Rotating Magnetic Field in AC Machines

1 Introduction

In a DC machine, the stator winding is excited by DC current and hence the field produced by this winding is time invariant in nature. In this machine the conversion of energy from electrical to mechanical form or vice versa is possible by one of the following ways:

1. rotating the rotor in the field produced by the stator
2. feeding external dc current through carbon brushes to the rotor

2 Pre-lab questions

$$\text{Let, } XX = \text{Last two digits of your roll number}$$
$$g_1(t) = \cos(\omega t) \text{ and } g_2(t, \theta) = \cos(\omega t)\cos(\theta)$$

1. Take $\omega = 2\pi f$, where $f = XX \times 50$. Vary ωt from 0 to 2π. Plot $g_1(t)$ vs t using MATLAB (or any other suitable software)

2. Take $\omega = 2\pi f$, where $f = XX \times 50$. Vary ωt from 0 to 2π.
   Take $\theta = 0$ to 2π. Plot $g_2(t, \theta)$ vs t; for $\theta = XX$
   Plot $g_2(t, \theta)$ vs θ; for $\omega t = 0, \pi/4, \pi/2, 2\pi/3$

3 Theory

Now consider three coils A, B and C of N turns each, displaced in space by 120° and connected to a balanced 3 phase system as shown in Fig. 1. (Note that the stator winding of 3 phase induction machine is distributed in a large number of slots as shown in Fig. 2). The expressions for the current

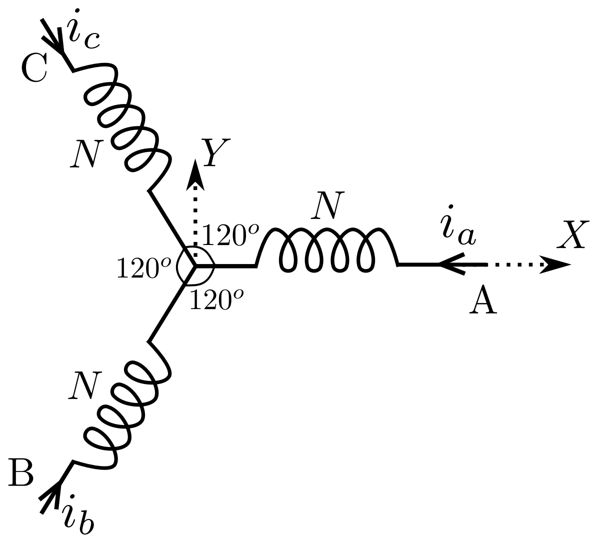

Figure 1: Coil arrangement to produce rotating magnetic field

drawn by these coils are given by:

$$\begin{aligned} i_a &= I\sin(\omega_s t) \\ i_b &= I\sin(\omega_s t + 120^o) \\ i_c &= I\sin(\omega_s t + 240^o) \end{aligned} \tag{1}$$

where $\omega_s = 2\pi F_1$ is supply frequency in rad/s and F_1 is supply frequency in Hertz. When this alternating current flows through the coil it produces a pulsating magnetic field whose amplitude and direction depend on the instantaneous value of the current flowing through the coil. Each phase winding produces a similar magnetic field displaced by 120° degrees in **space** from each other.

The steps involved in determining the magnitude and position of the resultant field produced by these coils are as follows:

1. Resolve the field produced by individual coil along x and y axes
2. Determine $\sum x$ and $\sum y$ components
3. Find the magnitude and angle of the resultant magnetic field with respect to the axis of coil-A

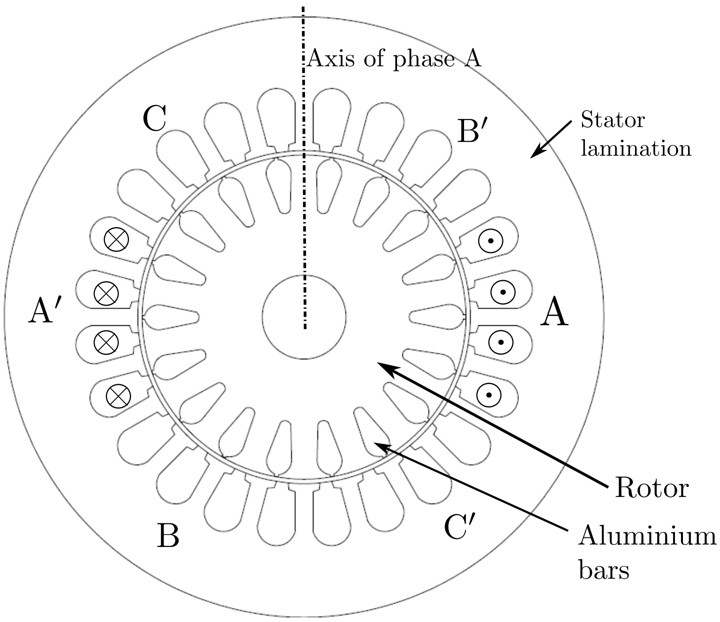

Figure 2: Distributed coil arrangement for 2 pole 3 phase induction machine

The sum of the x-axis component of the field produced by the three coils is given by:

$$\begin{aligned} \sum x &= Ni_a + Ni_b\cos 120^\circ + Ni_c\cos 240^\circ \\ &= Ni_a - \frac{N}{2}(i_b + i_c) = \frac{3}{2}Ni_a \qquad \text{...as } i_a + i_b + i_c = 0 \end{aligned} \tag{2}$$

Similarly,

$$\begin{aligned} \sum y &= 0 + Ni_b\sin 120^\circ + Ni_c\sin 240^\circ \\ &= \frac{\sqrt{3}}{2}N(i_b - i_c) \end{aligned} \tag{3}$$

The magnitude and angle of the resultant magnetic field are given by

$$\begin{aligned} R &= \sqrt{\left(\sum x\right)^2 + \left(\sum y\right)^2} \\ \theta &= \tan^{-1}\frac{\sum y}{\sum x} \end{aligned} \tag{4}$$

$\omega_s t$	i_a	i_b	i_c	$\sum x$	$\sum y$	R	θ
0^o	0	$+(\sqrt{3}/2)I$	$-(\sqrt{3}/2)I$	0	(3/2)NI	(3/2)NI	90^o
30^o	I/2	I/2	-I	(3/4)NI	$(3\sqrt{3}/4)NI$	(3/2)NI	60^o
90^o	I	-I/2	-I/2	(3/2)NI	0	(3/2)NI	0^o
180^o	0	$-(\sqrt{3}/2)I$	$+(\sqrt{3}/2)I$	0	-(3/2)NI	(3/2)NI	180^o

Table 1: MMF produced by three phase windings at various instantaneous values of currents

Table 1 gives the x and y axis components of the field produced by each coil, $\sum x$ and $\sum y$ components, and the magnitude and angle of the resultant magnetic field for various instantaneous values of the input current. It can be observed that the resultant of the three mmf (magneto-motive force or field) vectors is a vector whose magnitude remains constant (1.5 times the amplitude of mmf produced by the individual phases alone) and its position depends on the instantaneous value of input currents.

When the instantaneous value of phase-A current is zero (corresponding values of phases B and C are $(\sqrt{3}/2)$I and $-(\sqrt{3}/2)$ I respectively) the resultant field is aligned along the y-axis. When the input cycle completes 90° the resultant field also rotates by the same amount. In other words, **the result of displacing the three windings by 120^o in space phase and displacing the winding currents by 120^o in time phase is a single positive revolving field of constant magnitude**. (Another mathematical proof can be found in [1]). Under balanced three phase conditions, the three phase winding produces an air gap mmf wave which rotates at synchronous angular velocity determined by the supply frequency alone. If P is the number of poles, the speed of the rotating magnetic field is

$$\omega_m = \omega_s \frac{2}{P} \text{ radians (mechanical)/sec} \qquad \text{... as } 1^\circ\text{elec} = \frac{2}{P}^\circ \text{ mech} \tag{5}$$

If N_s is the speed of the stator magnetic field in 'rpm', then

$$\frac{2\pi N_s}{60} = \frac{2}{P} 2\pi F_1 \Rightarrow N_s = \frac{120 F_1}{P} \tag{6}$$

4 Procedure

Instructions to TAs/ RAs: There is an opened induction machine in the lab. A sample machine is also there at the FEEDBACK apparatus. Show the setup to students and identify various parts like coil-sides, insulation, laminations etc.

4.1 Demonstration Procedure

1. Connect the three phase winding to a three phase supply.
2. Apply a small fraction (say 10%) of rated voltage.
3. Place magnetic compass needle inside the rotor. The needle should start rotating. This demonstrates that there is rotating magnetic field.

References

[1] A. E. Fitzgerald, C. Kingslay, and S. Umans, *Electric Machinery.* New Delhi: Tata McGraw Hill, 2002.

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