

Ac machine windings

Introduction

- ❑ The Armature winding of a machine is defined as an arrangement of conductors' design to produce emfs by relative motion in a magnetic field.
- ❑ Electrical machines employ groups of conductors distributed in slots over the periphery of the armature.
- ❑ The groups of conductors are connected in various types of series-parallel combination to form Armature winding.
- ❑ The conductors **connected in series** so as **to increase the voltage rating**.
- ❑ They are **connected in parallel** to **increase the current rating**.
- ❑ Some of the commonly used terms associated with windings are as follow:

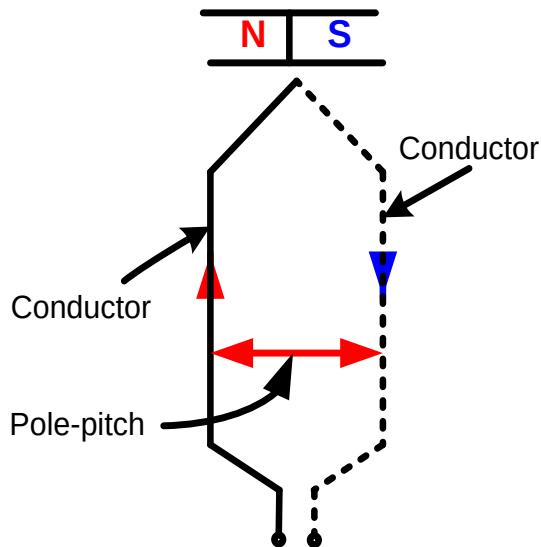
Common Terminologies associated with ac windings

□ Conductor:

- The active length of a wire or strip in the slot.

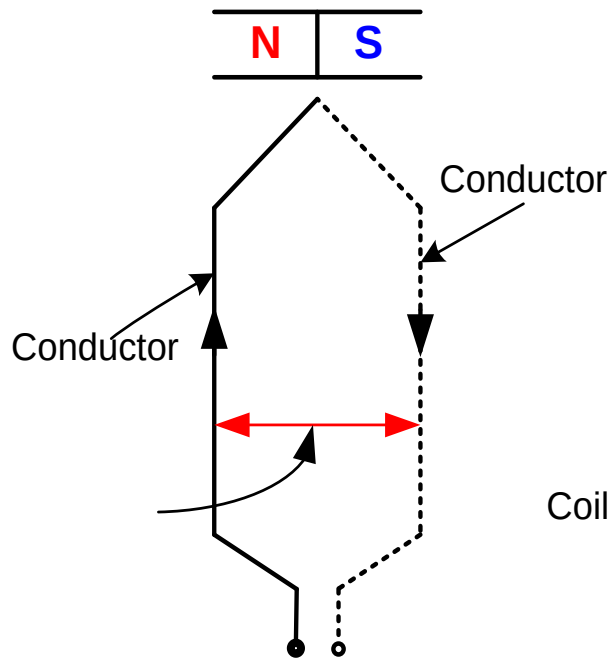
□ Turn:

- A turn consists of two conductors separated from each other by a pole pitch or nearly so, and connected in series as shown in fig.(a)
- The conductors forming a turn are kept a pole pitch apart in order that the emf in two are additive to produce maximum resultant emf.

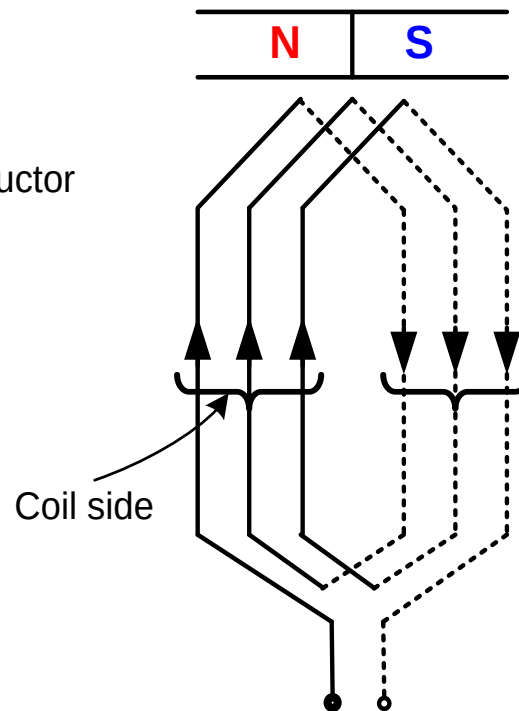


a) Single turn coil

- ❑ **Coil:** A coil may consist of a single turn or may consist of many turns, placed in almost similar magnetic position, connected in series.
- ❑ **Coil-Side:** A coil consists of two coil sides, which are placed in two different slots, which are almost a pole pitch apart.
- ❑ The group of conductors on one side of the coil form one coil side while the conductors on the other side of the coil situated a pole pitch (or approximately a pole pitch apart) forms the second coil side.

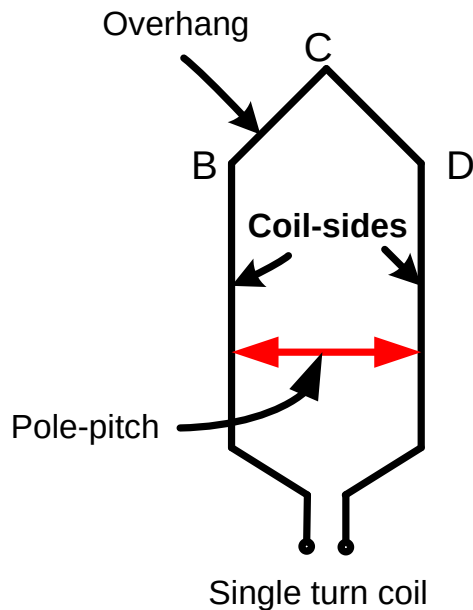


a) Single turn coil



b) 3 turns coil

- ❑ The connections joining the conductors form the **end connectors** or in the mass, **the overhang or end winding**.
- ❑ When the coil sides forming a coil are spaced exactly one pole pitch apart they are said to be of **full-pitch**.
- ❑ However, the coil span may be less than a pole pitch, in which case the coil is described as **short pitched or chorded**.



TYPES OF AC MACHINES WINDINGS



They are two basic physical types for the windings. They deal differently with the mechanical problem for arranging coils in sequence around the armature.



The two types are:

- 1. Single layer winding and**
- 2. Double layer winding**

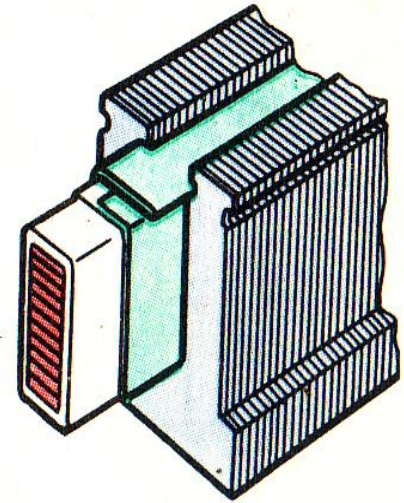
1. SINGLE LAYER WINDING

⌚ Fig (a) below shows an arrangement for a single layer winding.

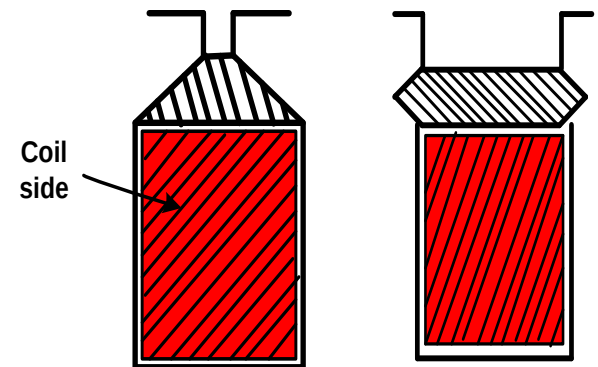
⌚ In this type of winding arrangement one coil side of a coil occupies the whole of the slot.

⌚ Single layer winding are not used for machine having commutator.

⌚ Single layer winding allow the use of semi-closed and closed types of slots.



(a)



Semi-closed
slot

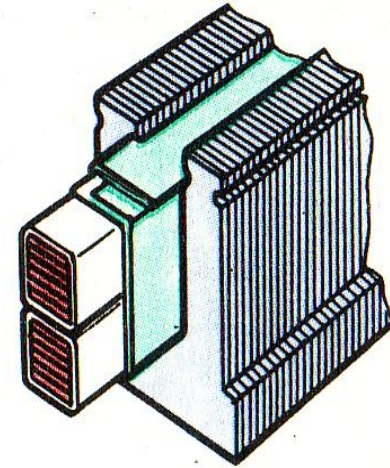
Open slot

2. DOUBLE LAYER WINDING

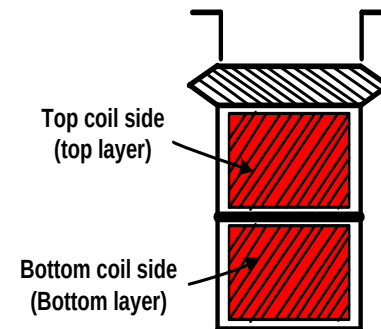
⌚ The double layer winding have identical coils with one coil side of each coil lying in top half of the slot and the other coil side in bottom half of another slot exactly or approximately one pole pitch. Fig (a)

⌚ Each layer may contain more than one coil side in case large numbers of coils are required (fig c).

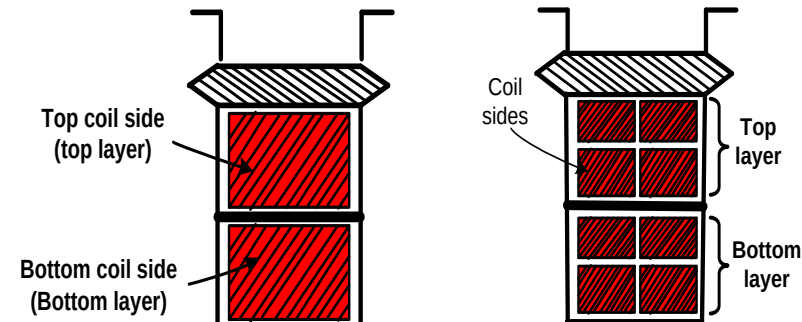
⌚ Figure (c) shows the arrangement wherein there are 8 coil sides per slot. Open slots are frequently used to house double layer windings.



(a)



(b)



(c) 13

NUMBER OF PHASES AND PHASES SPREAD

- ❑ An ac winding, meant to be user for a 'm' phase system, should produce emfs of equal magnitude in all the phase.
- ❑ These emfs should have identical waveforms and equal frequency.
- ❑ Their displacement in time should be $\gamma = 2\pi/m$ electrical radians.
- ❑ This is obtained by having similar pole phase groups (a pole phase group is defined as a group of coils of a phase under one pole) and arranging the groups to have an effective displacement of $\gamma = 2\pi/m$ electrical radians in space.

- Consider the case of a 12-slot armature having 2 poles and wound for three phases as show in fig below (a). If the flux density wave shape is considered sinusoidal, the emfs of the conductors in the slots can be represented as a phasors displaced from each other by an (electrical) angle, as shown in Fig(a).

$$\alpha_s = \frac{\pi P}{S} = \frac{\pi}{6} \text{radian} = 30^\circ$$

- If the winding is divided into three groups (one for each phase) spread over two pole pitches, the electrical displacement in space between the groups is $2\pi/3$ electrical radian or 120° electrical.
- Each phase is located in four consecutive slots and so the phase spread is $4 \times 30^\circ = 120^\circ$ electrical.
- If the conductors in the slots are connected as per the phasor diagram fig (b) , the summation of conductors emfs would give three emfs displaced 120° in time following a phase sequence of ABC in time. The space sequence is also ABC.

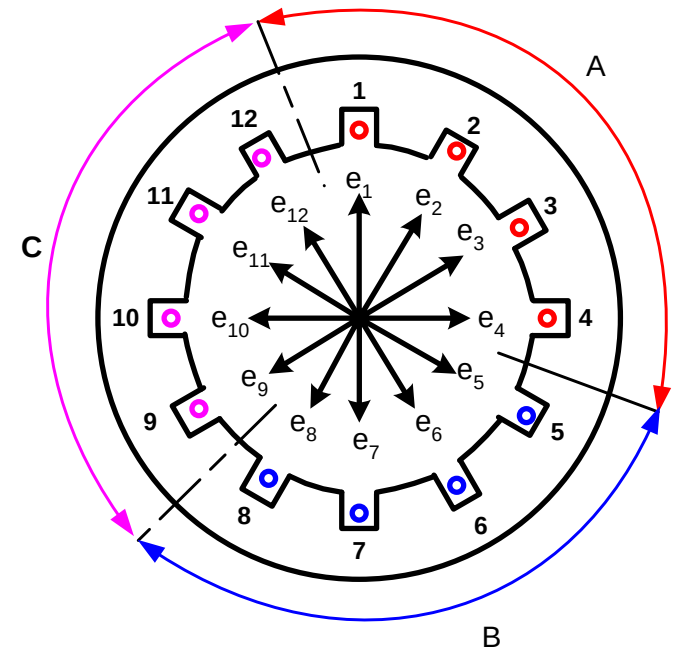


Fig.(a)

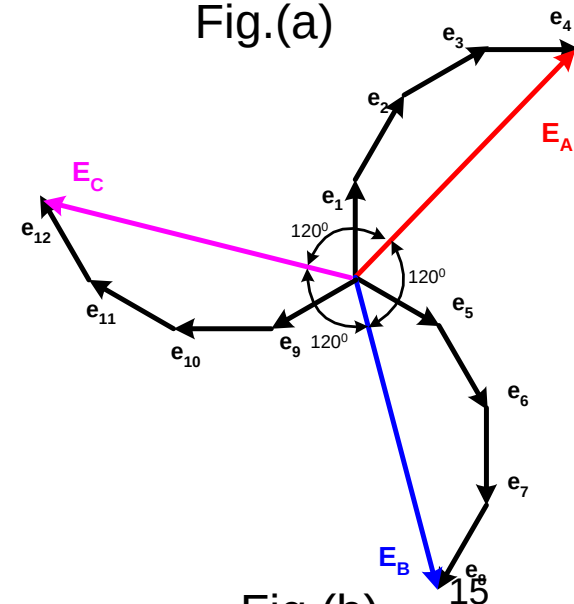
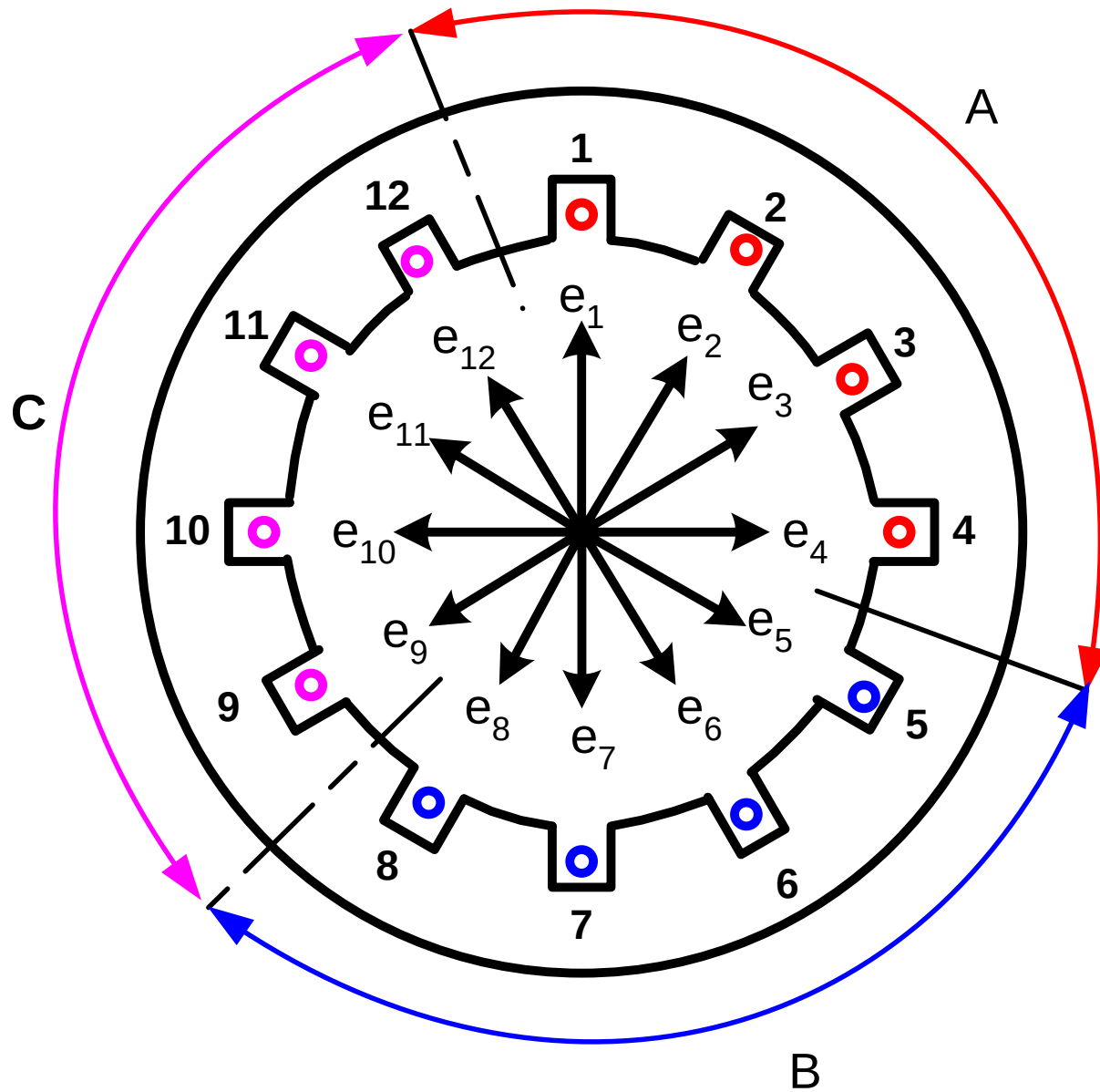


Fig.(b)



- ❑ Let the winding be split up into six 60° phase groups spread over two pole pitches as shown in fig (a).
- ❑ Conductors of phase A are placed in slots, 1,2 and 7,8.
- ❑ Conductors of phase B are placed in slots 5,6 and 11,12.
- ❑ Conductors of phase C are placed in slots 3,4 and 9,10.
- ❑ Conductors in slot 7,8 are return conductors for conductors in slots 1,2.
- ❑ Conductors in slots 11,12 are return conductors for conductors in slots 5,6.
- ❑ Conductors in slots 3,4 are return conductors for conductor in slots 9,10.
- ❑ If the conductors were connected as represented by the phasor diagram (b), we would still get three equal emfs displaced by 120° in time following a phase sequence ABC.
- ❑ The space sequence being A C' B A' C B'. Thus it is clear that with six 60° phase groups (three 60° groups per pole) spread over pole pitches, it is possible to obtain three equal emfs displaced 120° in time.

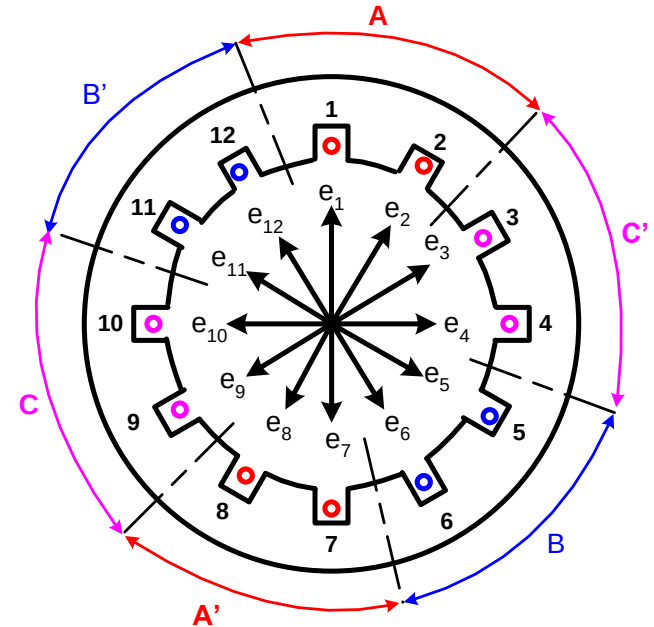


Fig.(a)

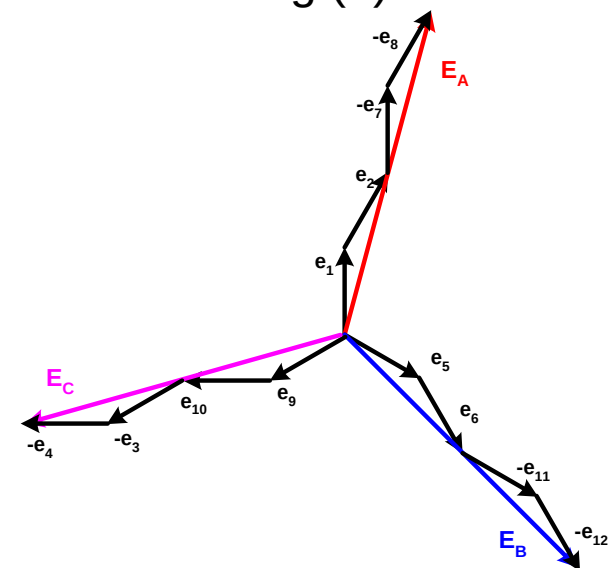
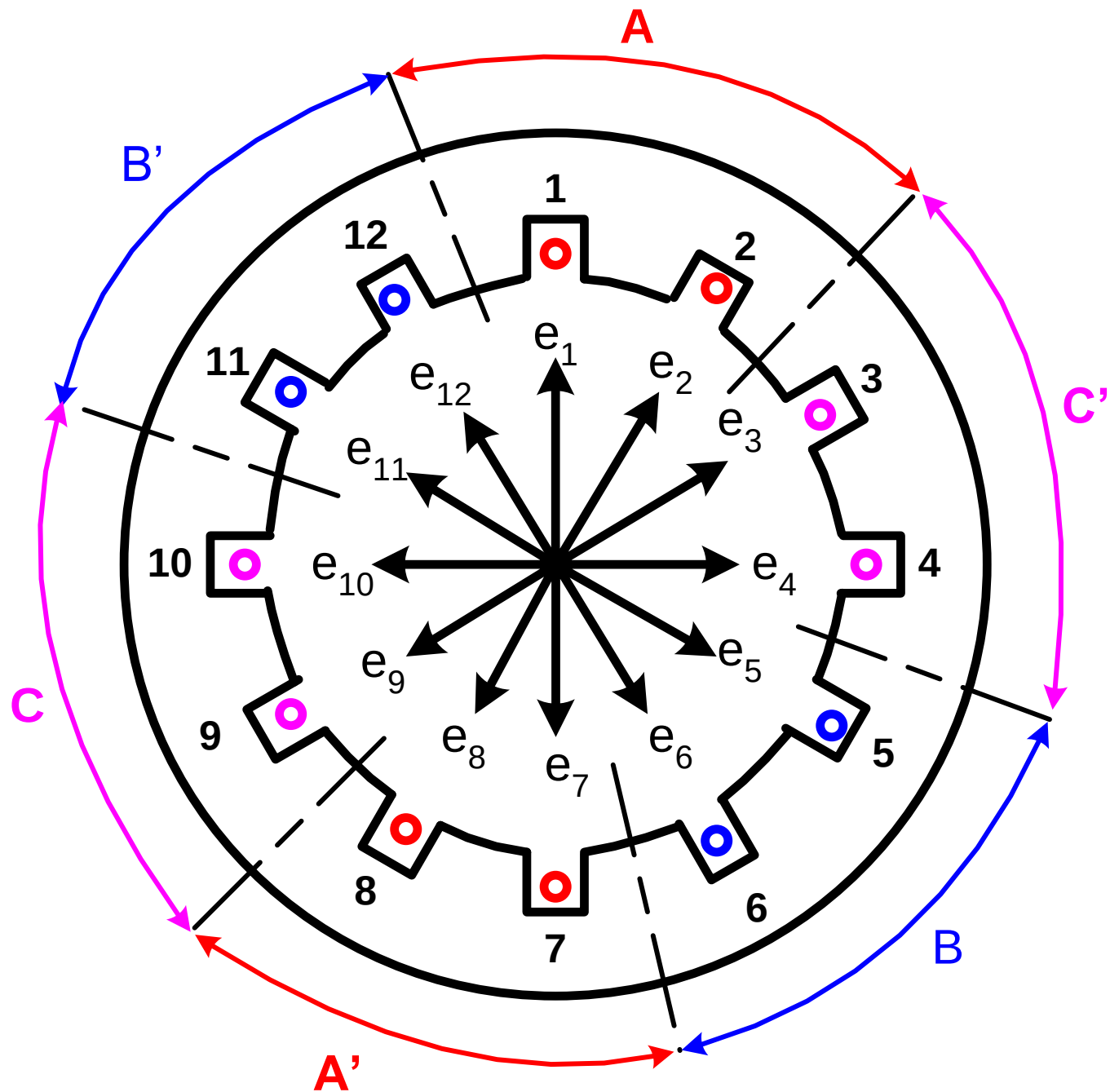


Fig.(b)



TYPES OF SINGEL LAYER WINDINGES

- ❑ The three most common types of single layer windings are
 - 1. Concentric windings (Unequal coil span)**
 - 2. Chain windings (equal coil span)**
 - 3. Mush windings (equal coil span)**

CONCENTRIC WINDING

- ⌚ Three-phase concentric winding consists of coil groups laid in the slots so that all the coils of each group are concentric.
- ⌚ That is, the coil with the smallest slot pitch is surrounded by the coil with the next larger slot pitch and so on to make up a coil group.
- ⌚ Each coil consists of several turns and the cross-over from one coil to the next is indicated by a short slanted line (jumper).
- ⌚ In order to construct the diagram for a winding, the following data must be known:

S - The number of slots in the stator

P – The number of poles

m – The number of phases

Y_s – The pitch of the winding

a – The number of parallel circuits in the windings

- ⌚ The pitch of the winding is determined by the formula

$$Y_s = \frac{S}{P}$$

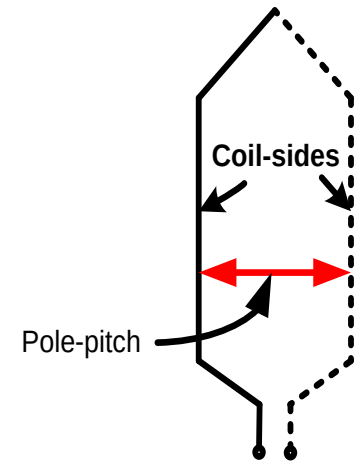
- ⌚ The pitch is the distance between two sides of a coil expressed as the difference between the numbers of the slots in which the sides lie.

- ⌚ Another important value of the winding of ac machines is the number of slot per phase per pole denoted by the letter q . It can be determined by the formula

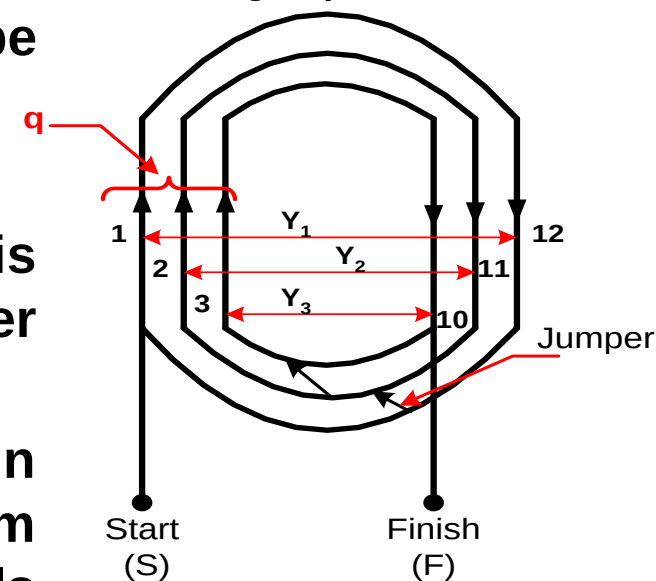
$$q = \frac{S}{P \cdot m}$$

- ⌚ Sometimes q is called a pole-phase group is defined as a group of coils of a phase under one pole.

- ⌚ The number of slots per pole per phase in concentric winding can be seen directly from the diagram. It is equal to the number of coils in a coil group.



A coil-group with 3-coils



CONNECTING COIL GROUPS INTO PHASES

- ❑ As soon as all the coils have been laid in the slots, the coil groups are connected in to phases.
- ❑ Each group is provided with two leads for the start and finish of the group.
- ❑ The total number of leads is therefore twice the number of coil groups.
- ❑ A stator winding must have six leads brought out to the terminal panel these leads being the beginnings and ends of the three phases.
- ❑ All the remaining leads must be interconnected in the respective phases with in the winding.
- ❑ It is now necessary to decide in order to determine the beginnings and ends of each phase.

IN GENERAL TWO MAINS RULES ARE FOLLOWED

- ❑ The distance between the beginning of the phase and the distance between the ends of the phase must be equal to 120 electrical degrees.
- ❑ Any slot can be chosen as the beginning of the first phase.
- ❑ The coil groups in each phase should be interconnected by joining there unlike leads, i.e. start to finish, or finish to start.

Example#1: on concentric winding

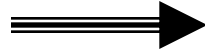
Given data

S=24; p=4; m=3; a=1; type=Concentric

• **Solution**

a) The number of coil groups, K

$$K = 3 \cdot \frac{P}{2} = 3 \cdot \frac{4}{2} = 6$$



i.e. there is two coil groups per phase

b) The number of slots per pole per phase, q

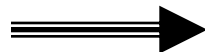
$$q = \frac{S}{m \cdot p} = \frac{24}{3 \cdot 4} = 2$$



i.e. there are two coils in a group

c) Coil pitch

$$Y_s = \frac{S}{p} = \frac{24}{4} = 6$$



Full-Pitch (average pitch)

∴ The shorter coil pitch = $Y_s - 1 = 6 - 1 = 5$
The larger coil pitch = $Y_s + 1 = 6 + 1 = 7$

d) The electrical angle, γ

$$\gamma = 180 \cdot P = 180 \cdot 4 = 720^\circ$$

e) The angle between adjacent slots, α

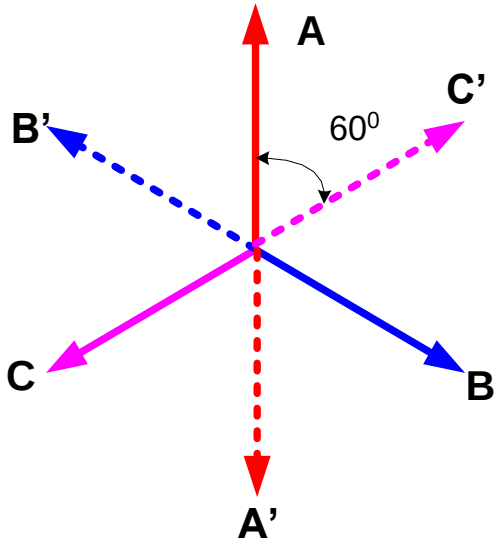
$$\alpha = \frac{\gamma}{S} = \frac{720^\circ}{24} = 30^\circ$$

f) The distance between the beginning of each phase, λ

$$\lambda = \frac{120^\circ}{\alpha} = \frac{120^\circ}{30^\circ} = 4 \text{ slots}$$

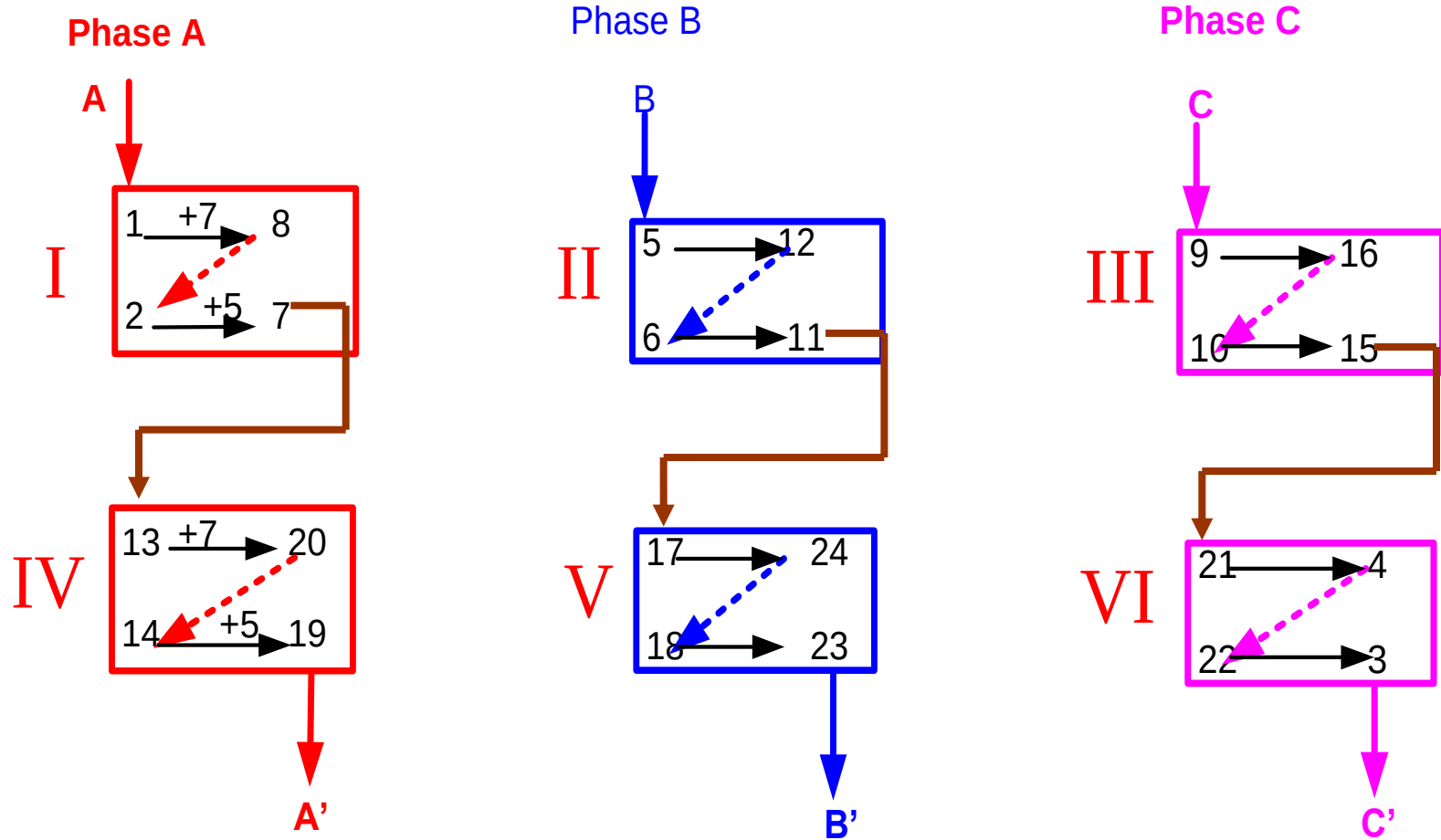
g) If the beginning of Phase A is slot 1, then the beginning of phase B is slot $1 + \lambda = 5$ and the beginning of phase C is slot $1 + 2\lambda = 1 + 8 = 9$

Phase sequence



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	A	C'	C'	B	B	A'	A'	C	C	B'	B'	A	A	C'	C'	B	B	A'	A'	C	C	B'	B'

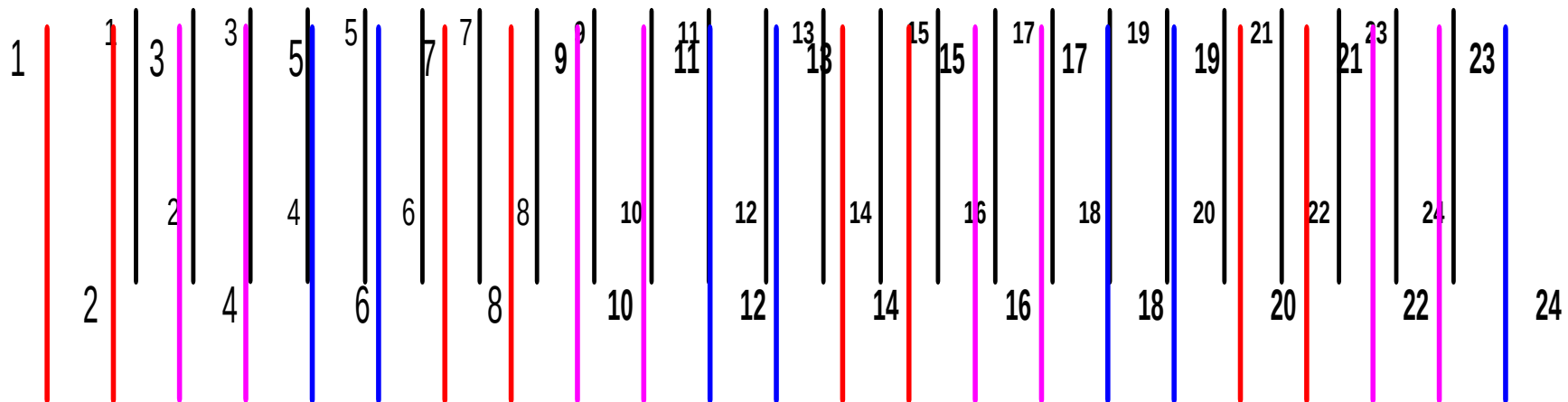
connection Diagrams



PROCEDURE FOR CONSTRUCTING OF CONCENTRIC WINDINGS

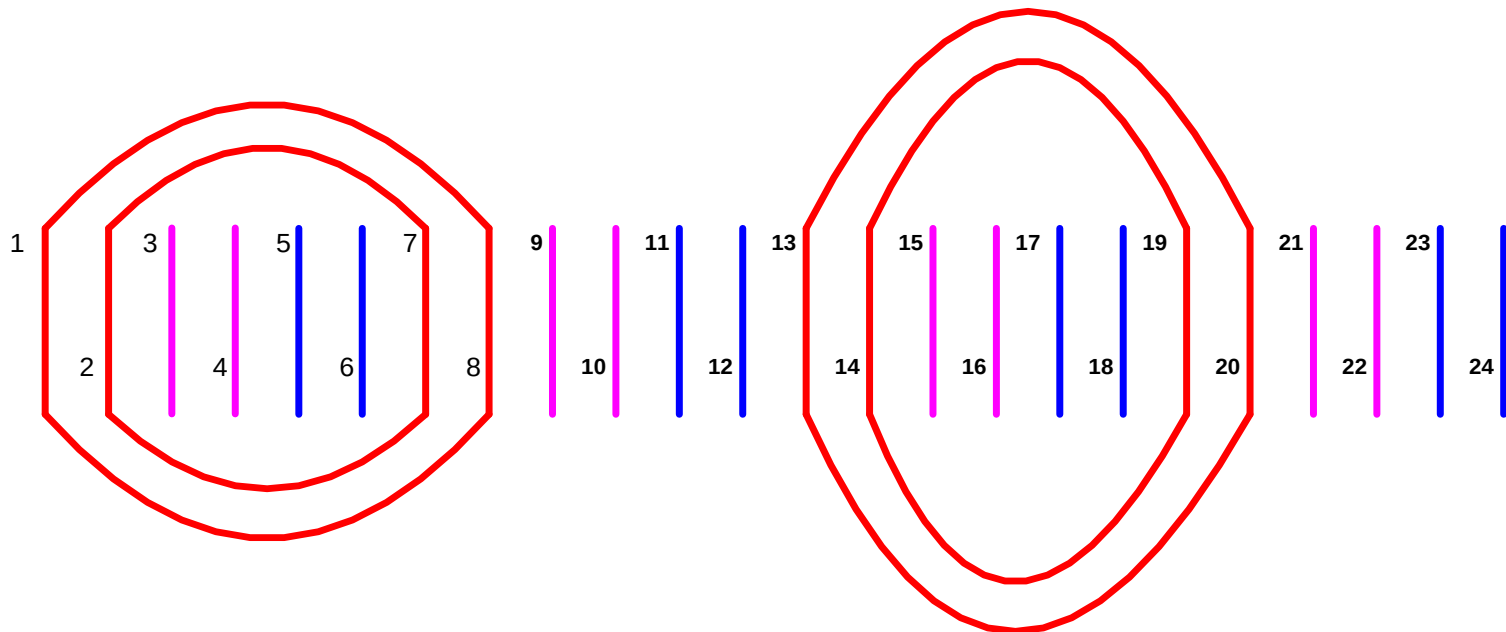
Data: $S = 24$, $P = 4$, $a = 1$, $q = 2$, $K = 6$

1. Draw 24 vertical lines and number them



Coil Groups of Phase A

2. The first and second slots will be occupied by left-hand sides of the first coil group of phase A.
3. Leave four, or $2q$ slots free for other two phases occupy slots 7 & 8 with the right hand side of the first coil group.
4. Next to it will lie a second coil group of the same size which occupies slots 9,10,15,16.



Coil Groups of Phase B

- ❑ In order to find, where the second phase (B) should begin, it is necessary to know the angle between slots in electrical degrees.

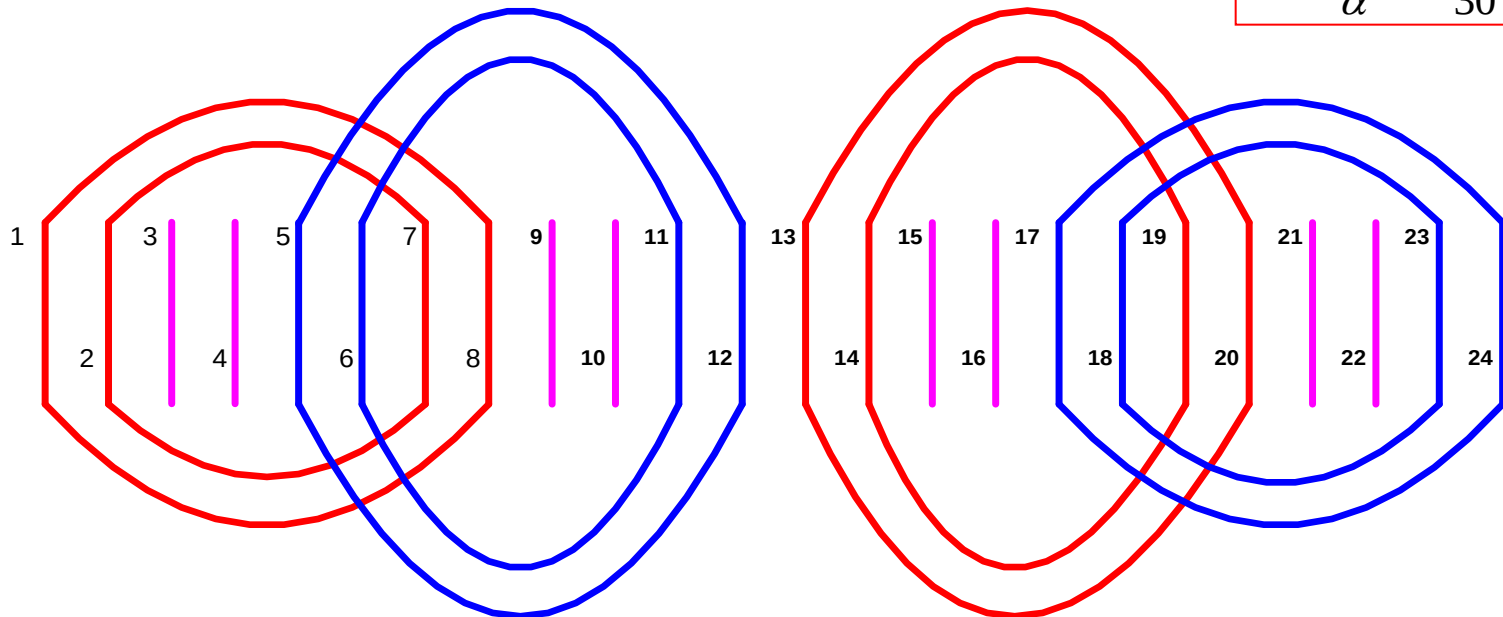
$$\gamma = 180 \cdot P = 180 \cdot 4 = 720^\circ - \text{Electrical degree}$$

- ❑ The angle between adjacent slots, α

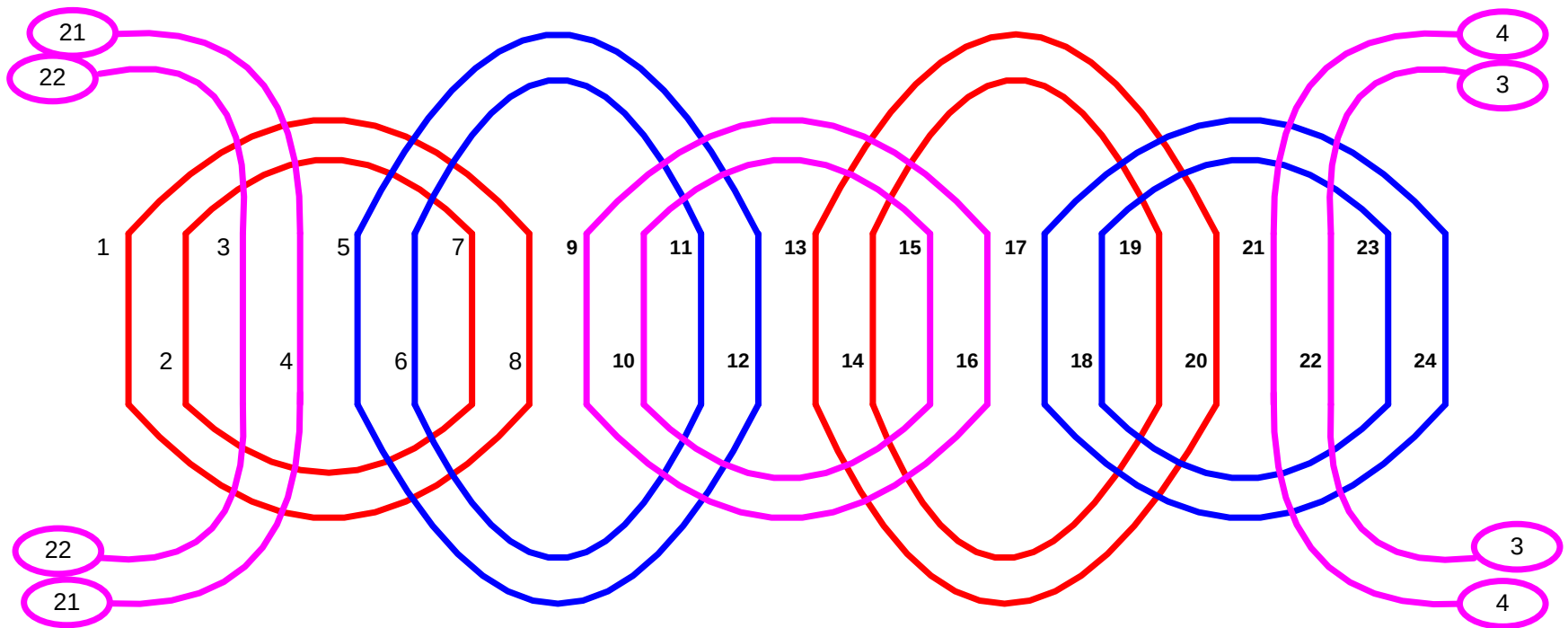
$$\alpha = \frac{\gamma}{S} = \frac{720^\circ}{24} = 30^\circ$$

- ❑ The distance between phase beginnings will have

$$\lambda = \frac{120^\circ}{\alpha} = \frac{120^\circ}{30^\circ} = 4 \text{ slots}$$



Coil Groups of Phase C



Current direction



N

1-6



S

7-12



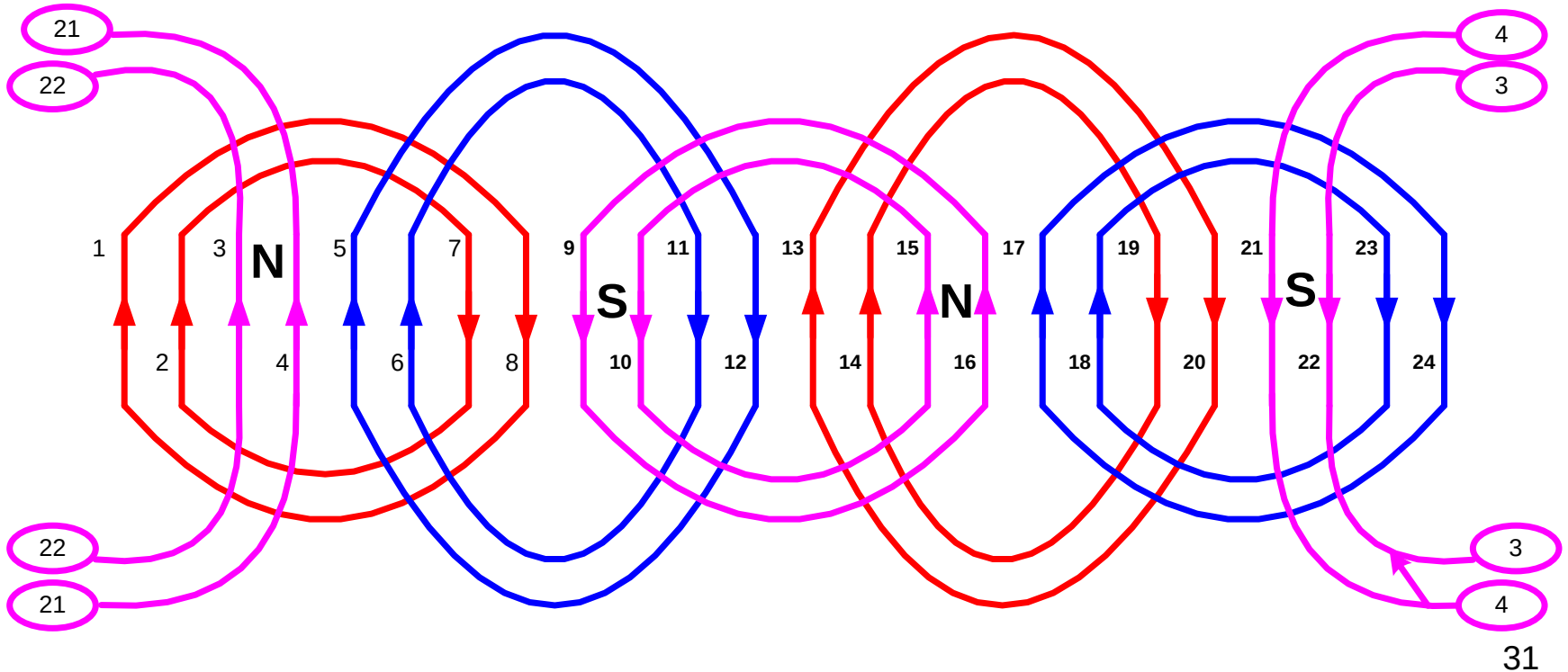
N

13-18

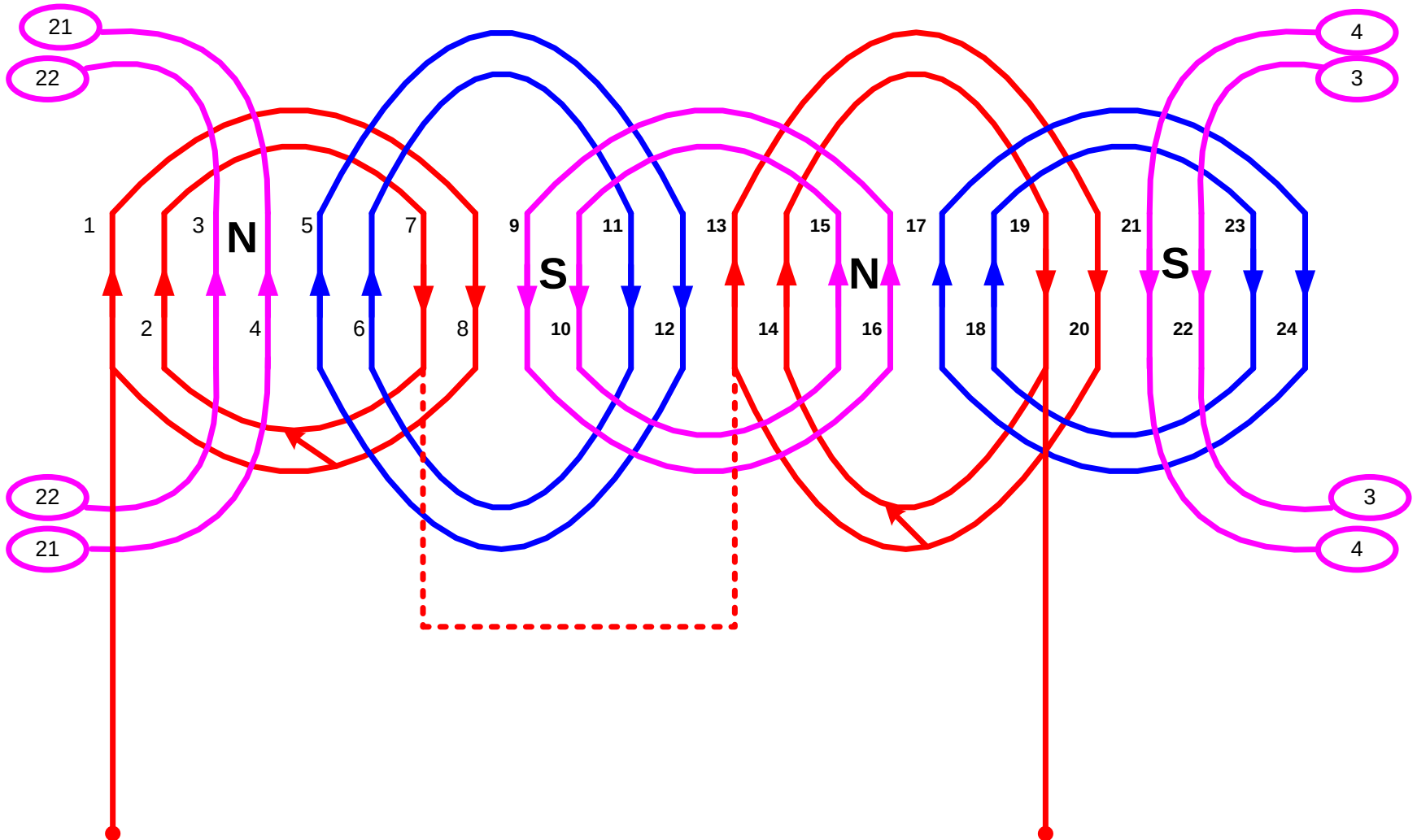


S

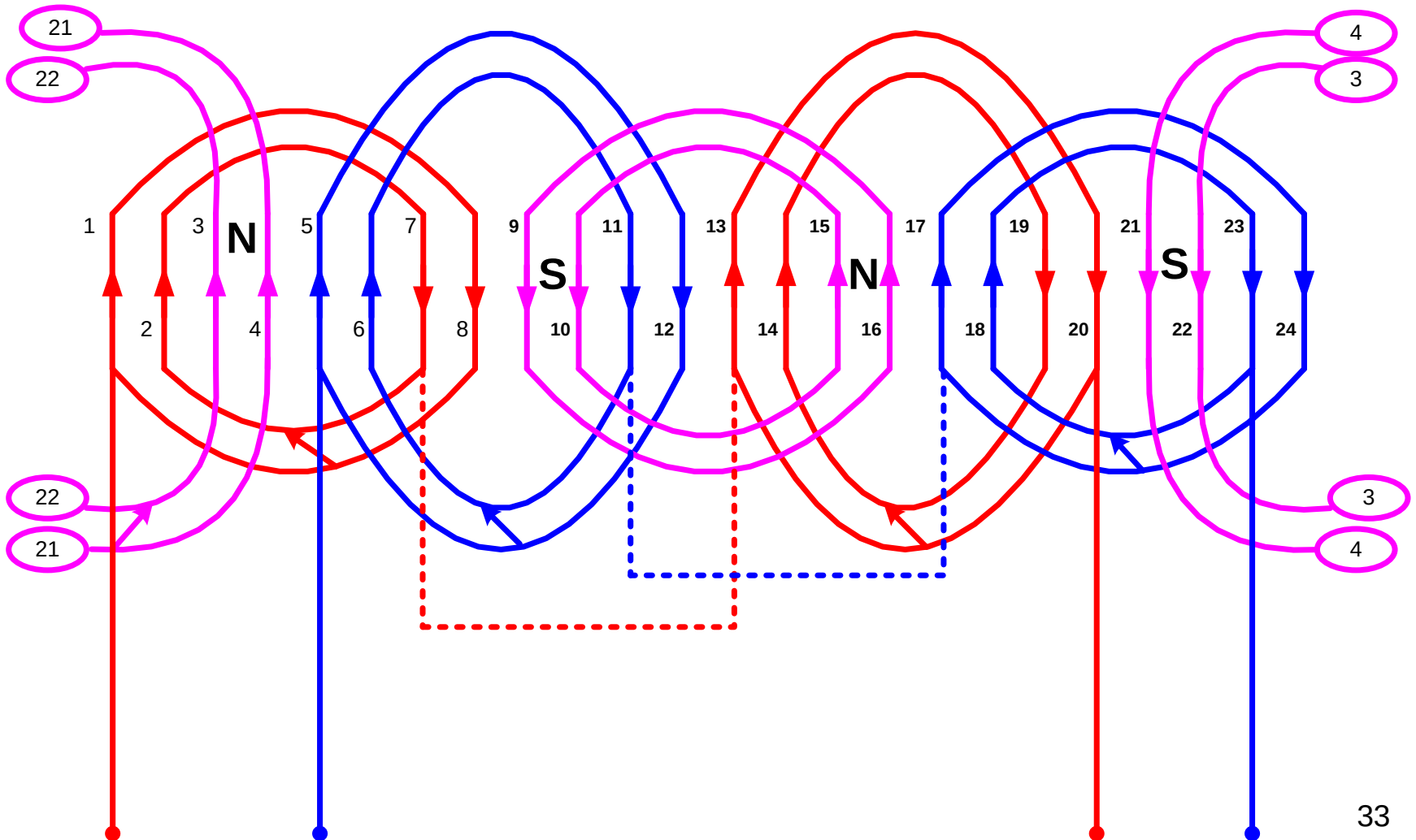
19-24



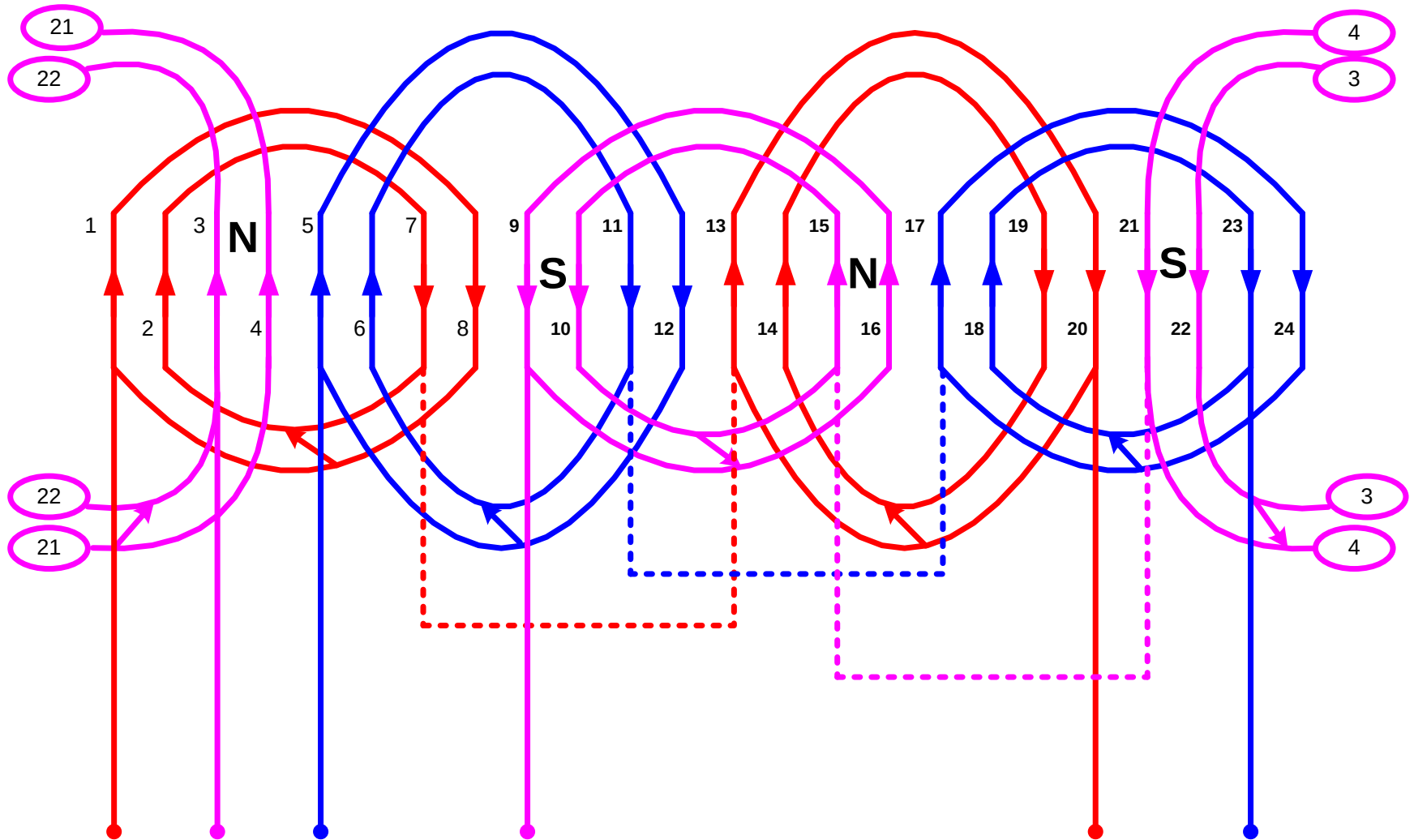
Phase A – Coil groups interconnection



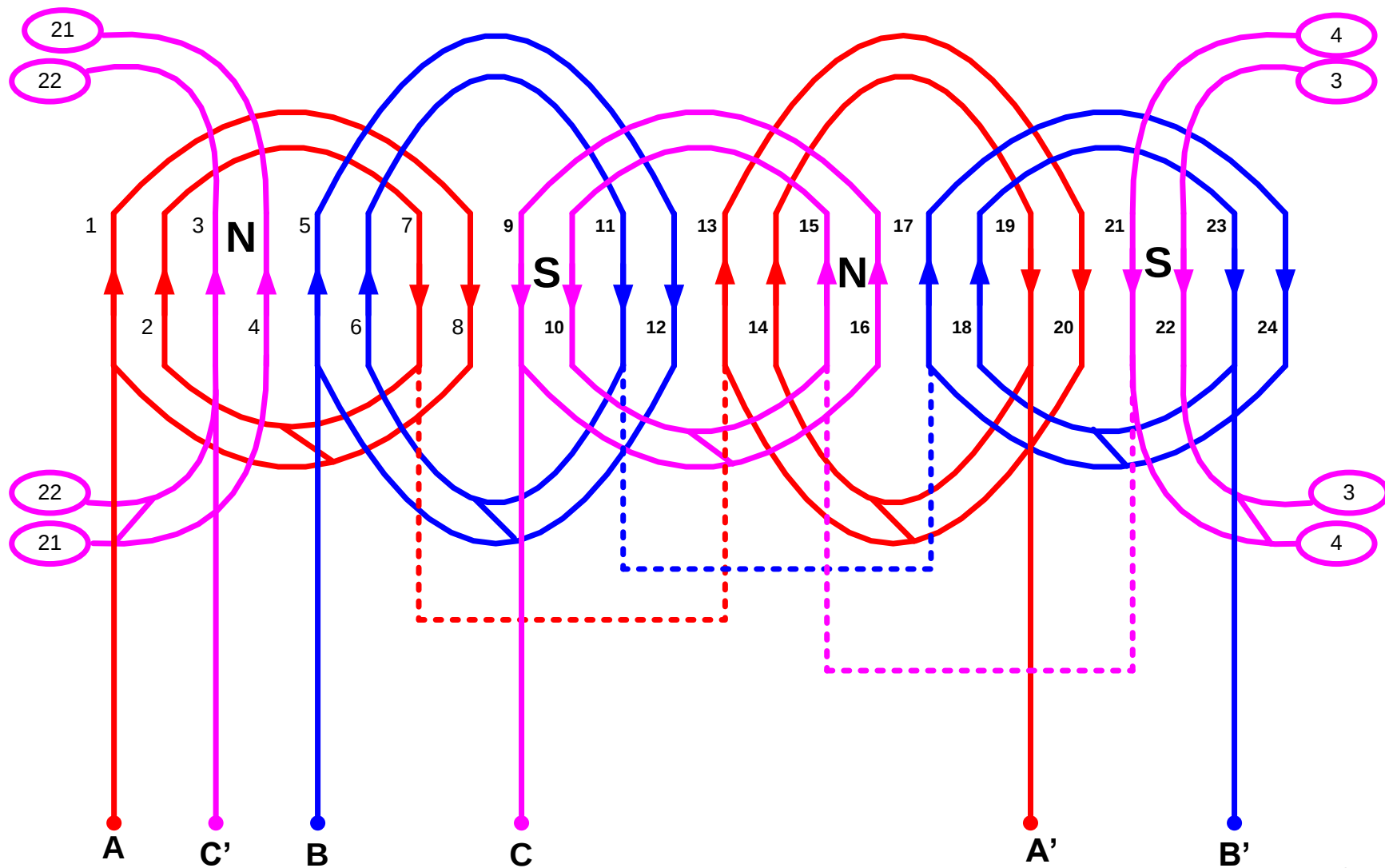
Phase B – Coil groups interconnection

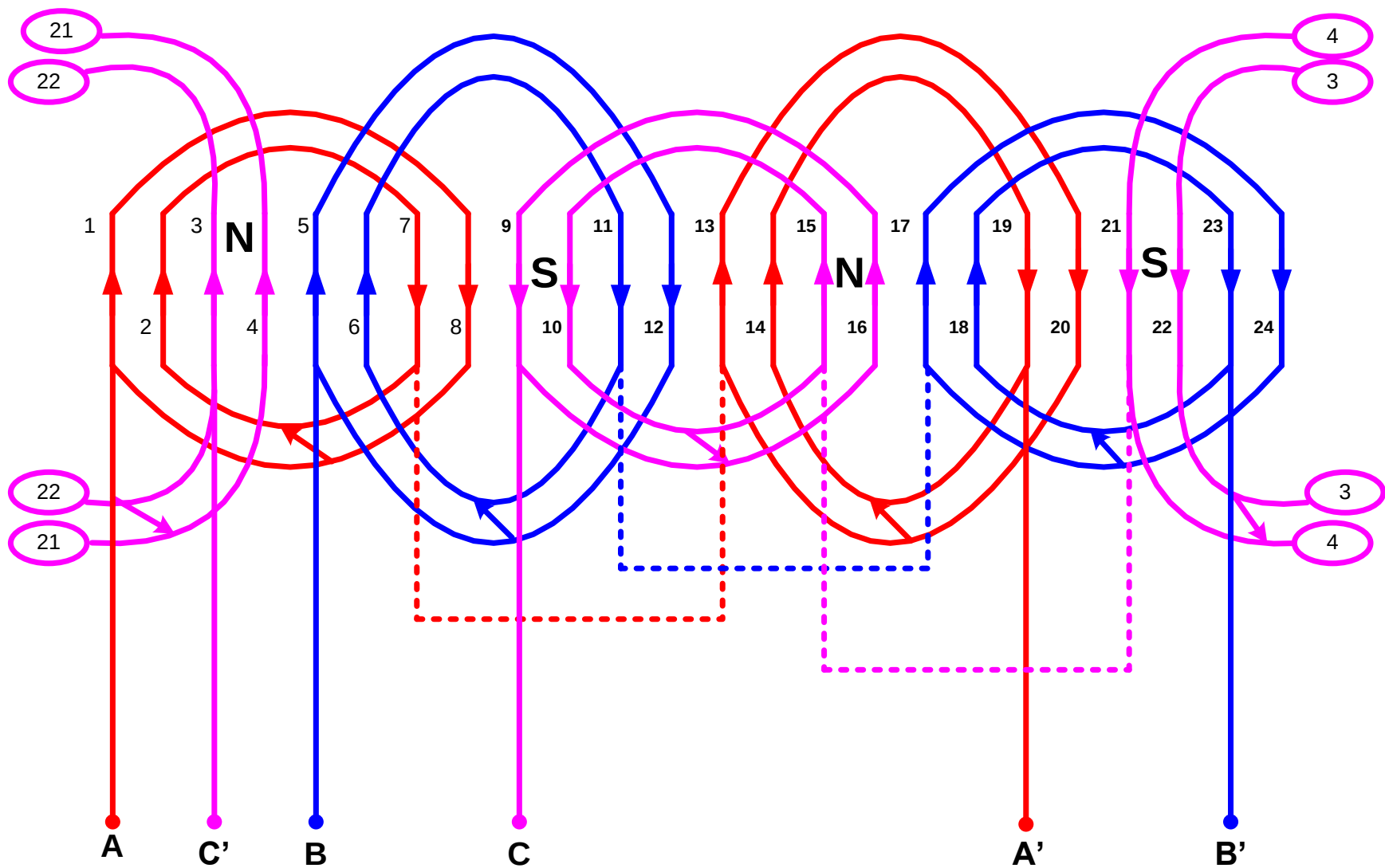


Phase C – Coil groups interconnection



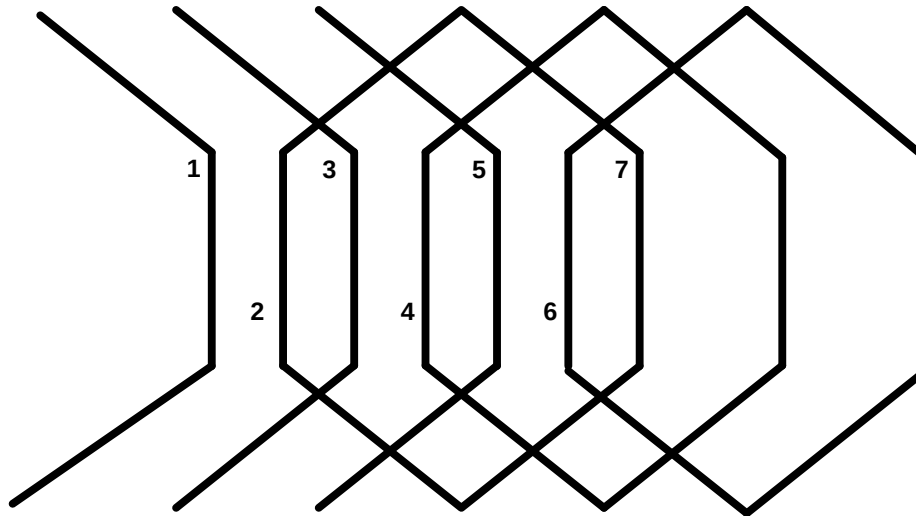
Terminals





CHAIN WINDING

- In all aspects, this winding is similar to that of mush winding except that both coil sides of a coil have equal length and diamond shape.

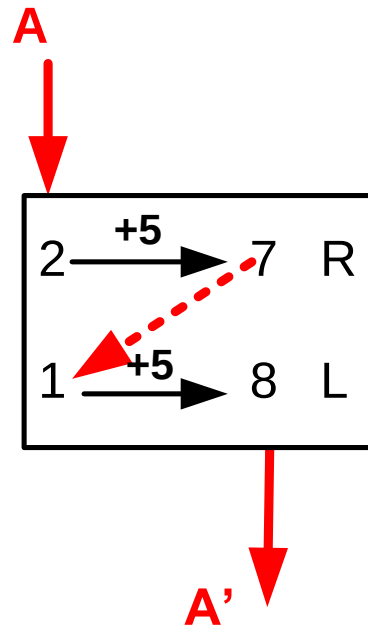


Example # 2 : on Chain Winding

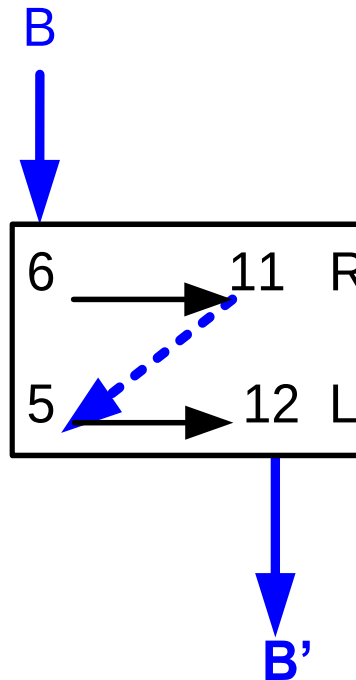
- Using the data and the solution of Example #2, construct the single-layer chain winding diagram.

Connection diagrams

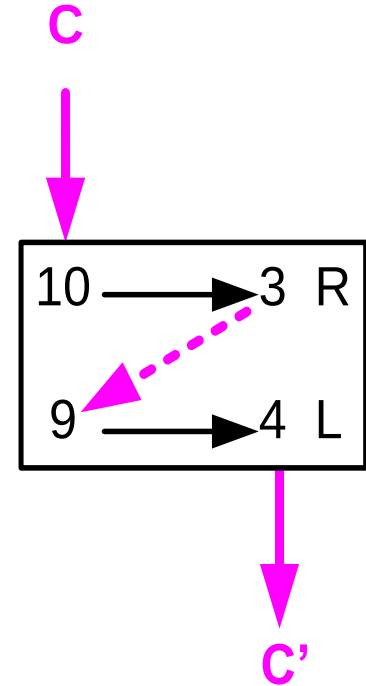
Phase A



Phase B



Phase C

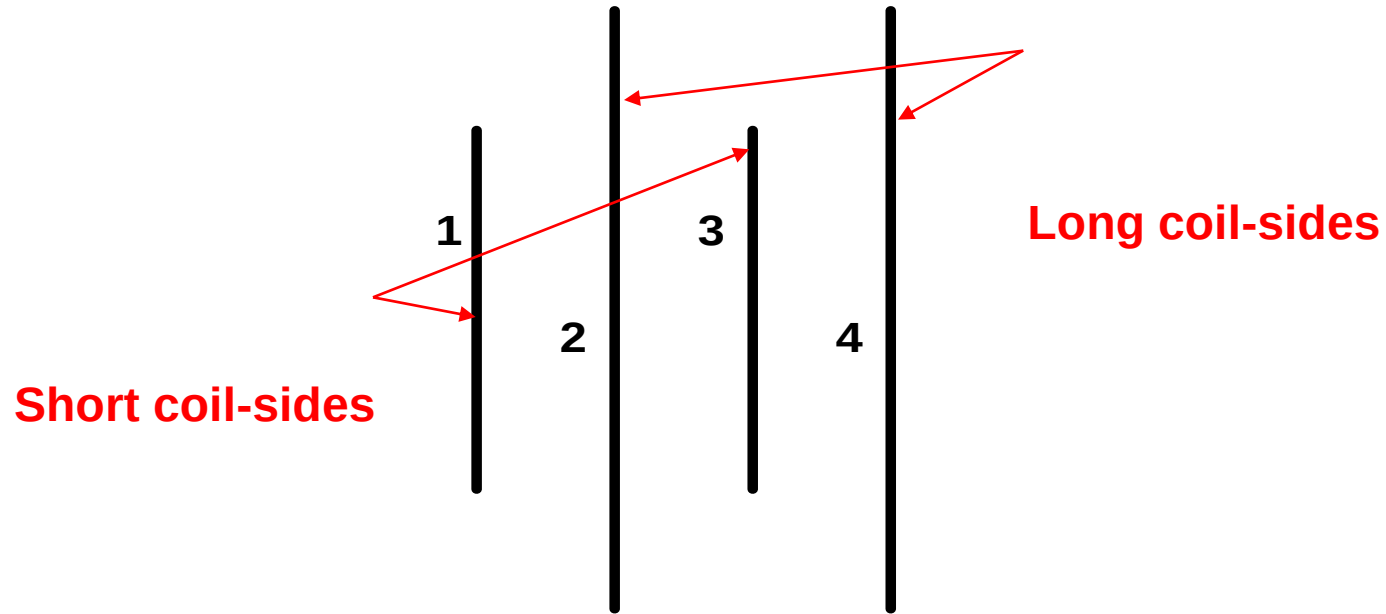


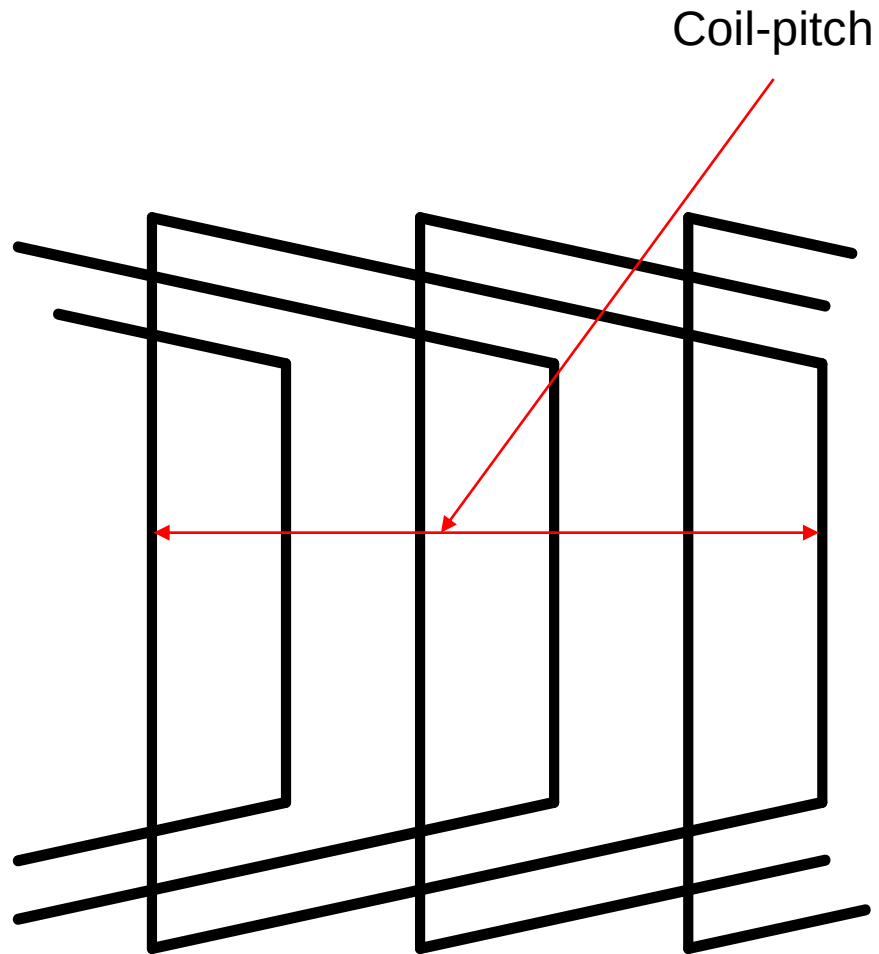


MUSH WINDING

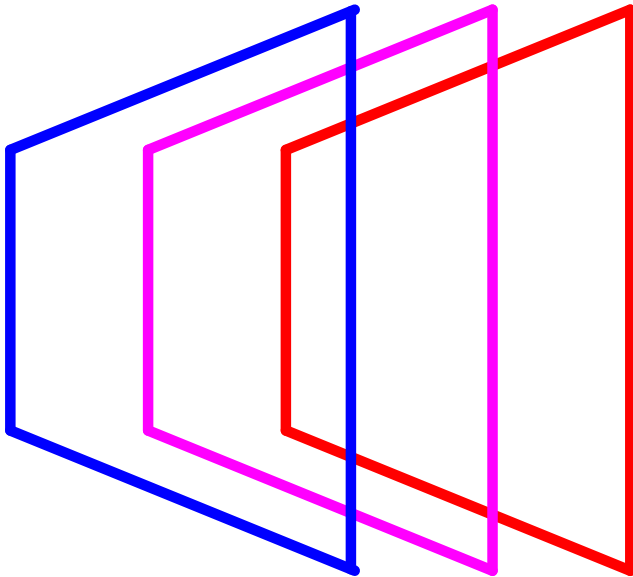
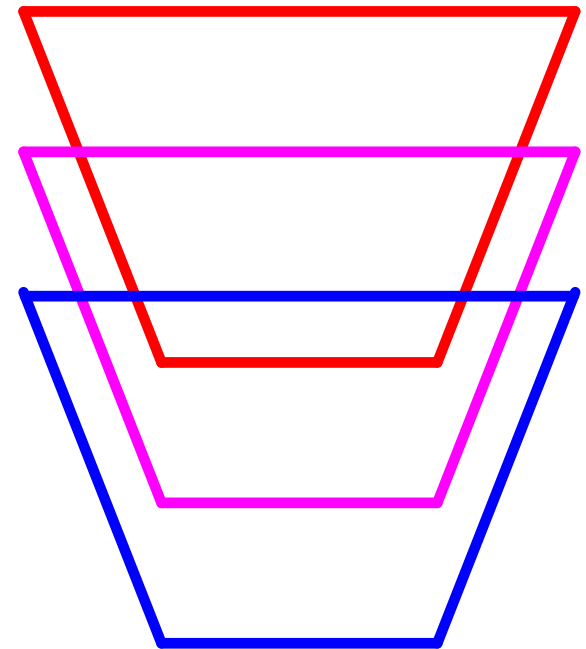
- ❑ This winding is very commonly used for small induction motors having circular conductors.
- ❑ This is a single layer winding where all the coils have same span (unlike the concentric winding where coils have different spans).
- ❑ Each coil is wound on a former, making one coil side shorter than the 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 also be 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.

Coil-sides of mush winding arrangement inside the slots





Basket winding



Points to be remembered

The following should be kept in mind while designing a brush 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 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 a even numbered slot and the other in a odd number slot giving a coil span which is an odd integer.

Example#3: on mush winding

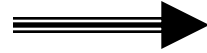
Given data

S=12; p=2; m=3; a=1; type=Mush

• **Solution**

a) The number of coil groups, K

$$K = 3 \cdot \frac{P}{2} = 3 \cdot \frac{2}{2} = 3$$



i.e. there is one coil group per phase

b) The number of slots per pole per phase, q

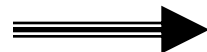
$$q = \frac{S}{m \cdot p} = \frac{12}{3 \cdot 2} = 2$$



i.e. there are two coils in a group

c) Coil pitch

$$Y_s = \frac{S}{p} = \frac{12}{2} = 6$$



Full-Pitch

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

d) The electrical angle, γ

$$\gamma = 180 \cdot P = 180 \cdot 2 = 360^\circ$$

e) The angle between adjacent slots, α

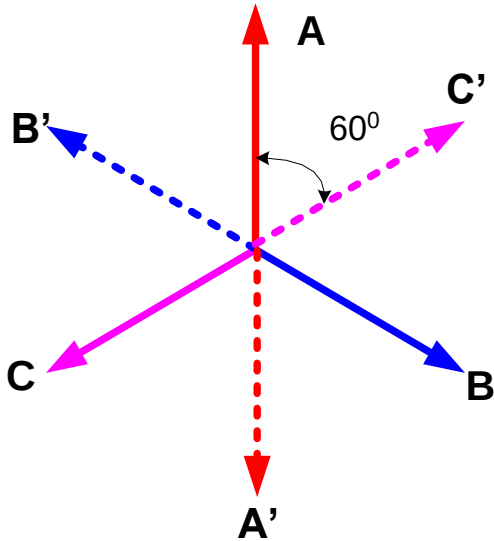
$$\alpha = \frac{\gamma}{S} = \frac{360^\circ}{12} = 30^\circ$$

f) The distance between the beginning of each phase, λ

$$\lambda = \frac{120^\circ}{\alpha} = \frac{120^\circ}{30^\circ} = 4 \text{ slots}$$

g) If the beginning of Phase A is slot 1, then the beginning of phase B is slot $1+\lambda=5$ and the beginning of phase C is slot $1+2\lambda=1+8=9$

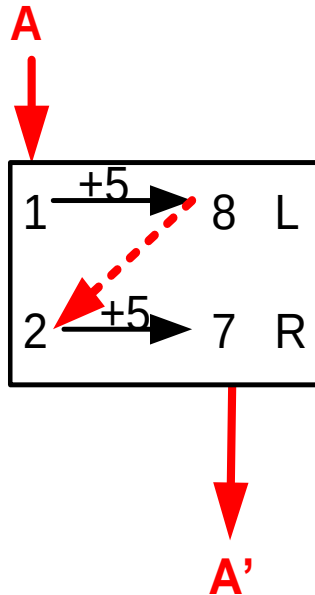
Phase sequence



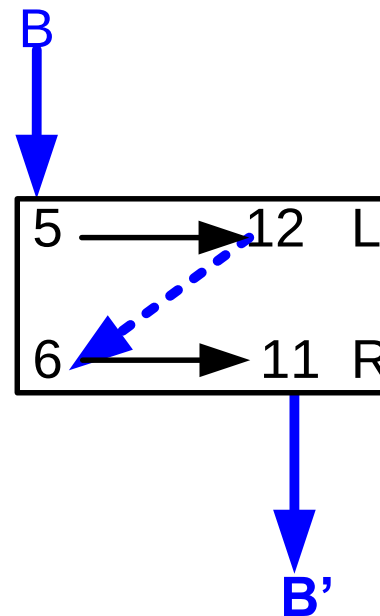
1	2	3	4	5	6	7	8	9	10	11	12
A	A	C'	C'	B	B	A'	A'	C	C	B'	B'

Connection Diagrams

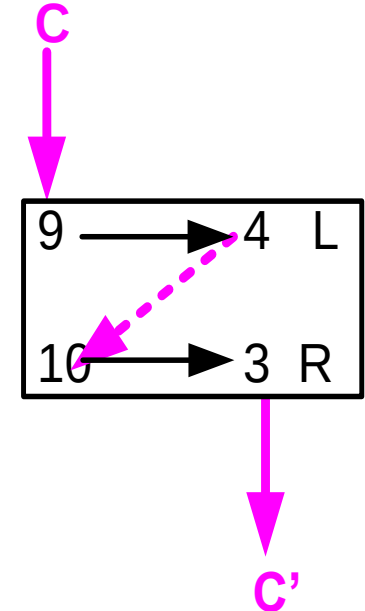
Phase A



Phase B



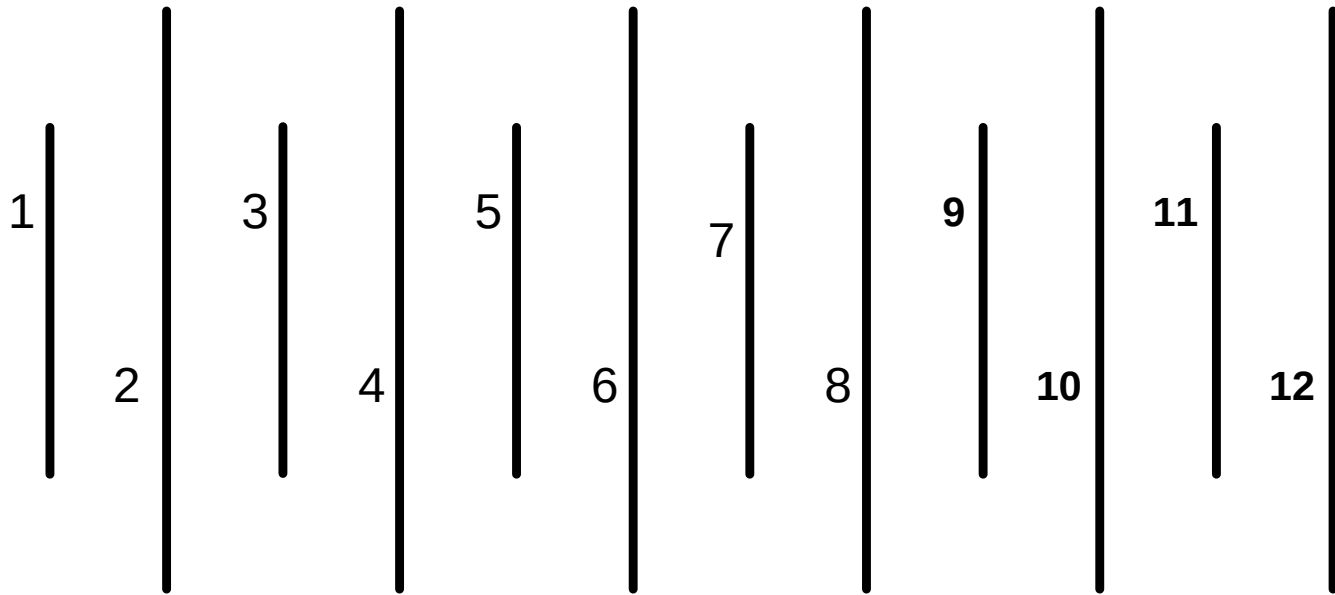
Phase C

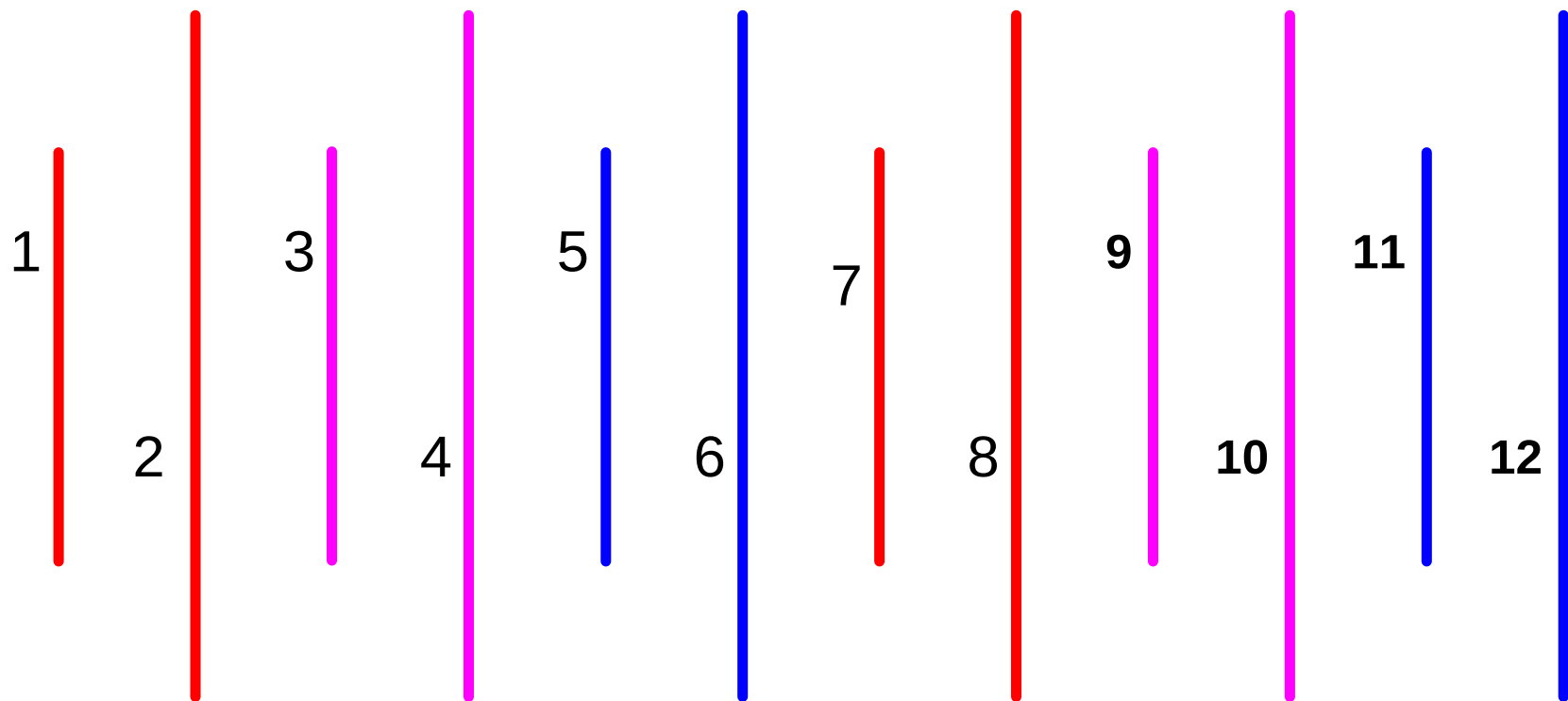


PROCEDURE FOR CONSTRUCTING OF MUSH WINDINGS

Data: $S = 12$, $P = 2$, $a = 1$, $q = 2$, $K = 3$

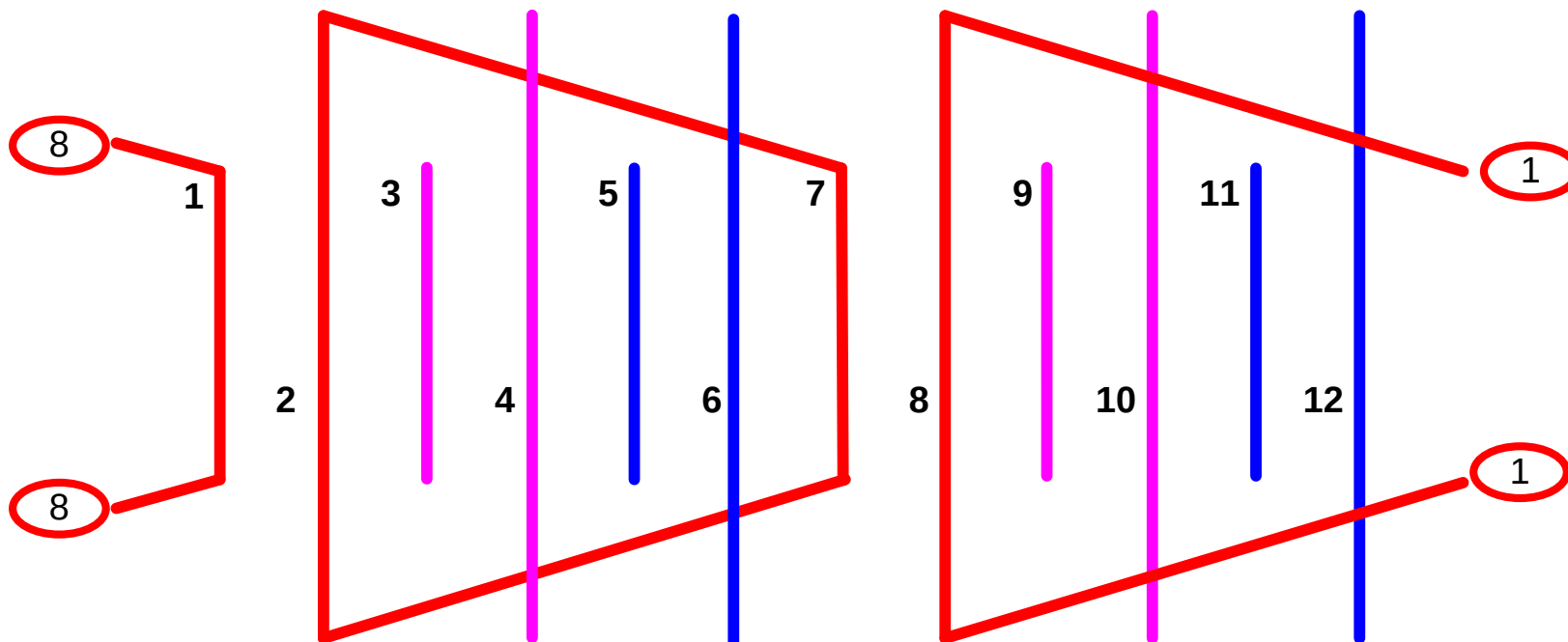
1. Draw 12 vertical lines with short and long coil-sides consequently and number them



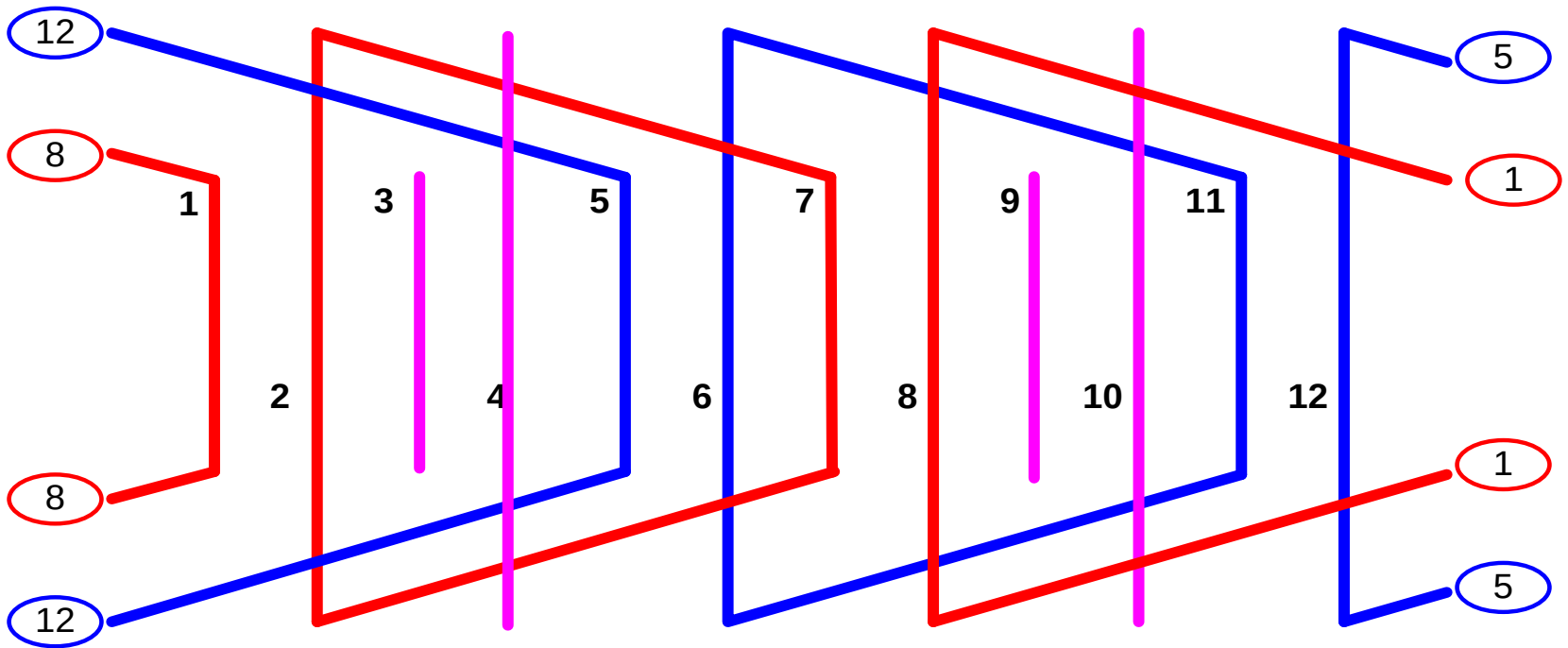


Coil group of Phase A

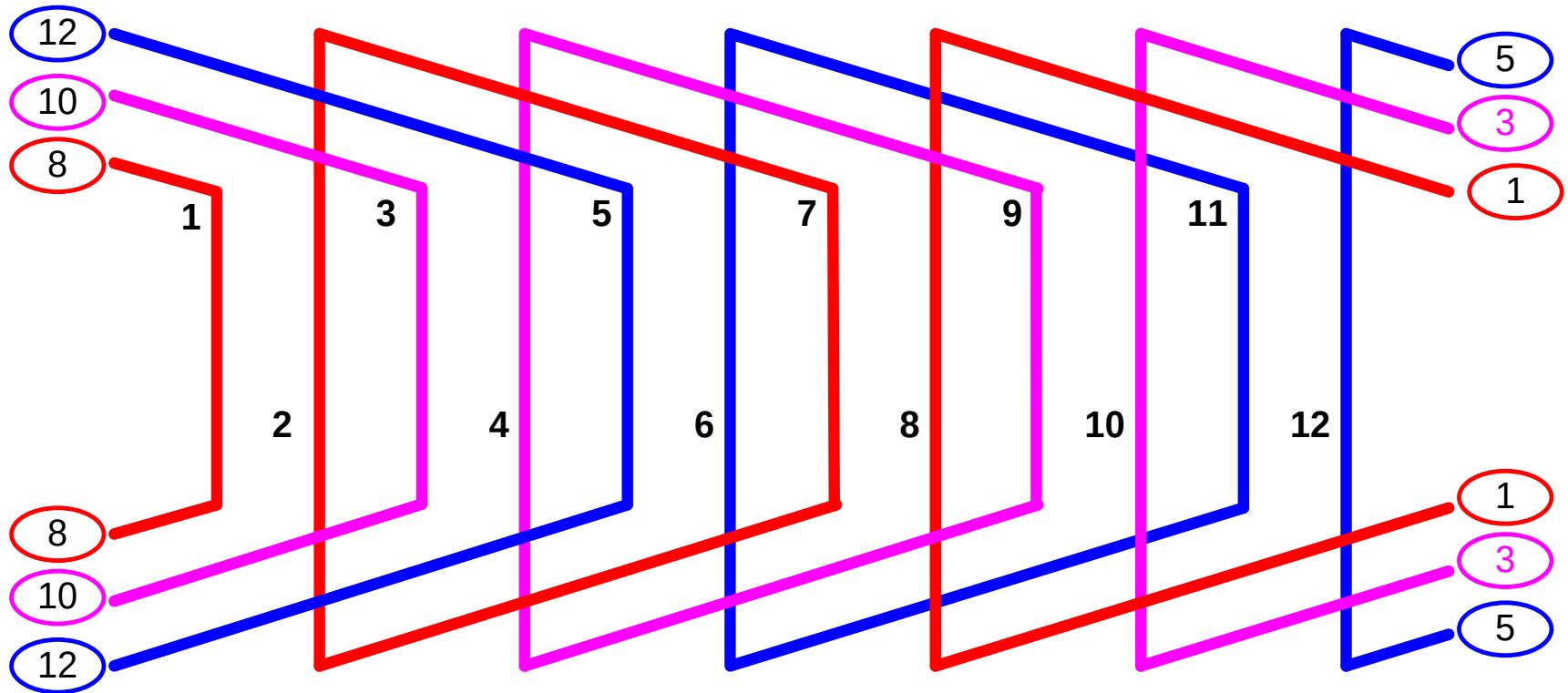
- Lay down coil-group belonging to phase A inside the slots 1,2 and 7,8.



Coil group of Phase B



Coil group of Phase C



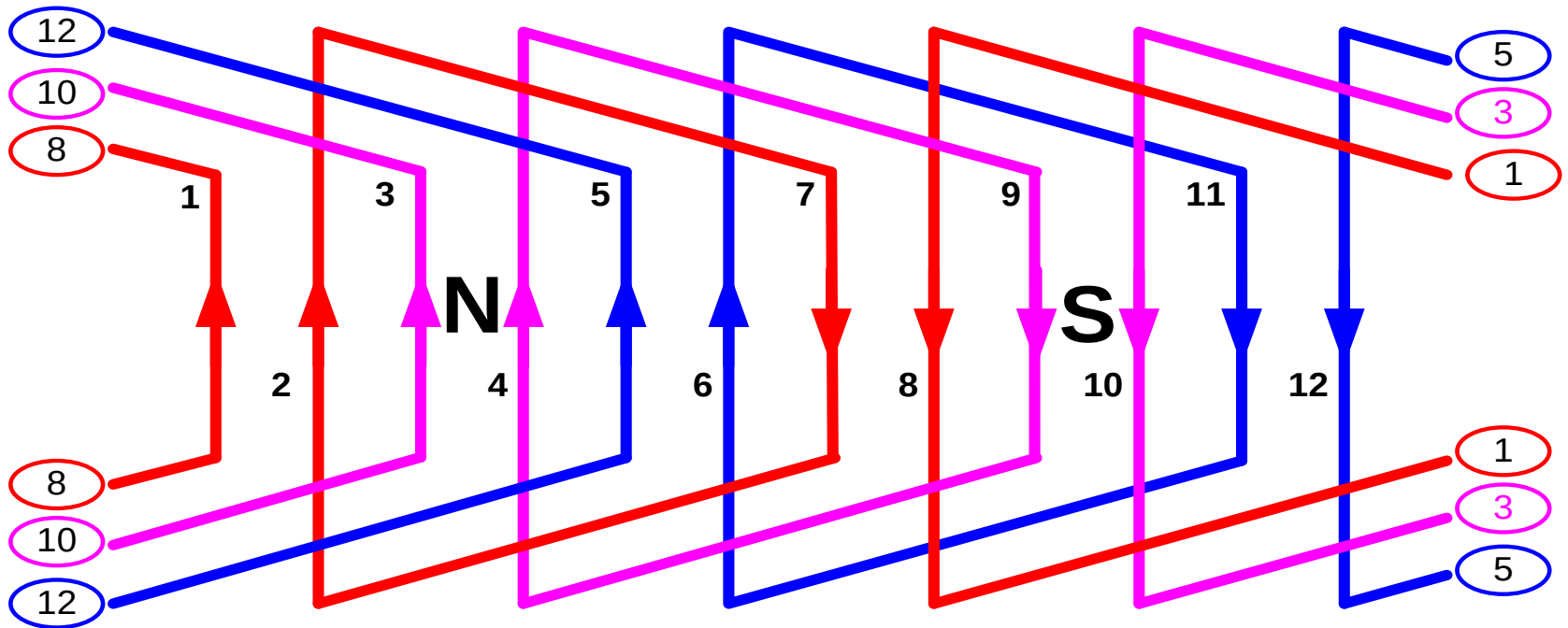
Current direction



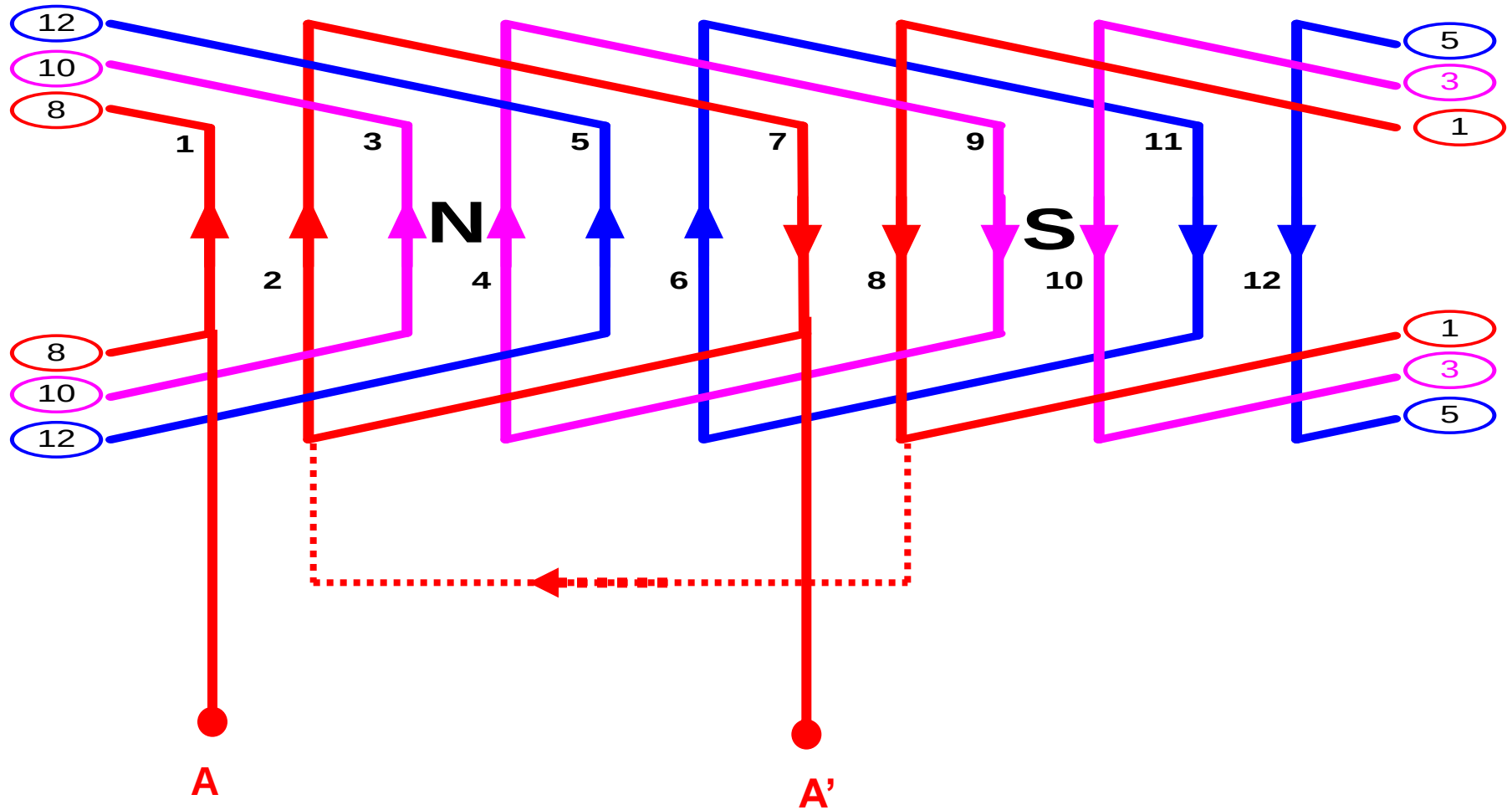
N
1-6



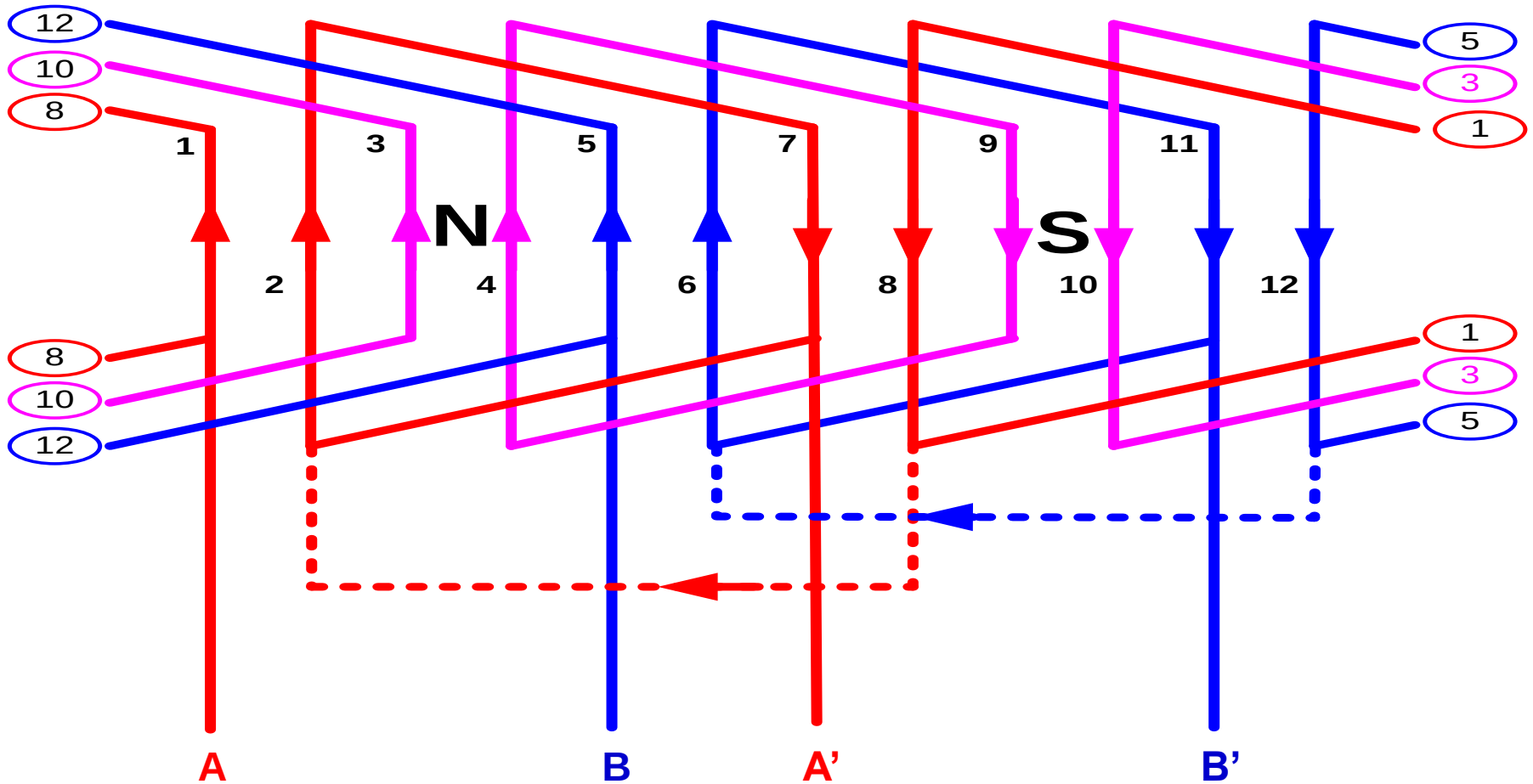
S
7-12



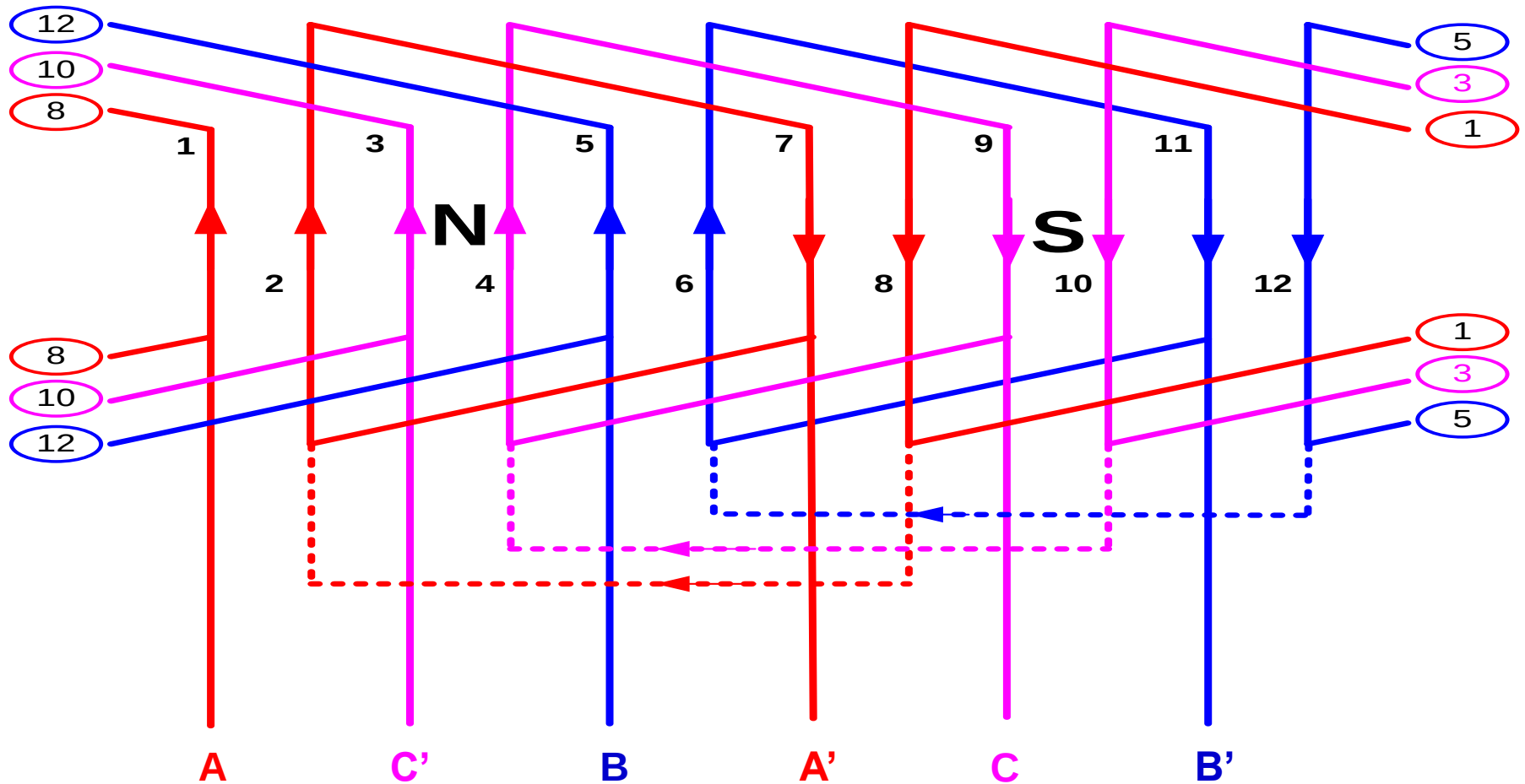
Phase A: Coil group interconnection



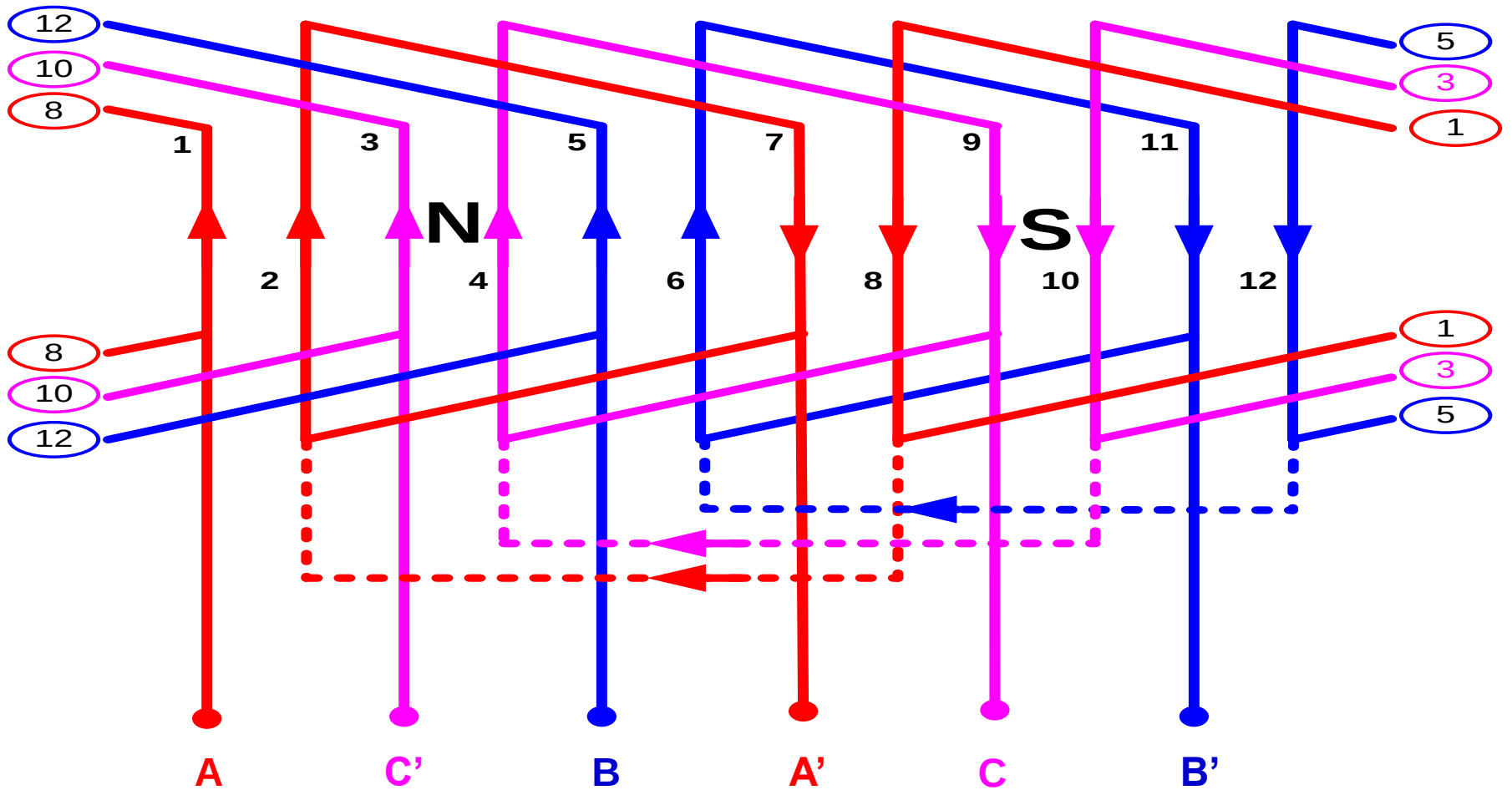
Phase B: Coil group interconnection



Phase C: Coil group interconnection



Terminals



DOUBLE LAYER

Double layer windings differ from single layer winding mainly on the following main points:

- ❑ Each slot is occupied by the side of two coils and each coil is arranged to form two layer round stator.
- ❑ One layer of the winding lies in the bottom half of the slots and the other in the top half of slots.
- ❑ Unlike the concentric winding double layer winding consists of identical coils all of the same shape and pitch.
- ❑ In a double layer winding, the coil pitch is the distance between the top and the bottom sides of the coil expressed by the number of slots spanned or by the coil sides or by the number of slots occupied by each coil side.
- ❑ A coil pitch may be full or fractional. Majority stator windings use a fractional pitch because
 - ✓ *The amount of copper used in the overhang (end winding) reduced and hence a saving on copper, and*
 - ✓ *The magnitude of certain harmonics in the emf and also mmf is reduced.*

The full pitch is determined by

$$Y_s = \frac{S}{P}$$

- ❑ Usually the full pitch is shortened by one-sixth i.e. for example if the full pitch is 12 a fractional will be 10.
- ❑ Since the coils are wound with a continuous length of wire there are no connections between turns.

Double Layer Three phase windings

- ❑ The main value characterizing the two layer winding is the number of slots per pole per phase.

$$q = \frac{S}{P \cdot m}$$

- ❑ By looking double layer winding externally, it is not possible to determine q .
- ❑ The total number of coils in two layer winding is equal to the number of slot since each side of a coil occupies one half of a slot which is equivalent to occupying one full slot per coil.
- ❑ In order to avoid making solder joints between coils, several coils, depending upon slots per pole per phase, are generally wound from a single length of wire in to full coil group.
- ❑ The number of coil groups per phase is a equal to the number of poles the whole winding. That is

$$\frac{K}{m} = P$$

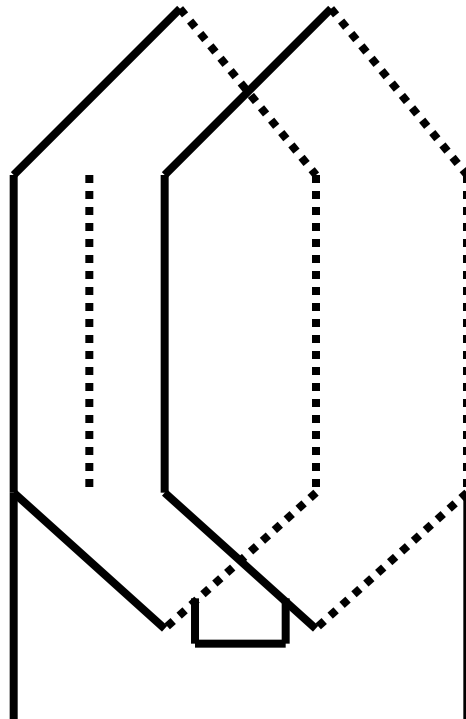


$$K = mP$$

- ❑ This is, twice that in a single-layer winding.

Rule for double layer windings

- ❑ The coil groups should be connected to each other by joining the leads of like polarity i.e. the finish of one group to the finish of the next group and the start of one group to the start of the next group.



Example # 4: on double layer winding

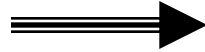
Given data

$S=12$; $p=2$; $m=3$; $a=1$; type=Double layer: the pitch shortened by one slot

• **Solution**

a) The number of coil groups, K

$$K = 3 \cdot P = 3 \cdot 2 = 6$$



i.e. there is two coil groups per phase

b) The number of slots per pole per phase, q

$$q = \frac{S}{m \cdot p} = \frac{12}{3 \cdot 2} = 2$$



i.e. there are two coils in a group

c) Coil pitch

$$Y_s = \frac{S}{p} = \frac{12}{2} = 6$$



Full-Pitch

Let us shorten the pitch by one slot and make $Y_s = 5$.

d) The electrical angle, γ

$$\gamma = 180 \cdot P = 180 \cdot 2 = 360^\circ$$

e) The angle between adjacent slots, α

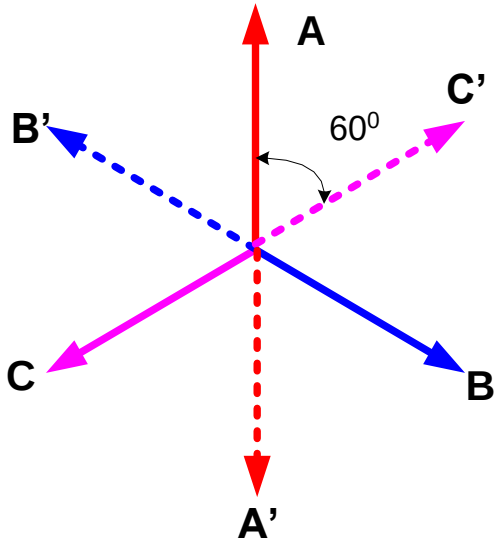
$$\alpha = \frac{\gamma}{S} = \frac{360^\circ}{12} = 30^\circ$$

f) The distance between the beginning of each phase, λ

$$\lambda = \frac{120^\circ}{\alpha} = \frac{120^\circ}{30^\circ} = 4 \text{ slots}$$

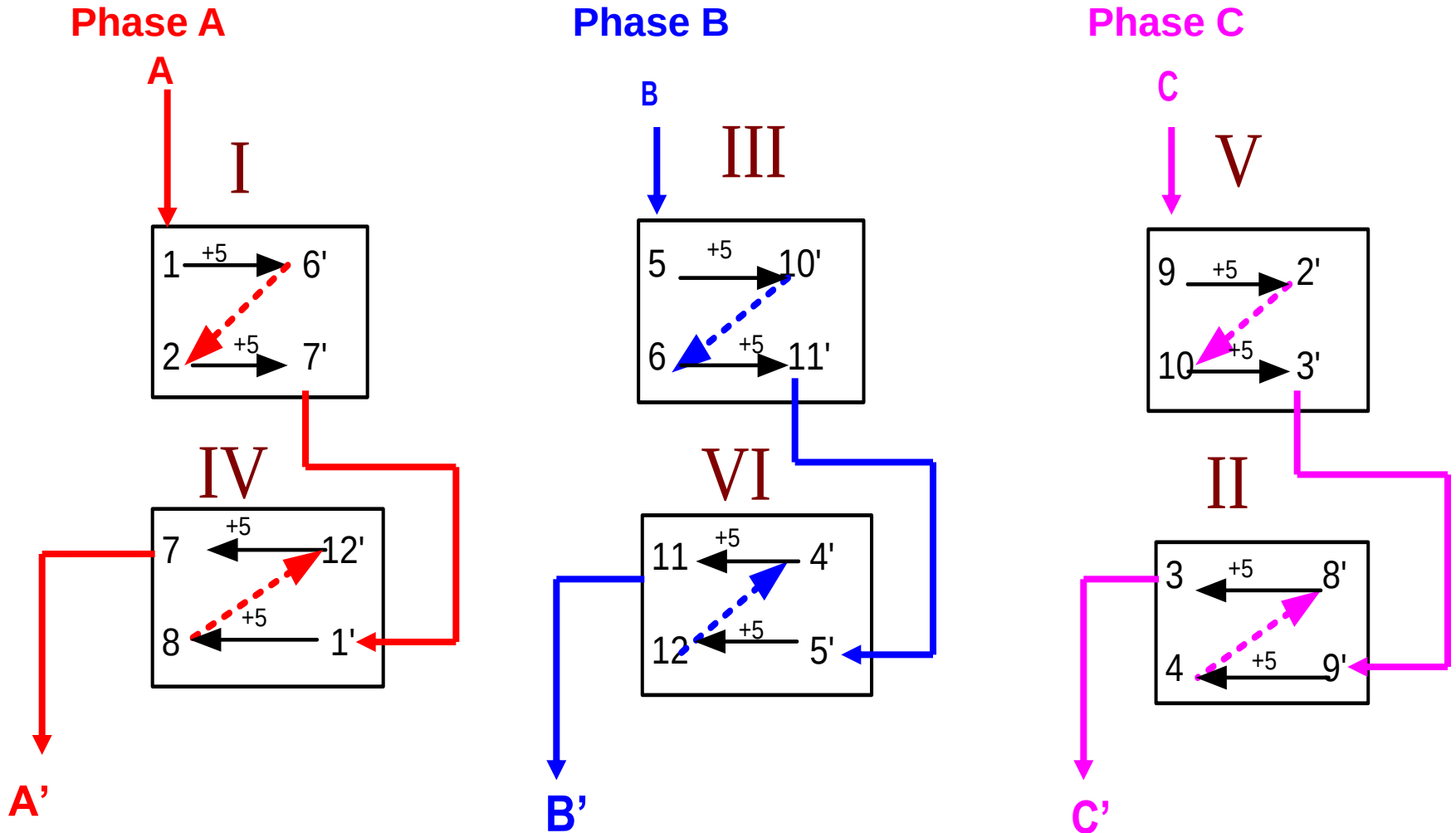
g) If the beginning of Phase A is slot 1, then the beginning of phase B is slot $1+\lambda=5$ and the beginning of phase B is slot $1+2\lambda=1+8=9$

Phase sequence (Top layer Coil-sides)



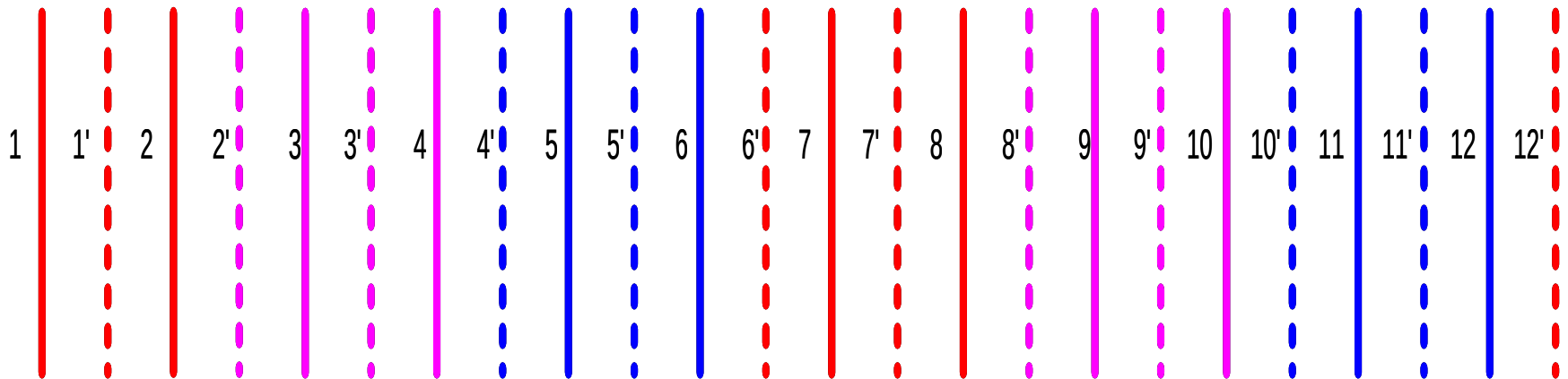
1	2	3	4	5	6	7	8	9	10	11	12
A	A	C'	C'	B	B	A'	A'	C	C	B'	B'

Connection Diagrams

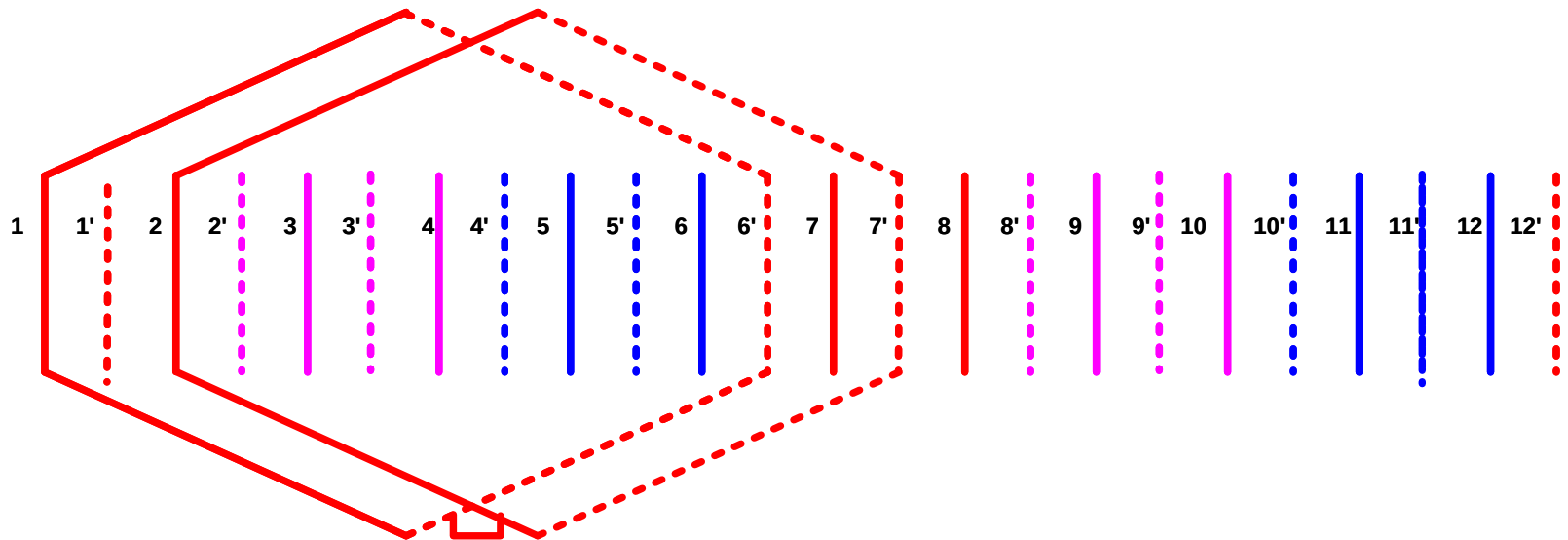


PROCEDURE FOR CONSTRUCTING OF DOUBLE LAYER WINDINGS

- Draw 24 vertical lines to represent the two coil sides lying in each of the 12 slots. For each slot the full line at the left hand side will represent a top a coil side and broken line at the right hand side a bottom coil side.

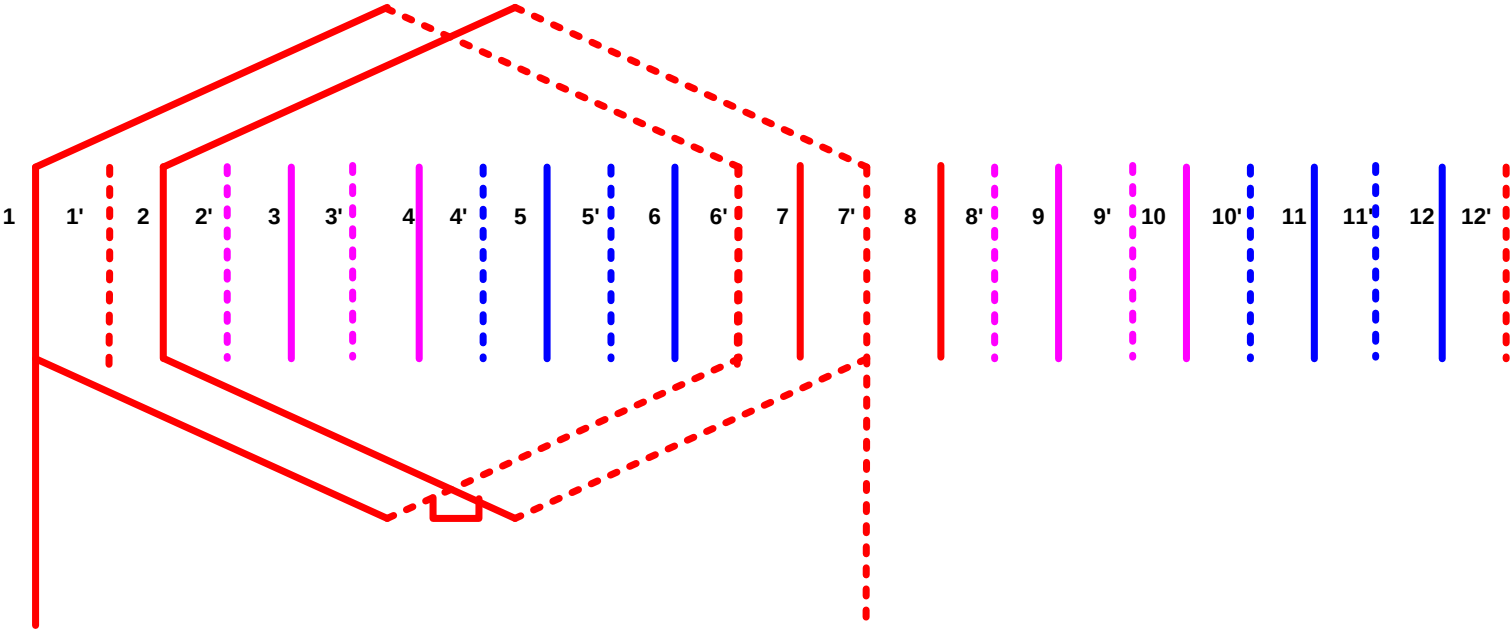


- ❑ The top part of slot 1 will be taken as the beginning of the first phase. According to the selected fractional pitch, the conductor from slot 1 is now connected to that in the bottom coil side in slot $1 + 5 = 6'$.

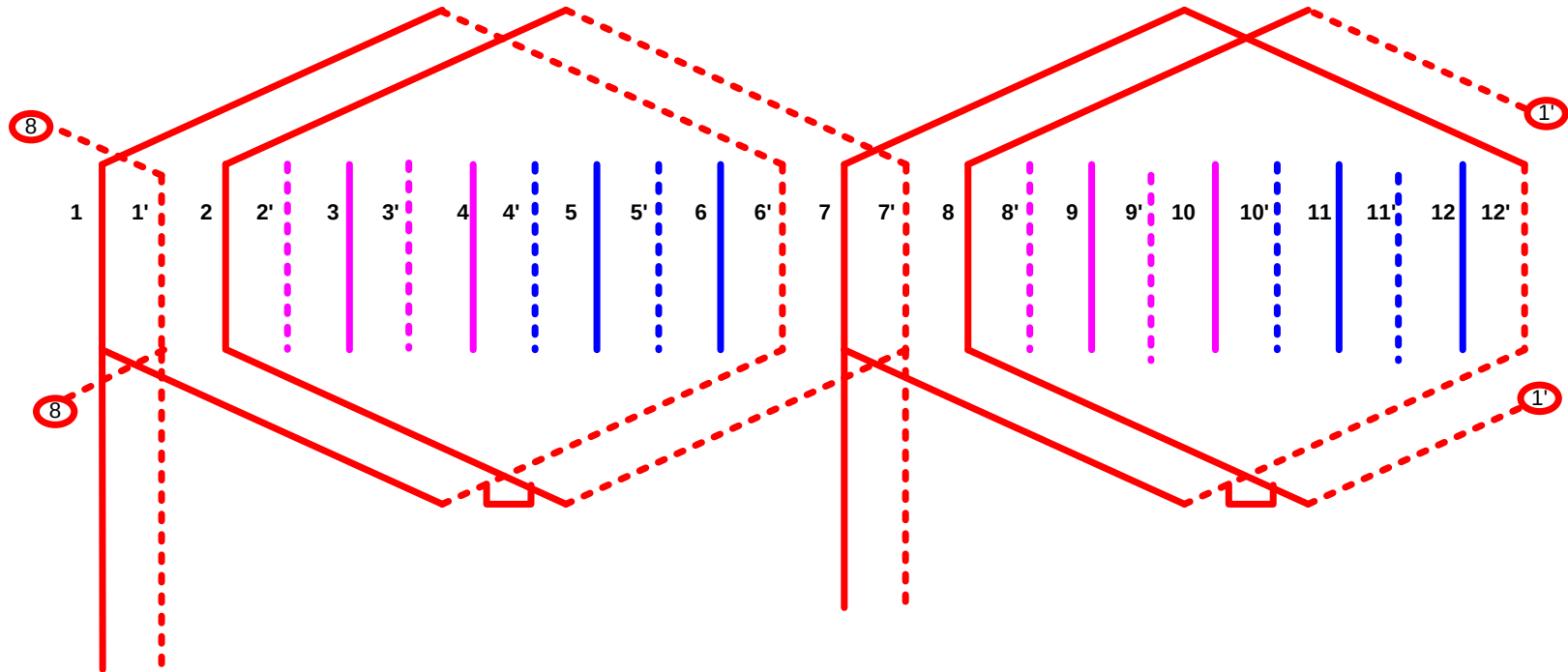
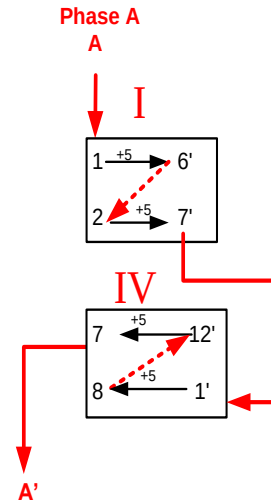




Since $q = 2$ i.e. each coil group will consists of two coils. The conductor must therefore leave the bottom of slot 6 to enter the top of slot 2 and from there the bottom of slot 7. The lead emerging from slot 7 will be finish of the first coil group.

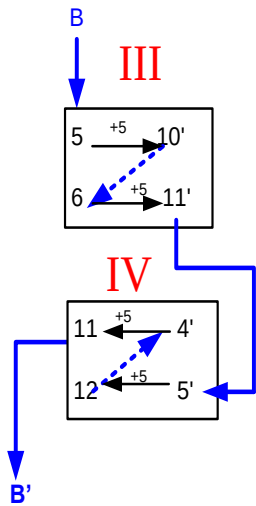
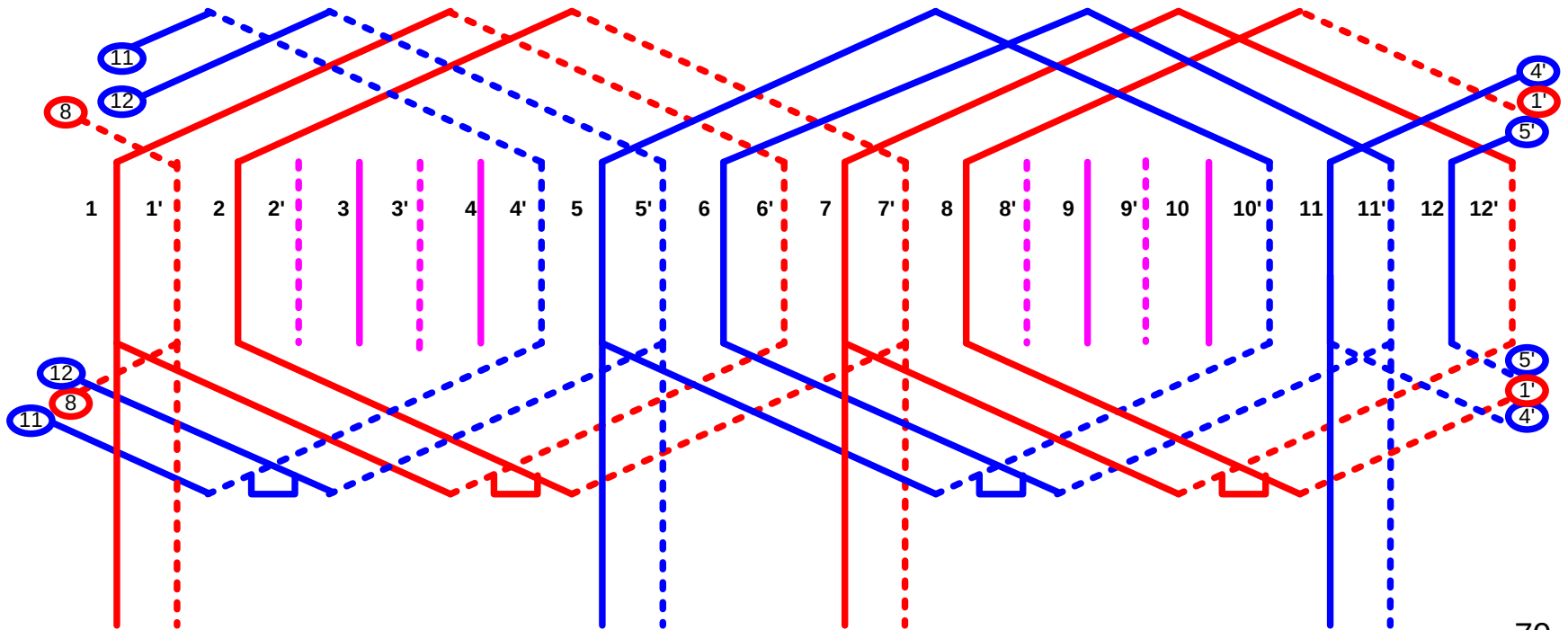


Phase A : Coil groups



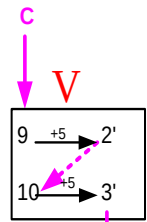
Phase B

Phase B: Coil groups

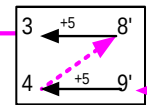
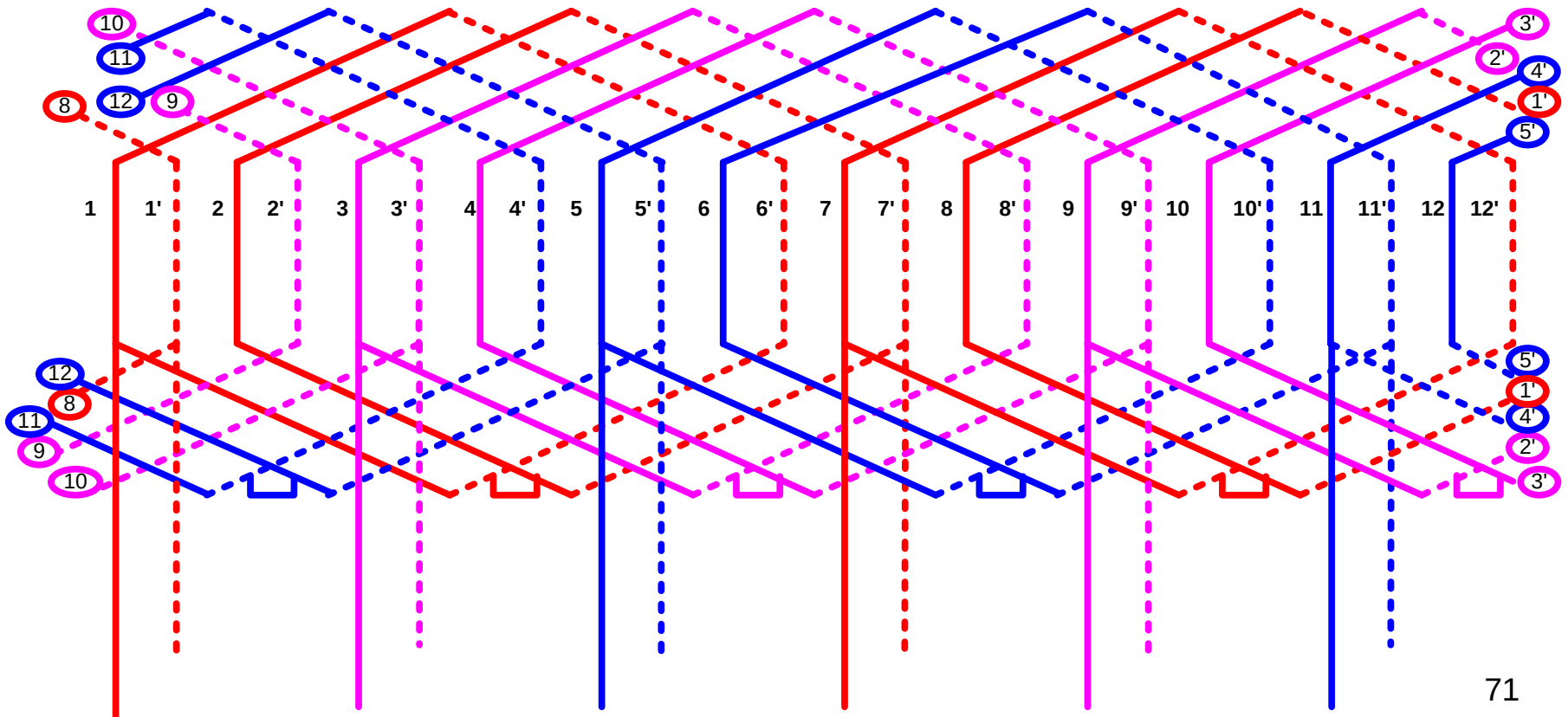


Phase C: Coil groups

Phase C



II



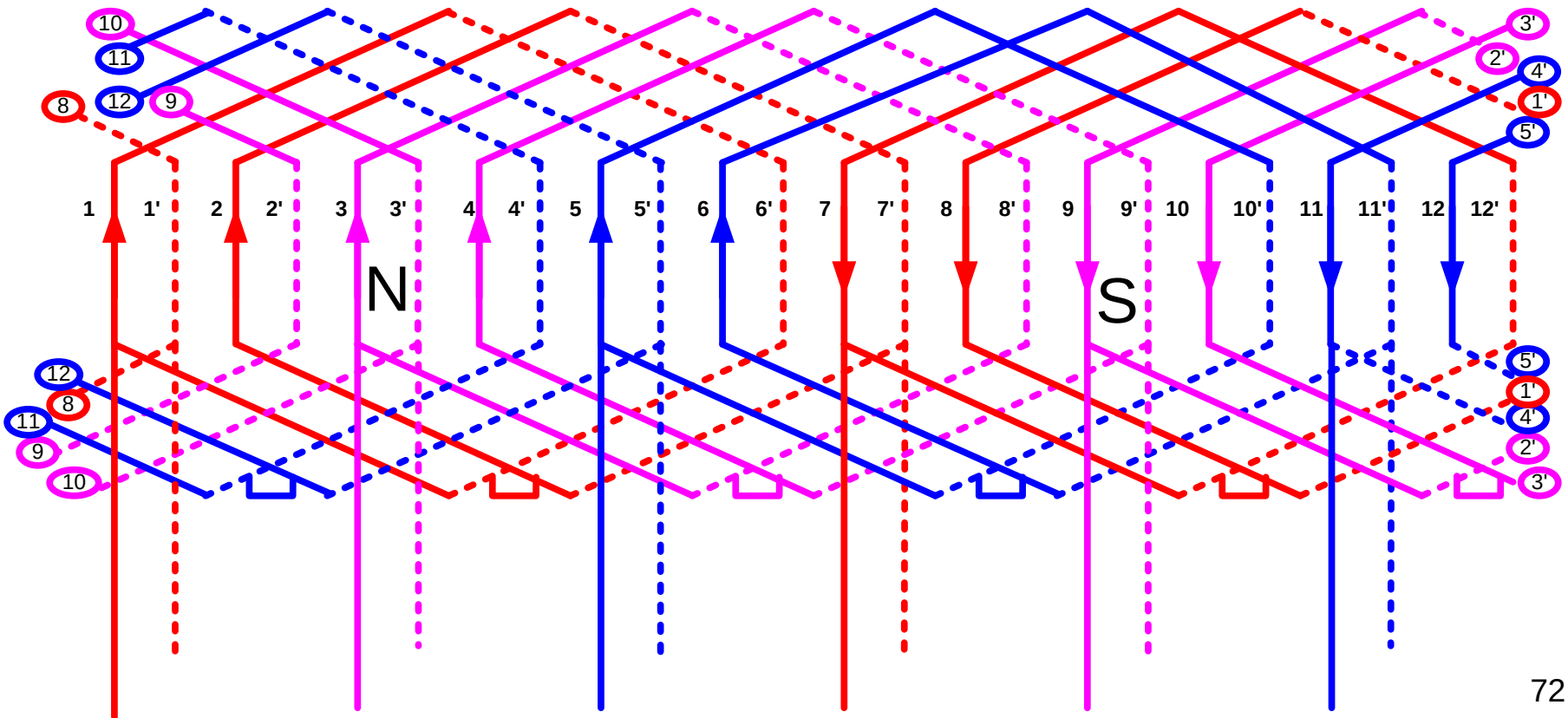
Current direction



N
1-6



S
7-12



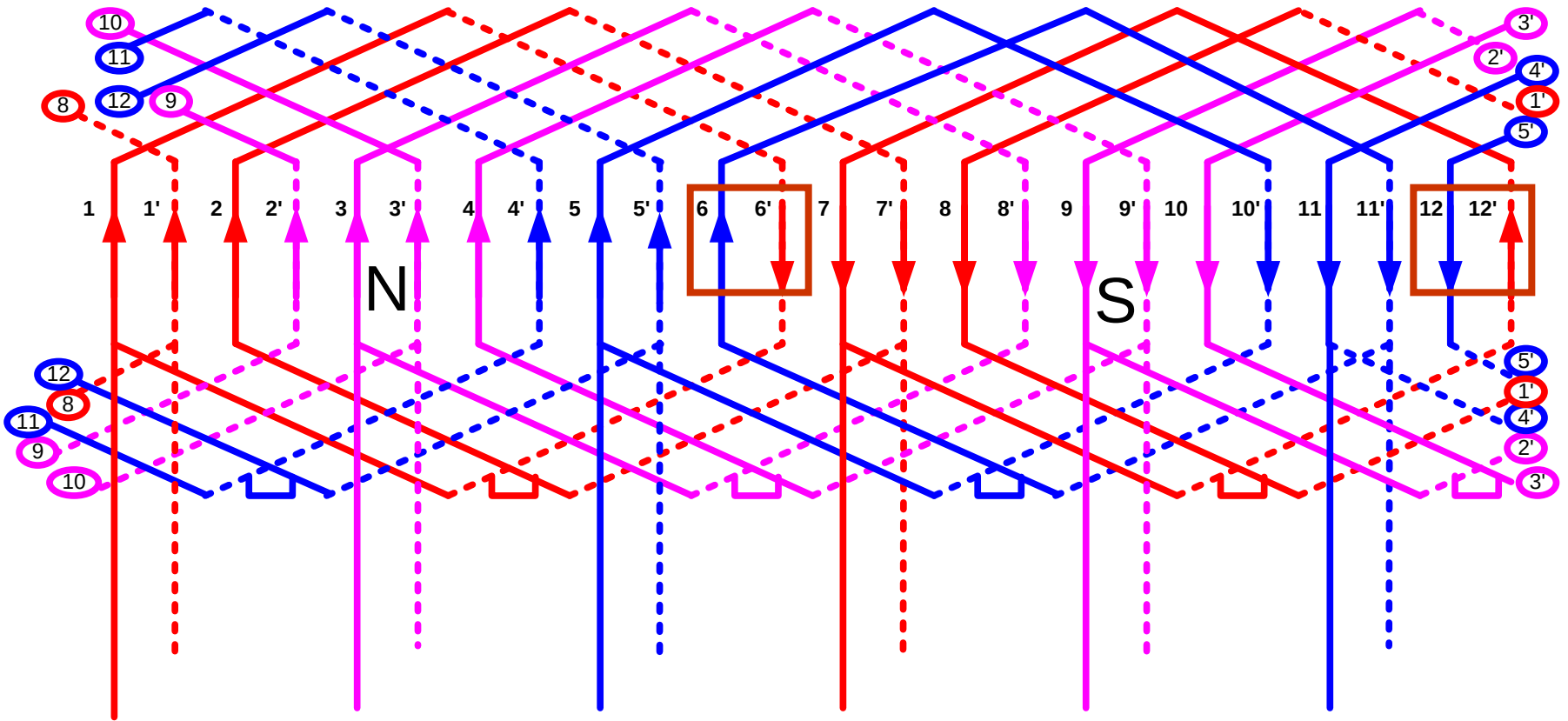
Current direction



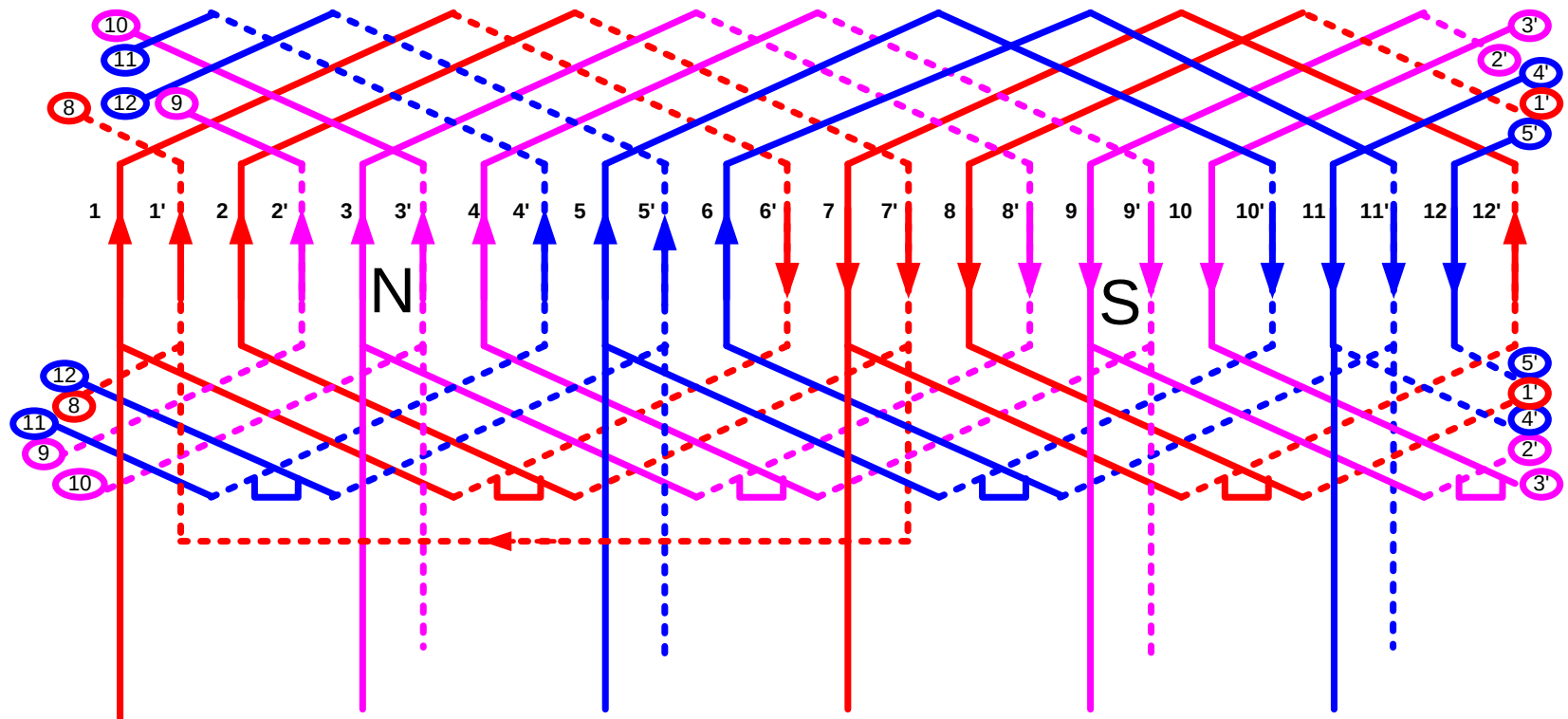
N
1-6



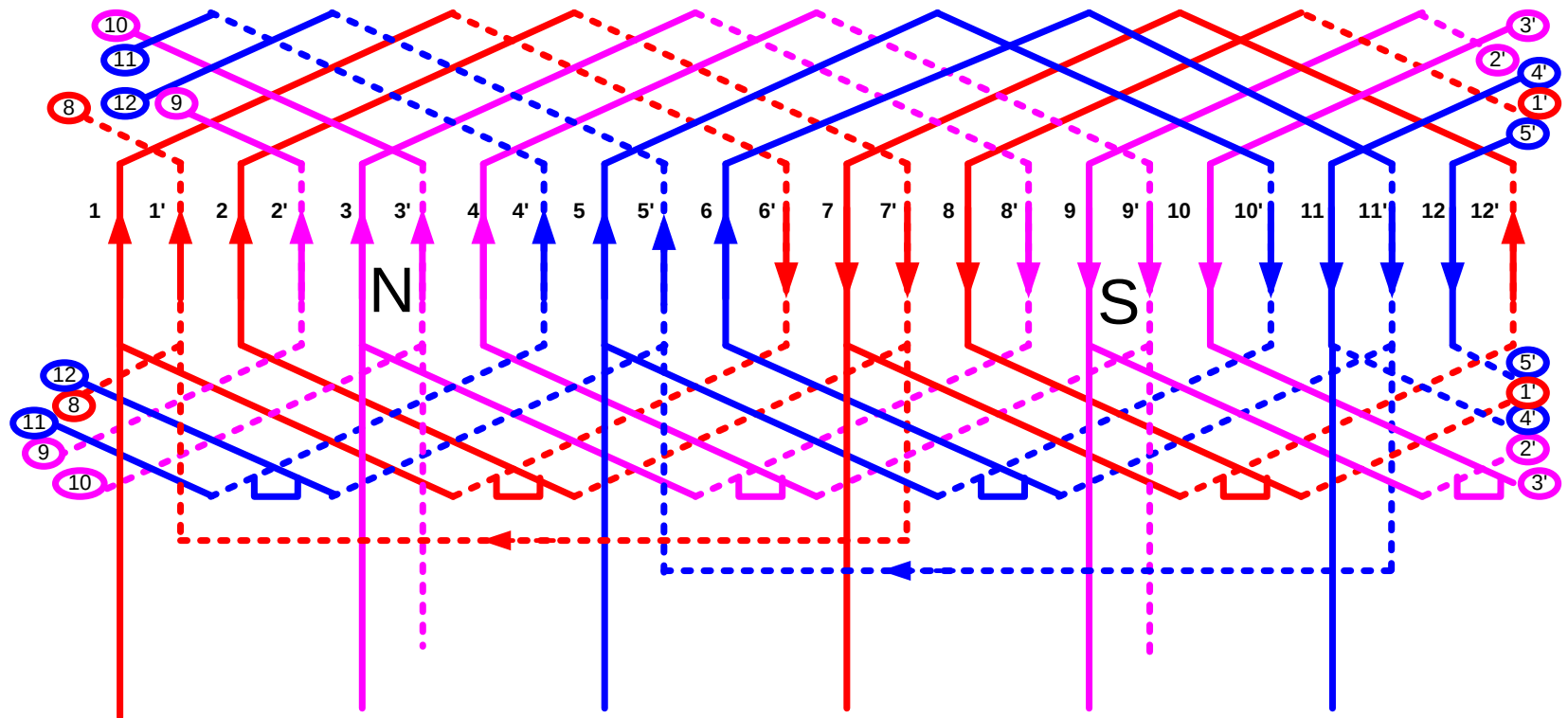
S
7-12



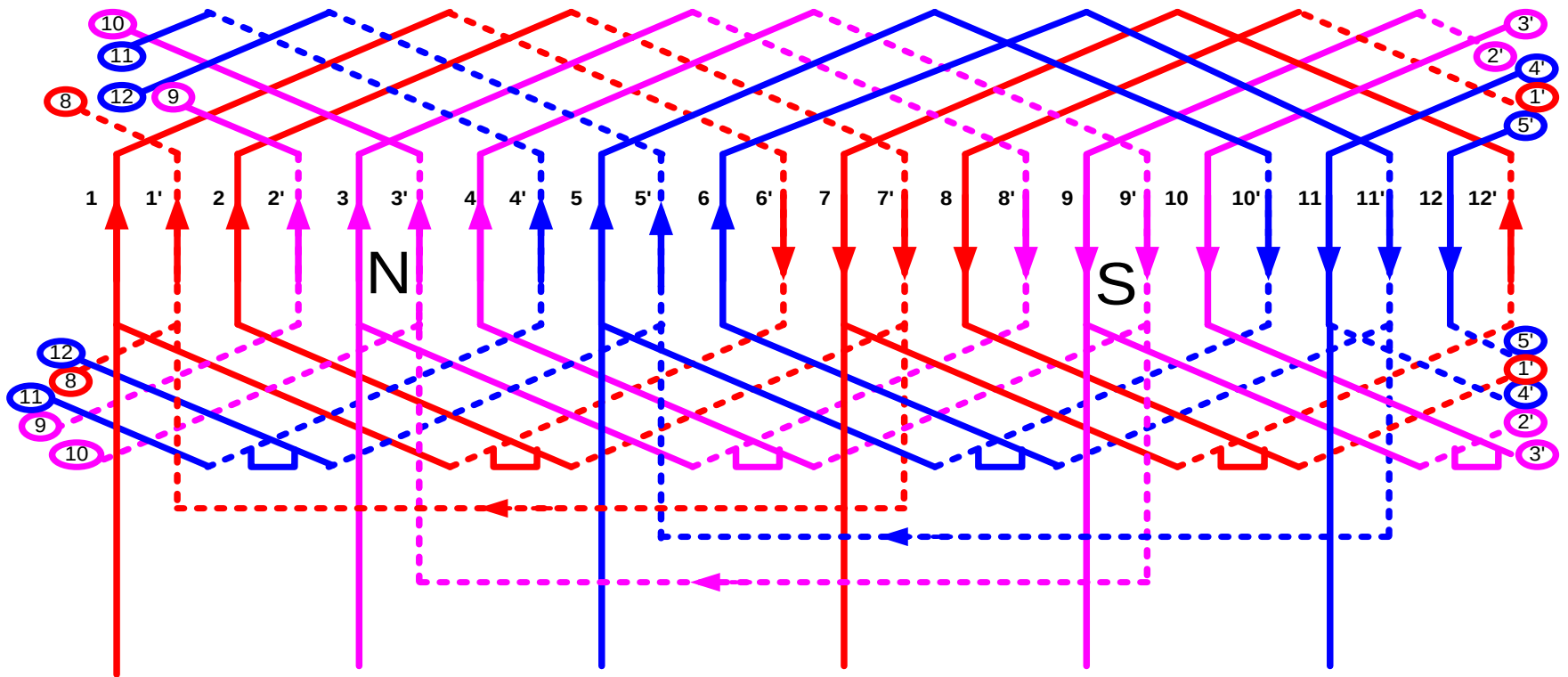
Phase A: Coil groups interconnection



Phase B: Coil groups interconnection



Phase C: Coil groups interconnection



Terminal leads

