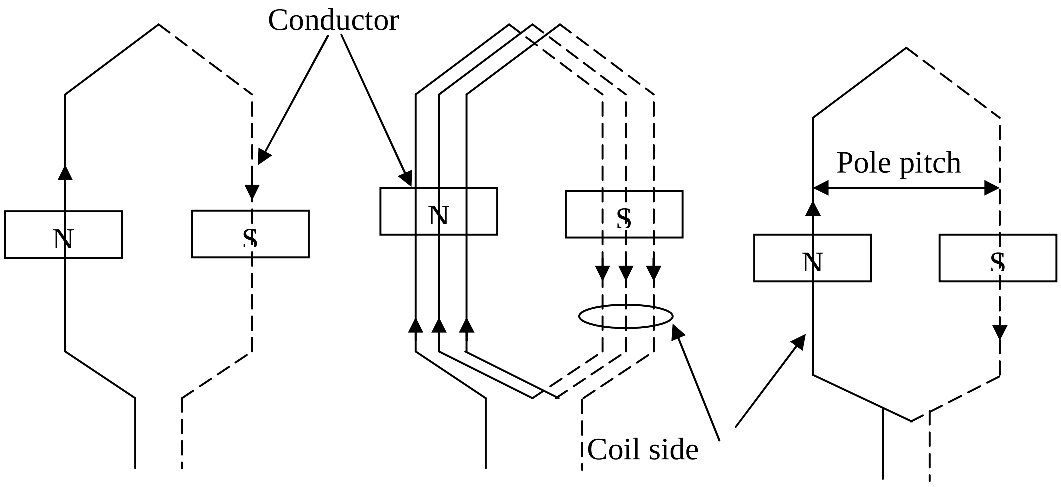
COMPUTER AIDED ELECTRICAL DRAWING (CAED) 10EE65

Winding Diagrams: (i) DC Winding diagrams (ii) AC Winding Diagrams

Terminologies used in winding diagrams:
Conductor: An individual piece of wire placed in the slots in the machine in the magnetic field.

Turn: Two conductors connected in series and separated from each other by a pole pitch so that the emf induced will be additive.

Coil: When one or more turns are connected in series and placed in almost similar magnetic positions. Coils may be single turn or multi turn coils.



(a) Single turn Coil (b) 3 – turn coil (c) Multi turn coil

Fig. 1 Different types of winding coils representations

Coil group: One or more coil single coils formed in a group forms the coil group.

Winding: Number of coils arranged in coil group is said to be a winding.

Pole Pitch: Distance between the poles in terms of slots is called pole pitch.

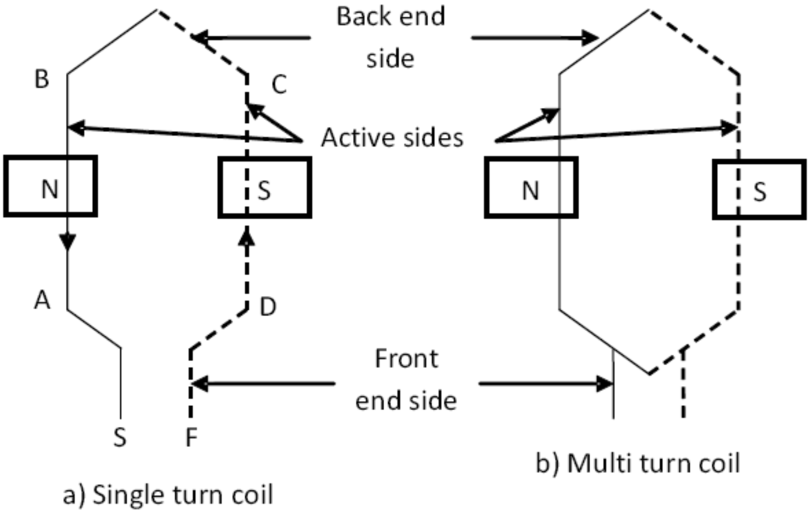


Fig. 2 Single and Multi turn coils

Full Pitch winding: If the coil pitch for a winding is equal to pole pitch the winding is called full pitch winding Fig .
Chorded winding: When the pitch of the winding is less than the full pitch or pole pitch then the winding is called short pitch winding or chorded winding.

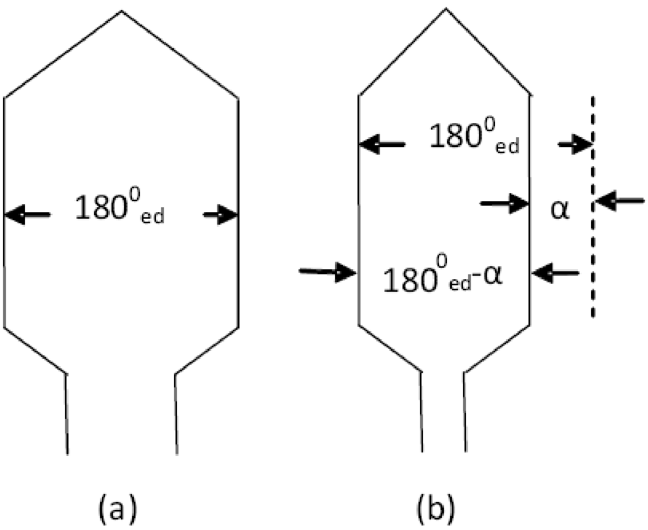


Fig. 3 Full pitched and short pitched coils

Single layer winding: Only one coil side placed in one slot.

Double layer winding: Two coil sides are placed in a single slot. Single and double layer windings are shown in Fig 4

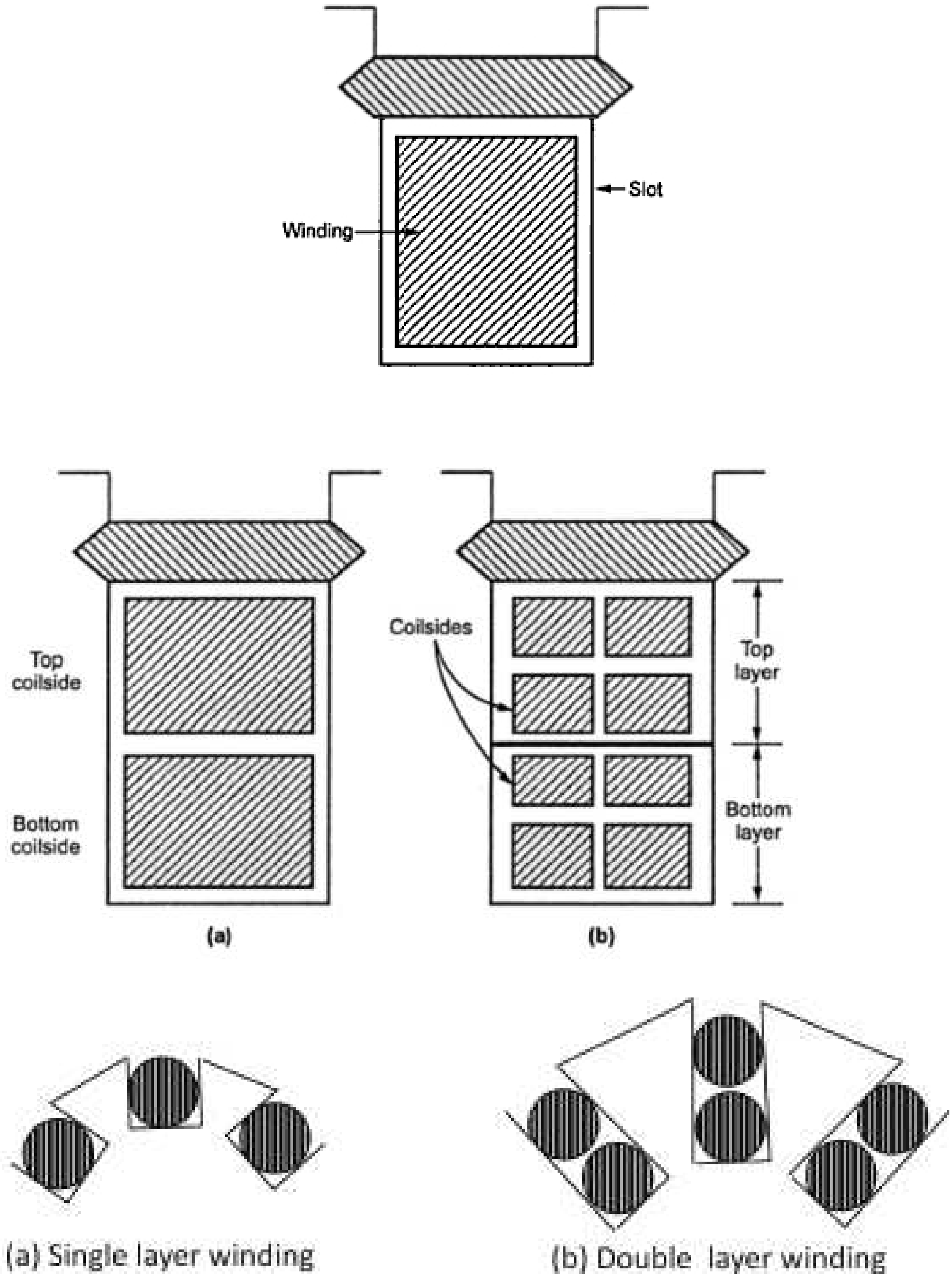


Fig.4 Single and double layer windings

Classification of windings: Closed type and open type winding

Closed type windings: In this type of winding there is a closed path around the armature or stator. Starting from any point, the winding path can be followed through all the turns and starting point can be reached. Such windings are used in DC machines.

Open windings: There is no closed path in the windings. Such windings are used in AC machines.

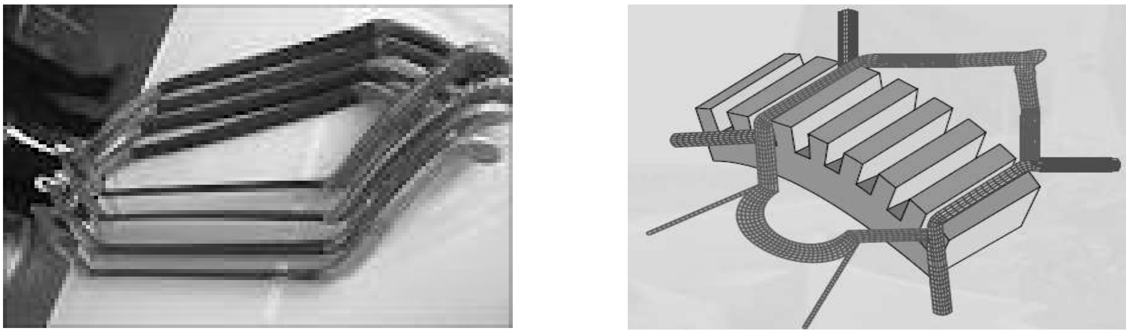


Fig. 5 Photographs of the windings and coils

DC Windings: Two types of windings (a) Lap winding (b) Wave winding
These two types of windings differ in two ways (i) number of circuits between positive and negative brushes, (ii) the manner in which the coil ends are connected. However the coils of both lap and wave windings are identically formed.

TYPES AND SHAPES OF WINDING WIRES: The winding wires used in electrical motors are classified as follows. 1) Round wires 2) Rectangular straps 3) Stranded wires
1. Round Wires: It has thin and thick conductors and are used in semi-closed slot type motors and mush winding rotors. It is wounded in reels and available in Kilograms.
2. Rectangular straps: It is used in open type slot motors. These conductors are available as long straps in meters. They are used in the following places. 1) Low voltage motor windings. 2) Used as conductor in high current motor. 3) Series field motor winding coils.

Winding Pitches:

Back Pitch: The distance between top and bottom coil sides of a coil measured around the back of the armature is called back pitch and is designated as y_b. Back pitch is approximately equal to number of coil sides per layer. Generally back pitch is an odd integer.
Front Pitch: The distance between two coil sides connected to the same commutator segment is called the front pitch and is designated as y_f.
Winding Pitch: The distance between the starts of two consecutive coils measured in terms of coil sides is called winding pitch and is designated as Y.
$Y = y_b - y_f$ for lap winding $Y = y_b + y_f$ for wave winding

Commutator pitch: The distance between the two commutator segments to which the two ends of a coil are connected is called commutator pitch and is designated as y_c and is measured in terms of commutator segments.

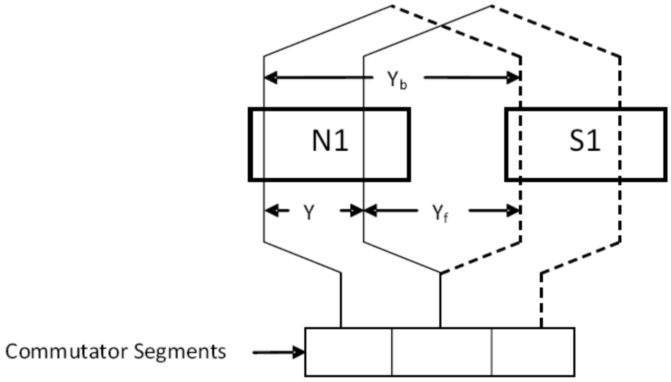


Fig. 6 Lap winding

Lap Winding: The winding in which successive coils overlap each other hence it is called lap winding. In this winding end of one coil is connected to the commutator segment and start of the adjacent coil situated under the same pole as shown in fig. 6. Lap winding is further divided as simplex and Duplex lap winding.

Simplex lap winding: In this type of winding finish F1 of the coil 1 is connected to the start S2 of coil 2 starting under the same pole as start s1 of coil 1.
We have back pitch $y_b = 2c/p \pm k$ where c = number of coils in the armature, p = number of poles, k = an integer to make y_b an odd integer.

Important rules for Lap winding:
Let Z = Number of conductors
P = number of poles
Y_b = Back pitch
Y_f = Front pitch
Y_c = Commutator pitch
Y_a = Average pole pitch
Y_p = Pole pitch
Y_R = Resultant pitch

1. Y_b (Back pitch) and Y_f (Front pitch) must be approximately equal to Y_p (Pole pitch)
2. Y_b (Back pitch) must be less or greater than Y_f (Front pitch) by 2m where m is the multiplicity of the winding. When Y_b is greater than Y_f the winding progresses from left to right and is known as progressive winding. . When Y_b is lesser than Y_f the winding progresses from right to left and is known as retrogressive winding. Hence $Y_b = Y_f \pm 2m$.
3. Y_b and Y_f must be odd.
4. Y_b and Y_f may be equal or differ by ±2. + for progressive winding, - for retrogressive winding
5. $Y_a = (Y_b + Y_f) / 2 = Y_p$
6. Y_R (Resultant pitch) is always even.
7. $Y_c = m$, m = 1 for simplex winding; m = 2 for duplex winding

8. Number of parallel paths = mp = number of brushes.

Simplex wave winding: In this type of winding finish F1 of the coil 1 is connected to the start Sx of coil x starting under the same pole as start s1 of coil 1.

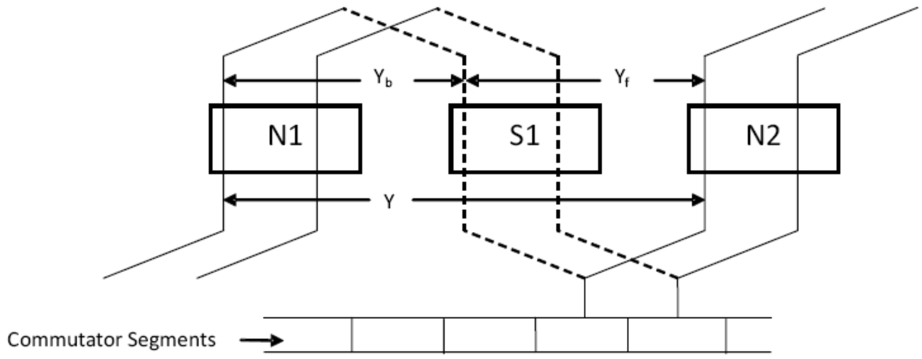


Fig. 7 wave windings

Wave winding: In wave winding the end of one coil is not connected to the beginning of the same coil but is connected to the beginning of another coil of the same polarity as that of the first coil as shown in fig. 7. Important rules for Wave winding:

1. Y_b (Back pitch) and Y_f (Front pitch) must be approximately equal to Y_p (Pole pitch)
2. Y_b and Y_f must be odd.
3. Y_b and Y_f may be equal or differ by ±2. + for progressive winding, - for retrogressive winding
4. $Y_c = (Y_b + Y_f) / 2$ and should be a whole number.

Dummy coils: The wave winding is possible only with particular number of conductors and poles and slots combinations. Some times the standard stampings do not consist of the number of slots according to the design requirements and hence the slots and conductor combination will not produce a mechanically balanced winding. Under such conditions some coils are placed in the slots, not connected to the remaining part of the winding but only for mechanical balance. Such windings are called dummy coils.

Equalizer rings or Equalizer connections in Lap winding: This is the thick copper conductor connecting the equipotential points of lap winding for equalizing the potential of different parallel paths.
Sequence diagram or ring Diagram: The diagram obtained by connecting the conductors together with their respective numbers. This diagram is used for finding the direction of induced emf and the position of brushes.
Ex.1 Draw the winding diagram of a D C Machine with 4 poles, 14 slots, progressive, double layer lap winding. Show the position of brushes and direction of induced emf.
Soln: Number of poles = 4 ; Number of slots = 14, Number of conductors = 14 x 2 = 28
Pole pitch = Number of conductors/pole = 28/4 = 7
We have pole pitch = $(Y_b + Y_f) / 2 = Y_p$
Hence

$(Y_b + Y_f) = 14$
$(Y_b - Y_f) = 2$
Solving above equations $Y_b = 8$ and $Yf = 6$
back pitch $y_b = 2c/p \pm k$
For lap winding both Y_b and Y_f must be odd and differ by 2
Satisfying the above condition $Y_b = 7$ and $Y_f = 5$ (Winding diagram and ring diagrams are shown below)

Winding Table:

At the back $Y_b = 7$ coil side → connected to coil side	At the front $Y_f = 5$ coil side → connected to coil side	At the back $Y_b = 7$ coil side → connected to coil side	At the front $Y_f = 5$ coil side → connected to coil side
1+7 = 8 3+7 = 10 5+7 = 12 7+7 = 14 9+7 = 16 11+7 = 18 13+7 = 20 15+7 = 22	8 – 5 = 3 10 – 5 = 5 12 – 5 = 7 14 – 5 = 9 16 – 5 = 11 18 – 5 = 13 20 – 5 = 15 22 – 5 = 17	17 +7 = 24 19+7 = 26 21+7 = 28 23+7 = 30 (2) 25+7 = 32 (4) 27+7 = 34 (6)	24 – 5 = 19 26 – 5 = 21 28 – 5 = 23 30 – 5 = 25 32 – 5 = 27 34– 5 = 29 (1)

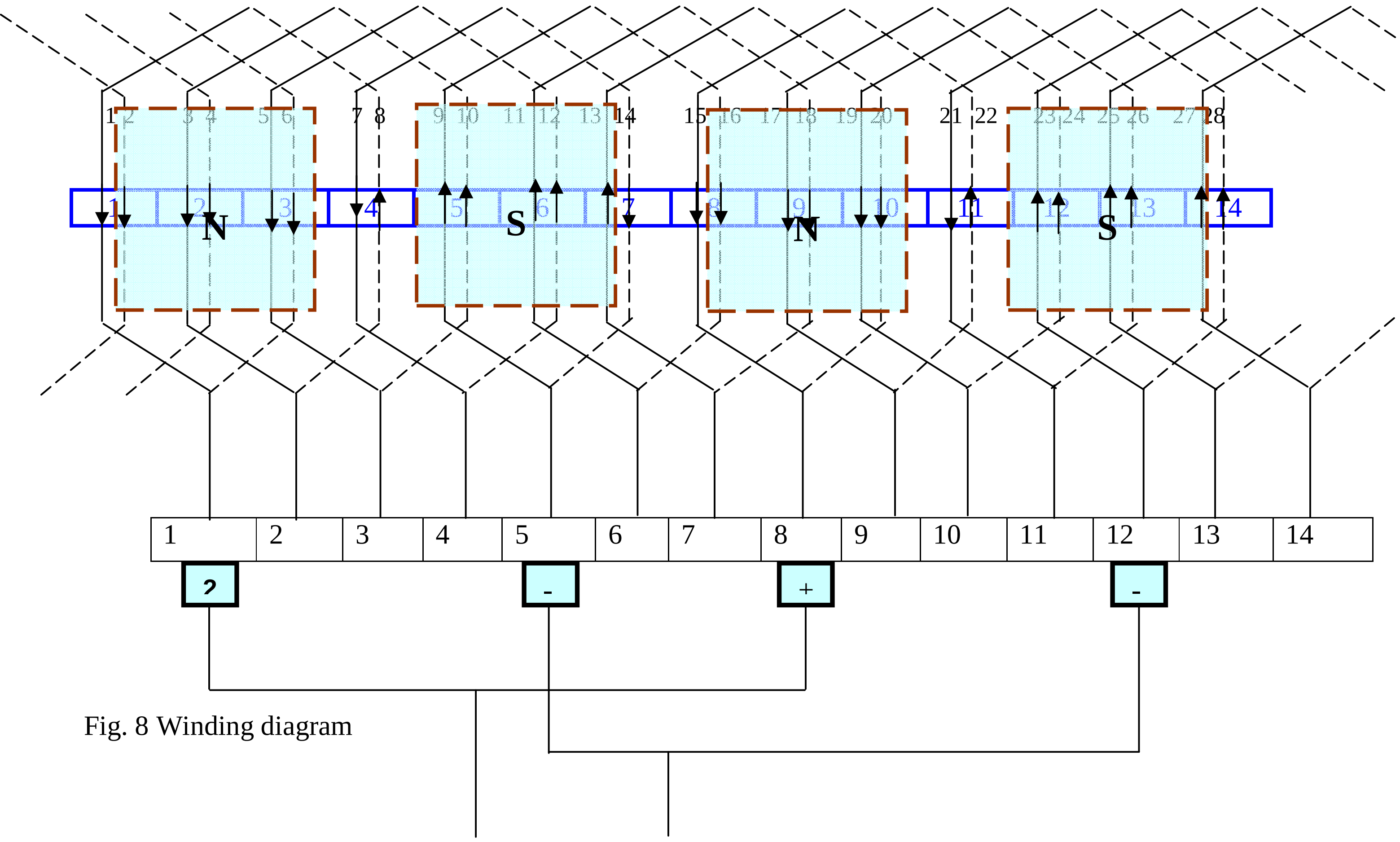


Fig. 8 Winding diagram

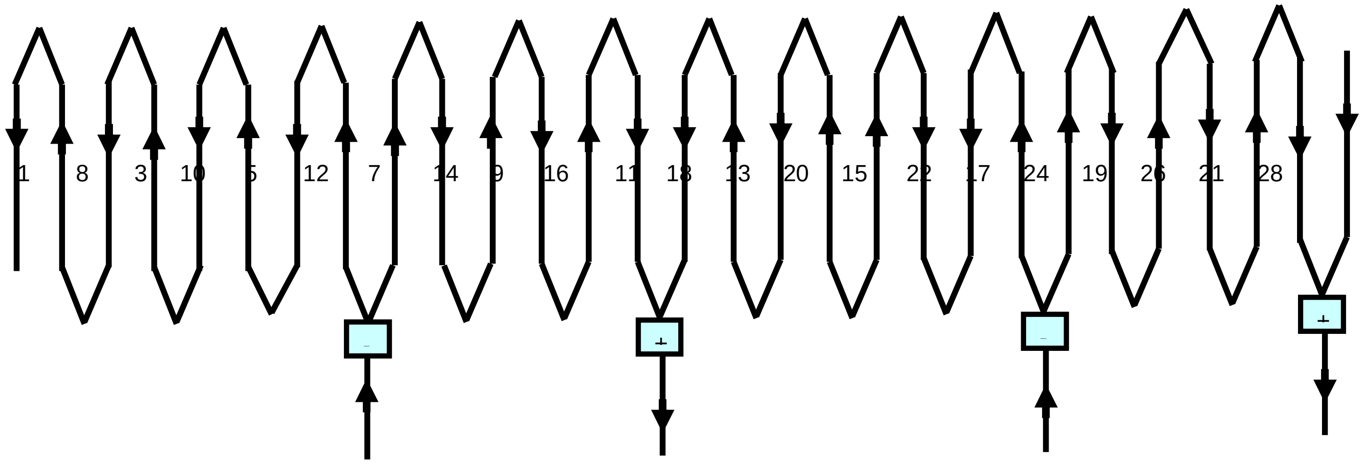


Fig. 9 Ring diagram

Ex. 2 Develop the single layer winding for a D C machine having 32 armature conductors and 4 poles. Mark the poles Draw the sequence diagram, indicate the position of the brushes and the direction of induced emf and show the equiliser connections.

Soln: Number of conductors = 32 Pole pitch = 32/4 = 8;
pole pitch = $(Y_b + Y_f) / 2 = Y_p$
Hence
$(Y_b + Y_f) = 16$ and $(Y_b - Y_f) = 2$ hence $Y_b = 9$ and $Y_f = 7$

(Winding diagram and ring diagrams are shown below)

Winding Table:

At the back $Y_b = 9$ coil side → connected to coil side	At the front $Y_f = 7$ coil side → connected to coil side	At the back $Y_b = 9$ coil side → connected to coil side	At the front $Y_f = 7$ coil side → connected to coil side
1+9 = 10	10 – 7 = 3	17 + 9 = 26	26 – 7 = 19
3+9 = 12	12 – 7 = 5	19 + 9 = 28	28 – 7 = 21
5+9 = 14	14 – 7 = 7	21 + 9 = 30	30 – 7 = 23
7+9 = 16	16 – 7 = 9	23 + 9 = 32	32 – 7 = 25
9+9 = 18	18 – 7 = 11	25 + 9 = 34(2)	34 – 7 = 27
11+9 = 20	20 – 7 = 13	27 + 9 = 36 (4)	36 – 7 = 29
13+9 = 22	22 – 7 = 15	29 + 9 = 38(6)	38 – 7 = 31
15+9 = 24	24 – 7 = 17	31 + 9 = 40(8)	40 – 7 = 33(1)

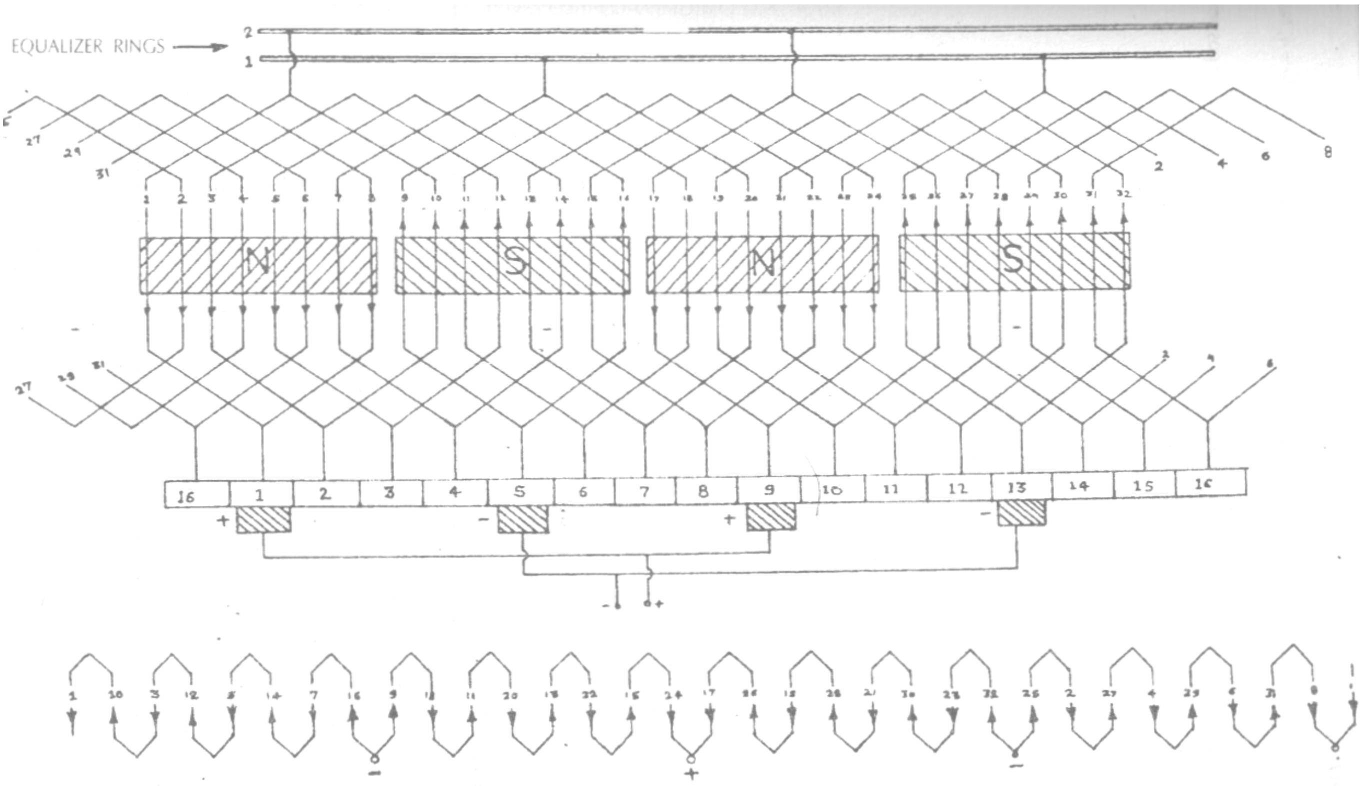


Fig. 10 Winding diagram and Ring Diagram

Ex 5. Develop a wave winding diagram for a DC machine having 34 armature conductors accommodated in 17 slots and 4 poles. Draw the sequence diagram indicate the position of the brushes, show the direction of induced emf.

Soln: Number of poles = 4, slots = 17

No of conductors = 34

For wave winding $(Y_b + Y_f)/2 = (Z \pm 2)/p$

$(Y_b + Y_f)/2 = 18$

Taking $Y_b = Y_f$

$Y_b = 9$ and $Y_f = 9$

(Winding diagram and ring diagrams are shown below)

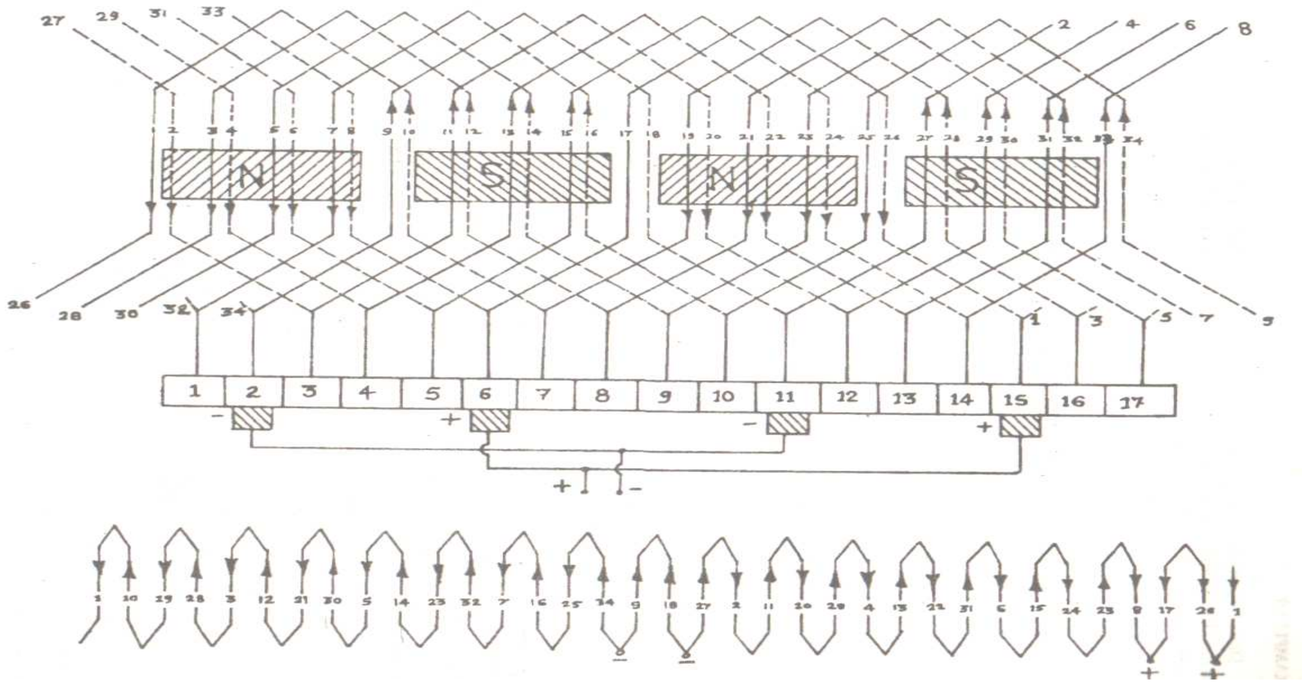


Fig. 11 Winding diagram and Ring Diagram

AC Windings:

Generally open windings except when delta connected

Classification:

Based on :

Supply: 1Φ & 3 Φ

Placing: Concentrated and Distributed

No. of layers: Single and Double layer

End connection: Lap, wave and concentric

The pitch: Full pitched and short pitched

Terms Used in AC windings:

Balanced winding: If the number of coils per pole per phase is same and a whole number then the winding is balanced winding.
Unbalanced winding: If the number of coils per pole per phase is not a whole number then the winding is balanced winding.
Slot angle: Slot angle = 180^0/ pole pitch (electrical degrees)
Full pitched winding: The pitch of the coil is equal to full pitch or equal to 180^0 then the coil is called the full pitched winding.
Short pitched winding or short chorded winding: If the pitch of the coil is less than 180^0 or less than the full pitch then the coil is called short pitched coil.
Coil span: Coil span is the distance between two coil sides measured in terms of slots.
Coil span = winding pitch/slot angle; For full pitched winding 180/slot angle

Ex.1: Draw the developed winding diagram of a 3 phase induction motor with 18 slots, 2 poles, single layer, full pitched winding with delta connection.

Soln: No. of slots per pole per phase = 18/(2 x 3) = 3
Pole pitch = no. of conductor / pole = 18/2 = 9
Slot angle = 180/ pole pitch = 180/9 = 20^0
Full pitched winding = coil span = 180
Coil span = winding pitch/slot angle = 180/20 = 9 slots

Winding Table:

Phase	1st pole	2nd pole
R	1 + 9 = 10	11+ 9 = 20 (2)
	3 + 9 = 12	
		13 + 9 = 22(4)
B	5 + 9 = 14	15 + 9 = 24 (6)
Y	7 + 9 = 16	17 + 9 = 26 (8)
	9 + 9 = 18	

Connections: Rs = 1, Ys = 1 + 120/slot angle = 1+120/20 = 7; Bs = 1 + 240/slot angle = 1+ 240/20 = 13

Winding Diagram

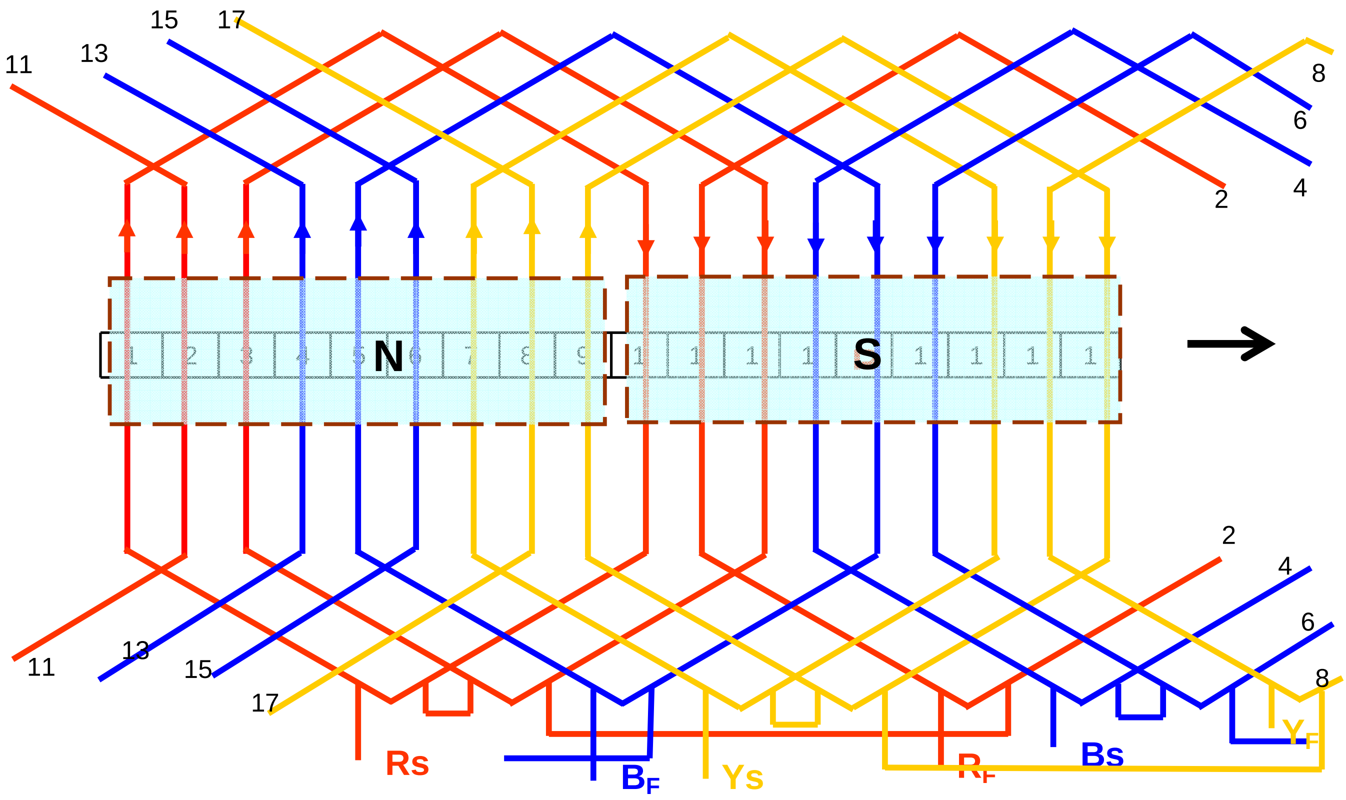


Fig. 12 Winding diagram

Ex.2. Develop the winding diagram of a 5 HP, 440 volts, 3phase 4 pole induction motor with 24 slots, double layer full pitched lap winding.

Soln: No of poles = 4, No. of slots = 24, Phases = 3

No. of slots per pole per phase = 24/(2 x 4) = 2

Pole pitch = No. of slot/pole = 24/4 = 6

Winding pitch = full pitch =180^0

Slot angle = 180/pole pitch = 180/6 = 30^0

Starting of phases: Rs = 1 (0^0)   Ys = 5 (120^0)   Bs = 9 (240^0)

Winding Diagram

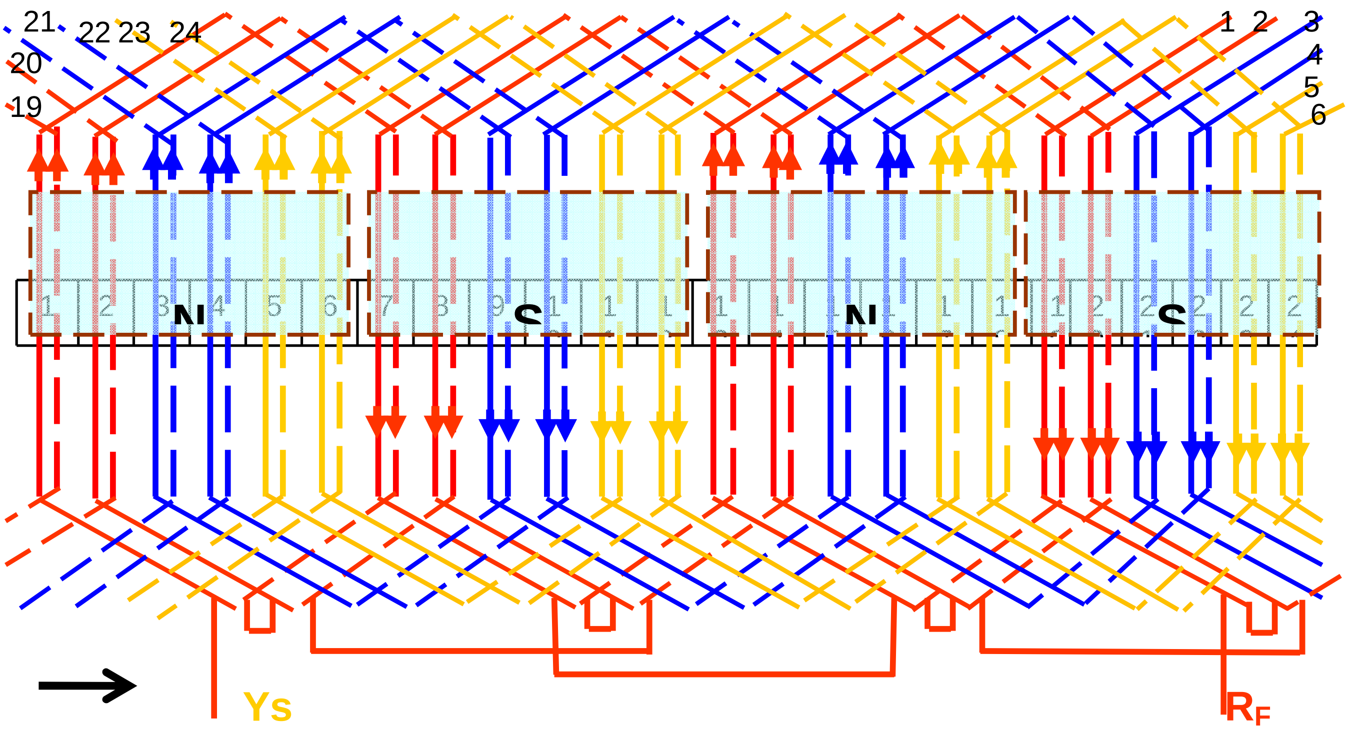


Fig. 13 Winding diagram

Ex. 3. Design and draw the developed winding diagram of an alternator with following details: No of poles = 2 no. of phases = 3, No. of slots = 24, single layer lap winding, short pitched by one slot.

Soln:

No. of poles = 2; No. of conductors = 24;

Pole pitch = 24/2 = 12; no of slots/pole /phase =24/ (2x3) = 4

No. of coils = 24/2 = 12

No of coils/pole/phase = 12/(2x3) = 2

Slot angle = 180/pole pitch = 180/12 = 15^0

Winding pitch = 180 – (slot angle x no of slots shorted) = 180 – 1 x15 = 165

Hence coil span = 165^0 = 11 slots

Connections: Rs = 1, Ys = 1 + 120/15 = 9; Bs = 1 + 240/15 = 17

Winding Table:

Phase	1st pole	2nd pole
R	1 + 11= 12	13 + 11 = 24
	3 + 11 = 14	15 + 11 = 26 (2)
B	5 + 11 = 16	17 + 11 = 4
	7 + 11 = 18	19 + 11 = 6
Y	9 + 11 = 20	21 + 11 = 8
	11 + 11 = 22	23 + 11 = 10

Winding Diagram:

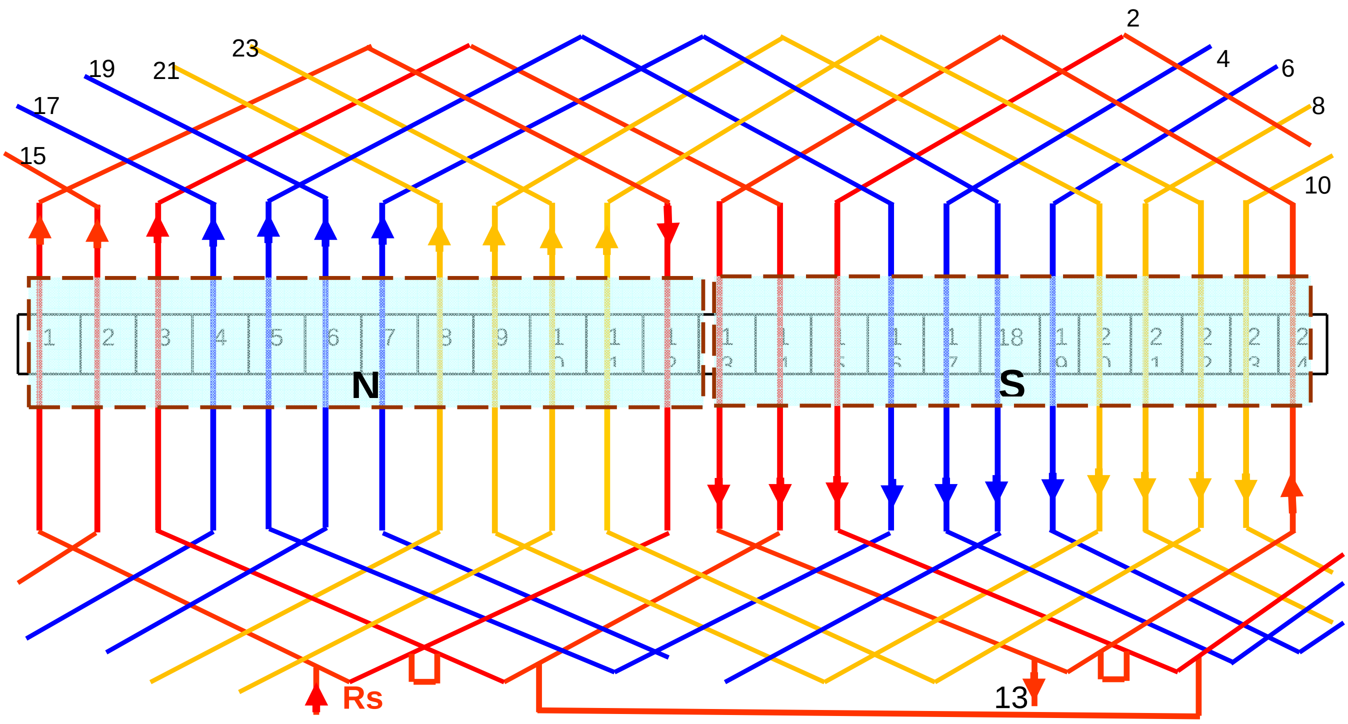


Fig. 14 Winding diagram

Ex. 4. Design and draw the developed winding diagram of an alternator with following details: No of poles = 4 no. of phases = 3, No. of slots = 24, single layer wave winding, delta connected.

Soln:

No. of poles = 4; No. of conductors = 24;

Pole pitch = 24/4 = 6; no of slots/pole /phase =24/ (4x3) = 2

No. of coils = 24/2 = 12

Slot angle = 180/pole pitch = 180/6 = 30^0

Winding pitch = 180 – (slot angle)

= 180 – 30= 150

Hence coil span = 180^0 / 30 = 6 slots

Yb = 6 and Yf = 6

Connections: Rs = 1, Ys = 1 + 120/30 = 5; Bs = 1 + 240/30 = 9

Winding Table:

Phase		
R	1 + 6 = 7	7 + 6 = 13
	13 + 6 = 19	19 + 6 = 25 (1)
	(1 + 1) + 6 = 8	8 + 6 = 14
	14 + 6 = 20	
B	9 + 6 = 15	15 + 6 = 21
	21 + 6 = 27(3)	3 + 6 = 9
	10 + 6 = 16	16 + 6 = 22
	22 + 6 = 28 (4)	
Y	5 + 6 = 11	11 + 6 = 17
	17 + 6 = 23	23 + 6 = 29 (5)
	6 + 6 = 12	12 + 6 = 18
	18 + 6 = 24	

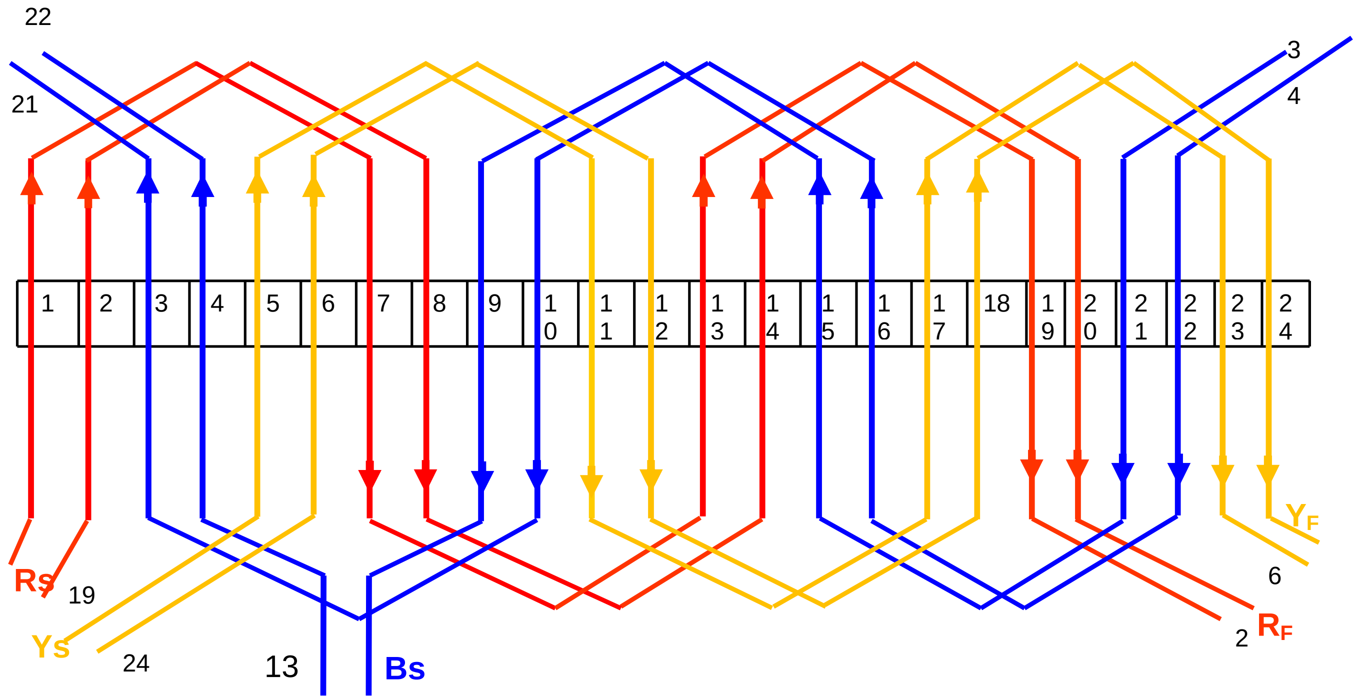


Fig. 15 Winding diagram

Ex. 5. Design and draw the developed winding diagram of an AC motor with following details: No of poles = 4 no. of phases = 3, No. of slots = 24, double layer wave winding, star connected.

Soln:

No. of poles = 4; No. of conductors = 24;

Pole pitch = 24/4 = 6; no of slots/pole /phase = 24 / (4x3) = 2

No. of coils = 24/2 = 12

Slot angle = 180/pole pitch = 180/6 = 30^0

Winding pitch = 180 – (slot angle)

= 180 – 30= 150

Hence coil span = 180^0 / 30 = 6 slots

Connections: Rs = 1, Ys = 1 + 120/30 = 5; Bs = 1 + 240/30 = 9

Yb = 13 and Yf = 11

Winding Table:

Phase

R	1 + 13 = 14	14 + 11 = 25
	25 + 13 = 38	38 + 11 = 49(1)
	2 + 13 = 15	15 +11 = 26
	26 + 11 = 37	37 + 11 = 48

B	17+ 13 = 30	30 + 11 = 41
	41 + 13 = 54 (6)	8 + 11 = 19
	19 + 13 = 32	32 + 11 = 43

43 + 13 = 56 (8)   8 + 11 = 19

Y 9 + 13 = 22   22 + 11 = 33
33 + 13 = 46   46 + 11 = 57 (9)
11 + 13 = 24   24 + 11 = 35
35 + 13 = 48   48 + 11= 59 (11)

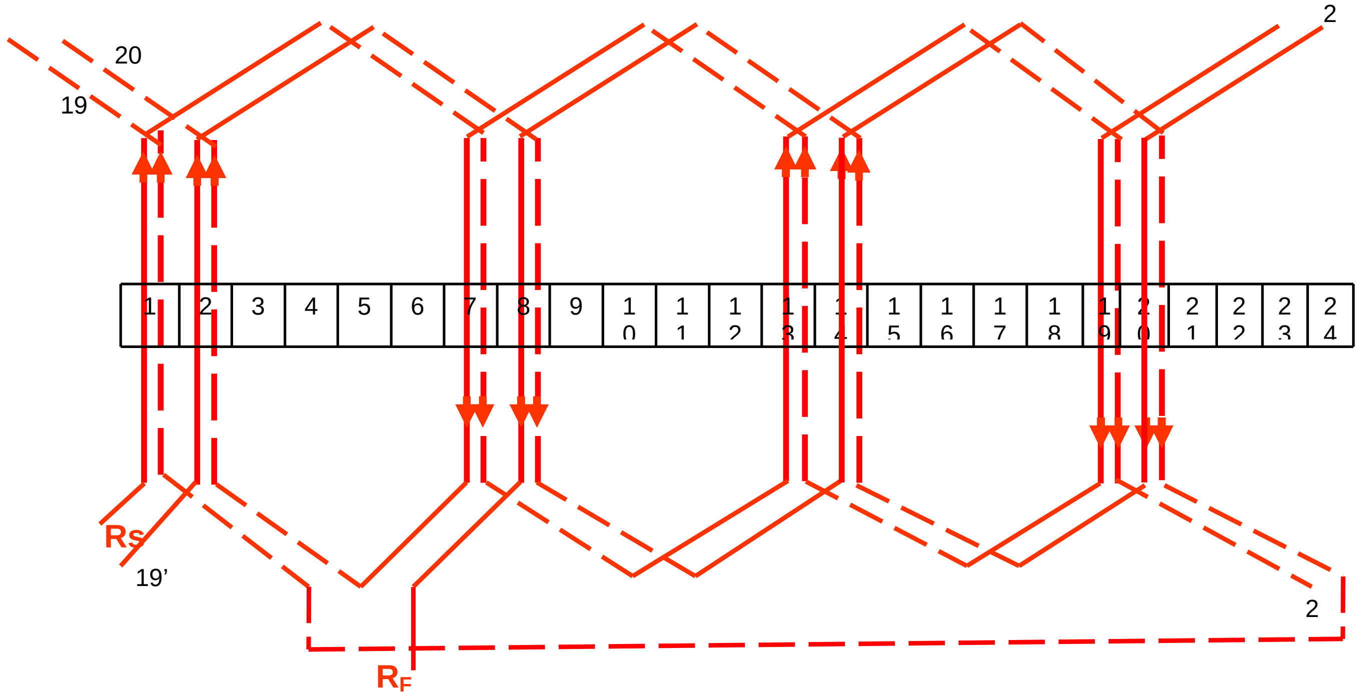


Fig. 16 Winding diagram for R phase only

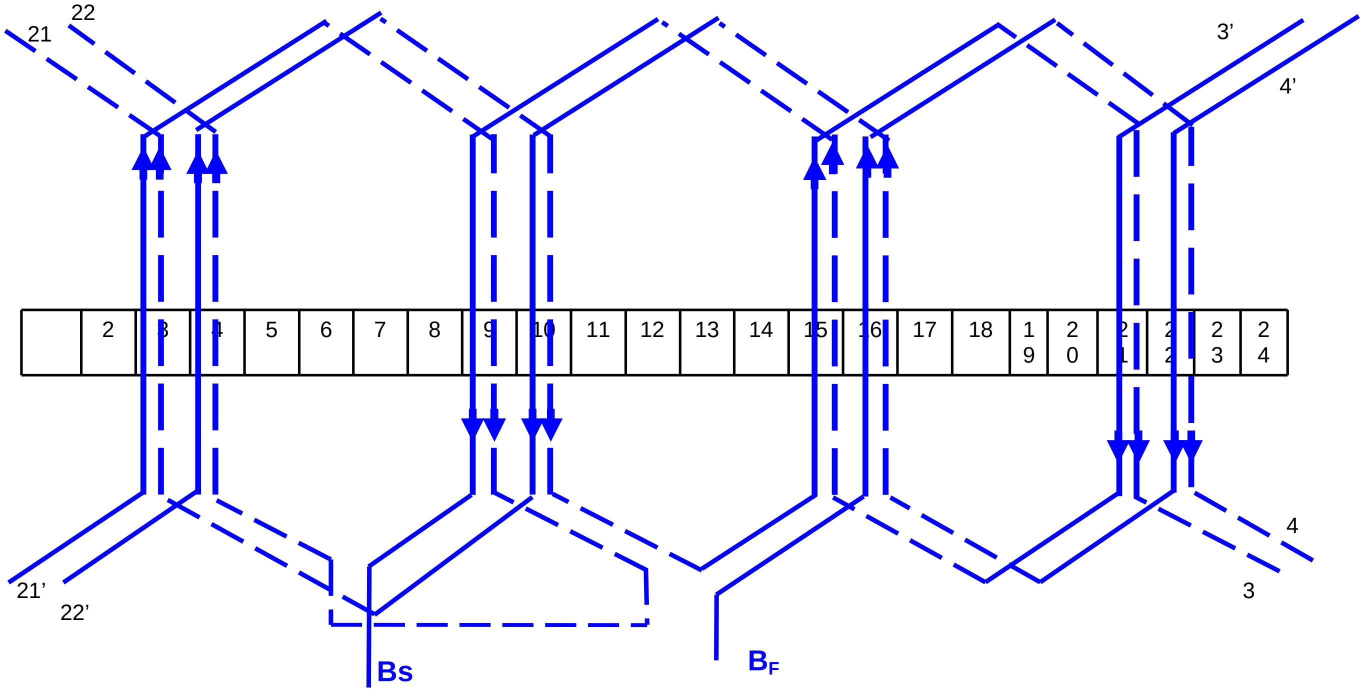


Fig. 17 Winding diagram for B phase only

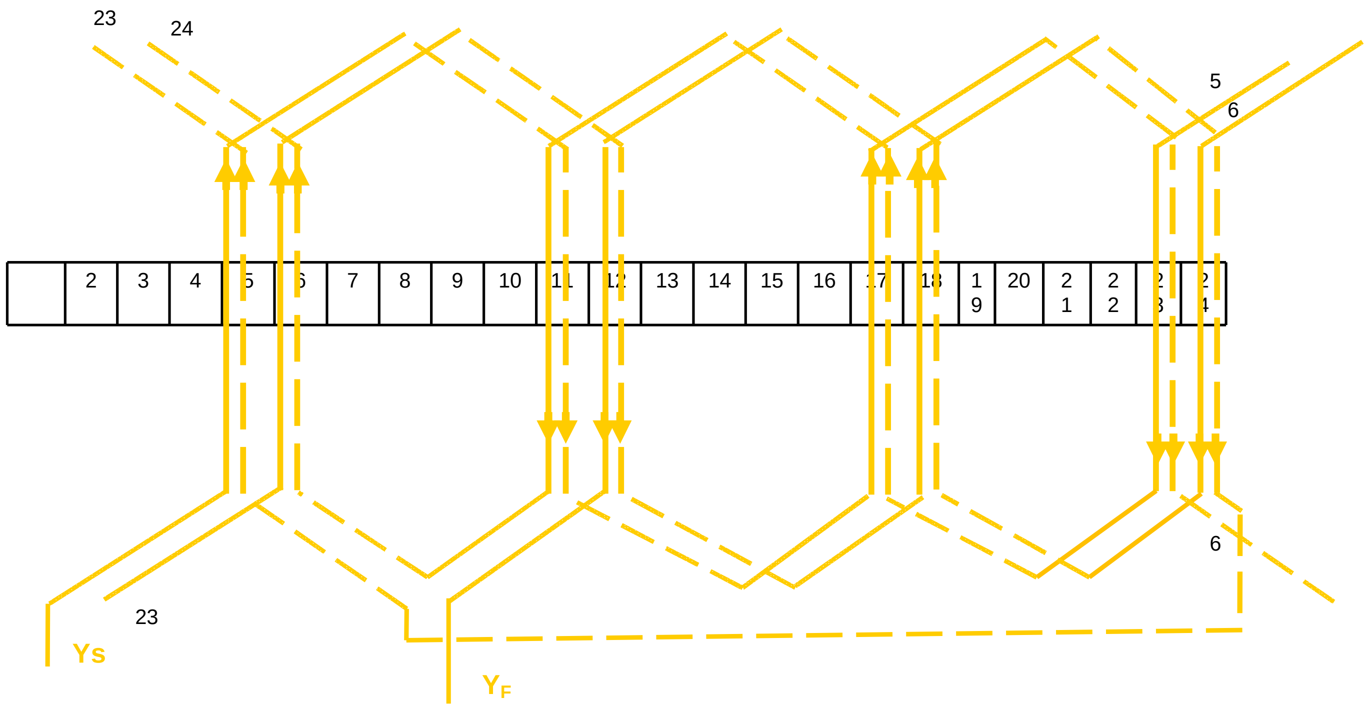


Fig. 18 Winding diagram for Y phase only

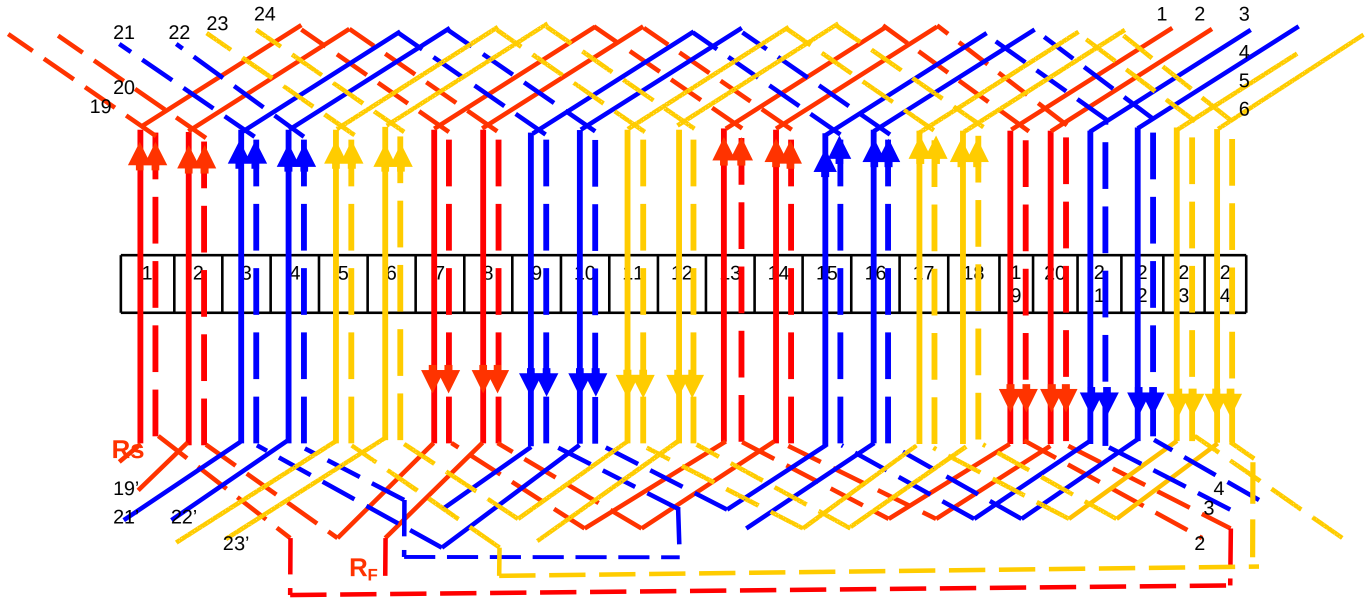


Fig. 19 Winding diagram for RYB phases

Short chorded winding or Fractional slot winding:

- Coil pitch in poly phase machines is usually less than pole-pitch and such a winding arrangement is called short pitch or chorded or fractional slot winding.
- Usually the coil pitch varies from 2/3 pole pitch to full pole pitch.
- A coil span less than 2/3 pole pitch is not used in practice. Because a chording more than 1/3 pole pitch would noticeably reduce the phase emf.
- Advantages of short pitched,(chorded, fractional slot) windings are:-
  - *The amount of copper used in the overhang (end winding) reduced and hence a saving on copper,*
  - *The magnitude of certain harmonics in the emf and also mmf is suppressed.*

<u>Note :-</u>

- In integral full pitch winding, a slot contains coil sides of the same phase.
- In integral chorded pitch winding, some slots contain coil sides pertaining to different phases.
- Interconnection between the phase belts of chorded three phase winding is done in a similar manner to that explained earlier for full pitch winding.

<u>For example</u> *:*

➢ Consider a motor stator with 36 slots wound for six poles.

Such a motor will have synchronous speed of 1,000 rpm and the number of slots per pole per phase is :-

$$q = \frac{36}{6X3} = 2$$

- If the same stator is rewound for the lower speed say, 750 rpm, i.e., for 8 poles, the number of slots per pole per phase will then be:-

$$q = \frac{36}{8X3} = 1\tfrac{1}{2} = \frac{3}{2}$$

- In induction motors such cases usually arise when stators with the same number of slots are wound for more than one speed or number of poles

- For fractional slot windings, however, from the view point of symmetry, the number of slots must be divisible by the number of phases. i.e 3

- Limitations of fractional slot windings are
  - It can be used only with double-layer windings
  - The number of parallel circuits is limited

- The fractional-slot winding differs from the integral-slot winding in that it must be composed of coil groups with different numbers of coils and each phase must occupy the same number of slots, otherwise the winding would be unbalanced.

- Usually, the fractional-slot winding is a combination of two types of coil groups:
  - One in which the number of coils in the group is equal to the integer part of the number of slots per pole per phase.

  - The other in which the number of coils is one greater than in the first type.

- If for example, the number of slots per pole per phase is 2 ½, the winding will be built up of alternating coil groups containing two and three coils each, every two-coil group being followed by a three-coil group.
  2-3-2-3-2-3…….

- Because of the alternation, the number of slots per pole per phase is:-
- Sometimes the fractional number of slots per pole per phase is expressed as an improper fraction, i.e.

$$q = \frac{c}{d}$$

In the example above, c = 5 and d = 2
To obtain a balanced or symmetrical winding, it is necessary that $\frac{S}{t \cdot m}$ be equal to a whole number.

Where, *S - being the number of slots,*
– *t - the largest common factor for S and P, and*
– *m - the number of phases.*

Arranging fractional slot windings with the aid of tables:

- The coil groups in a fractional-slot winding are easily arranged with the aid of a table.
- Taking a sheet of millimeter lined paper, the table is drawn with as many horizontal lines as there are poles, and each line is divided into 3C boxes, where C is the numerator of the improper fraction representing the slots per pole per phase and 3 is no. of phases.
- The table is next divided by vertical lines forming three equal columns for the three phases with C boxes per phase.
- Following this, in ordinal succession, the boxes are filled in with the numbers of the slots at intervals of d boxes, where d is the denominator of the fraction expressing the number of slots per pole per phase.

Example -

Given:- S = 27, p = 6, m = 3, q = 1½ = 3/2

Solution

The largest common factor t for S = 27 and p = 6 is:-

S = 27 = 3 x 3 x 3

p = 6 = 2 x 3

then, t = 3 and S/(t x m) = 27 / (3x3) = 3 is a whole number.

1. draw a table where no. rows = no. of poles and each column of three phases with C no. of sub columns, where, C is the numerator of the improper fraction.

2. Fill the boxes starting from the extreme left top box with cross or consecutive numbers (representing adjacent slots) as shown in table below. Proceed to the right marking crosses/numbers separated from each other by denominator of the improper fraction of no. of slots per phase per pole.

Table I Details of position of conductors in slots

No. Of Poles	PHASE R			PHASE B			PHASE Y		
N	1		2		3		4		5
S		6		7		8		9	
N	10		11		12		13		14
S		15		16		17		18	
N	19		20		21		22		23
S		24		25		26		27	

Winding table Interpretation:

- Reading the table horizontally line by line, write down the letter of the respective phase each time a cross/number appears in its column.
- This reveals the following sequence of the coils of each phase under consecutive poles.
  RRBYY, RBBY, RRBYY, RBBY, RRBYY, RBBY
- Each letter indicates the coils of each phase, and like letters succeeding one another indicate how many coils of the same phase the group will contain.
- Thus, in our example, the sequence shows that it is necessary to prepare nine groups of two coils each and nine single coils.
- They will occupy (9 x 2) + 9 = 27 slots with the following arrangement.
- 2,1,2; 1,2,1; 2,1,2; 1,2,1; 2,1,2; 1,2,1.
  N S N S N S

Summary on Fractional-slot Winding:

- When the integer before the fraction is greater than unity, the numbers in the sequence table must be that integer and a number increased by one.
- Thus, for example, when q = 1 ½ , the sequences will contain repeating single and two-coil groups (1-2), while in the case where q = 2 ½ the repeating sequences will contain two-coil and three coil groups (2-3).
- The number of integers in a period is equal to the denominator d of the improper fraction expressing the slots per pole per phase; the sum of the integers is equal to c, the numerator of the improper fraction.
- Thus, when the period consists of five integers, (1-2-1-2-2), the sum of the integers is 8, i.e., it is equal to the numerator of the fraction.

Ex. 6. Design and draw the developed winding diagram of an AC motor with following details: No of poles = 6 no. of phases = 3, No. of slots = 27, double layer lap winding, star connected.

Soln:

No. of poles = 6; No. of conductors = 27;
Pole pitch = 27/6 = 4.5; no of slots/pole /phase = 27 / (6x3) = 1.5
Slot angle = 180/pole pitch = 180/4.5 = 40^0
Winding pitch = 180 – (slot angle)
= 180 – 40= 140
Hence coil span = 180^0 / 40 = 4.5 slots

Connections: Rs = 1, Ys = 1 + 120/40 = 4; Bs = 1 + 240/40 = 7

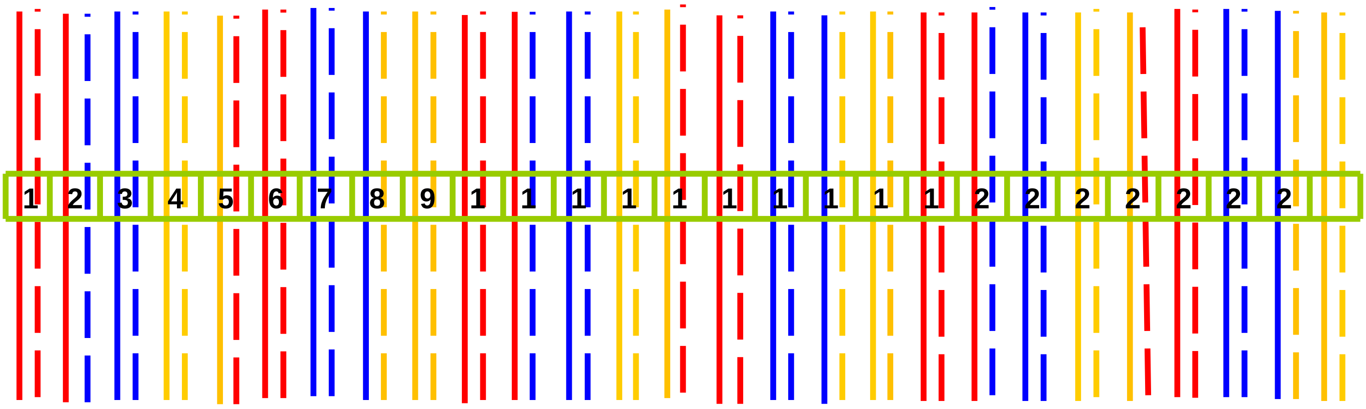


Fig. 20 Placement of conductors of Winding diagram

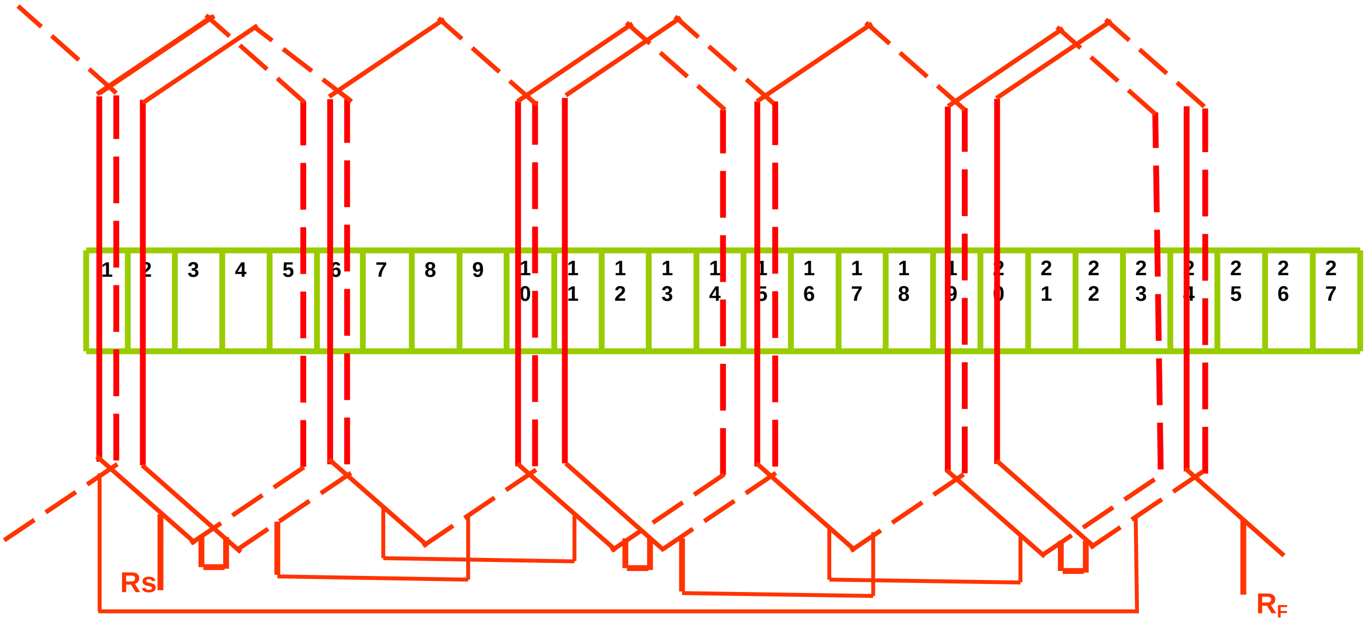


Fig. 21 Winding diagram for R phase only

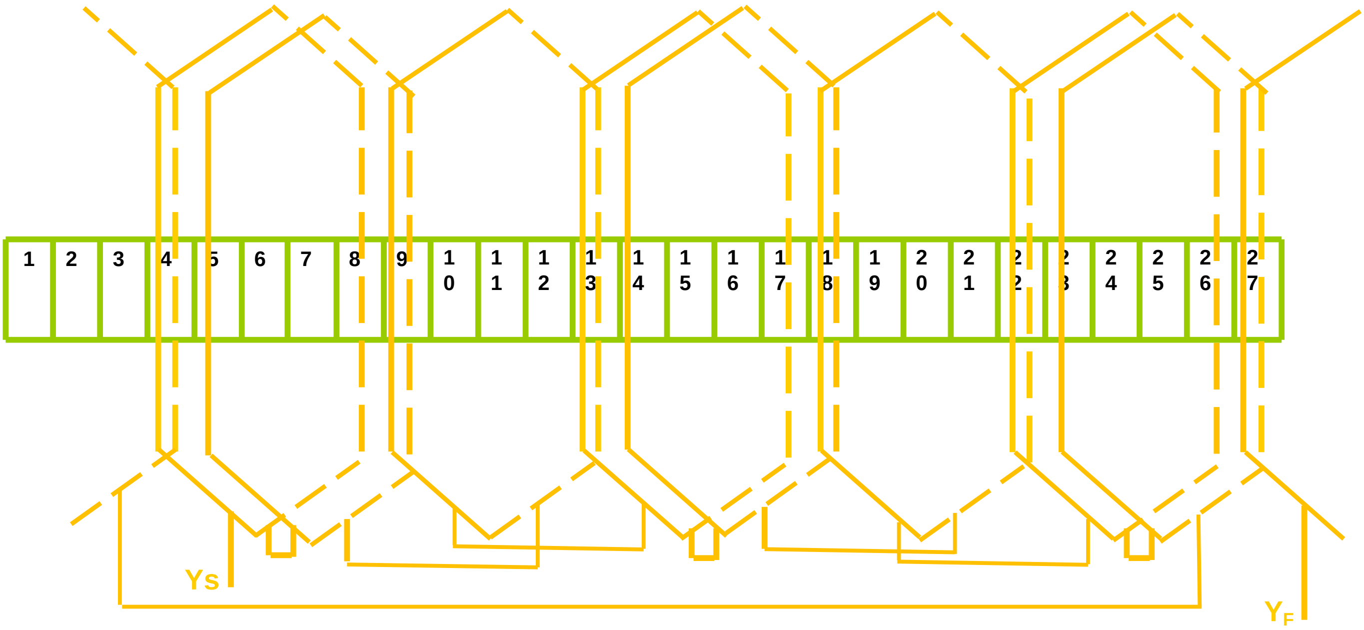


Fig.22 Winding diagram for Y phase only

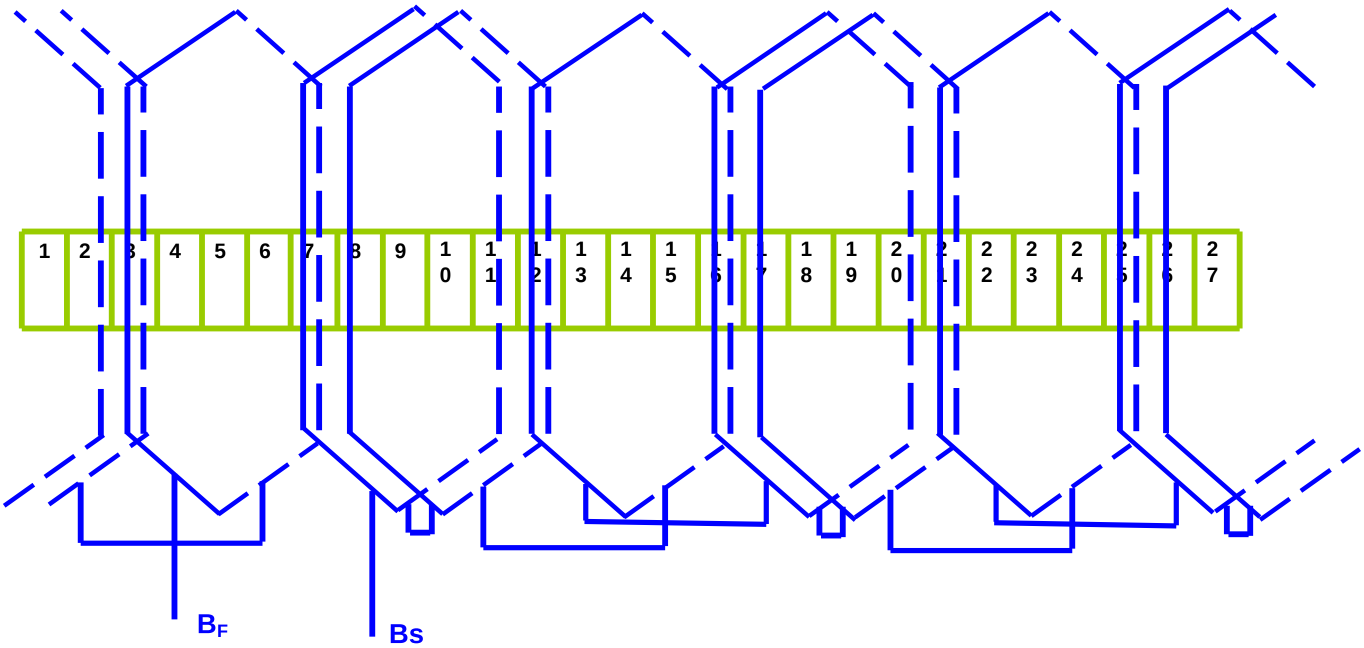


Fig. 23 Winding diagram for B phase only

MUSH WINDING:

- This winding is very commonly used for small induction motors having circular conductors.
- This is a single layer winding where all the coils have same span (unlike the concentric winding where coils have different spans).
- Each coil is wound on a former, making one coil side shorter than the other.
- The winding is put on the core by dropping the conductors, one by one into previously insulated slots.
- The short coil sides are placed first and then the long coil sides. The long and short coil sides occupy alternate slots.
- It will be also observed that the ends of coil situated in adjacent slots cross each other i.e. proceed to left and right alternatively.
- That is why sometimes it is known as *a basket winding*.

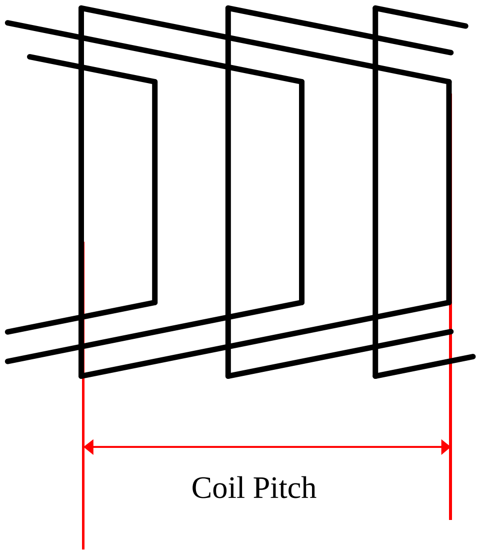


Fig. 24 Mush winding over one coil pitch

Points to be remembered:

The following should be kept in mind while designing a mush winding, that is

- The coils have a constant span.
- There is only one coil side per slot and therefore the number of coil sides are equal to number of slots.
- There is only one coil group per phase per pole pair and therefore, the maximum number of parallel paths per phase is equal to pole pair.
- The coil span should be odd. Thus for a 4 pole 36 slot machine, coil span should be 36/4=9 while for a 4 pole 24 slot machine, the coil span should not be 24/4=6; it should be either 5 or 7 slots. This is because a coil consists of a long and a short coil side. The long and short coil sides are placed in alternate slots and hence one coil will be in an even numbered slot and the other in an odd numbered slot giving a coil span which is an odd integer.
-

Example: Consider the winding data with mush winding

Given data: S = 12; p = 2; m = 3; type= Mush

No. of coil groups per phase = $\boxed{K = 3 \cdot \frac{P}{2} = 3 \cdot \frac{2}{2} = 3}$

No. of coils in a group = $\boxed{q = \frac{S}{m \cdot p} = \frac{12}{3 \cdot 2} = 2}$

Coil pitch = $Y_S = \frac{S}{p} = \frac{12}{2} = 6$

This is an even number and hence the winding is not possible with an even coil span. Therefore , it is shortened by one slot and a coil span of 5 slots is used.

The electrical angle, γ = $\gamma = 180 \cdot P = 180 \cdot 2 = 360^{\circ}$

The angle between adjacent slots, α = $\alpha = \frac{\gamma}{S} = \frac{360^{\circ}}{12} = 30^{\circ}$

The distance between the beginnings of each phase, $\lambda = \frac{120^{\circ}}{\alpha} = \frac{120^{\circ}}{30^{\circ}} = 4\,slots$

If the beginning of Phase R is slot 1, then the beginning of phase Y is slot 1+λ = 5 and the beginning of phase B is slot 1+2λ = 1+8 = 9

Coil group of Phase A: Lay down coil-group belonging to phase A inside the slots 1,2 and 7,8.

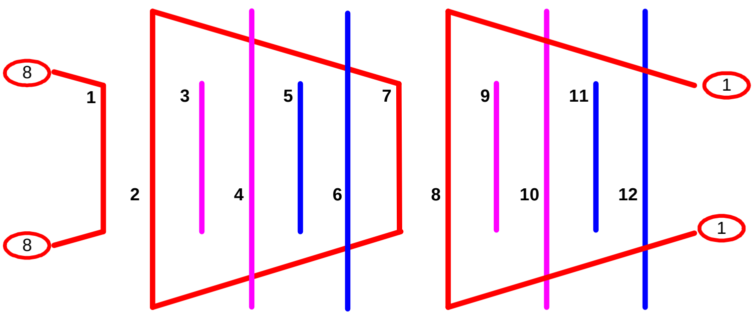


Fig. 25 Winding diagram showing coil group of Phase A

Coil group of Phase B:

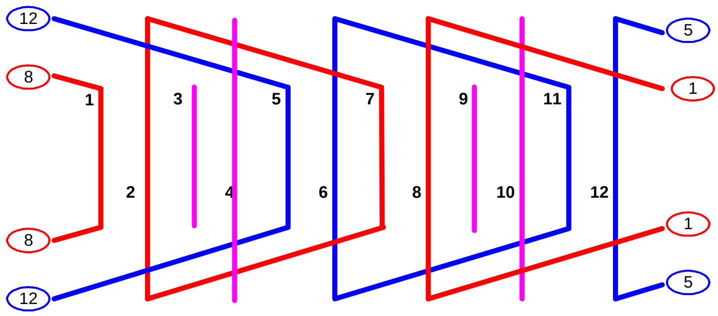


Fig. 26 Winding diagram showing coil group of Phase B

Coil group of Phase C:

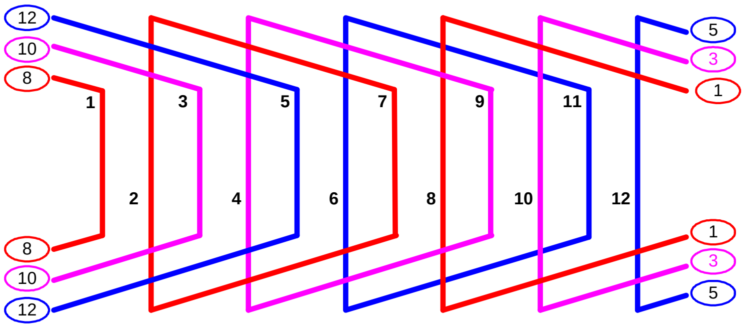


Fig. 27 Winding diagram showing coil group of Phase C

Phase A, B & C Coil group interconnections and Terminals

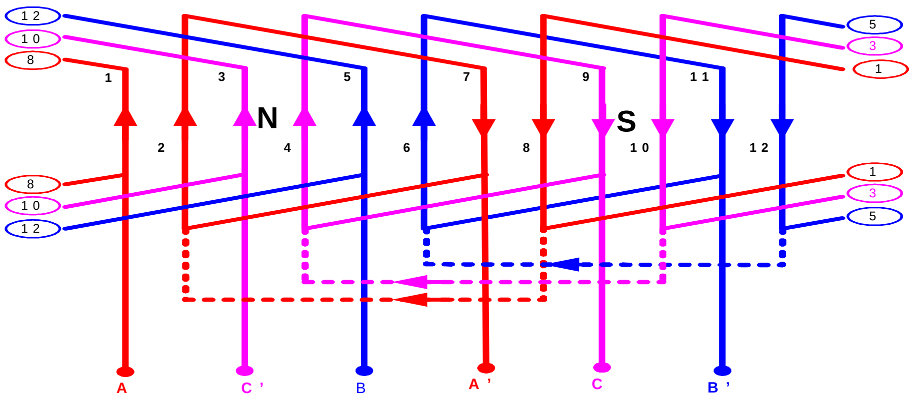


Fig. 28 Winding diagram for mush winding

Ex. Design and draw the developed winding diagram of an AC motor with following details: No of poles = 4 no. of phases = 3, No. of slots = 24, single layer mush winding.

Soln:

No. of poles = 4; No. of conductors = 24;

Pole pitch = 24/4 = 5 (should be odd)

no of slots/pole /phase = 24 / (4x3) = 2

Slot angle = 180 x 2 /pole pitch = 180 x 2 / 24 = 15

Connections: Rs = 2, Bs = 2 + 120/15 = 10; Ys = 2 + 240/15 = 18

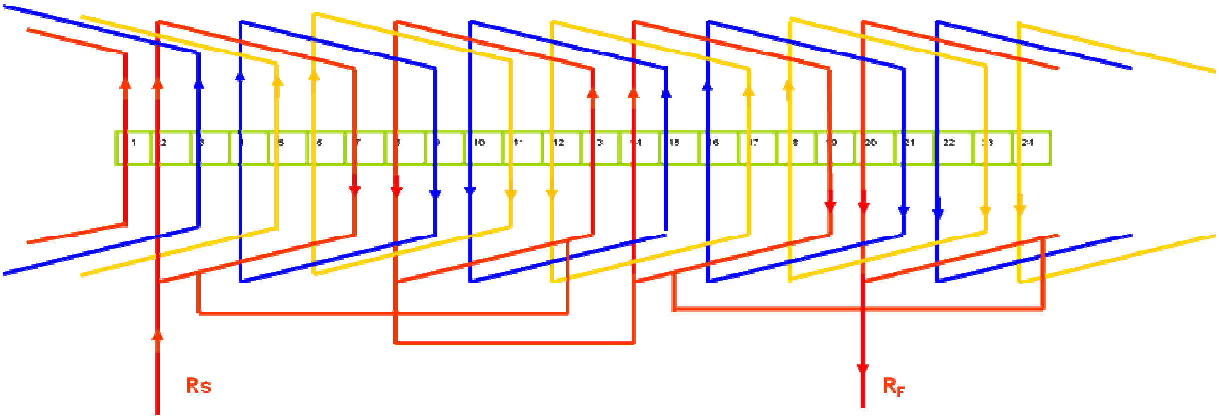


Fig. 29 Winding diagram for all 3 phases

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