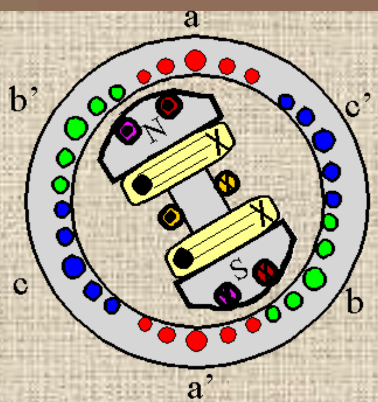
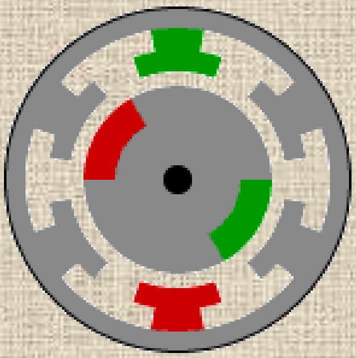
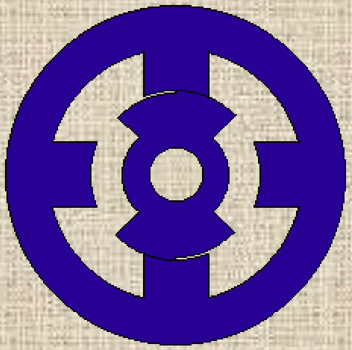
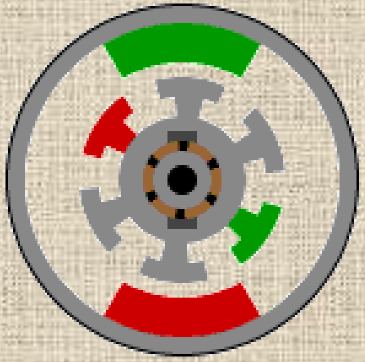
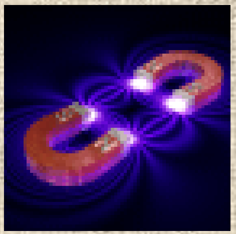
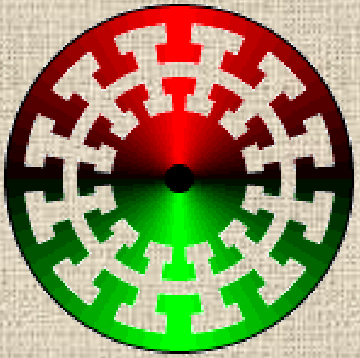


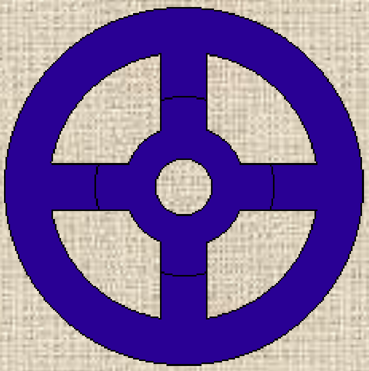
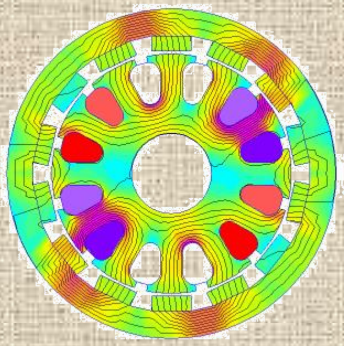
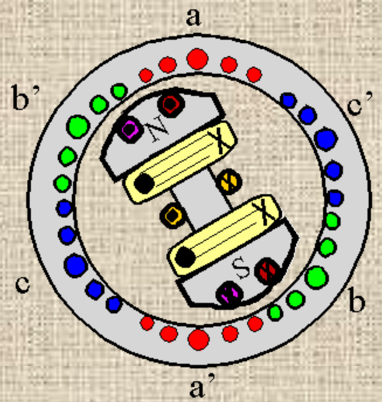




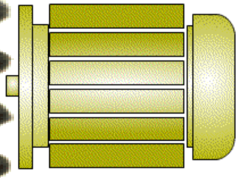
EE552 ELECTRICAL MACHINES III

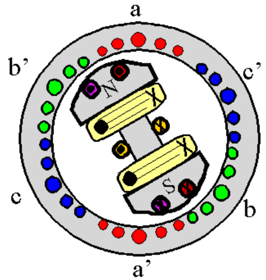
LECTURE 8





LECTURE NOTES

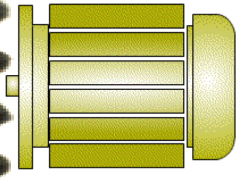


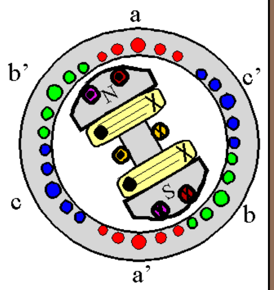
ELECTRICAL MACHINES III

EE552

SPRING 2018

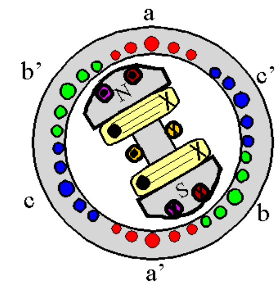
Dr : MUSTAFA AL-REFAI





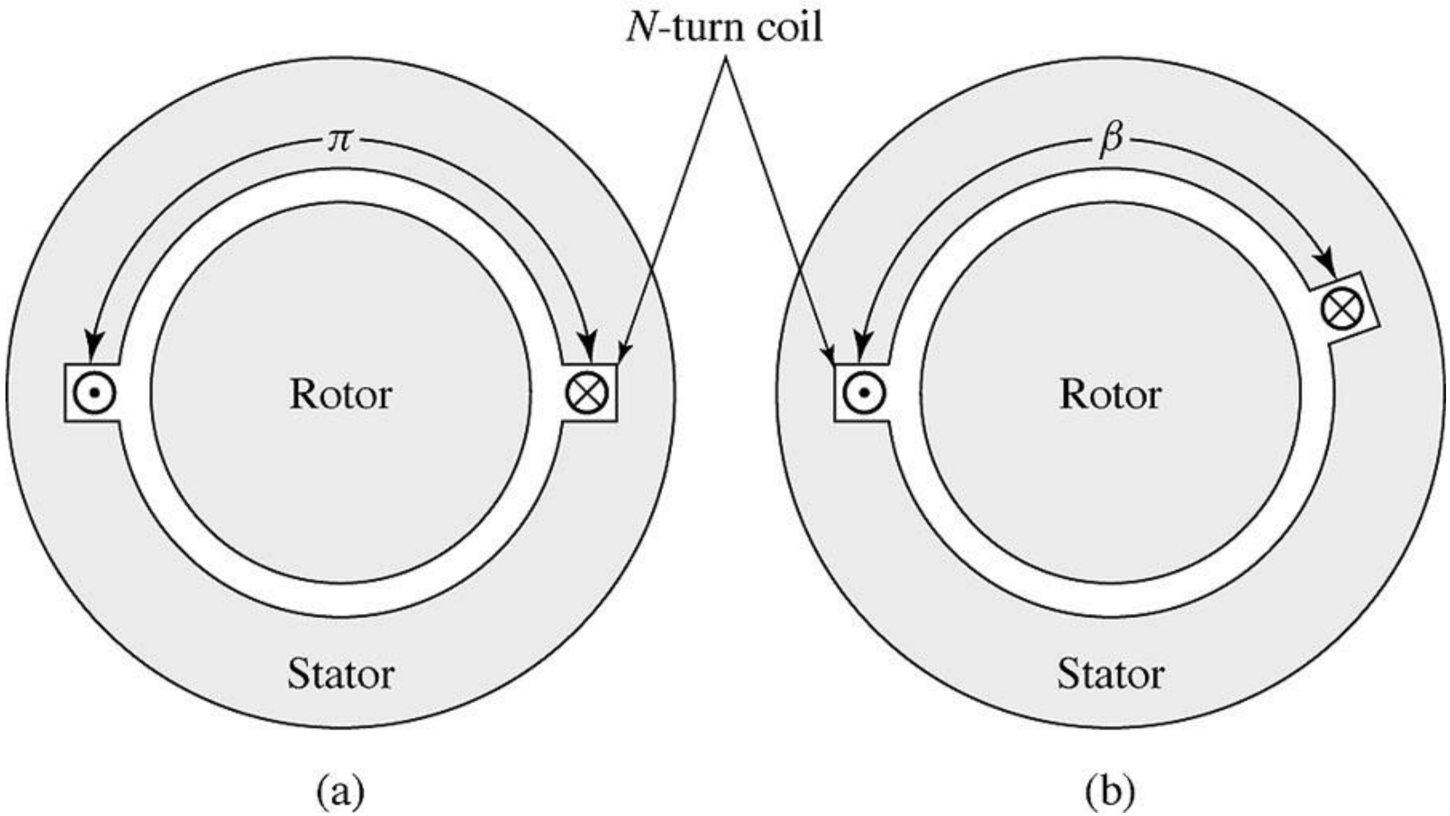
LECTURE 8

SYNCHRONOUS GENERATOR

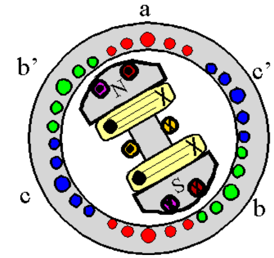


(a) full-pitch coil and

(b) fractional-pitch coil.



Fractional Pitch Coil

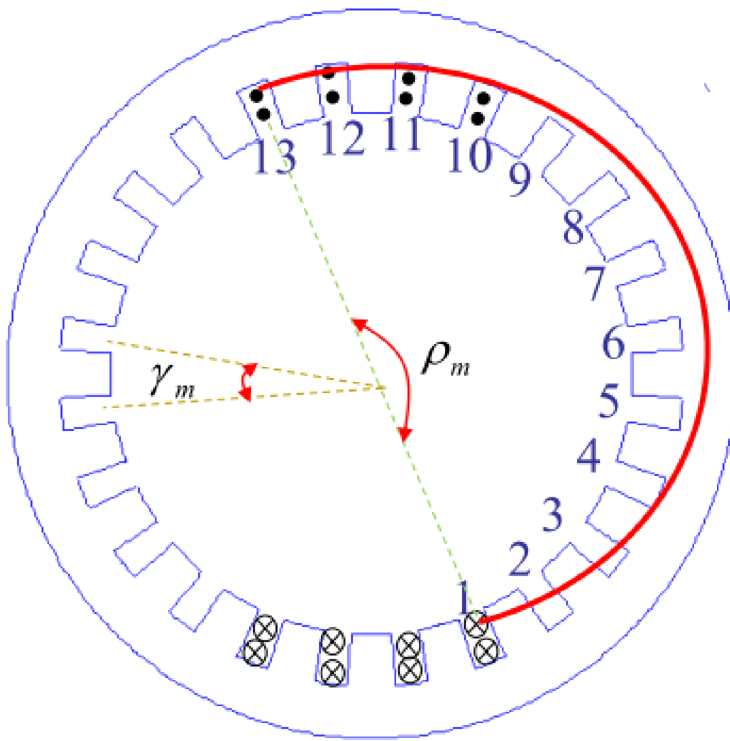


24 slots, 2 pole, 3 phase

$$\rho_P = \frac{2\pi}{2} = \pi$$

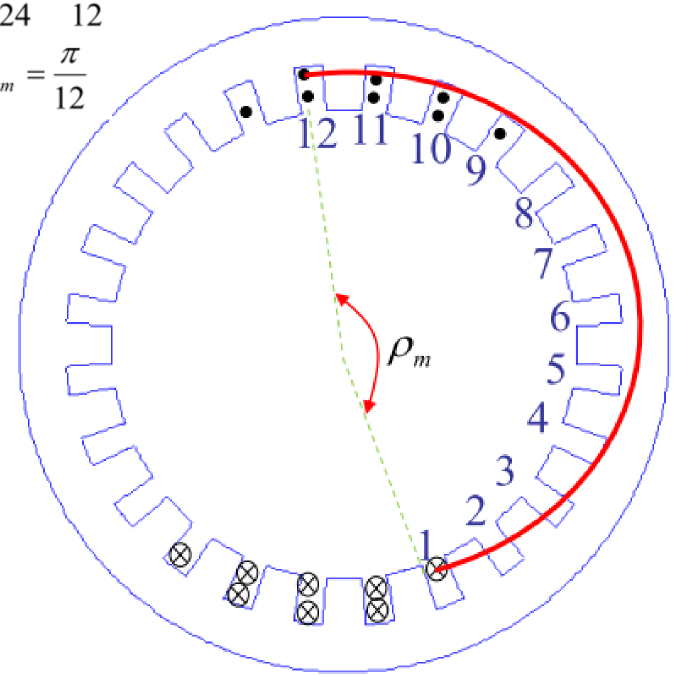
$$\gamma_m = \frac{2\pi}{24} = \frac{\pi}{12}$$

$$\gamma = \gamma_m = \frac{\pi}{12}$$



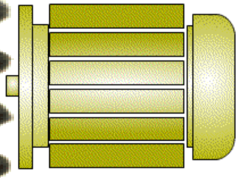
Phase A, full-pitch

$$\rho = \rho_m = \pi = 180^o$$

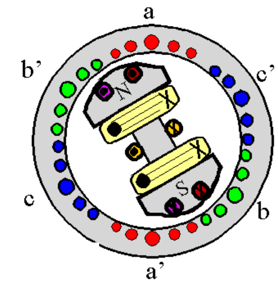


Phase A, (11/12)-pitch

$$\rho = \rho_m = \frac{11}{12}\pi = 165^o$$



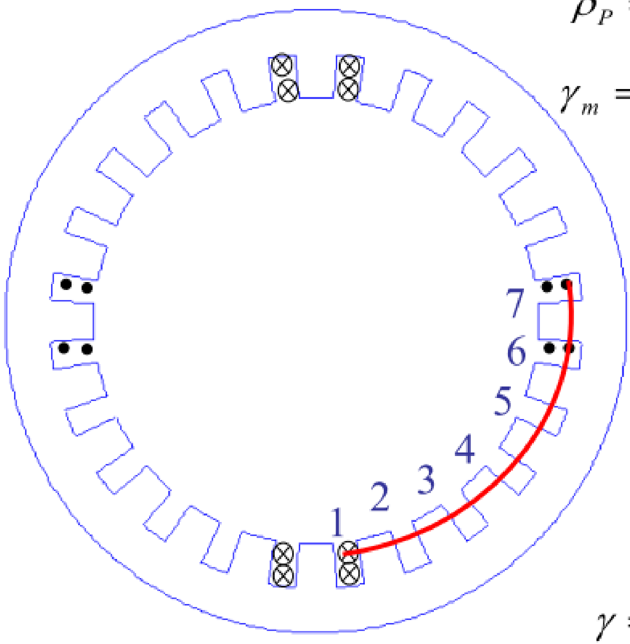
Fractional Pitch Coil

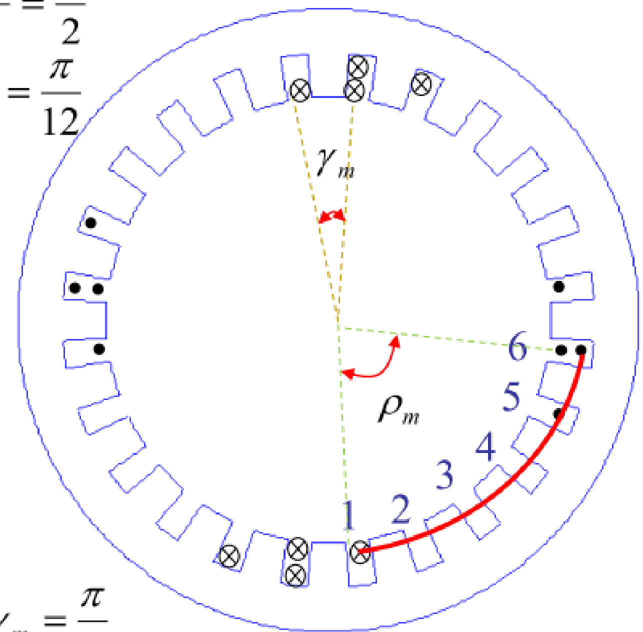


24 slots, 4 pole, 3 phase

$$\rho_P = \frac{2\pi}{4} = \frac{\pi}{2}$$

$$\gamma_m = \frac{2\pi}{24} = \frac{\pi}{12}$$





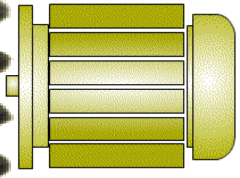
$$\gamma = \frac{4}{2}\gamma_m = \frac{\pi}{6}$$

Phase A, full-pitch

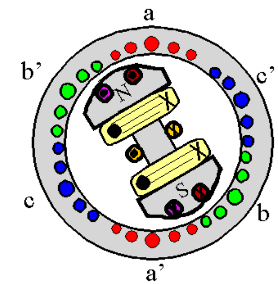
$$\rho_m = \frac{\pi}{2} = 90^\circ \qquad \rho = \pi = 180^\circ$$

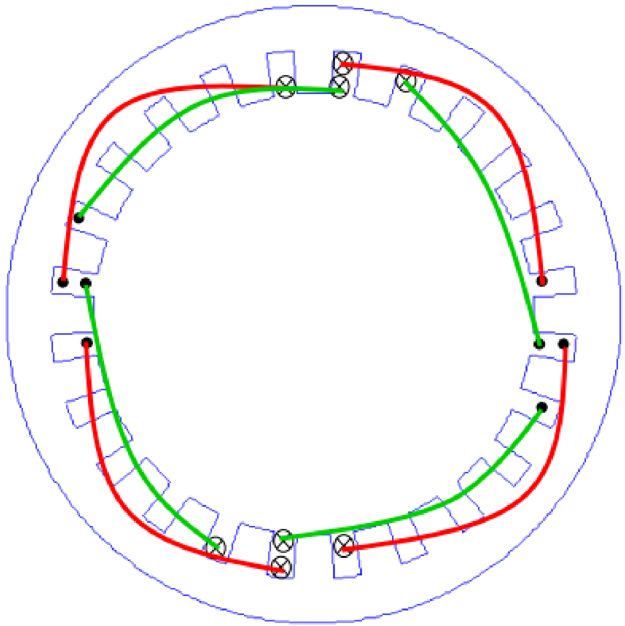
Phase A, (5/6)-pitch

$$\rho_m = \frac{5}{6}\frac{\pi}{2} = \frac{5\pi}{12} = 75^\circ \qquad \rho = \frac{5}{6}\pi = 150^\circ$$



Group





4 pole, 3 phase, 24 slot machine
Phase A, (5/6)-pitch

This group consists of 2 coils.

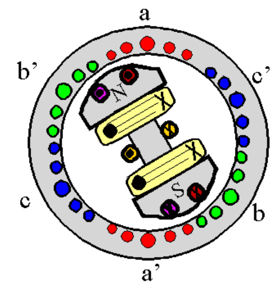
Number of coils per group:

$$q = \frac{\text{Number of Stator Slots }(S)}{\text{Number of phases }(m) \times \text{Number of poles }(P)}$$

$$q = \frac{S}{3P} \quad \text{for 3 phase machine}$$

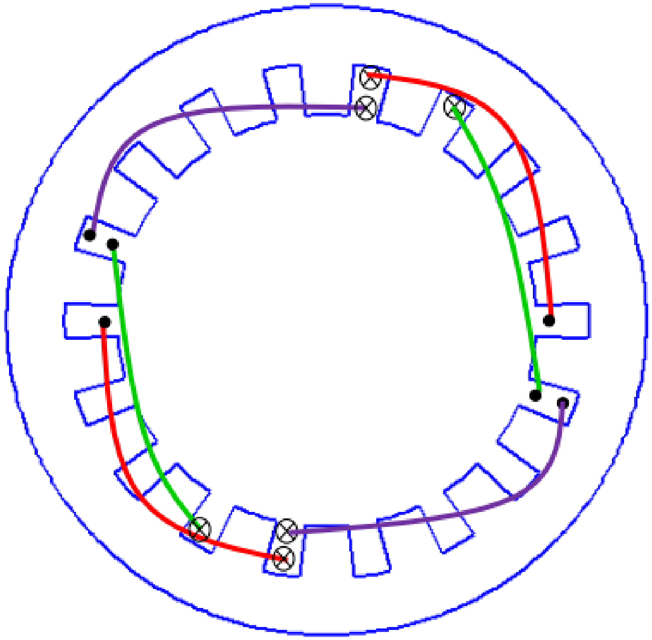
Number of coils = Number of slots for double layer winding

Number of groups = Number of poles (P) for double layer winding



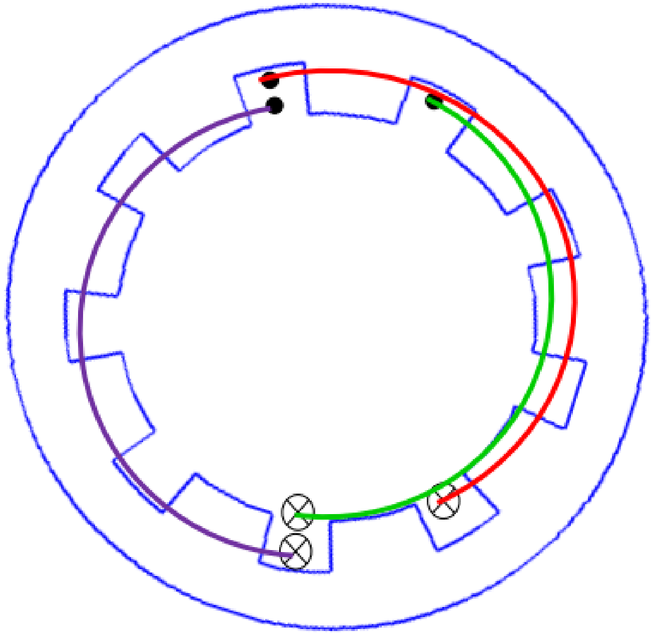
Group

q can take fractional number



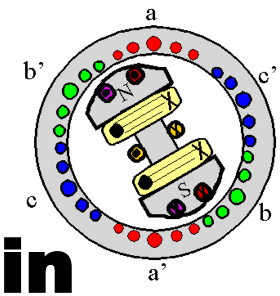
$$q = \frac{18}{3 \times 4} = 1.5$$

4 pole, 3 phase, 18 slot

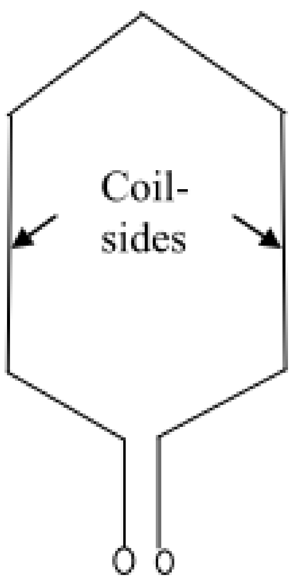


$$q = \frac{9}{3 \times 2} = 1.5$$

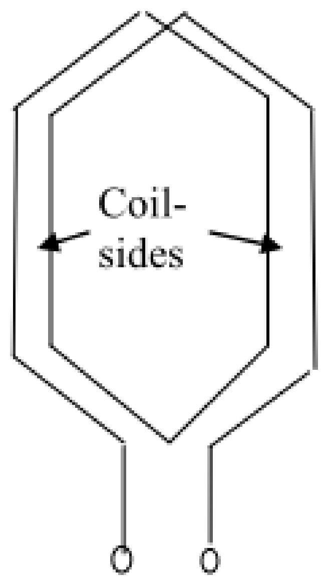
2 pole, 3 phase, 9 slot



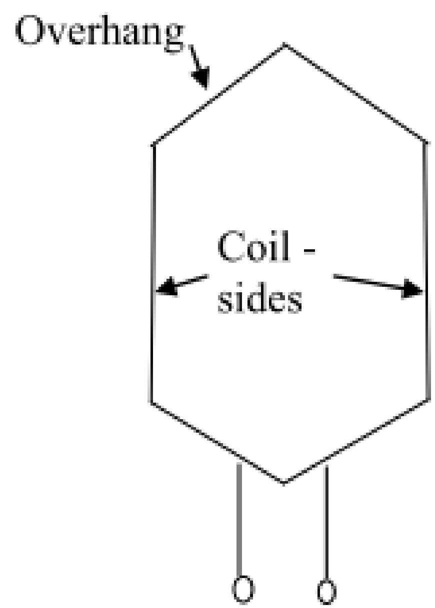
The number of conductors (C) in any coil-side is equal to the number of turns (N) in that coil.



One-turn coil

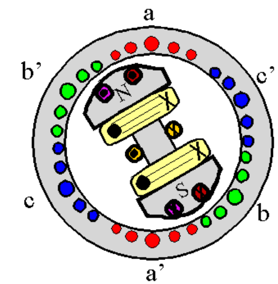


two-turn coil



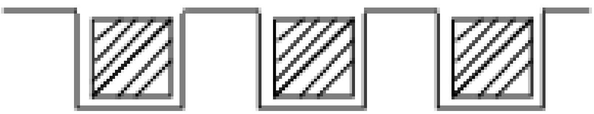
multi-turn coil

Single- layer and double layer windings.



□ Single- layer winding

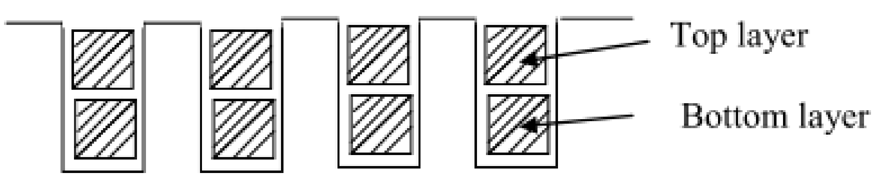
- One coil-side occupies the total slot area
- Used only in small ac machines



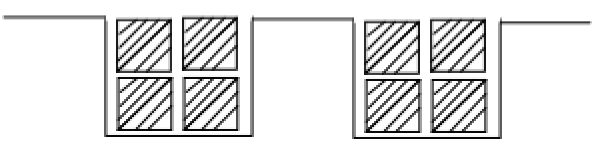
one coil-side per slot

□ Double- layer winding

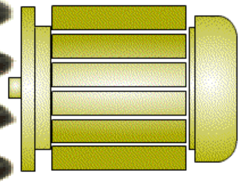
- Slot contains even number (may be 2,4,6 etc.) of coil-sides in two layers
- Double-layer winding is more common above about 5kW machines

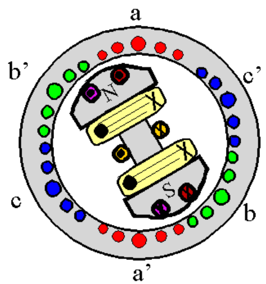


Two coil –sides per slot



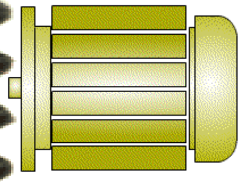
4-coil-sides per slot

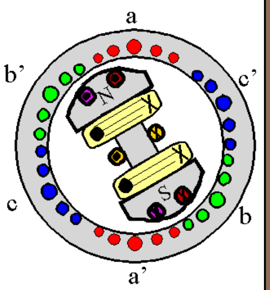




The advantages of double-layer winding over single layer winding are as follows:

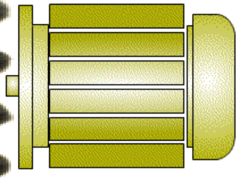
a. Easier to manufacture and lower cost of the coils
b. Fractional-slot winding can be used
c. Chorded-winding is possible
d. Lower-leakage reactance and therefore , better performance of the machine
e. Better emf waveform in case of generators



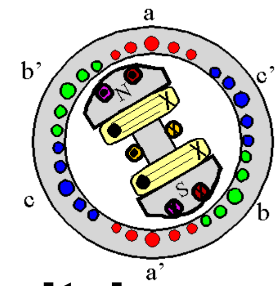


Pole – pitch. A pole pitch is defined as the peripheral distance between **identical points on two adjacent poles. Pole pitch is always equal to 180 electrical.**

Coil–span or coil-pitch. The distance between the two coil-sides of a coil is called coil-span or coil-pitch. It is usually measured in terms of teeth, slots or electrical degrees.



Chorded-coil.



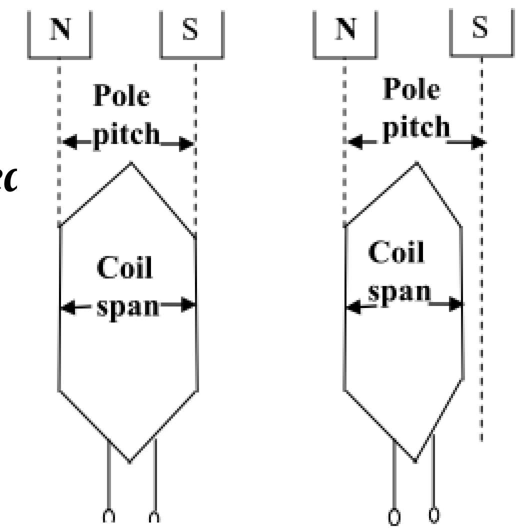
❑ **If the coil-span (or coil-pitch) is equal to the pole-pitch, then the coil is termed a full-pitch coil.**

❑**in case the coil-pitch is <u>less</u> than pole-pitch, then it is called *chorded*, *short-pitch* or *fractional-pitch coil***

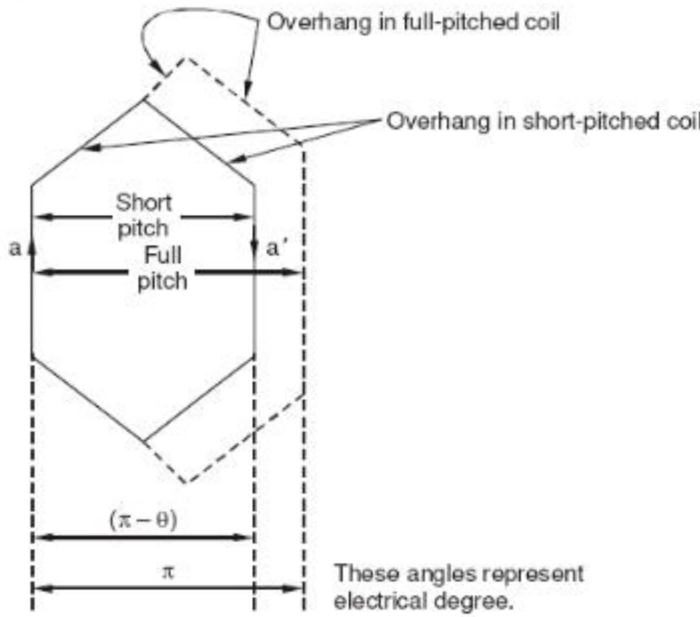
➢ **if there are S slots and P poles, then pole pitch $Q = S/p$ slots per pole**

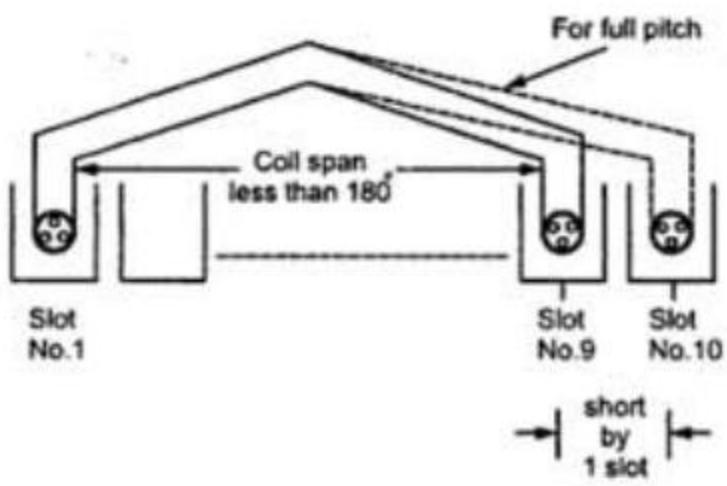
➢ **if coil-pitch $y = S/P$, it results in *full-pitch winding***

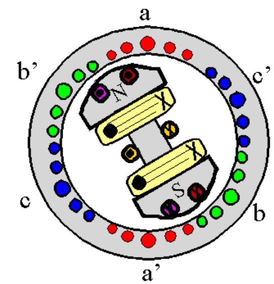
➢ in case coil-pitch $y < S$, it results in ***chordec*** *short-pitched* or *fractional-pitch*

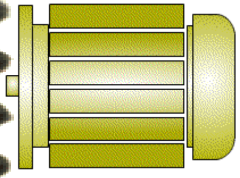


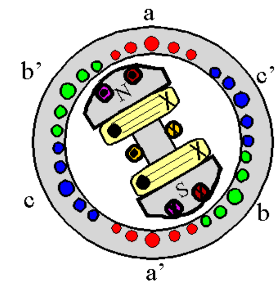
Full-pitch coil **Short-pitched or chorded coil**


Overhang in full-pitched coil
Overhang in short-pitched coil
Short pitch
Full pitch
a
a′
(π − θ)
π
These angles represent electrical degree.


For full pitch
Coil span less than 180°
Slot No.1
Slot No.9
Slot No.10
short by 1 slot


a
b'
c'
c
b
a'
N
S





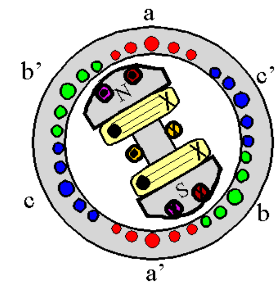
In AC armature windings, the separate coils may be connected in several different manners, but the two most common methods are lap and wave

In polyphase windings it is essential that

- **The generated emfs of all the phases are of equal magnitude**
- **The waveforms of the phase emfs are identical**
- **The frequency of the phase emfs are equal**

- The phase emfs have mutual time-phase displacement of electrical radians. $\beta = \dfrac{2\pi}{m}$
- Here m is the number of phases of the a.c. machine.

Electrical Radians and Synchronous Speed (cont'd)



$$\theta_e = \frac{P}{2}\theta_m = p\theta_m$$ electrical rads.

$$\omega_e = \frac{P}{2}\omega_m = p\omega_m$$ electrical rads./sec.

frequency of induced voltage

$$f = \frac{P}{2}\frac{N}{60} = p\frac{N}{60} = p\frac{\omega_m}{2\pi}$$ Hz

where P= # of poles

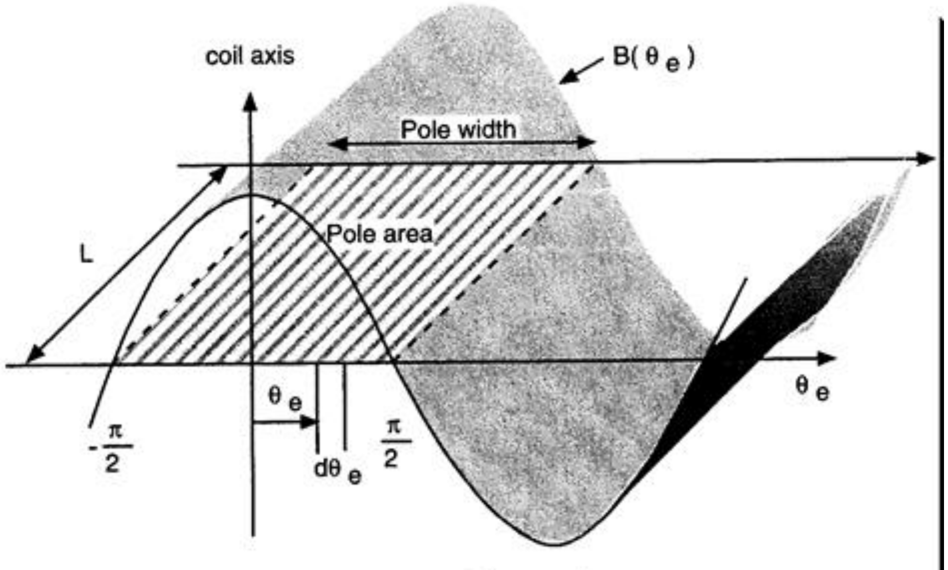
p=# of pole pairs and

N=synchronous speed of rotor (rpm)

Flux per Pole

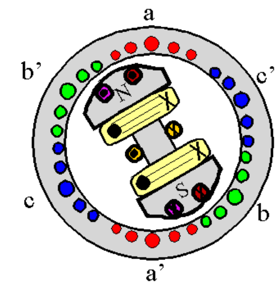
Consider a sinusoidally distributed flux density, $B(\theta_e)=B_{pk}\cos\theta_e$. The flux per pole is given by:

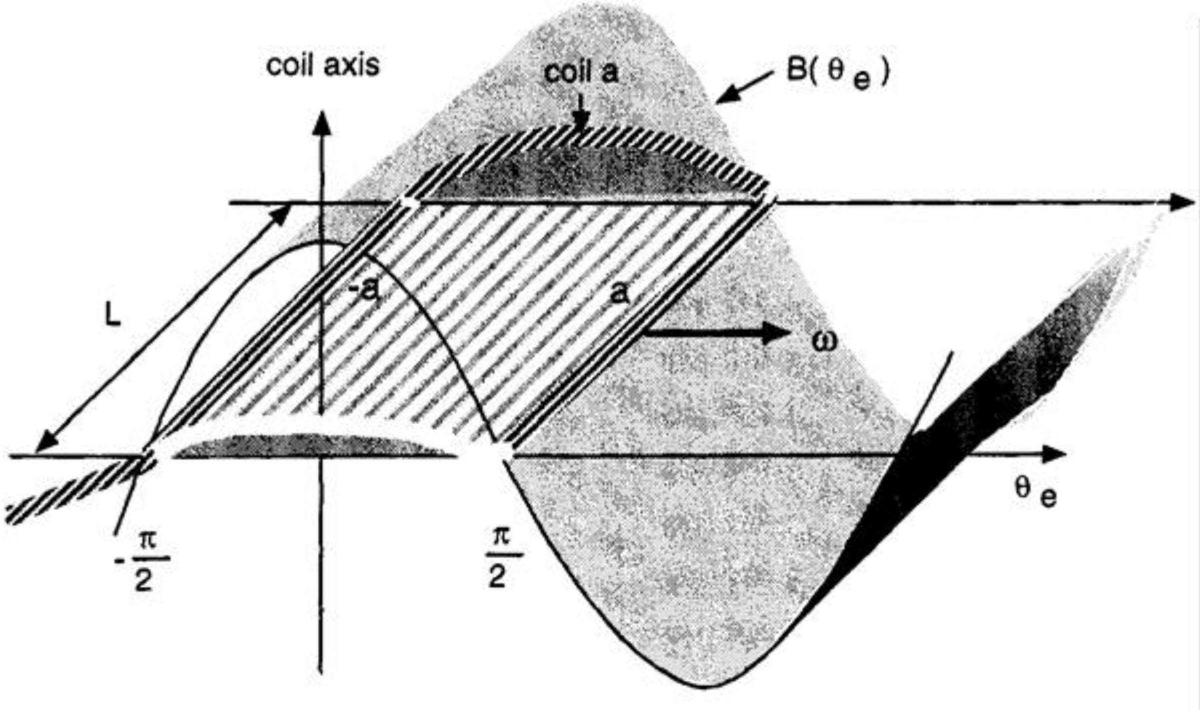
$$\phi_{pole} = \int_{-\pi_e/2}^{\pi_e/2} B_{pk}\cos\theta_e lRd\theta_m = \frac{4}{P}B_{pk}lR$$



Flux per pole.

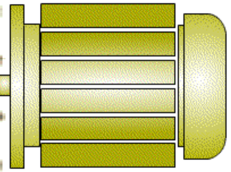
Induced Voltage



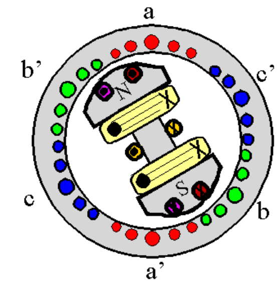


Full-pitch coil moving relative to flux density, *B*.

Full-pitched coil w/N turns moving laterally w.r.t. sinusoidal flux density.



Induced Voltage (cont'd)



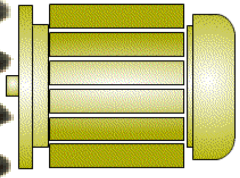
At t=0 coil's axis coincides w/flux density wave peak.
Thus, at time t, flux linked by coil is given by:

$$\lambda(t) = N\phi_{pole}\cos(\omega_e t)$$

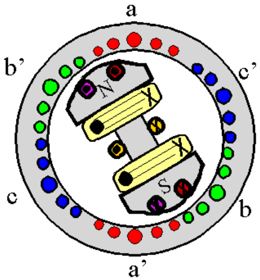
$\therefore$ induced voltage in full-pitch coil is given by:

$$e = \frac{d\lambda}{dt} = N\frac{d\phi_{pole}}{dt}\cos\omega_e t - \omega_e N\phi_{pole}\sin\omega_e t$$

$\uparrow$ transformer voltage $\qquad$ $\uparrow$ speed voltage



RMS Value of Induced Voltage



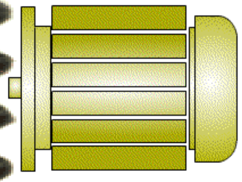
RMS value of sinusoidally varying speed voltage term is:

$$E_{rms} = 4.44\, f N \phi_{pole}$$

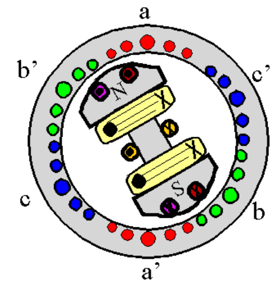
In high power ac machines may have distributed or short-pitch windings. Use distribution and pitch factors (k_d and k_p respectively) to account for these designs. The rms value of the induced voltage under these conditions becomes:

$$E_{rms} = 4.44\, f k_w N \phi_{pole}$$

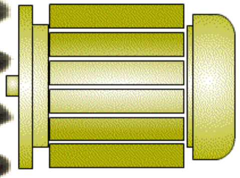
where $k_w = k_d k_p$ is the winding factor.



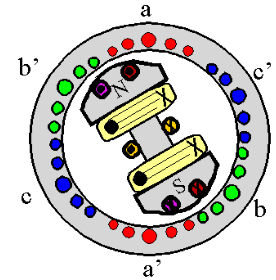
Distribution Factor



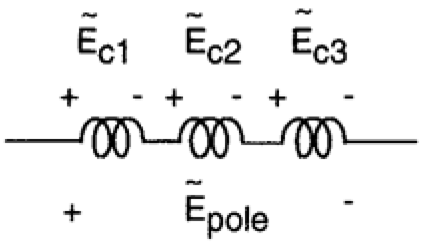
Phase windings may have series/parallel coils under a different pole-pair. Within each pole-pair region, the coils of a distributed winding are spread out over several pairs of slots.



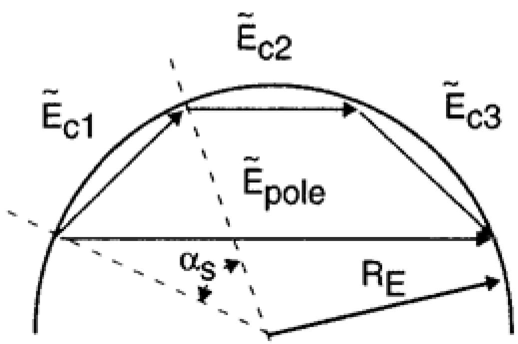
Distribution Factor (cont'd)



The voltages induced in component coils for a single phase winding occupying adjacent slots will be separated by the slot angle separating them α_s^e (electrical angle subtended by arc between two

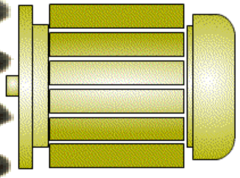


Coils of a pole

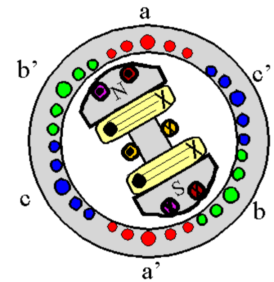


Result of coil's phasor voltages

Resultant voltage of series full-pitch coils under each pole.



Distribution Factor (cont'd)



The distribution factor can be defined as the ratio of the resultant voltage with coils distributed to resultant voltage if coils were in one location, i.e.

$$k_d = \frac{\text{Resultant voltage of coils under one pole-pair } |E_{pole}|}{\text{Arithmetic sum of coil voltages } \Sigma_i |E_{ci}|}$$

If a phase winding has q coils/phase/pole,

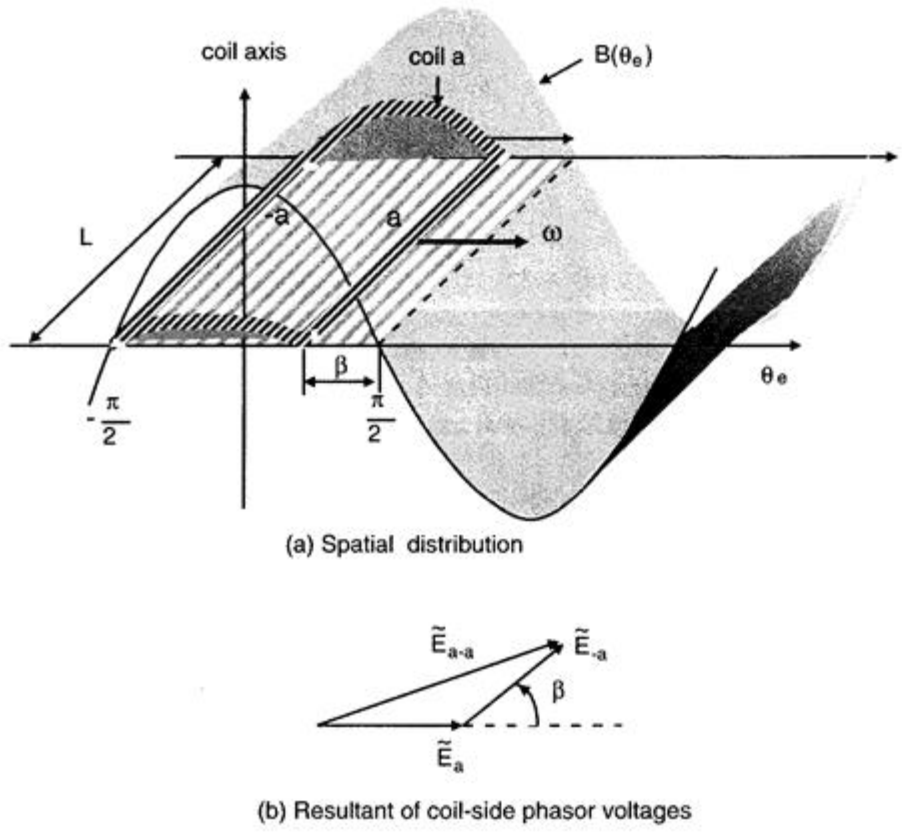
$|E_{pole}| = 2R_E \sin(q\alpha_s^e/2)$ and

$|E_{ci}| = 2R_E \sin(\alpha_s^e/2)$, and

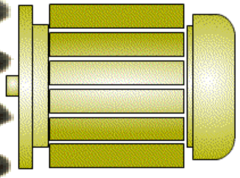
$$k_d = \frac{\sin(q\alpha_s^e/2)}{q\sin(\alpha_s^e/2)}$$

Pitch Factor

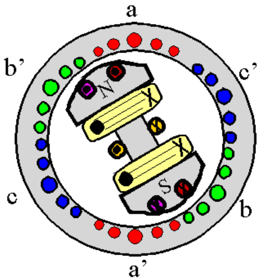
Short-pitching is when coils with less than one pole-pitch are used.



Resultant of coil-side voltages of a fractional-pitch coil.

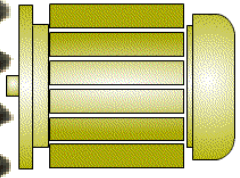


Pitch Factor (cont'd)

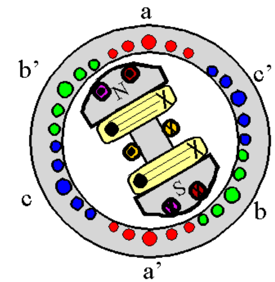


Short-pitching is used in machines with fractional-slot windings (non-integral slots/pole or slots/pole/phase) in a double-layer winding arrangement. Allows for a finite set of stampings with a fixed number of slots to be used for different speed machines.

Also, short-pitching can be used to *suppress certain harmonics in the phase emfs*. Although short-pitching also offers shorter end connections, the *resultant fundamental phase emf* is reduced.



Pitch Factor (cont'd)

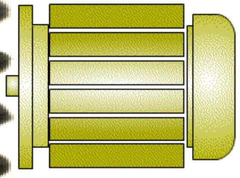


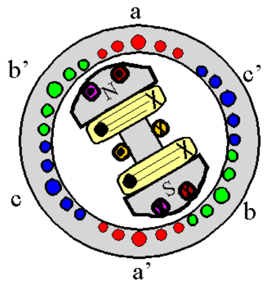
The pitch factor k_p is defined by:

$$k_p = \frac{\text{Resultant voltage in short-pitch coil}}{\text{Arithmetic sum of voltages induced in full coil}}$$

With sinusoidal voltages, each coil voltage is the phasor sum of its two coil-side voltages. Thus, for coil a, $E_{ca} = E_a + E_{-a}$

=> $$k_p = \frac{\tilde{E}_{ca}}{2|\tilde{E}_a|} = \cos\frac{\theta_e}{2}$$




a
b'
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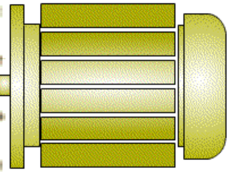

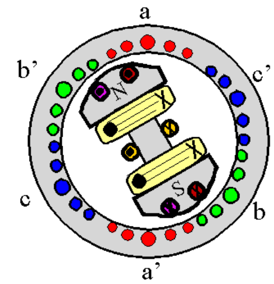
a
b'
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N
S
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END OF LECTURE 8