LECTURE NOTES
ON
ENERGY CONVERSION-II
5TH SEMESTER

PREPARED BY
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CHAPTER-1 ALTERNATOR

Date- 18.08.20

* ALTERNATOR :-

→ The machine which produces 3-ϕ AC power from mechanical power is called synchronous generator or alternator.

→ The working of an alternator is based on the principle that when the flux linking to a conductor changes, an emf is induced in the conductor.

→ In an alternator the field winding is placed on the rotating part (i.e., rotor) and the armature winding is placed on the stationary part (i.e., stator). The DC source called exciter is generally a small DC shunt or compound generator mounted on the shaft of the alternator.

→ When the rotor is rotated by a prime mover the stator or armature conductor are cut by the magnetic flux of rotor poles. So, emf is induced in the armature conductor due to electromagnetic induction.

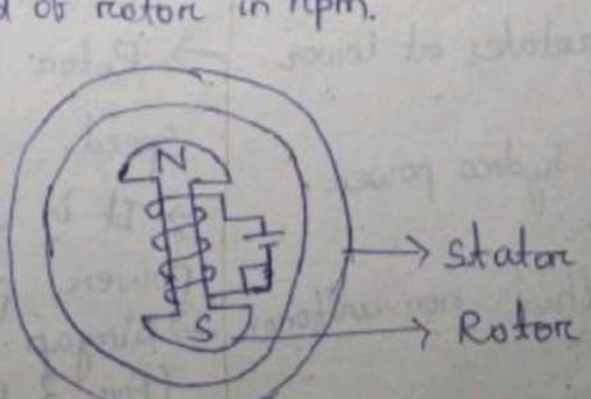
→ The induced emf is alternating since 'N' & 'S' poles of the rotor alternately pass the armature conductor. The direction of induced emf can be given by fleming's Right hand rule. and frequency is

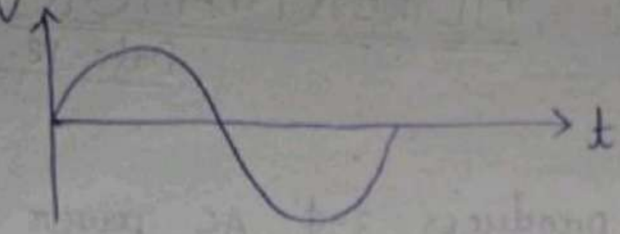
$$F = \frac{PN}{120}$$

P = No. of pole

N = Speed of rotor in rpm.

Diagram :-





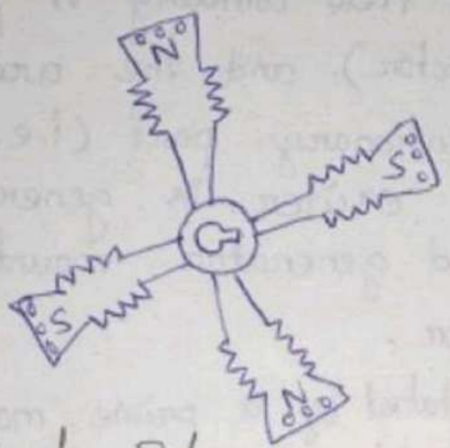
Date- 19.08.20

* TYPES OF ROTOR :-

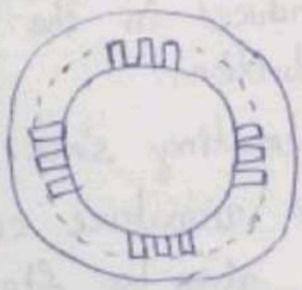
There are two types of rotor.

i) Salient pole Rotor.
ii) Cylindrical Rotor.

i) Salient Pole Rotor :-



ii) Cylindrical Rotor :-



Salient Pole Rotor	Cylindrical Rotor
→ The diameter is more.	→ The diameter is less.
→ Length is less.	→ Length is more.
→ Centrifugal force is more.	→ Centrifugal force is less.
→ The Rotor rotates at lower Speed.	→ Rotor rotates at higher speed.
→ It is used in hydro power plant	→ It is used in thermal power plant.
→ Airgap length is non-uniform.	→ Airgap length is uniform. (For 2 pole Rotor - 3600 rpm, 4 Pole Rotor - 1800 rpm

Date - 20.08.20

* DAMPER WINDING :-

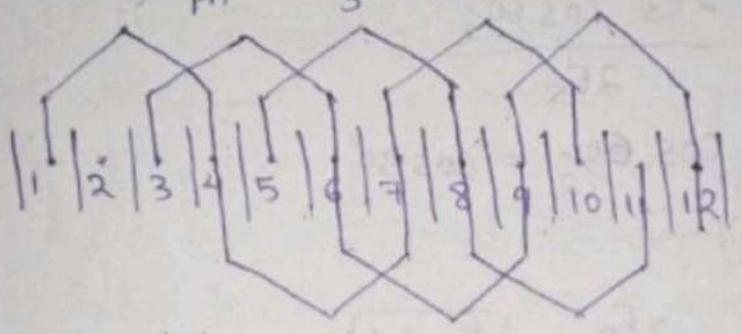
copper bars are inserted on the pole shoe and shorted by 2 end rings called Damper winding. This dampers are useful in preventing hunting (speed fluctuation) in a alternator and needed in to provide starting torque in Synchronous motor.

Armature winding :-

$S = 12$, $P = 4$

Pole pitch $= S/P = 12/4 = 3$

slot / pole / ph $= \frac{3}{3} = 1$



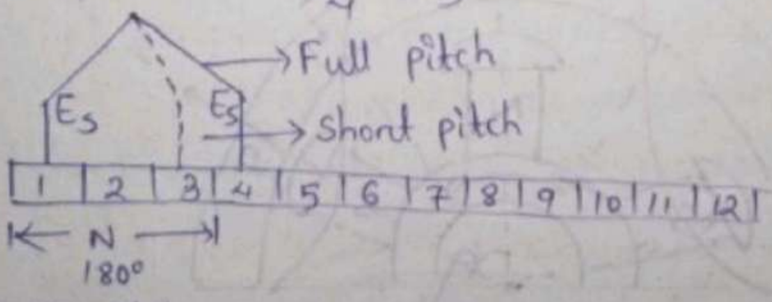
Full Pitch Coil :-

Coil having span is equal to 1 pole pitch i.e., spanning over 180° is called full pitch coil.

For example :

$S = 12$, $P = 4$

Pole pitch $= 12/4 = 3$



Full pitch $= E_S + E_S = 2E_S$

Short pitch $= E_S$

→ If the coil sides are placed on 1 and 4 then it is full pitch.

Date - 20.08.20

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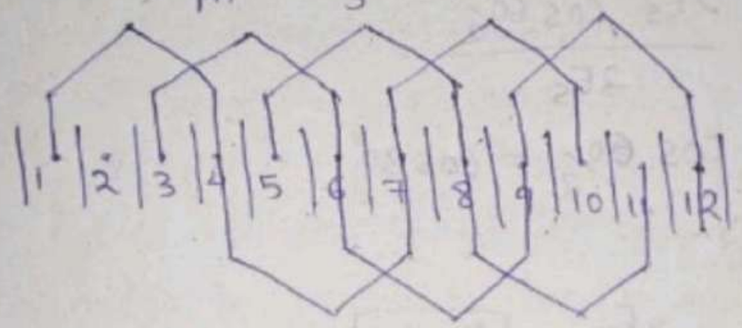

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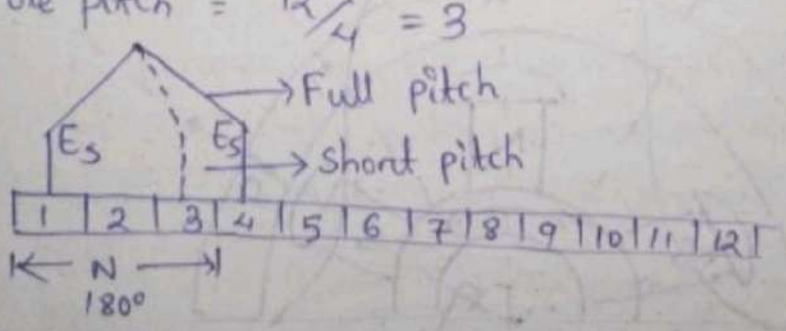


Full pitch $= E_s + E_s = 2E_s$

Short pitch $= E_s$

→ If the coil sides are placed on 1 and 4 then it is full pitch.

→ If the coil sides are placed in the slots 1 & 3 then it is called short pitch or Fractional pitch and short by an angle 60°.

→ Short pitch coil are usually used because they save copper of end connection generated emf waveform is improved. So, harmonics is less. So, eddy current and hysteresis loss are reduced. But the induced voltage is reduced.

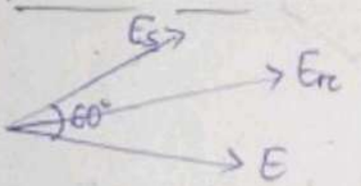
* PITCH FACTOR OR COIL SPAN FACTOR (K_p or K_c)

$$\text{Pitch Factor} = \frac{\text{Vector Sum of induced emf per coil}}{\text{Arithmatic sum of induced emf per coil}}$$

$$= \frac{2E_s \cos 60/2}{2E_s}$$

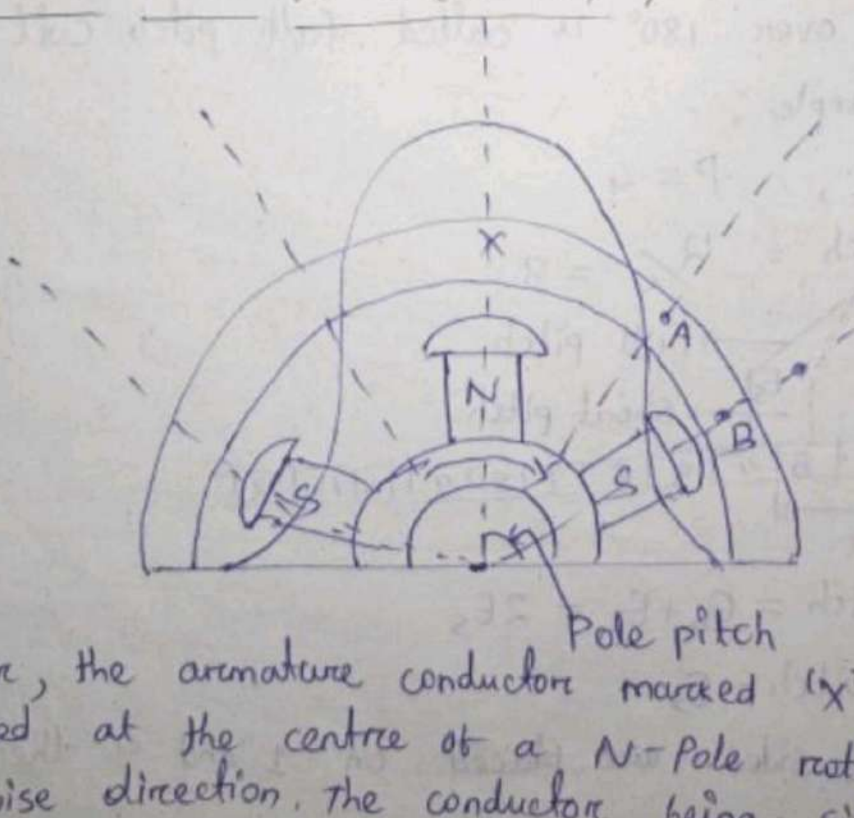
$$= \cos 60/2 = \cos 30°$$

Short pitch coil :-



$K_p < 1$

* SPEED AND FREQUENCY :-



Consider, the armature conductor marked 'X' in figure situated at the centre of a N-Pole rotating in clockwise direction. The conductor being situated at the place of maximum flux density will have maximum

emf induced in it.
When the conductor is in the interpolar gap, as at A, it has minimum because flux density is minimum there. Again, when it is at the centre of a S-pole, it has maximum emf induced in it, because flux density at B is maximum. But the direction of the emf when conductor is over a N-pole is opposite to that when it is over a S-pole.
The emf in an armature conductor goes through one cycle in angular distance equal to twice the pole pitch, as shown in figure.

Let, P = Total number of magnetic poles
N = Rotative speed of the rotor in r.p.m.
f = Frequency of generated e.m.f in Hz.

Since, one cycle of emf is produced when a pair of poles passes past a conductor, the number of cycles of emf produced in one revolution of the rotor is equal to the number of pair of poles.

∴ No. of cycles/revolution = $P/2$

and No. of revolutions/second = $N/60$

∴ Frequency $= \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120}$ Hz

$$\therefore \boxed{f = \frac{PN}{120} \text{ Hz.}}$$

'N' is known as the synchronous speed, because it is the speed at which an alternator must run, in order to generate emf of the required frequency. In fact, for a given frequency and given number of poles, the speed is fixed. For producing a frequency of 60Hz, the alternator will have to run at the following speeds:

No. of poles	2	4	6	12	24	36
Speed (r.p.m)	3600	1800	1200	600	300	200

Date - 21.08.20

Question :- 1

Calculate the pitch factor for the under given winding.

i) 36 stator slots, 4 poles, coil span 1 to 8.

ii) 72 stator slots, 6 poles, coil span 1 to 10.

iii) 96 stator slots, 6 poles, coil span 1 to 12.

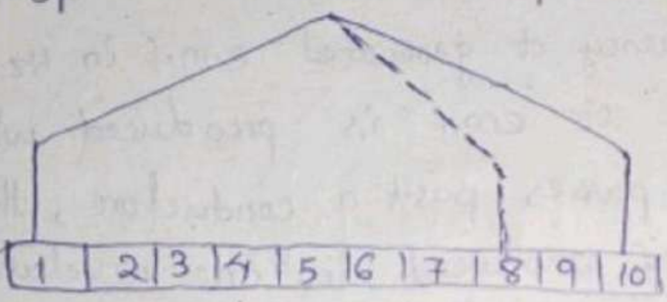
Sketch the 3 coil span.

Ans :- i) $S = 36$

$P = 4$

Pole pitch $= \frac{36}{4} = 9$

Coil span = 1 to 8 (Short pitch by 2 slots)



9 slots = 180°

1 slot $= \frac{180^\circ}{9} = 20^\circ$

$\alpha =$ ~~20+20 = 40~~ $^\circ$ $\frac{2}{9} \times 180^\circ = 40^\circ$

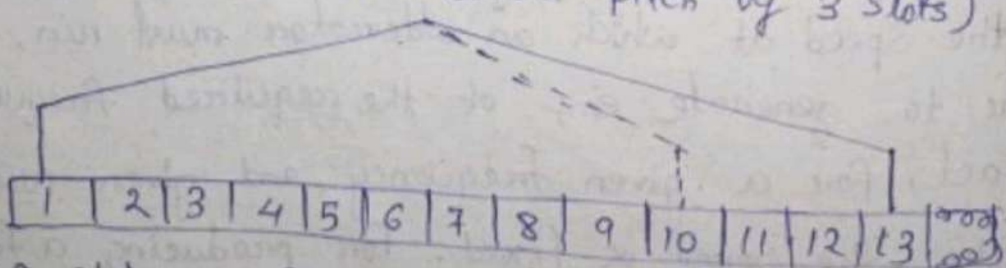
Pitch factor $= K_P = \cos\frac{\alpha}{2} = \cos\frac{40^\circ}{2} = \cos 20^\circ = 0.939$

ii) $S = 72$

$P = 6$

Pole pitch $= \frac{72}{6} = 12$

Coil span = 1 to 10 (Short pitch by 3 slots)



12 Slots = 180°

1 Slot $= \frac{180^\circ}{12} = 15^\circ$

~~α = 15+15+15 = 45~~ $^\circ$ $\alpha = \frac{3}{12} \times 180^\circ = 45^\circ$

Pitch factor $= \cos\frac{\alpha}{2} = \cos\frac{45^\circ}{2} = 0.923$

iii) $S = 96$

$P = 6$

coil span = 1 to 12 (Short pitch by 5 slots)

Pole pitch $= \frac{96}{6} = 16^\circ$

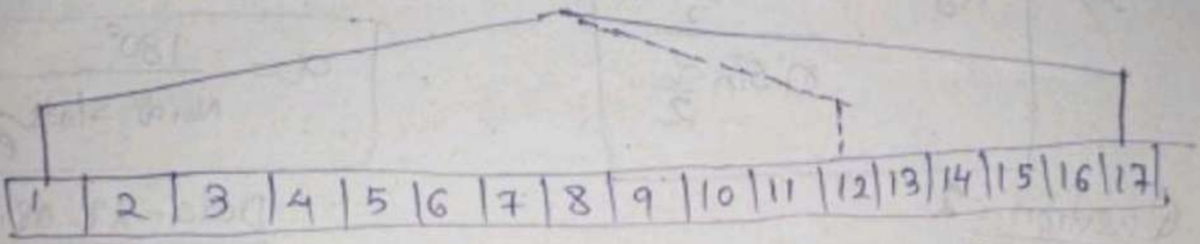
16 slots = 180°

1 Slot $= \frac{180}{16} = 11.25$

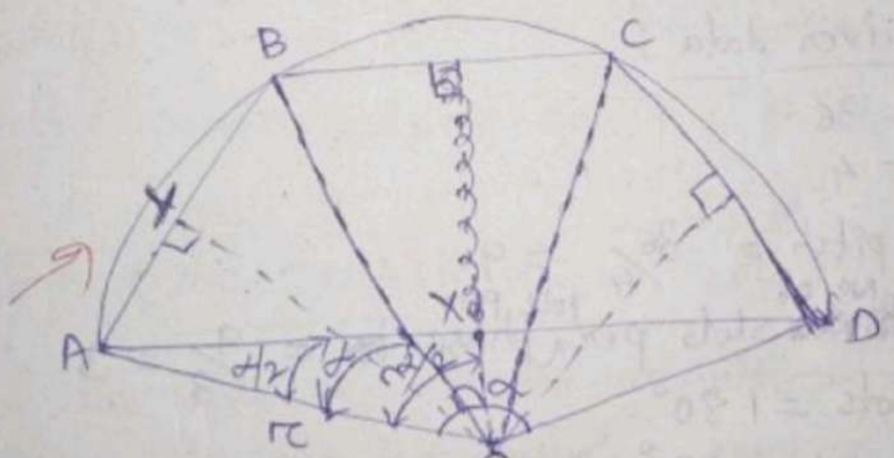
$\alpha = 5 \times 11.25 = 56.25$

Pitch factor $= k_p = \cos\frac{\alpha}{2} = \cos\frac{56.25}{2}$

$= 0.881$



* DISTRIBUTION FACTOR (K_d) :-



→ A winding with only 1 slot per pole per phase is called concentrating winding. In this type of winding the emf generated per phase is equals to arithmatic sum of the individual coil emf.s in that phase.

→ However, if the coil per phase are distributed over several slots in space (i.e. distributed winding the emfs in the coil are not in phase (i.e., phase difference is not zero but are displaced from each by a slot angle 'α' . n = slots per pole per phase

→ Distribution factor is defined as,

K_d is given by,

$$K_d = \frac{\text{Vector sum of induced voltage per phase}}{\text{Arithmatic sum of induced voltage per phase}}$$

$$\Rightarrow K_d = \frac{2AY}{n\,2AX} = \frac{2r \sin n\alpha/2}{n\,2r \sin \alpha/2}$$

$$\Rightarrow \boxed{K_d = \frac{\sin \frac{n\alpha}{2}}{n \sin \frac{\alpha}{2}}}$$

$$\boxed{\alpha = \frac{180°}{\text{No. of slots/pole}}}$$

Question : 1 Date - 22.08.20

Calculate the distribution factor for a 36 slots 4 pole single layer, 3-ϕ winding.

Ans : Given data :-

$S = 36$

$P = 4$

Pole pitch = $36/4 = 9$

No. of slots per pole per phase = $9/3 = 3$

9 slots = 180°

$\Rightarrow 1 \text{ slot} = \frac{180°}{9} = 20°$

$\alpha = 20°$

$n\alpha = 3 \times 20° = 60°$

$$K_d = \frac{\sin n\alpha/2}{n \sin \alpha/2} = \frac{\sin 60/2}{3 \sin 20/2}$$

$$= \frac{\sin 30°}{3 \sin 10°} = \frac{1/2}{3 \sin 10°}$$

$\boxed{K_d = 0.959}$

Date - 23.08.20

Q.3 A part of an alternator winding consists of 6 coils in series. Each coil having an emf of 10V rms induced in it. The coils are placed in successive slots, and between each slot and the next there is an electrically phase shift of 30°. Find the emf of the 6 coils in series.

Ans: Given data :-

$E = 10V$ rms

$\alpha = 30^\circ$, $K_d = \frac{\sin \frac{n\alpha}{2}}{n \sin \alpha/2}$

$\Rightarrow K_d = \frac{\sin \frac{6\times 30}{2}}{6 \sin \frac{30}{2}} = \frac{\sin 90^\circ}{6 \sin 15^\circ}$

$= 0.643$

$K_d = \frac{\text{Vector sum of induced emf per phase}}{\text{Arithmatic sum of induced emf per phase}}$

Arithmatic sum of induced emf/ph $= 6\times 10 = 60V$

$\Rightarrow$ Vector sum of induced emf per phase $= 0.64 \times 60$

$= 38.58 V/ph$

$\therefore$ Emf of the 6 coils in series $= 38.58 V/ph$

Q.4 Find the value of K_d for an alternator with 9 slot per pole for the following cases.

i) 1 winding in all the slots,

ii) 1 winding using only the 1st 2/3 of slots,

iii) 3 equal winding placed sequentially in 60° group.

Ans: Given data :

Pole pitch = 9

9 Slots = 180°

$\beta = \frac{180^\circ}{9} = 20^\circ$

i) $S = 9$, $n = 9$

9 slots = 180°

$\beta = \frac{180^\circ}{9} = 20^\circ$, $K_d = \frac{\sin \frac{n\beta}{2}}{n \sin \frac{\beta}{2}}$

$$K_d = \frac{\sin \frac{9 \times 20}{2}}{9 \sin \frac{20}{2}}$$

$= 0.639$

$\therefore$ $K_d = 0.639$

ii) $S = 9$

$n = \frac{2}{3}$ of $9 = \frac{2}{3} \times 9 = 2 \times 3 = 6$

$n = 6$

$\beta = 20^\circ$, $K_d = \frac{\sin \frac{n\beta}{2}}{n \sin \beta/2}$

$$K_d = \frac{\sin \frac{6 \times 20}{2}}{6 \sin \frac{20}{2}} = 0.831$$

$\therefore$ $K_d = 0.831$

iii) $180^\circ \rightarrow 9$ slots

$1^\circ \rightarrow \frac{9}{180}$ slots

$60^\circ \rightarrow \frac{9}{180} \times 60$ slots $= 3 = n$

$\beta = 20^\circ$

$$K_d = \frac{\sin \frac{3 \times 20}{2}}{3 \sin \frac{20}{2}} = 0.95$$

$\therefore$ $K_d = 0.95$

Q.5 Calculate the distribution factor for a single phase alternator having 6 slots per pole.

i) When all slots are wound.

ii) When only four adjacent slots per pole are wound and the remaining slots being unwound.

Ans:- Given data :-

i) $S = 6$

$n = 6$

6 slots ⟶ 180°

1 slot ⟶ $\frac{180^\circ}{6} = 30^\circ$

$\therefore \beta = 30^\circ$

When all slots are wound,

$$K_d = \frac{\sin \frac{n\beta}{2}}{n \sin \frac{\beta}{2}} = \frac{\sin \frac{6 \times 30}{2}}{6 \sin \frac{30}{2}}$$

$$= \frac{\sin 90^\circ}{6 \sin 15^\circ}$$

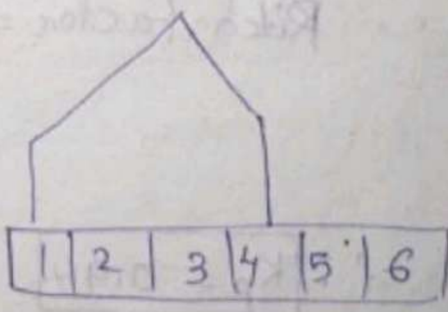
$$= 0.644$$

$\therefore \boxed{K_d = 0.644}$

ii) $S = 6$

$n = 4$

$\beta = 30^\circ$



$$K_d = \frac{\sin \frac{n\beta}{2}}{n \sin \frac{\beta}{2}} = \frac{\sin \frac{4 \times 30}{2}}{4 \sin \frac{30}{2}}$$

$$= \frac{\sin 60^\circ}{4 \sin 15^\circ} = 0.836$$

$\therefore \boxed{K_d = 0.836}$

Q.6 The stator of a 3-ϕ alternator has 9 slots per pole and carries a balanced three-phase, double layer winding. The coils are short-pitched and the coil-pitch is 7 slots. Find the distribution factor and pitch factor.

Ans:- Given data :-

$$\beta = \frac{180^\circ}{\text{No. of slots/pole}}$$

$$= \frac{180^\circ}{9} = 20^\circ$$

n = No. of slots/Pole/phase

$$= 9/3 = 3$$

Pitch factor $= K_p = \cos\frac{\alpha}{2}$

α = short-pitch angle

The coil is short pitched by 2 slots.

$$\alpha = \frac{2}{9} \times 180^\circ$$

$$= 40^\circ$$

$\therefore$ Pitch factor $= K_p = \cos\frac{\alpha}{2}$

$$= \cos\frac{40}{2} = \cos 20^\circ$$

$$= 0.94$$

$\therefore$ $\boxed{K_p = 0.94}$

$\beta = 20^\circ$

$\therefore$ Distribution factor $= K_d = \dfrac{\sin\frac{n\beta}{2}}{n\sin\frac{\beta}{2}}$

$$= \frac{\sin\frac{3\times 20}{2}}{3\sin\frac{20}{2}} = 0.95$$

$\therefore$ $\boxed{K_d = 0.95}$

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* E.M.F. EQU...

Let, Z = No. of ... per p...

ϕ = Flu...

P = No...

N = Rot...

In one revoluti... conductor is cut ...

$d\phi$ = ...

$\therefore$ Average emf ...

= d.../d...

Since there ar...

$\therefore$ Average e.m.f ...

R.M.S. value of ...

$\therefore$ E_{rms}/ph...

If K_p and K_d are ... factor of the a...

E_{rms}/pha...

sometimes the t... conductors per p...

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$$= \cos\frac{40}{2} = \cos 20^\circ$$

$$= 0.94$$

$\therefore$ $\boxed{K_p = 0.94}$

$\beta = 20^\circ$

$\therefore$ Distribution factor $= K_d = \dfrac{\sin\frac{n\beta}{2}}{n\sin\frac{\beta}{2}}$

$$= \frac{\sin\frac{3\times 20}{2}}{3\sin\frac{20}{2}} = 0.95$$

$\therefore$ $\boxed{K_d = 0.95}$

Date- 24.08.20

* E.M.F. EQUATION OF AN ALTERNATOR :-

Let, Z = No. of conductors or coil sides in series per phase.

ϕ = Flux per pole in webers

P = Number of rotor poles

N = Rotor speed in r.p.m

In one revolution (i.e., 60/N second), each stator conductor is cut by $P\phi$ webers i.e.,

$$d\phi = P\phi \; ; \; dt = 60/N$$

∴ Average emf induced in one stator conductor

$$= \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

Since there are Z conductors in series per phase,

∴ Average e.m.f / phase $= \frac{P\phi N}{60} \times Z$

$$= \frac{P\phi Z}{60} \times N$$

$$= \frac{P\phi Z}{60} \times \frac{120f}{P} \quad \left(\because N = \frac{120f}{P}\right)$$

R.M.S. value of e.m.f/phase = Average value/phase × Form factor

$$= 2f\phi Z \times 1.11$$

$$= 2.22 f\phi Z \text{ volts}$$

∴ E_{rms} / phase = $2.22 f\phi Z$ volts --- (i)

If K_p and K_d are the pitch factor and distribution factor of the armature winding, then

E_{rms}/phase = $2.22 K_p K_d f\phi Z$ volts — (ii)

sometimes the turns (T) per phase rather than conductors per phase are specified.

Then eqⁿ (ii) becomes :

$$E_{rms}/\text{phase} = 4.44\, K_p K_d f \phi T \text{ volts}$$

The line voltage will depend upon whether the winding is star or delta connected.

Q.1 A 3-ϕ, 16 pole alternator has a star connected winding with 144 slots and takes 10 conductors per slot. The flux per pole is 0.03 weber, sinusoidally distributed and the speed is 375 rpm. Find the frequency and phase voltage and line voltage. Assume full pitch coil.

Ans:- Given data :-

$P = 16$

$S = 144$

$\phi = 0.03$ wb

$N = 375$ rpm

$n = \frac{144}{16 \times 3}$ slots/pole/phase

$= \frac{144/16}{3} = 3$

$K_p = \cos\frac{\alpha}{2} = 1$ (∵ Full pitch)

$\beta = \frac{180°}{\text{slots/pole}} = \frac{180°}{144/16}$

$= 20°$

$K_d = \frac{\sin\frac{n\beta}{2}}{n\sin\frac{\beta}{2}} = \frac{\sin 3\times 20/2}{3\sin 20/2}$

$= \frac{\sin 30°}{3\sin 10°} = 0.96$

Conductor/slot/Ph $= Z = \frac{144 \times 10}{3} = \frac{1440}{3} = 480$

Frequency $(f) = \frac{N_s P}{120} = \frac{375 \times 16}{120} = 50$ Hz

$\therefore$ Emf/ph $= 2.22 \times K_p \times K_d \times f \phi Z$

$= 2.22 \times 1 \times 0.96 \times 50 \times 0.03 \times 480$

$= 1518.48V$ (Ans)

Line voltage $= E_L = \sqrt{3} \times E_{ph}$

$= \sqrt{3} \times 1518.48$

$= 2630.08$ V (Ans)

Q.2 Find the no-load phase and line voltage of a star connected 3-ϕ, 6 pole alternator which runs at 1200 rpm, having flux per pole of 0.1 wb. sinosoidally distributed. It's stator has 54 slots having double layer winding each coil has 8 turns and the coil is chorded by 1 slot.

Ans:- Given data :-

$P = 6$

$N = 1200$ rpm

$\phi = 0.1$ wb

$S = 54$

Each coil has 8 turns.

coil is chorded by 1 slot ($\because$ coil start from 1 to 9)

pole pitch $= \frac{54}{6} = 9$

$9 \rightarrow 180°$

$1 \rightarrow \frac{180}{9} = 20°$

$\alpha = 20°$

$K_p = \cos\frac{\alpha}{2} = \cos\frac{20}{2} = \cos 10° = 0.98$

$n = \text{Slots/pole/phase} = \frac{9}{3} = 3$

Z = slots × No. of turns $Z_{ph} = 144$

$= 54 \times 8 = 432$

$T = \frac{432}{2} = 216$, $T_{ph} = \frac{216}{3} = 72$

$f = \frac{PN}{120} = \frac{6 \times 1200}{120}$

$= 60\ Hz$

$\beta = \frac{180^\circ}{\text{slots/pole}} = \frac{180^\circ}{54/6}$

$= \frac{180 \times 6}{54} = 20^\circ$

$K_d = \frac{\sin \frac{n\beta}{2}}{n \sin \frac{\beta}{2}} = \frac{\sin \frac{3 \times 20}{2}}{3 \sin \frac{20}{2}}$

$= 0.96$

$\therefore Emf/_{ph} = 4.44 \times K_p \times K_d \times \phi \times f \times Z$

$= 4.44 \times 0.98 \times 0.96 \times 0.1 \times 60 \times 144$

$= 1804.52 V$

$\therefore$ No load phase voltage $= E_{ph} = 1804.52V$

Line voltage $= V_L = \sqrt{3} \times E_{ph}$

$= \sqrt{3} \times 1804.52$

$= 3125.52\ V$

$\therefore V_L = 3125.52\ V$

Date-25.08.20

* EFFECT OF HARMONICS ON PITCH FACTOR AND DISTRIBUTION FACTOR :-

If the short pitch angle (chording angle) is α° for the fundamental flux wave, then it's value for difference harmonics are for 3rd order harmonic $= 3\alpha$ for 5th order harmonic $= 5\alpha$ and so on.

$K_p = \cos \frac{\alpha}{2}$ for fundamental harmonics.

$K_p = \cos \frac{3\alpha}{2}$ for 3rd order harmonic.

$K_p = \cos \frac{5\alpha}{2}$ for 5th order harmonic.

Similarly, the distribution factor is also different for different harmonic. It's value become

$$K_d = \frac{\sin M\left(\frac{n\alpha}{2}\right)}{n \sin \frac{M\alpha}{2}}$$

where, M is the order of harmonics.

For fundamental harmonic, M = 1.

$$\therefore K_d = \frac{\sin \frac{n\alpha}{2}}{n \sin \frac{\alpha}{2}}$$

For 3rd order harmonic

$$K_d = \frac{\sin \frac{3n\alpha}{2}}{n \sin \frac{3\alpha}{2}}$$

For M = 5, $K_d = \frac{\sin \frac{5n\alpha}{2}}{n \sin \frac{5\alpha}{2}}$

Question

An alternator has 18 slots per pole and the 1st coil lies in slot 1 and 16. Calculate the pitch factor for fundamental, 3rd order and 5th order harmonics.

Ans:- Given data :-

Pole pitch = 18

coil span = 1 to 16

Full pitch = 18 + 1 = 19

Short pitch by, 19 − 16 = 3 slots.

$$\alpha = \frac{3}{18} \times 180$$

$$= 30^\circ$$

i) $K_{p1} = \cos \frac{\alpha}{2} = \cos \frac{30}{2} = 0.96$

ii) $K_p = \cos \frac{3\alpha}{2} = \cos \frac{3 \times 30}{2} = \cos 45^\circ = 0.707$

iii) $K_p = \cos\frac{5\alpha}{2} = \cos\frac{5\times30}{2} = \cos 75^\circ = 0.25$

iv) $K_p = \cos\frac{7\alpha}{2} = \cos\frac{7\times30}{2} = \cos 105^\circ = 0.259$

* ALTERNATOR ON LOAD :-

As the load of an alternator is varied it's terminal voltage is also found to vary. The variation of terminal voltage (V) is due to following reason.

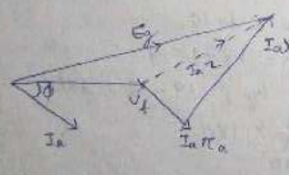
i) Voltage drop due to armature resistance.
ii) Voltage drop due to leakage reactance.
iii) Voltage drop due to armature reaction.

Armature Resistance :-

The armature resistance per phase r_a causes a voltage drop per phase of I_aR_a which is in phase with the armature current 'I' practically this voltage is negligible.

Armature Leakage reactance :-

When current flows through armature conductors flux are set up which do not cross the air gap but take different path. Such fluxes are called leakage flux and the reactance due to that flux is called leakage reactance.



Date - 26.08.20

* ARMATURE REACTION IN AN ALTERNATOR FOR UNITY POWER FACTOR :-

Ans :-

-> The effect of Armature (stator) flux on the flux produced by the rotor field poles is called Armature Reaction.

-> When the current flows through the armature winding of the an alternator, a flux is produced by the resulting MMF. This armature flux reacts with the main pole flux, causing the resultant flux to become either less than or more than the original main field flux.

-> For simplicity, we consider a 3 phase, 2 pole alternator shown in the figure below.

-> The winding of each pole is assumed to be concentrated, but the effects of armature reaction will be same as if a distributed winding were also used. The armature reaction in an alternator affects the main field flux and vary differently for different power factors.

-> Here armature reaction is discussed for following three conditions, namely unity power factor, zero power factor lagging and zero power factor leading. The power factor can be defined as the cosine angle betn the armature phase current & the induced EMF in the armature conductor.