{2}}{qsin(\frac{\alpha}{2})},\ k_w = k_p k_d \tag{7}$$

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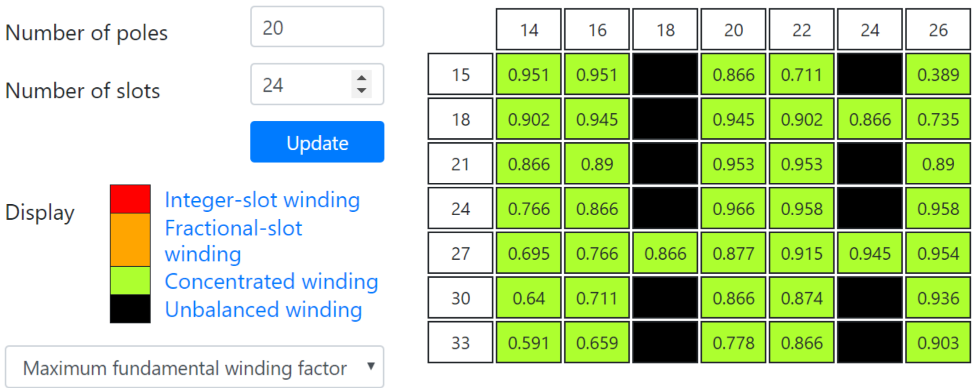

	14	16	18	20	22	24	26
15	0.951	0.951		0.866	0.711		0.389
18	0.902	0.945		0.945	0.902	0.866	0.735
21	0.866	0.89		0.953	0.953		0.89
24	0.766	0.866		0.966	0.958		0.958
27	0.695	0.766	0.866	0.877	0.915	0.945	0.954
30	0.64	0.711		0.866	0.874		0.936
33	0.591	0.659		0.778	0.866		0.903

FIGURE 1. Connection diagram of each coil. The design made with single layer although the graphic is showed with double layer.

where n denotes the harmonic number. For third harmonic the calculations are the followings.

$$k_p = 0,\ k_d = 0.707,\ k_w = 0 \tag{8}$$

For fifth harmonic;

$$k_p = -0.866,\ k_d = 0.259,\ k_w = -0.224 \tag{9}$$

The remark which are obtained from the question is;

- Third order harmonics are deleted when the coil span designed as 120°. The induced voltage is reduced due to short pitch (since k_w less than 1). However, the harmonic contents of the MMF are reduced also.

Fractional-Slot Winding Design

I chose 24 slot 20 poles machine as a fractional-slot design since it has maximum performance related to Emotor. The table I refer to can be found in Figure 1. The winding diagram and electrical angle of each slot can be found in Table 2. The distribution factor, pitch factor and winding factor calculations for the fundamental MMF used following method;

$$k_d = \frac{Vector\ Sum}{Scalar\ Sum} = \frac{1\underline{/0^{\circ}} + 1\underline{/330^{\circ}} + 1\underline{/0^{\circ}} + 1\underline{/330^{\circ}}}{1+1+1+1} = 0.966 \tag{10}$$

$$\lambda = 150^{\circ},\ k_p = sin(\frac{\lambda}{2}) = 0.966 \tag{11}$$

$$k_w = k_p\, k_d = 0.933 \tag{12}$$

The connection of each coil is showed in Figure 2.

I chose 27 slot 20 poles machine as a second fractional-slot design. The table I refer to can be found in Figure 1. The winding diagram and electrical angle of each slot can be found in Table 3. The distribution factor, pitch factor and winding factor calculations for the fundamental MMF are showed in (13-15). The comparison between two electrical machine in terms of pitch, distribution and winding factors (considering fundamental and third, fifth harmonics) are showed Table

TABLE 2. The winding diagram and electrical angle of each slot of 24 slot 20 pole fractional slot winding electrical machine

1	2	3	4	5	6	7	8	9	10	11	12
0°	150°	300°	90°	240°	30°	180°	330°	120°	270°	60°	210°
+A1	-A1	-B1	+B1	+C1	-C1	-A2	+A2	+B2	-B2	-C2	+C2
13	14	15	16	17	18	19	20	21	22	23	24
+A3	-A3	-B3	+B3	+C3	-C3	-A4	+A4	+B4	-B4	-C4	+C4
0°	150°	300°	90°	240°	30°	180°	330°	120°	270°	60°	210°

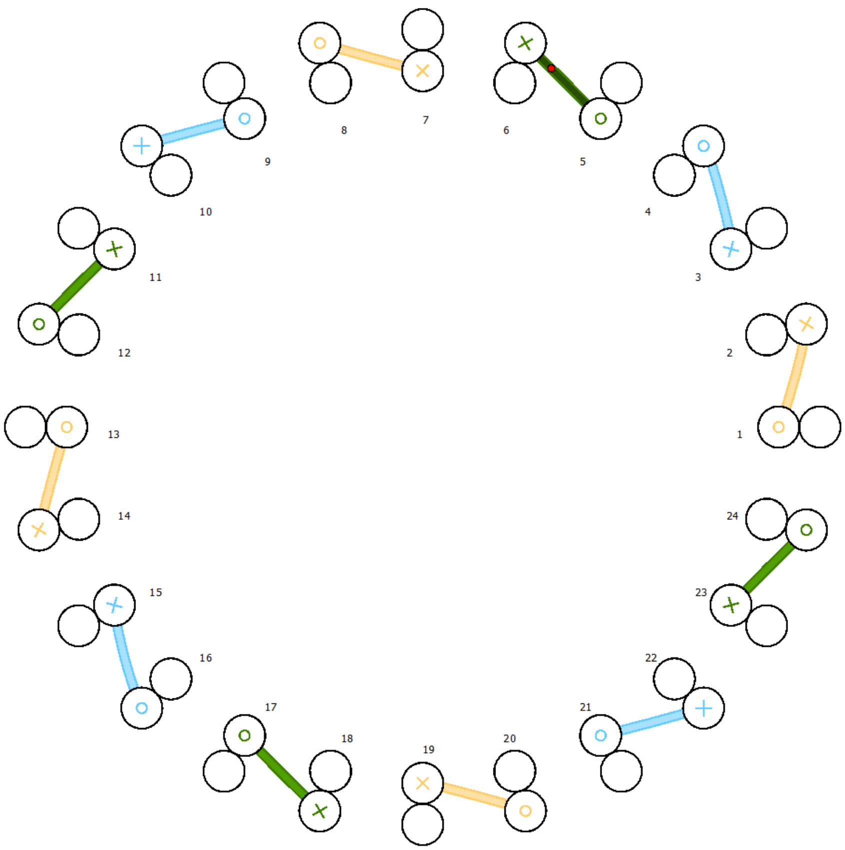

FIGURE 2. Connection diagram of 24 slots 20 poles fractional slot winding electrical machine

TABLE 3. The winding diagram and electrical angle of each slot for 27 slots 20 pole electrical machine.

1	2	3	4	5	6	7	8	9	10	11	12	13
-C9	-A1	-B1	-C1	C2	A2	B2	C3	-C4	-A3	-B3	-C5	-A4
A1	B1	C1	-C2	-A2	-B2	-C3	C4	A3	B3	C5	A4	-A5
0°	133.3°	266.7°	40°	173.3°	306.7°	80°	213.3°	346.7°	120°	253.3°	26.7°	160°

(13)
$$k_d = \frac{1\angle 0^\circ + 1\angle 306.7^\circ + 1\angle 346.7^\circ + 1\angle 26.7^\circ + 1\angle 293.3^\circ + 1\angle 333.3^\circ + 1\angle 333.3^\circ + 1\angle 13.3^\circ + 1\angle 320^\circ}{1+1+1+1+1+1+1+1+1} = 0.878$$

Table 4. Connection diagram of 27 slots 20 poles fractional slot winding electrical machine

14	15	16	17	18	19	20	21	22	23	24	25	26	27
A5	B4	C6	A6	-B5	-B5	-C7	-A8	-B6	B7	C8	A9	B7	-B8
-B4	-C6	-A6	A7	B5	C7	A8	B6	-B7	-C8	-A9	-B7	B8	C9
293.3°	66.7°	200°	333.3°	106.7°	240°	13.3°	146.7°	280 °	53.3°	186.7°	320°	93.3°	226.7°

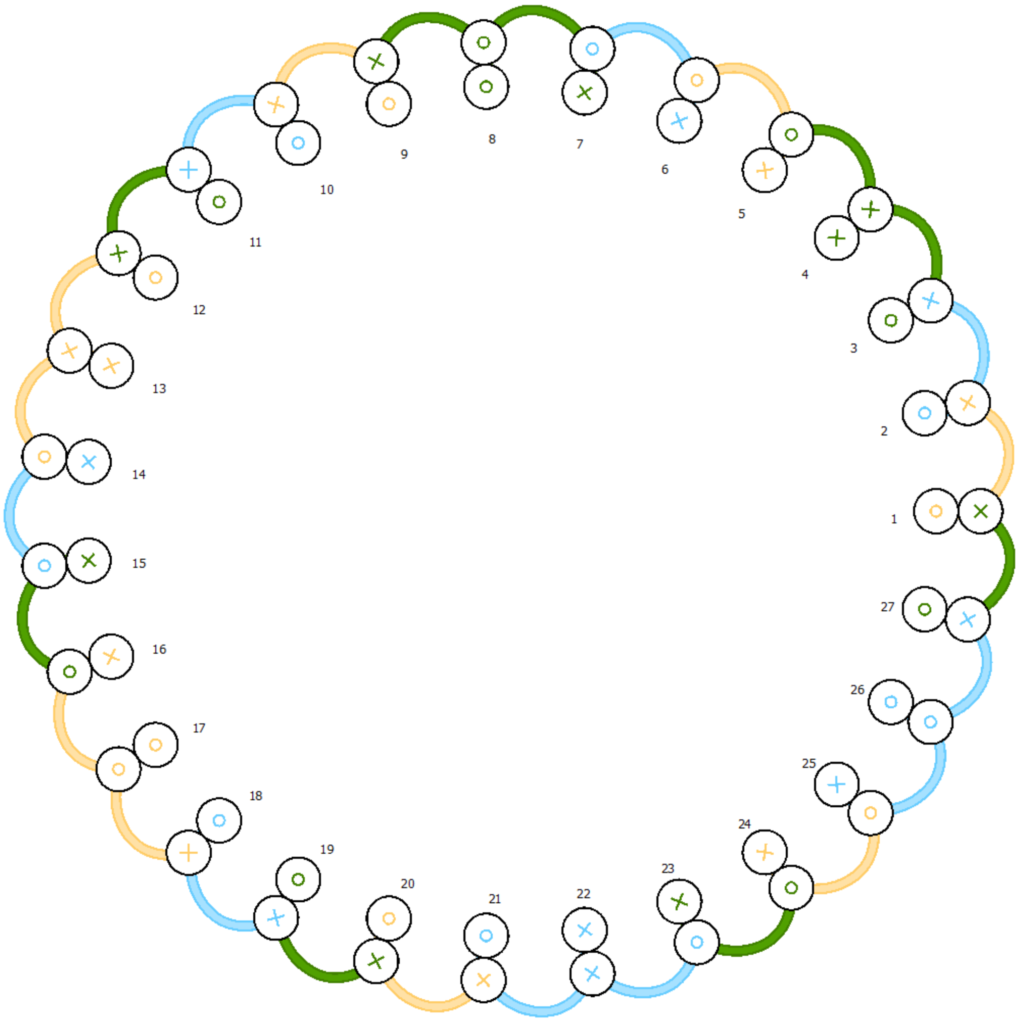

Figure 3. Caption

$$\lambda = 133.33°,\ k_p = sin(\frac{\lambda}{2}) = 0.918 \tag{14}$$

$$k_w = k_p\, k_d = 0.806 \tag{15}$$

2D FEA Modelling

TABLE 5. Pitch factors, distribution and winding factors for 24/20 and 27/20 electrical machines for fundamental,third and fifth harmonic MMF

	24/20	**27/20**
k_p, fundamental	0.966	0.918
k_d, fundamental	0.966	0.878
k_w, fundamental	0.933	0.806
k_p, third harmonic	-0.701	-0.342
k_d, third harmonic	0.707	0.219
k_w, third harmonic	-0.500	-0.074
k_p, fifth harmonic	0.259	-0.449
k_d, fifth harmonic	0.259	0.125
k_w, fifth harmonic	0.067	-0.056