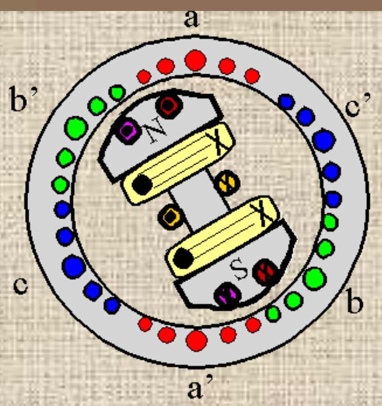
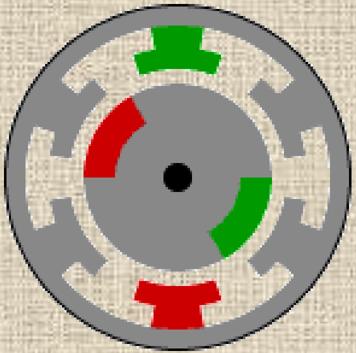
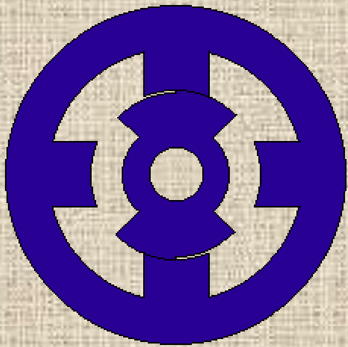
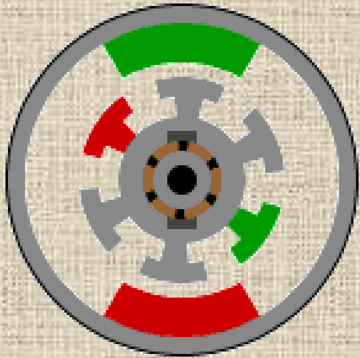
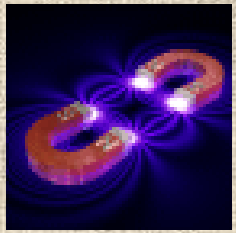
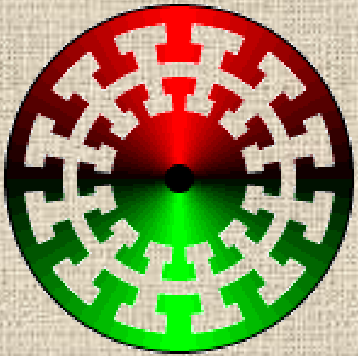


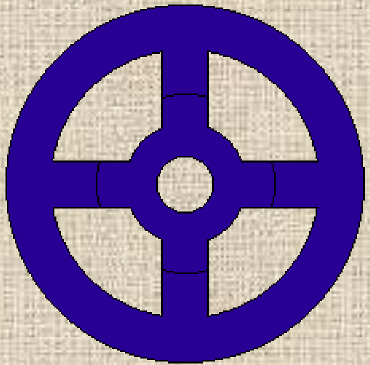
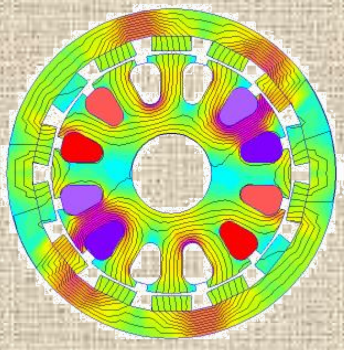
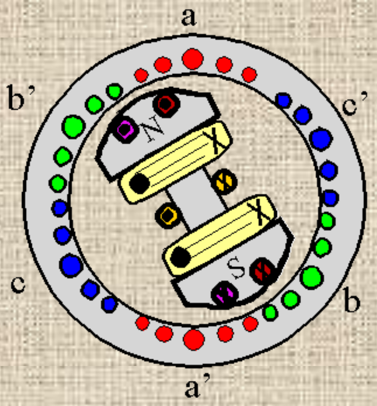




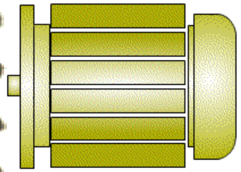
EE552 ELECTRICAL MACHINES III

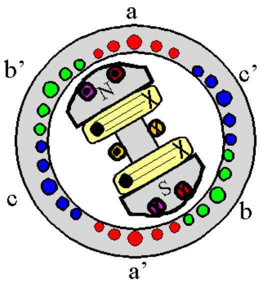
LECTURE 10





LECTURE NOTES

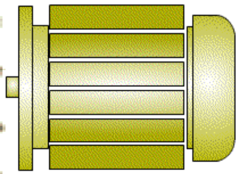


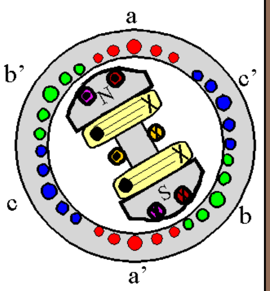
ELECTRICAL MACHINES III

EE552

SPRING 2018

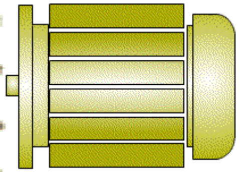
Dr : MUSTAFA AL-REFAI



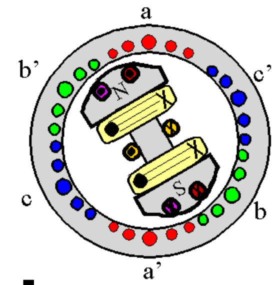


LECTURE 10

SYNCHRONOUS GENERATOR



Rotation speed of synchronous generator



By the definition, synchronous generators produce electricity whose frequency is synchronized with the mechanical rotational speed.

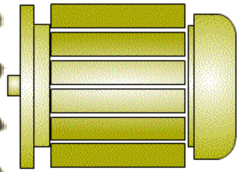
$$f_e = \frac{n_m P}{120}$$

Where f_e is the electrical frequency, Hz;

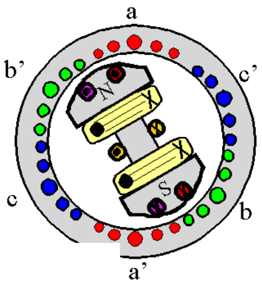
n_m is mechanical speed of magnetic field (rotor speed for synchronous machine), rpm;

P is the number of poles.

Steam turbines are most efficient when rotating at high speed; therefore, to generate 60 Hz, they are usually rotating at 3600 rpm and turn 2-pole generators. Water turbines are most efficient when rotating at low speeds (200-300 rpm); therefore, they usually turn generators with many poles.



MMF Wave of a Polyphase Winding

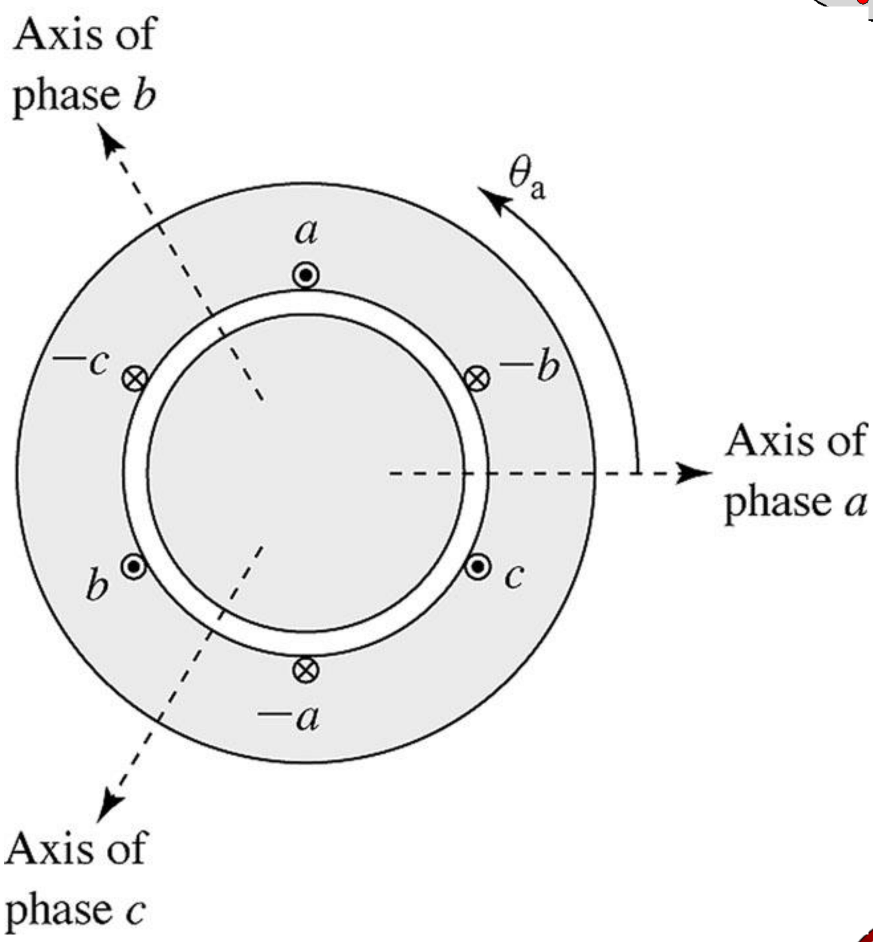


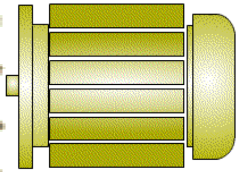
Simplified two-pole three-phase stator winding.

$$i_a = I_m \cos\omega_e t$$

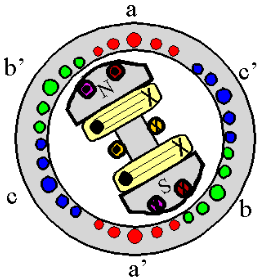
$$i_b = I_m \cos(\omega_e t - 120^0)$$

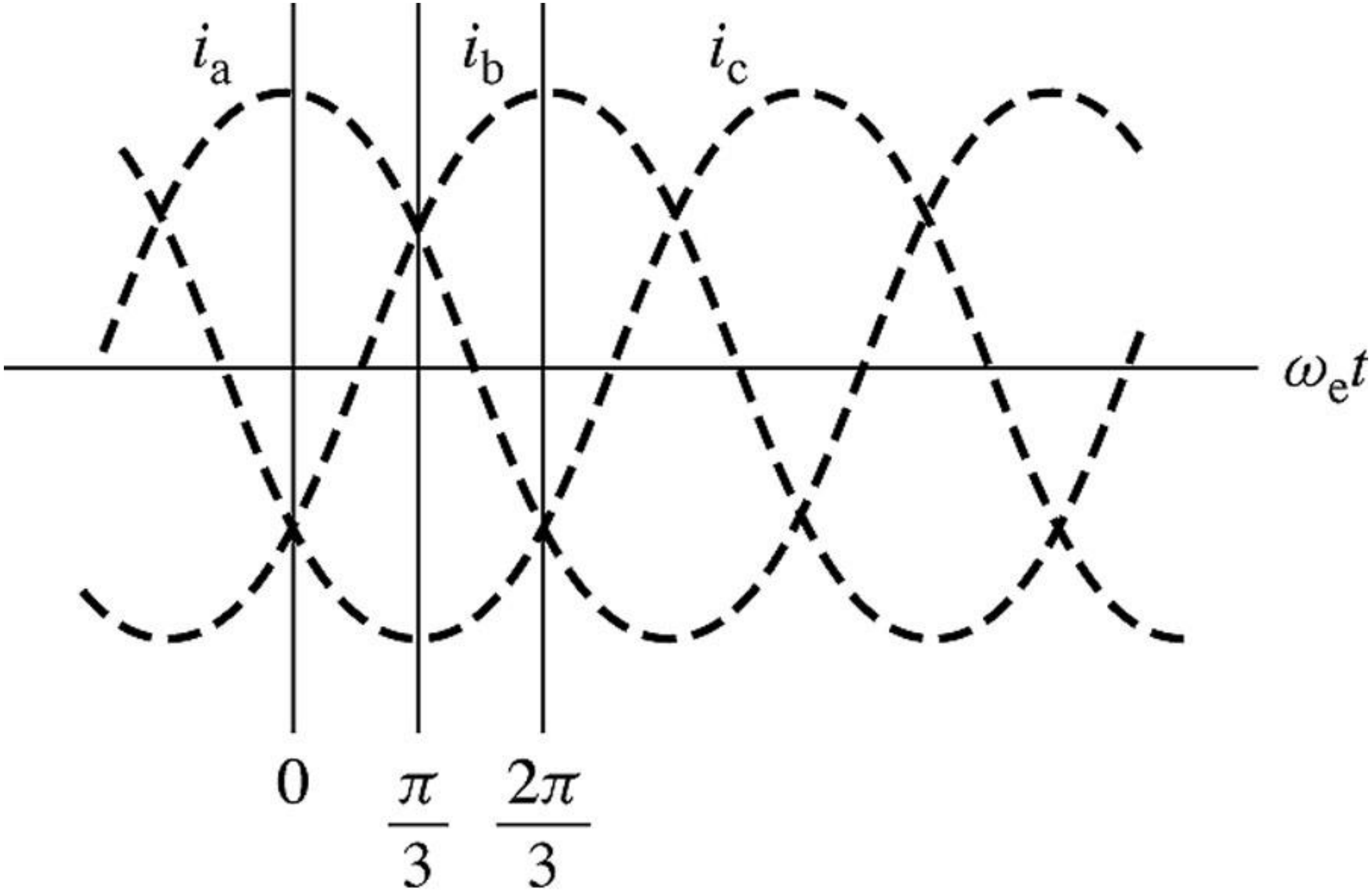
$$i_c = I_m \cos(\omega_e t + 120^0)$$



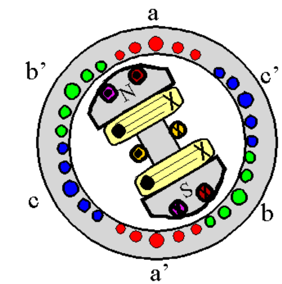


Instantaneous phase currents under balanced three-phase conditions.





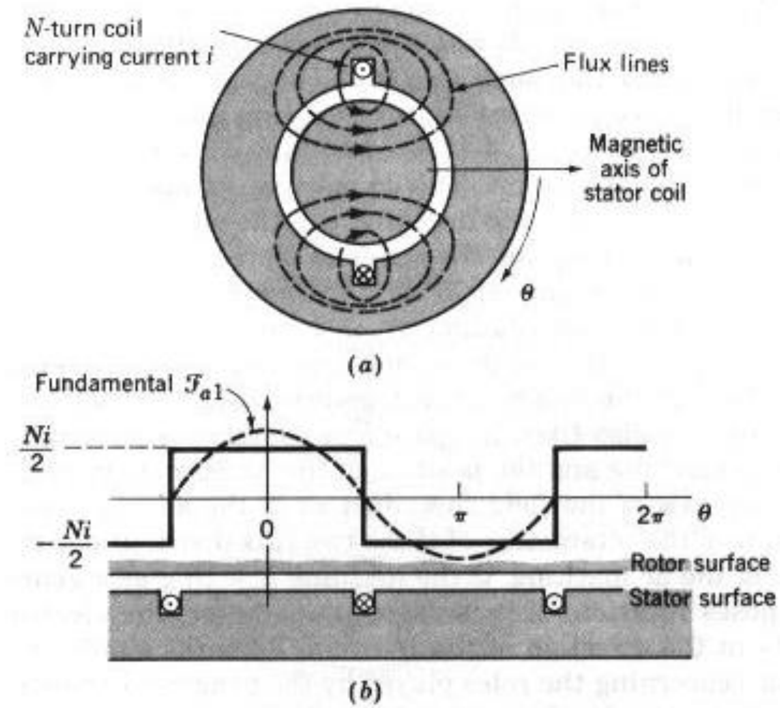
Magnetomotive Force (mmf) of AC Windings



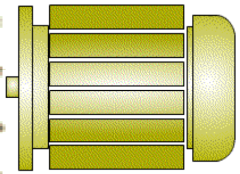
M.m.f. of a coil

- the variation of magnetic potential difference along the air –gap periphery is of rectangular waveform and of magnitude $\frac{1}{2}Ni$

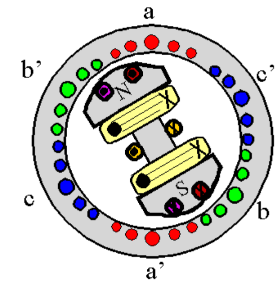
- The amplitude of mmf wave varies with time, but not with space
- The air –gap mmf wave is time-variant but space invariant
- The air –gap mmf wave at any instant is rectangular



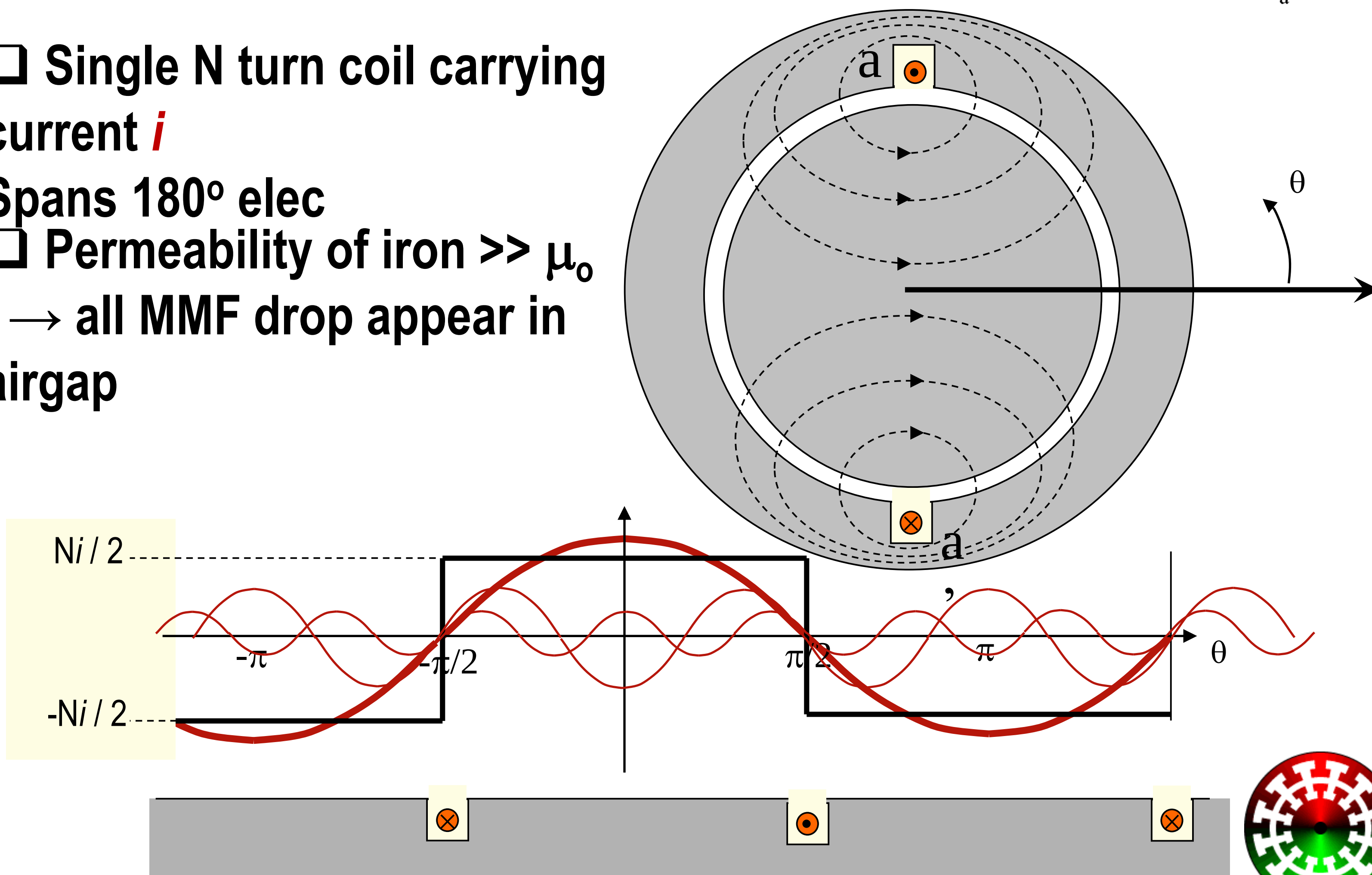
The mmf of a concentrated full-pitch coil.

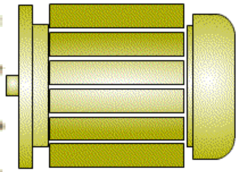


Rotating Magnetic Fields

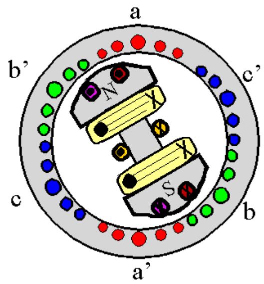


- Single N turn coil carrying current *i*
  Spans 180° elec
- Permeability of iron >> μ_o
  → all MMF drop appear in airgap





Rotating Magnetic Fields cont…



- The fundamental component of rectangular wave is found to be

$$F_{a1} = \frac{4}{\pi} \cdot \frac{Ni}{2} \cos\alpha = F_{1p} \cos\alpha$$

Where

α = electrical space angle measured from the magnetic axis of the stator coil

Here F_{1p} , the peak value of the sine mmf wave for a 2-pole machine is given by

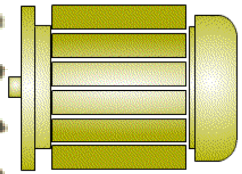
$$F_{1p} = \frac{4}{\pi} \cdot \frac{Ni}{2} \; AT \; per \; pole$$

When $i=0 \rightarrow F_{1p} = 0$

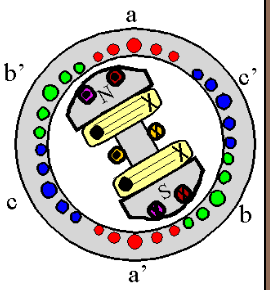
$i = I_{max} = \sqrt{2} I$

For 2-pole machine $$F_{1pm} = \frac{4}{\pi} \cdot \frac{N\sqrt{2}I}{2} \; AT \; per \; pole$$

For p-pole machine $$F_{1pm} = \frac{4}{\pi} \cdot \frac{N\sqrt{2}I}{P} \; AT \; per \; pole$$

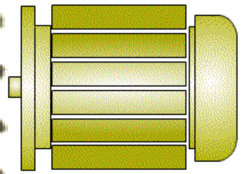


M.M.F of Distributed Winding

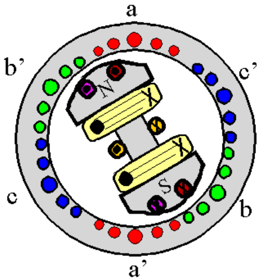


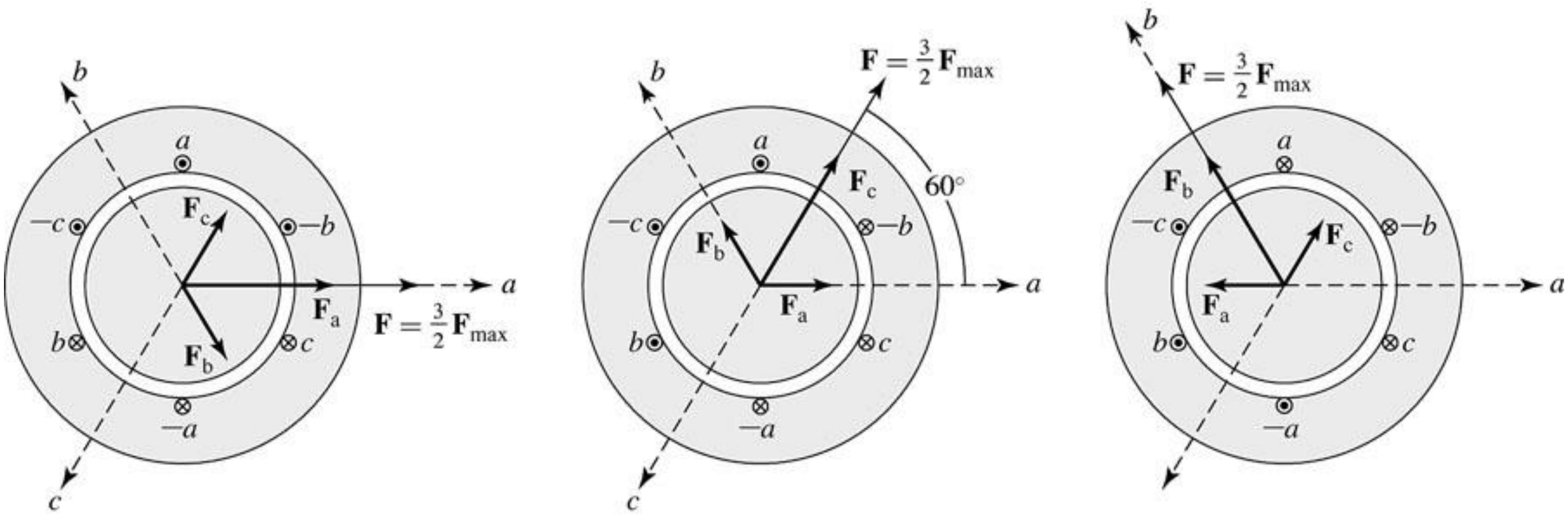
- The mmf distribution along the air gap periphery depends on the nature of slots, winding and the exciting current

- The effect of winding distribution has changed the shape of the mmf wave, from rectangular to stepped



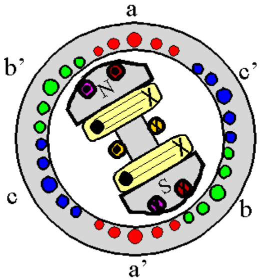
The production of a rotating magnetic field by means of three-phase currents.

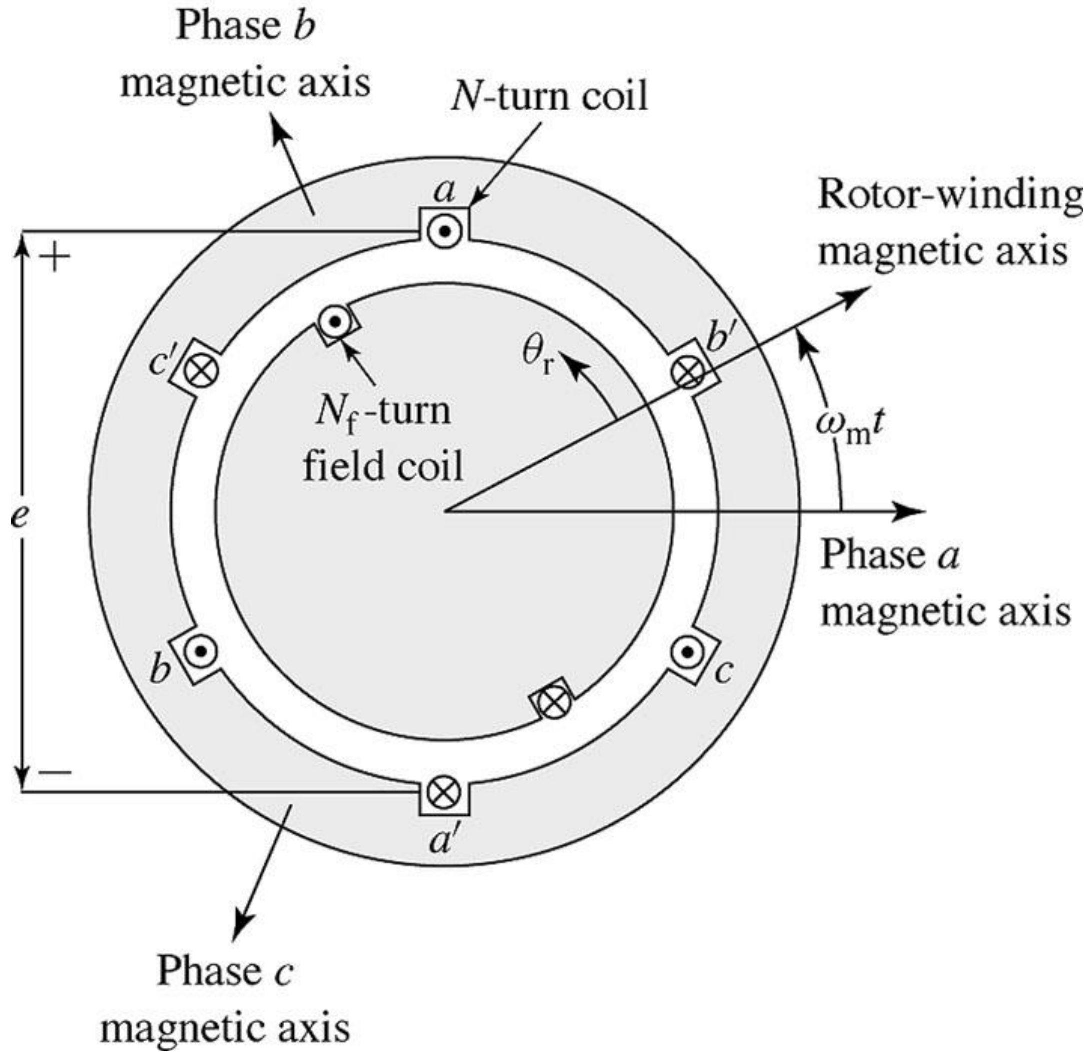




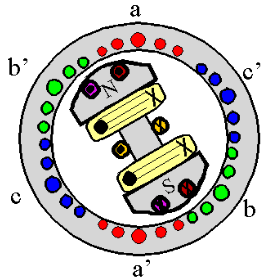
(a) (b) (c)

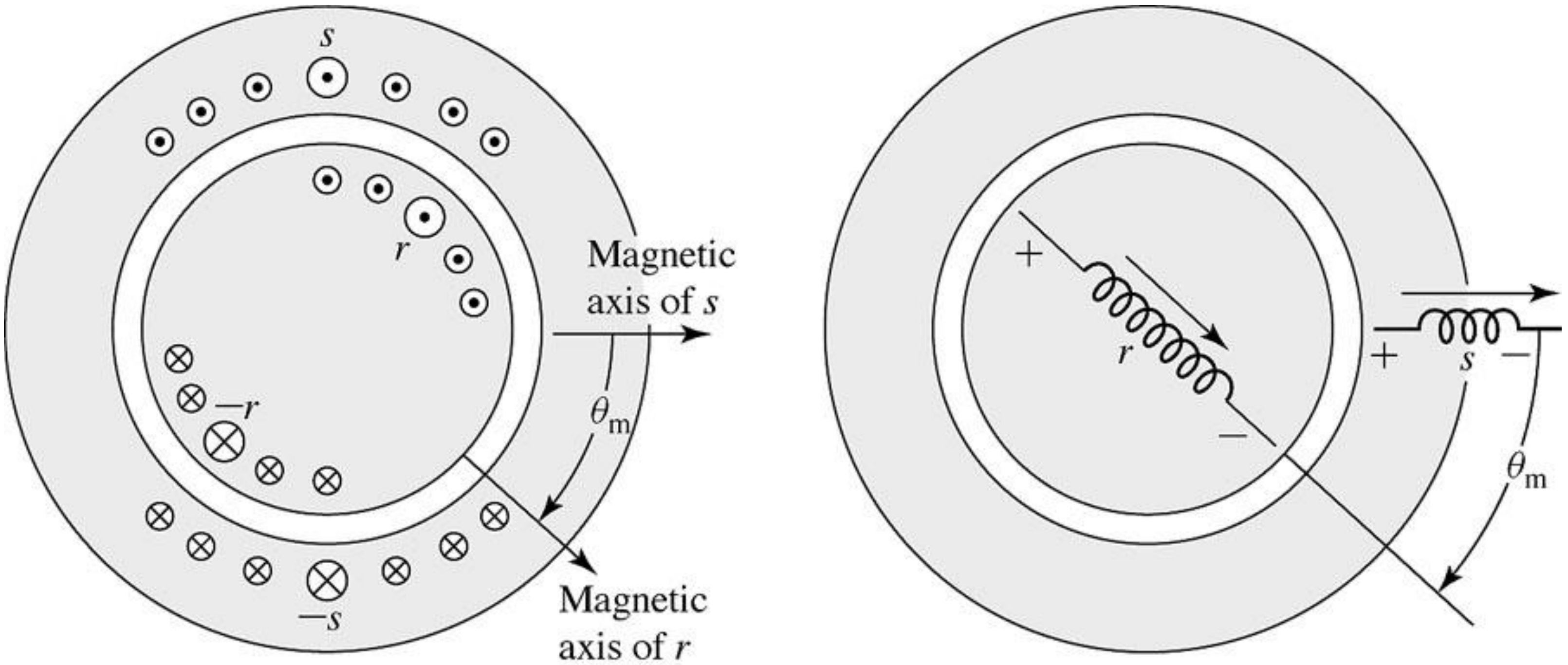
Cross-sectional view of an elementary three-phase ac machine.



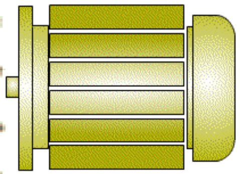


Elementary two-pole machine with smooth air gap: (a) winding distribution and (b) schematic representation.

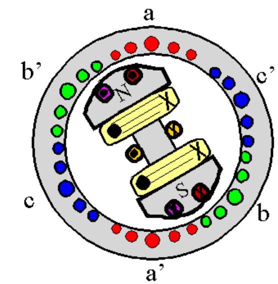




(a) (b)



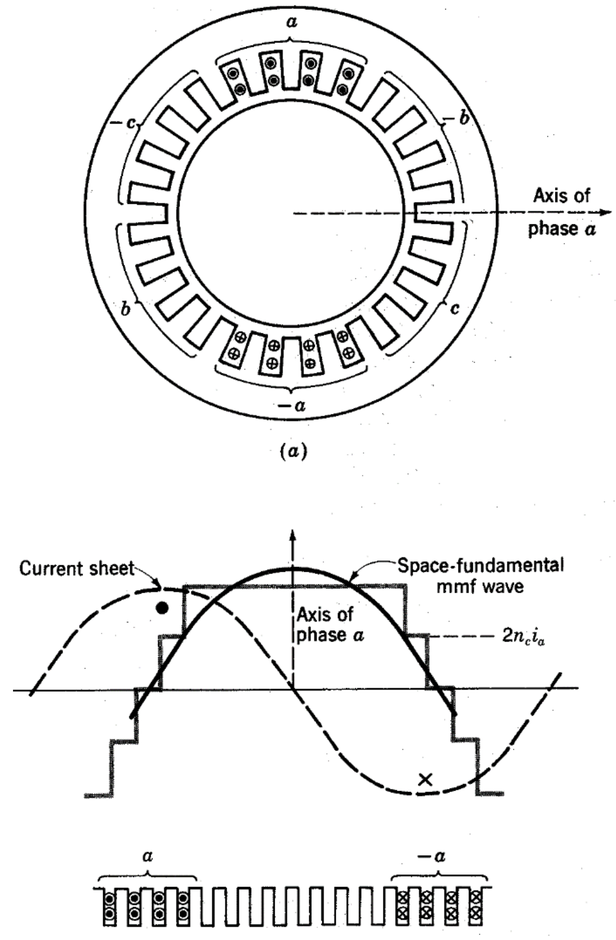
Elementary two-pole machine with smooth air gap: cont..



- The fundamental component of the resultant *mmf can be obtained by adding the fundamental* components of these individual coils, and it can expressed as

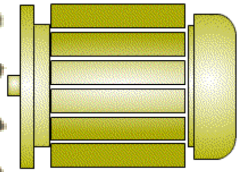
$$F_{a1} = \frac{4}{\pi}\frac{k_p N_{ph}}{P} i_a \cos\theta$$

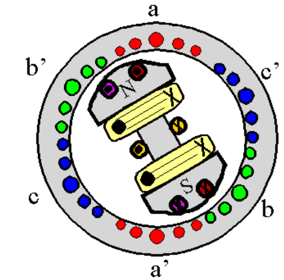
- **where *Nph* *is the total number of turns of the phase winding, which is formed by these coils, kd is known as the distribution factor of the winding, which is defined by***



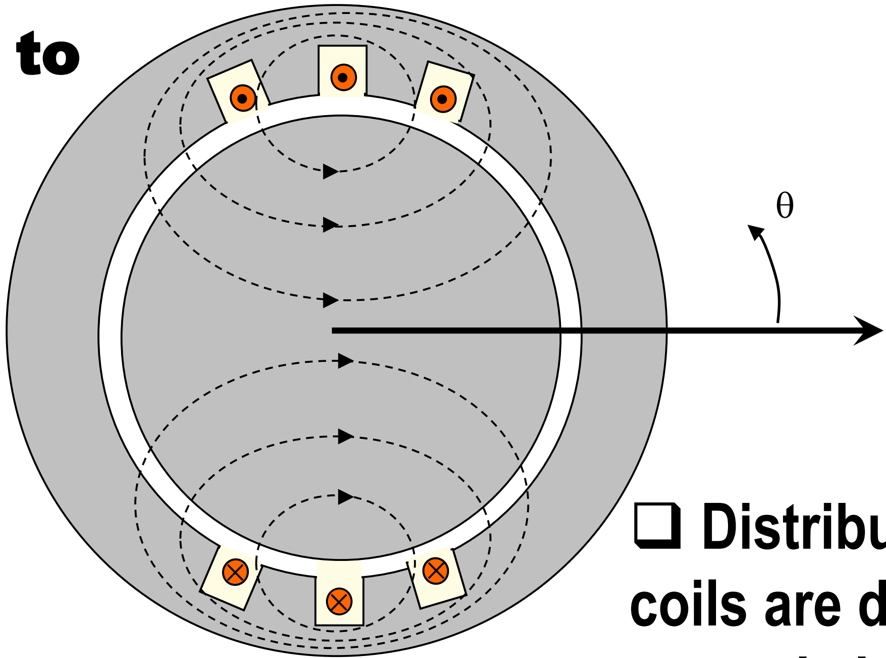
The mmf of one phase of a distributed two-pole three-phase winding with full-pitch coils.

Rotating field theory

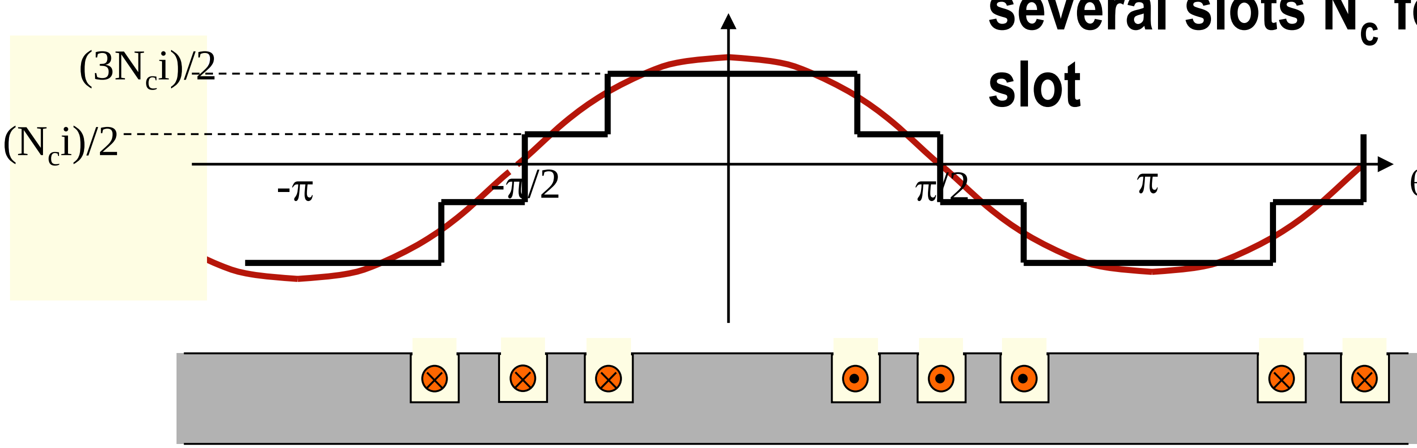




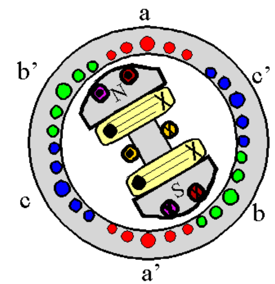
MMF closer to sinusoidal
- less harmonic contents



- Distributed winding – coils are distributed in several slots N_c for each slot



Rotating field theory cont..



Let $i_a = I_m \cos \omega t$, and we have

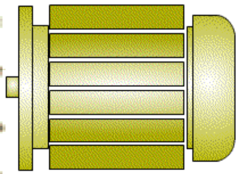
$$F_{a1} = \frac{4}{\pi}\frac{k_w N_{ph}}{P} I_m \cos\omega t \cos\theta$$
$$= F_m \cos\omega t \cos\theta$$

where
$$F_m = \frac{4}{\pi}\frac{k_w N_{ph}}{P} I_m$$

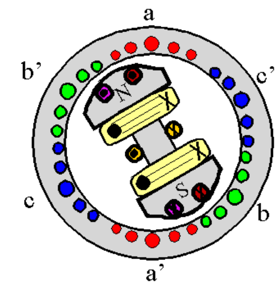
The *mmf of a distributed phase winding is a function of both space and time. When plotted* at different time instants as shown below, we can see that it is a pulsating sine wave. We call this type of *mmf as a* ***pulsating mmf.***

Because $\cos\alpha\cos\beta = \frac{\cos(\alpha-\beta)+\cos(\alpha+\beta)}{2}$, the above expression of the *mmf* fundamental component can be further written as

$$F_{a1} = \frac{F_m}{2}\cos(\theta - \omega t) + \frac{F_m}{2}\cos(\theta + \omega t)$$
$$= F_+ + F_-$$



Magnetic Field of Three Phase Windings



- Once we get the expression of *mmf for a single phase winding, it is not difficult to write* the expressions of *mmf's for three single phase windings placed* 120Deg *(electrical) apart and* excited by balanced three phase currents:

$$F_{a1} = F_m \cos\omega t \cos\theta = \frac{F_m}{2}\cos(\theta - \omega t) + \frac{F_m}{2}\cos(\theta + \omega t)$$

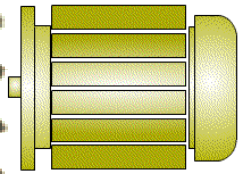
$$F_{b1} = F_m \cos(\omega t - 120^o)\cos(\theta - 120^o)$$

$$= \frac{F_m}{2}\cos(\theta - \omega t) + \frac{F_m}{2}\cos(\theta + \omega t - 240^o)$$

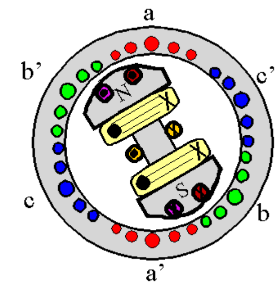
$$F_{c1} = F_m \cos(\omega t - 240^o)\cos(\theta - 240^o)$$

and

$$= \frac{F_m}{2}\cos(\theta - \omega t) + \frac{F_m}{2}\cos(\theta + \omega t - 480^o)$$



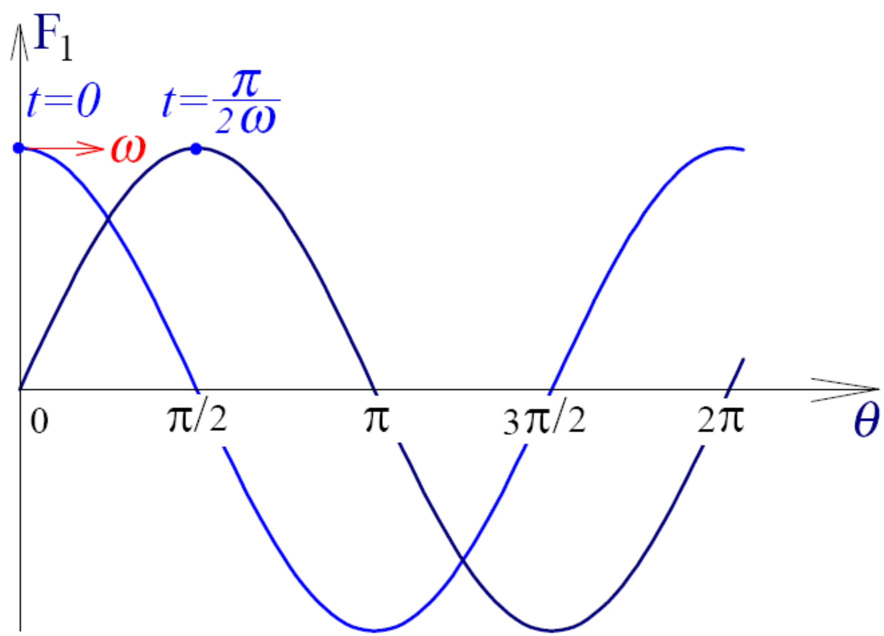
Magnetic Field of Three Phase Windings cont…



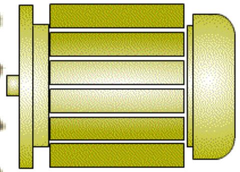
Therefore, the resultant *mmf* *generated by a three phase winding is*

$$F_1 = F_{a1} + F_{b1} + F_{c1} = \frac{3F_m}{2}\cos(\theta - \omega t)$$

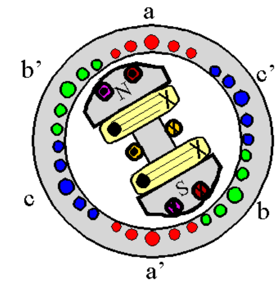
Note that $$\cos(\theta + \omega t) + \cos\left(\theta + \omega t - 240^o\right) + \cos\left(\theta + \omega t - 480^o\right) = 0$$



Rotating *mmf* in $+\theta$ direction



Magnetic Field of Three Phase Windings cont…



The above diagram plots the resultant *mmf* F_1 *at two specific time* $+\theta$ *stants:* $t=0$ *a* $(a\rightarrow b\rightarrow c)$ $t=\pi/2\omega$.

It can be readily observed that ***F_1 is a rotating mmf in the direction***

with a constant magnitude $3F_m/2$. ***The speed of this rotating mmf can be calculated as***

$$\omega_f = \frac{d\theta}{dt} = \frac{\pi/2}{\pi/2\omega} = \omega \qquad \text{rad/s (electrical)}$$

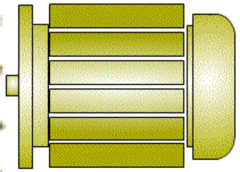
When expressed in mechanical radians per second and revolutions per minute, the speed of the rotating mmf can be expressed as

$$\omega_f = \frac{\omega}{P/2} \qquad \text{rad/s (mechanical)}$$

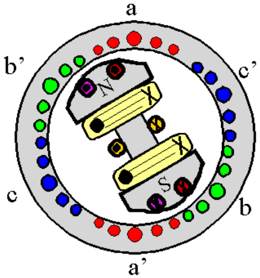
and

$$n_f = \frac{60\omega_f}{2\pi} = \frac{120f}{P} \qquad \text{rev/min}$$

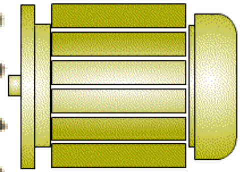
respectively



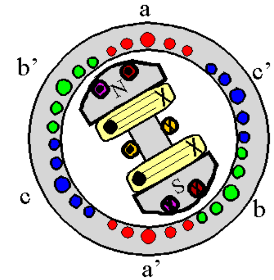
Magnetic Field of Three Phase Windings cont…



- **Again, for a machine with uniform air gap, the above analysis for *mmf* *is also* valid for the magnetic field strength and the flux density in the air gap.**
- **Therefore, *the speed of a rotating magnetic field is proportional to the frequency of the three phase excitation currents, which generate the field.***



Rotating Magnetic Field



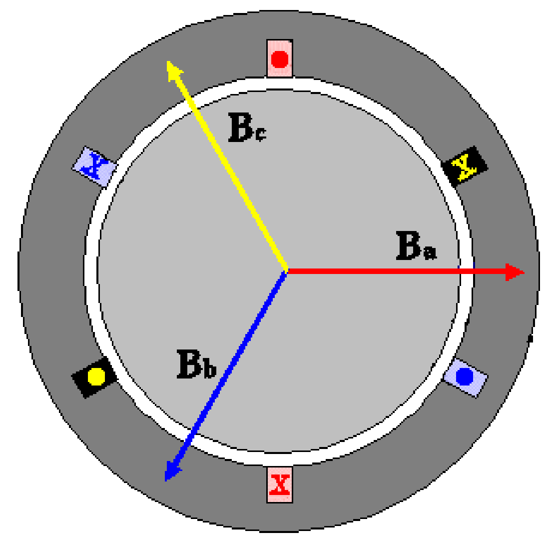
$$B_{net}(t) = B_a(t) + B_b(t) + B_c(t)$$

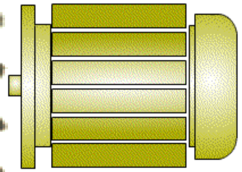
$$= B_M \sin(\omega t)\angle 0° + B_M \sin(\omega t - 120°)\angle 120° + B_M \sin(\omega t - 240)\angle 240°$$

$$= B_M \sin(\omega t)\hat{\mathbf{x}}$$

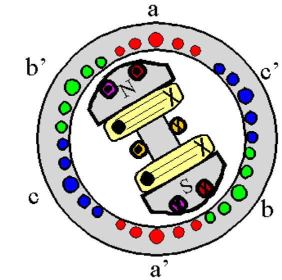
$$-[0.5 B_M \sin(\omega t - 120°)]\hat{\mathbf{x}} - [\frac{\sqrt{3}}{2} B_M \sin(\omega t - 120°)]\hat{\mathbf{y}}$$

$$-[0.5 B_M \sin(\omega t - 240°)]\hat{\mathbf{x}} + [\frac{\sqrt{3}}{2} B_M \sin(\omega t - 240°)]\hat{\mathbf{y}}$$





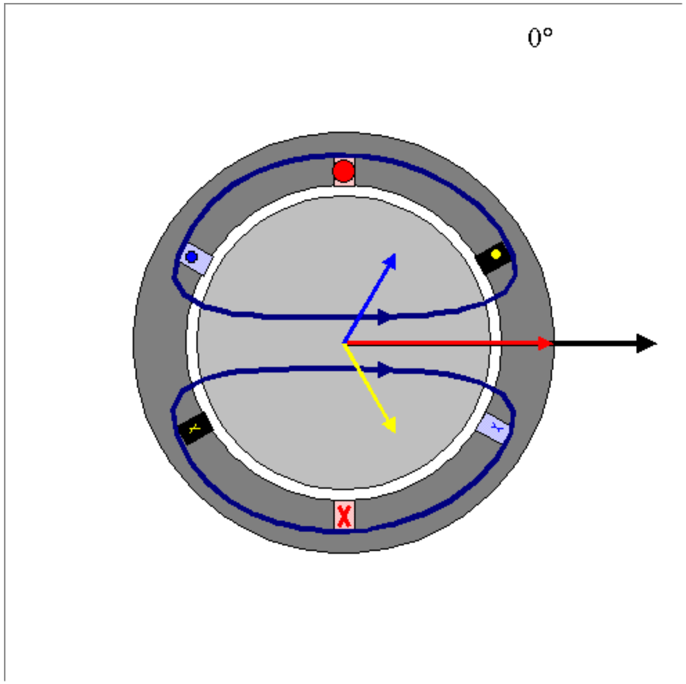
Rotating Magnetic Field



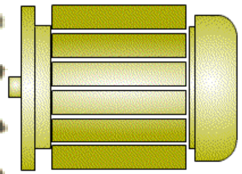
$$B_{net}(t) = [B_M \sin(\omega t) + \frac{1}{4} B_M \sin(\omega t) + \frac{\sqrt{3}}{4} B_M \cos(\omega t) + \frac{1}{4} B_M \sin(\omega t) - \frac{\sqrt{3}}{4} B_M \cos(\omega t)]\hat{\mathbf{x}}$$

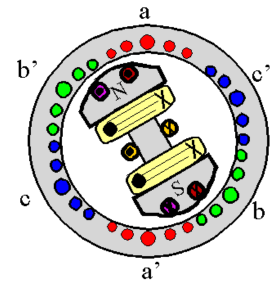
$$+[-\frac{\sqrt{3}}{4} B_M \sin(\omega t) - \frac{3}{4} B_M \cos(\omega t) + \frac{\sqrt{3}}{4} B_M \sin(\omega t) - \frac{3}{4} B_M \cos(\omega t)]\hat{\mathbf{y}}$$

$$= [1.5 B_M \sin(\omega t)]\hat{\mathbf{x}} - [1.5 B_M \cos(\omega t)]\hat{\mathbf{y}}$$




PresenterMedia




a
b'
c'
N
S
c
b
a'


PresenterMedia


PresenterMedia


PresenterMedia


PresenterMedia

END OF LECTURE 10