

Lesson 35

Constructional Features of D.C Machines

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35.1 Goals of the lesson

In this lesson, important constructional features of a D.C machine are presented along with a discussion on D.C armature winding.

Key Words: Field winding, armature winding, commutator segments & brush arrangement.

After going through this section students will have clear ideas about the followings:

- The function of commutator & brush in a D.C Machine.
- Double layer winding.
- Coil span & commutator pitch.
- Lap & wave winding and number of armature parallel paths.

35.2 Introduction

As pointed out earlier, D.C machines were first developed and used extensively in spite of its complexities in the construction. The generated voltage in a coil when rotated relative to a magnetic field, is inherently *alternating* in nature. To convert this A.C voltage into a D.C voltage we therefore need a *unit* after the coil terminals. This unit comprises of a number *commutator segments* attached to the shaft of the rotor and a pair of suitably placed stationary *carbon brushes* touching the commutator segments. Commutator segments together with the fixed brushes do the necessary rectification from A.C to D.C and hence sometimes called *mechanical rectifier*.

35.3 Constructional Features

Figure 35.1 shows a sectional view of a 4-pole D.C machine. The length of the machine is perpendicular to the paper. Stator has got 4 numbers of projected poles with coils wound over it. These coils may be connected in series in order that consecutive poles produce opposite polarities (i.e., N-S-N-S) when excited from a source. Double layer lap or wave windings are generally used for armature. Essentially all the armature coils are connected in series forming a closed armature circuit. However as the coils are distributed, the resultant voltage acting in the closed path is zero thereby ensuring no circulating current in the armature. The junctions of two consecutive coils are terminated on to the commutator segments. Stationary carbon brushes are placed *physically* under the center of the stator poles touching the rotating commutator segments.

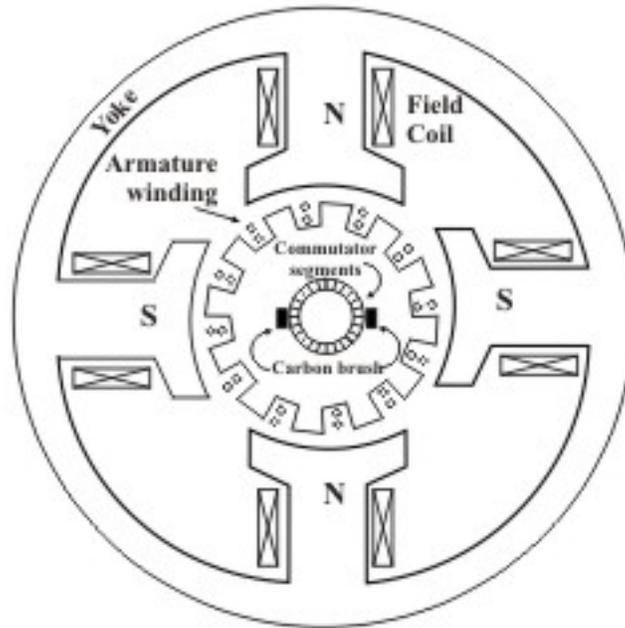


Figure 35.1: Sectional diagram of a D, C machine

Now let us examine how a D.C voltage is obtained across the brushes (armature terminals). Let us fix our attention to a particular position in space. Whichever conductor is present there right now, will have some definite induced voltage in it (dictated by $e = blv$). In course of rotation of the armature newer conductors will occupy this position in space. No matter which conductor comes to that particular position at any given point of time, it will have same voltage induced in it. This is true for all the positions although the magnitude and polarity of the voltages in different position may be different. The polarity of the voltage is opposite for conductor positions under north or south pole. Remembering that all the conductors are connected in series and brushes are suitably placed for obtaining maximum voltage, the magnitude of the voltage across the brushes will remain constant.

To understand the action of the commutator segments and brushes clearly, let us refer to the following figures (35.3 and 35.4) where a simple d.c machine working as generator are shown with armature occupying various positions. Armature has got a single rectangular coil with sides 1 and 2 shown in detail in figure (35.2). The two terminals 1 and 2 of the coil are firmly joined to commutator segments C1 and C2 respectively. Commutator segments C1 and C2, made of copper are insulated by mica insulation shown by lines between C1 and C2 and rotate along with the armature.

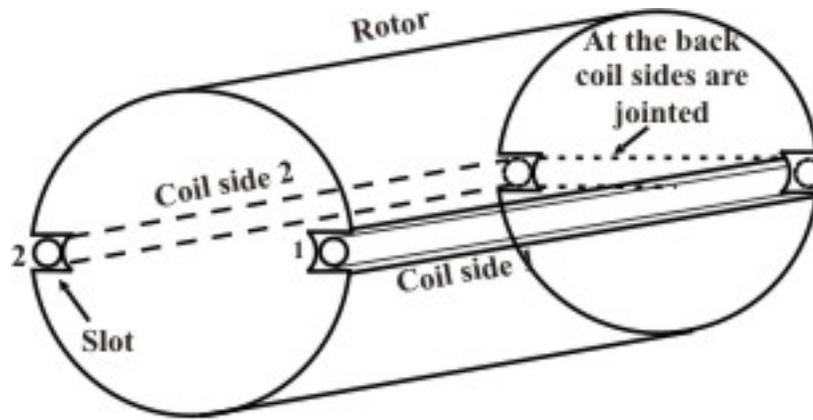


Figure 35.2: 3 dimensional view of a simple armature

B1 and B2 are stationary carbon brushes are placed over the rotating commutator in such a way that they always make electrical contact with the commutator segments. It is from the two brushes, two terminals are taken out and called the *armature* terminals. Brushes are kept in brush holders with a spring arrangement. Spring tension is so optimally adjusted that brushes make good contact with the commutator segments C1 and C2 and at the same time allows the rotor to move freely. Free end of conductors 1 and 2 are respectively terminated on C1 and C2. In other words any point on C1 represents free end of the conductor 1. Similarly any point on C2 represents free end of conductor 2. However, fixed brushes B1 and B2 make periodically contact with both C1 and C2 as rotor rotates. For clarity, field coils are not shown in the figure. Let us assume that the polarity of the projected stator poles are N and S. Let the armature be driven at a constant angular speed of ω in the ccw direction. Start counting time from the instant when the plane of the coil is vertical i.e., along the reference line. Position of the armature at this instant is shown in figure 35.3(i). There cannot be any induced voltage in conductors 1 and 2 at this position as no flux density component is available perpendicular to the tangential velocity of conductors 1 and 2.

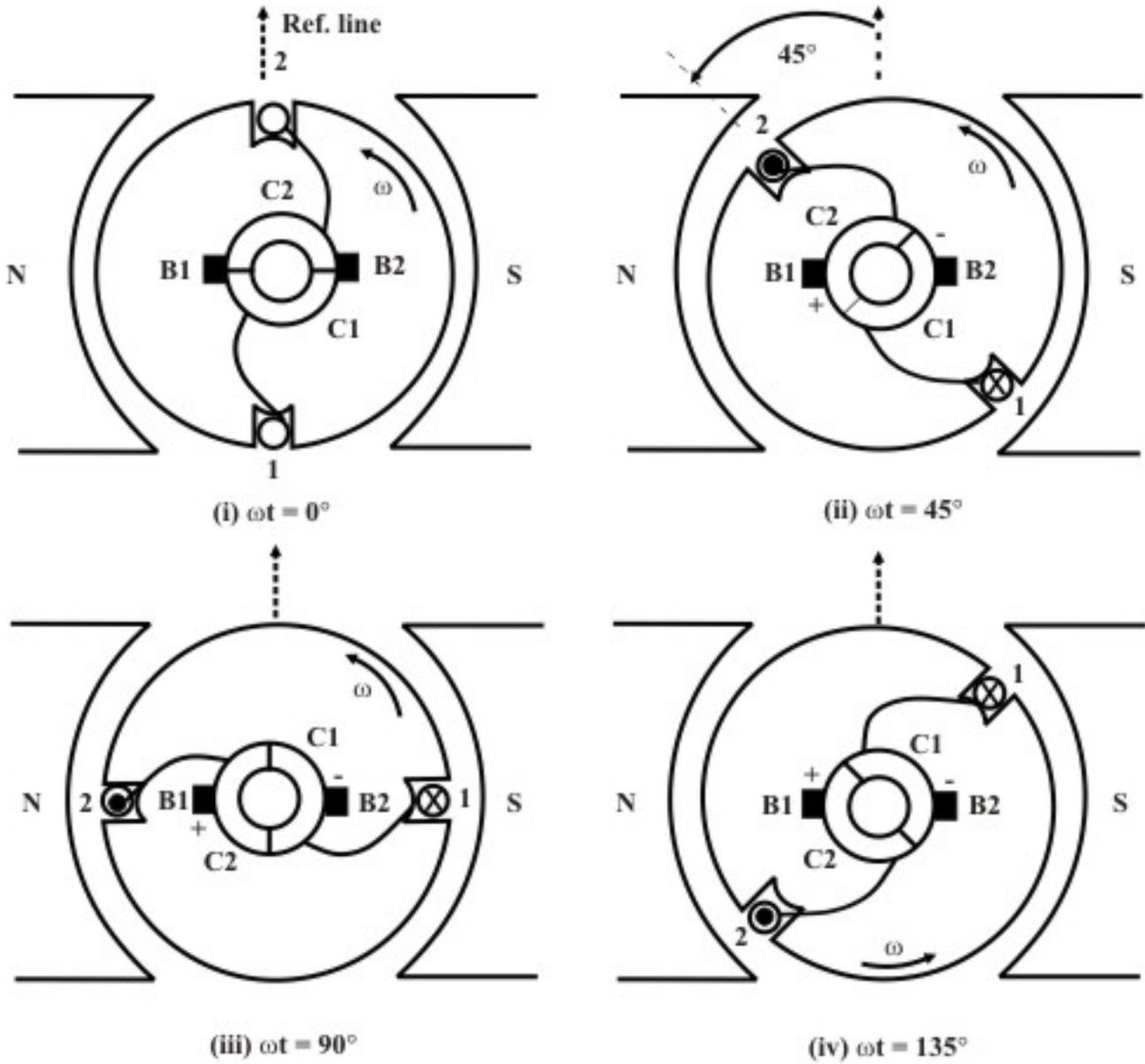


Figure 35.3: Explaining commutator & brush action

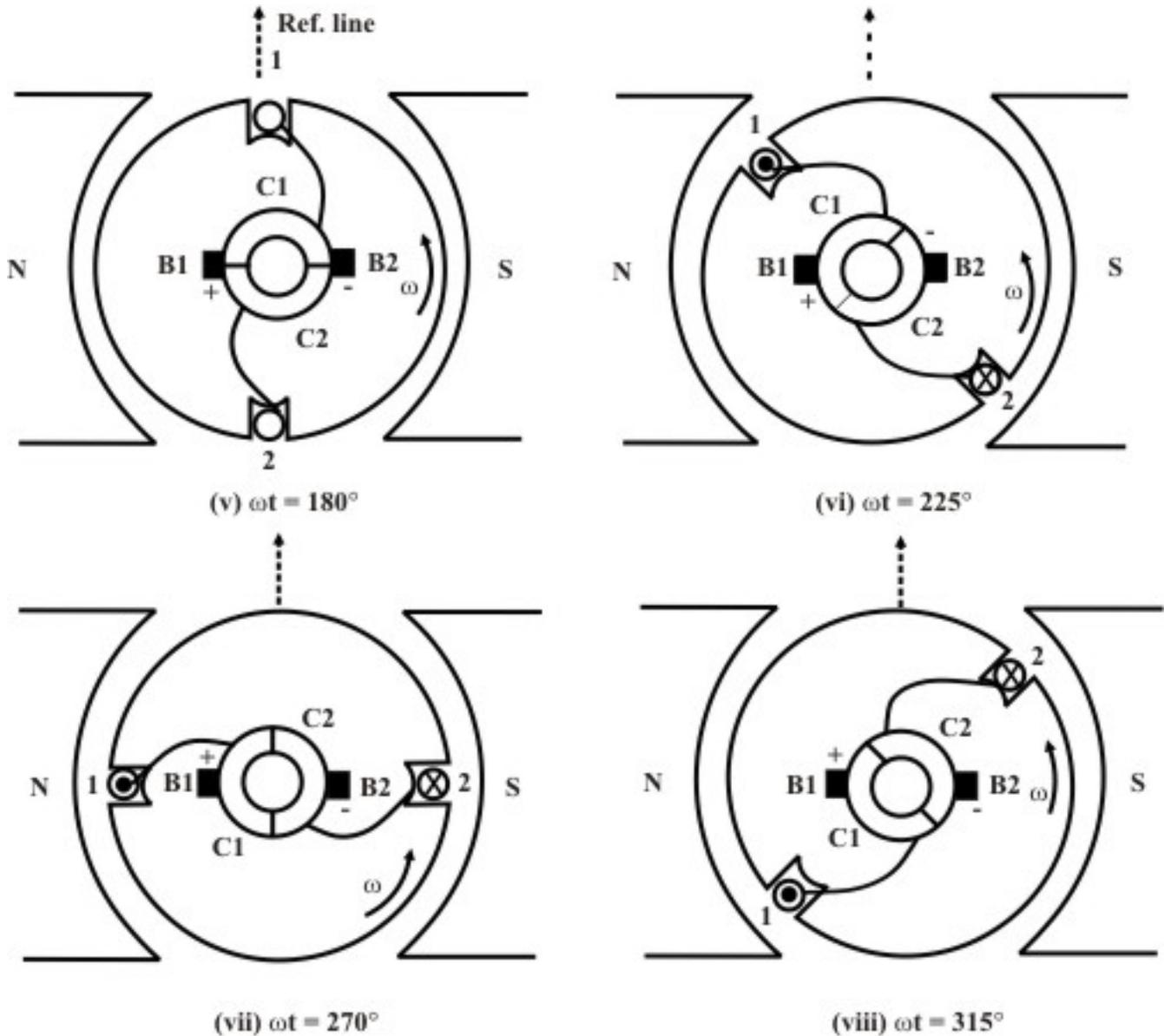


Figure 35.4: Explaining commutator & brush action

It is interesting to note that the coil is short circuited via commutator segment C2, brush B1, commutator segment C1 and brush B2 at $\omega t = 0$ position. This short circuiting does not however produce circulating current in absence of any voltage. Let the coil moves by some angle, say 45° as in figure 35.3(ii). Since conductor 2 is under the influence of N pole, polarity of the induced voltage in it will be \odot . Similarly conductor 1 being under the influence of the S pole, polarity of the induced voltage in it will be \otimes . Therefore across B1 and B2 we will get a voltage with B1 being +ve and B2 being -ve. The polarity of the voltage in conductors 2 and 1 does not change so long 2 remains under N pole (which automatically means 1 under S pole). Figures 35.3(i) to 35.3(iv) show some selected positions of the coil corresponding to $\omega t = 0^\circ$, $\omega t = 45^\circ$, $\omega t = 90^\circ$, $\omega t = 135^\circ$ and $\omega t = 180^\circ$. After this conductor 2 comes under S pole and conductor 1 under N pole. Therefore polarity of voltage in conductor 1 is \odot while polarity of voltage in conductor 2 is \otimes . B1 now makes contact with C1 and B2 makes contact with C2.

Thus polarity of B1 remains +ve as before and that of B2 remains –ve unaltered. Before going further you must understand very clearly the following:

1. Polarity of voltage across C1 and C2 will periodically reverse. This is because any point on C1 always means free end of conductor 1 and any point on C2 always means free end of conductor 2. In other words V_{C1C2} will be alternating in nature.
2. Polarity of voltage across B1 and B2 will not change with time – in the present case, B1 always remains +ve and B2 always – ve. Thus V_{B1B2} always remains *unidirectional*.
3. A particular brush is not associated with a fixed conductor but it makes contact with different conductors when they come at some fixed position in space. In this simple machine, any conductor coming between $0 < \omega t < 180^\circ$ in space will be connected always to B1.

Although, the voltage V_{B1B2} is always +ve (i.e., unidirectional), its magnitude does not remain constant, since $e = Blv$ and value of B is not constant under a pole. If B is sinusoidally distributed with $B = B_{max} \sin \theta$ [figure (35.5)], then variation of V_{C1C2} and V_{B1B2} are as shown in figures (35.6 and 35.7).

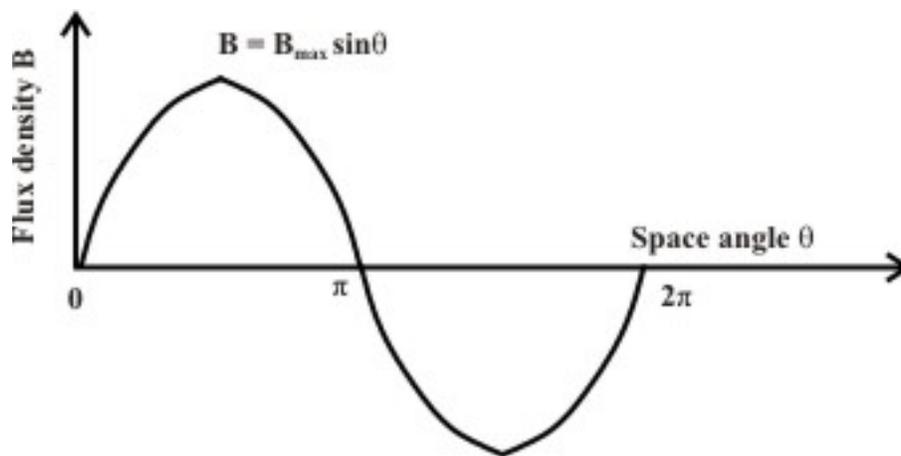


Figure 35.5: Flux density distribution in space

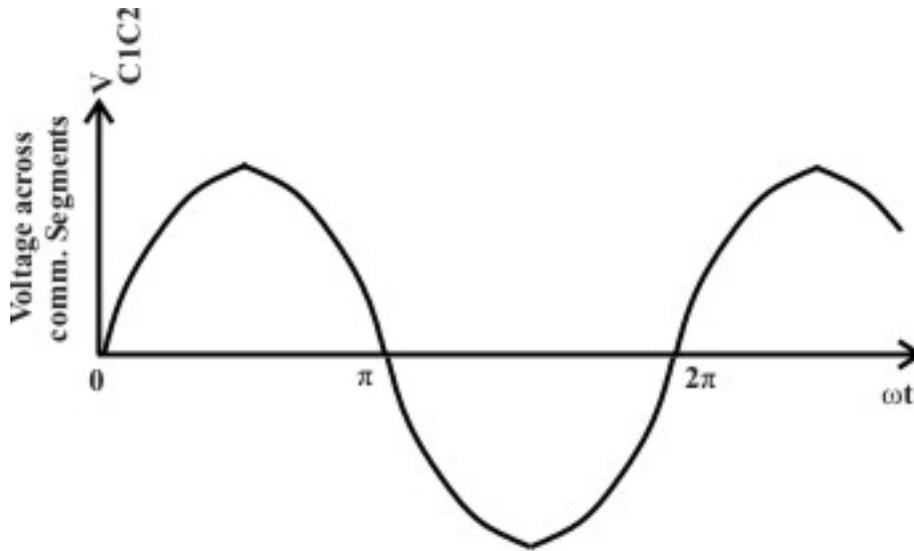


Figure 35.6: Voltage across commutator segments

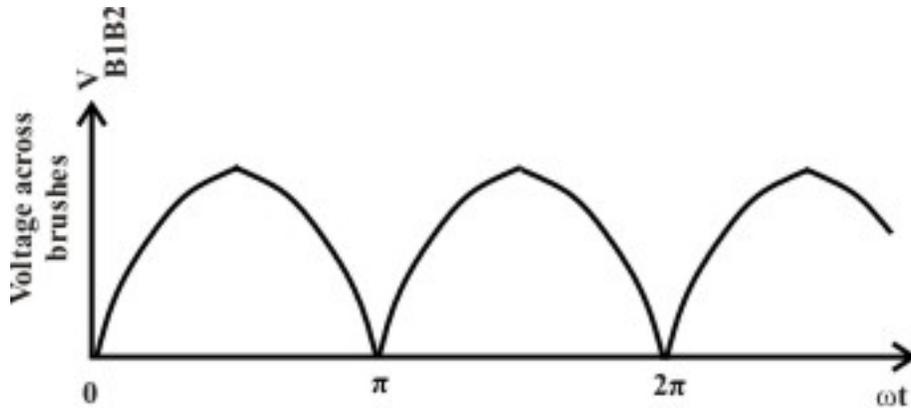


Figure 35.7: Voltage across brushes

The brush voltage (or armature voltage) obtained from this simple generator having a single turn in the armature, is unidirectional no doubt but the magnitude of the voltage is not constant with time. Therefore, to improve the quality of the voltage similar to the nature of a battery voltage, a single coil in the armature with two commutator segments will not do. In fact, a practical d.c machine armature will have large number of slots housing many coils along with a large number of commutator segments. All the coils are connected in series forming a closed circuit. However, no circulating current result as the net emf acting in the closed circuit is zero. Each coil ends are terminated on two commutator segments. Armature windings may be of different types (namely lap and wave), depending on which coil ends are terminated on specific commutator segments. For example, when ends of a coil are terminated on two *consecutive* segments, lap connected armature winding is obtained. On the other hand, if the ends of a coil are terminated on segments which are apart by approximately *two pole pitch*, a wave connected armature winding results. It can be shown that in armature, across the brushes there exists parallel paths denoted by a . Number of parallel paths (a) in case of lap winding is equal to the number poles (P) of the machine while $a = 2$ in case of wave winding. We shall discuss along with diagrams Simple lap and wave windings in the following sections. To know more about d.c

machine armature windings, one may refer to any standard book on Electrical Machine Design. It may be emphasized, that to analyse the performance of a d.c machine one should at least be aware of the fact that:

$$\begin{aligned} \text{Number of parallel paths in armature, } a &= P \text{ for LAP winding.} \\ \text{and } a &= 2 \text{ for WAVE winding.} \end{aligned}$$

35.4 D.C machine Armature Winding

Armature winding of a D.C machine is always closed and of *double layer* type. Closed winding essentially means that all the coils are connected in series forming a closed circuit. The junctions of the consecutive coils are terminated on copper bars called commutator segments. Each commutator segment is insulated from the adjacent segments by mica insulation. For reasonable understanding of armature winding, let us first get acquainted with the following terminologies.

- A **coil** has two coil sides occupying two distinct specified slots. Generally two maximize induced voltage in a coil, the spacing between them should be close to 180° electrical. This essentially means if at a given time one coil side is under the center of the north pole, the other coil side should be under the center of the south pole.
- **Coil span** is nothing but the spacing between the two coil sides of a coil. The spacing is expressed in terms of number of slots between the sides. If S be the total number of slots and P be the total number of poles then coil span is S/P . For 20 slots, 4 poles winding, coil span is 5. Let the slots be numbered serially as 1, 2, ..., 20. If one coil side is placed in slot number 3, the other coil side of the coil must occupy slot number 8 ($= 3 + 5$).
- **A Double layer winding** means that each slot will house two coil sides (obviously belonging to two different coils). Physically one coil side is placed in the lower portion of the slot while the other is placed above it. It is because of this reason such an arrangement of the winding is called a *double layer* winding. In the n th slot, coil side in the upper deck is numbered as n and the coil side in the lower deck is numbered as n' . In the 5th slot upper coil side is numbered as 5 and the lower coil side is numbered 5'. In the winding diagram, upper coil side is shown with firm line while the lower coil side is shown with dashed line.

Remembering that a coil has two coil sides, for a double layer winding total number of coils must be equal to the total number of slots.

- **Numbering a coil:** A coil is so *shaped*, that when it is placed in appropriate slots, one coil side will be in the upper deck and the other side will be in the lower deck. Suppose $S = 20$ and $P = 4$, then coil span is 5. Let the upper coil side of this coil be placed in slot number 6, the other coil side must be in the lower deck of slot number 11. The coil should now be identified as (5 - 11'). In other words coil sides of a coil are numbered depending on the slot numbers in which these are placed. A typical single turn and multi turn coils are shown in figure 35.8

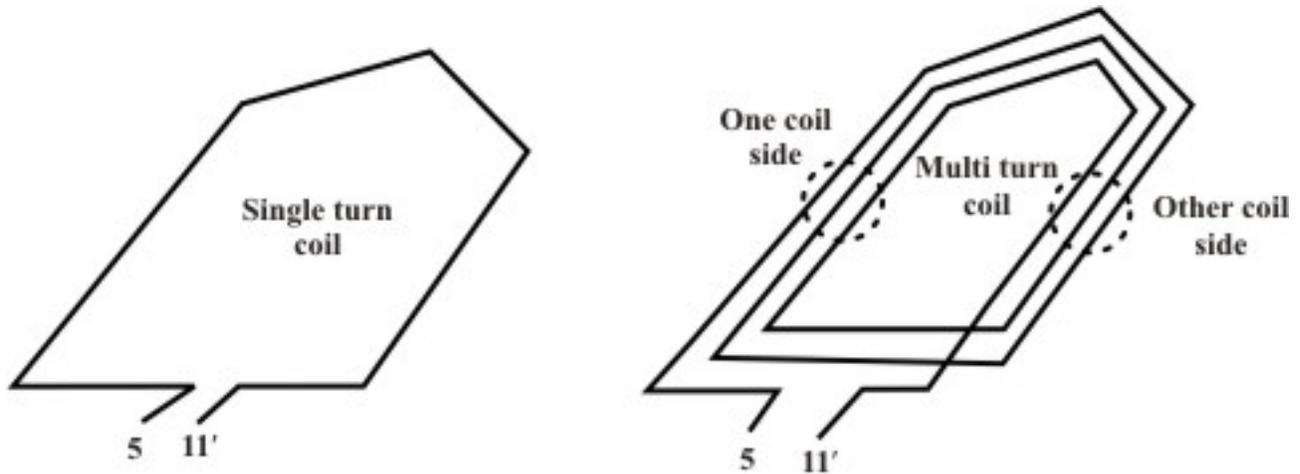


Figure 35.8: Single turn & Multi turn coil

- On a **Commutator segment** two coil sides (belonging to two different coils) terminate. $2S$ being the total number of coil sides, number of commutator segments must be equal to S , number of slots. Commutator segments can also be numbered as $1, 2, \dots, 20$ in order to identify them clearly.
- **Commutator pitch:** As told earlier, the free ends of the coil sides of a coil (say, $6 - 11'$) are to be terminated on to two specific commutator segments. The separation of coil sides of a coil in terms of number of commutator segments is called the *commutator pitch*, y_c . In fact the value of y_c decides the types of winding (lap or wave) which will result. For example, in case of lap winding $y_c = 1$.

35.4.1 Armature winding: General procedure

1. Type of winding (lap or wave), total number of slots S and total number of poles P will be given.
2. Calculate coil span ($\approx S/P$).
3. Calculate commutator pitch y_c . For lap winding $y_c = \pm 1$ and for wave winding $y_c = \frac{2(S \pm 1)}{P}$.
4. We have to complete the windings showing the positions of coil sides in slots, interconnection of the coils through commutator segments using appropriate numbering of slots, coil sides and commutator segments.
5. Finally to decide and place the stationary brushes on the correct commutator segments.

35.4.2 Developed diagram

Instead of dealing with circular disposition of the slots and the commutator segments, it is always advantageous to work with the developed diagram of the armature slots and the commutator segments as elaborated in figure 35.9. In the figure 35.9, actual armature with 8 slots and 8 commutator segments are shown.

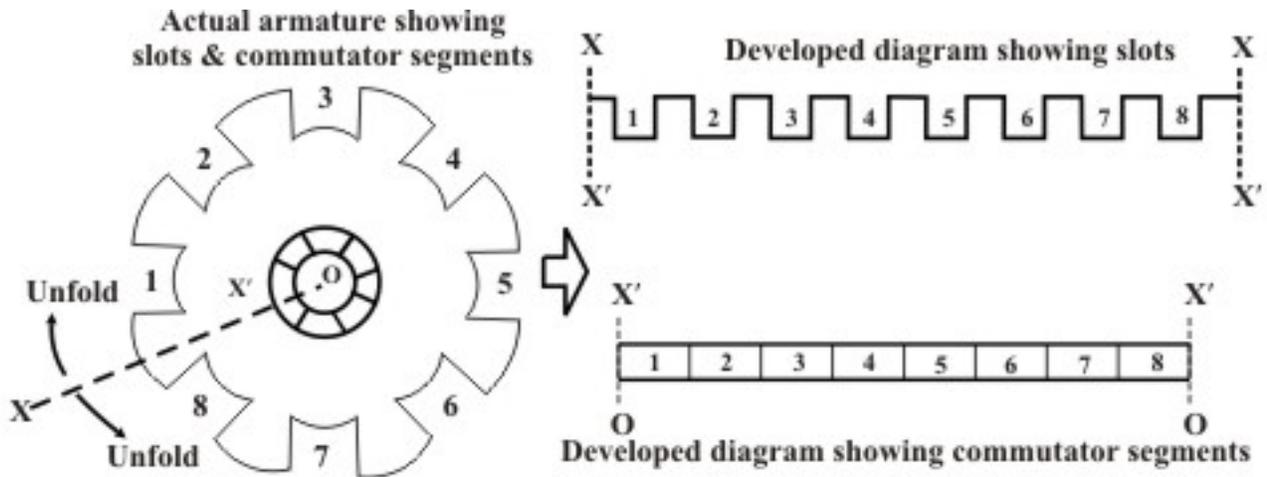


Figure 35.9: Actual and developed diagram of armature and commutator segments

Imagine the structure to be cut radially along the line $XX'O$ and unfolded along the directions shown to make it straight. It will result into straight and rectangular disposition of the slots and commutator segments.

35.5 Lap winding

Suppose we want to make a lap winding for a $P = 4$ pole D.C machine having a total number slots $S = 16$. So coil span is $16/4 = 4$. Commutator pitch of a progressive lap winding is $y_c = +1$. In figure 35.9 only the slots and commutator segments are shown in which it is very difficult to show the coil sides and hence coil connections. To view the coil sides / coils, we must look below from above the slots as depicted in figure 35.10. Once we number the slots, the numbering of the coil sides gets fixed and written. The upper coil side present in slot number 1 is shown by firm line and named 1 while lower coil side is shown by a dashed line (just beside the upper coil side) and named as 1'.

Let us now see how coils can be drawn with proper termination on the commutator segments. Since the coil span is 4, the first coil has sides 1 and 5' and the identification of the coil can be expressed as (1 - 5'). Let us terminate coil side 1 on commutator segment 1. The question now is where to terminate coil side 5'? Since the commutator pitch y_c is +1, 5' to be terminated on commutator segment 2 ($= y_c + 1$). In D.C armature winding all coils are to be connected in series. So naturally next coil (2 - 6') should start from commutator segment 2 and the coil side 6' terminated on segment 3 as shown in figure 35.11. It may be noted that in a lap winding there exist a single coil between any two consecutive commutator segments.

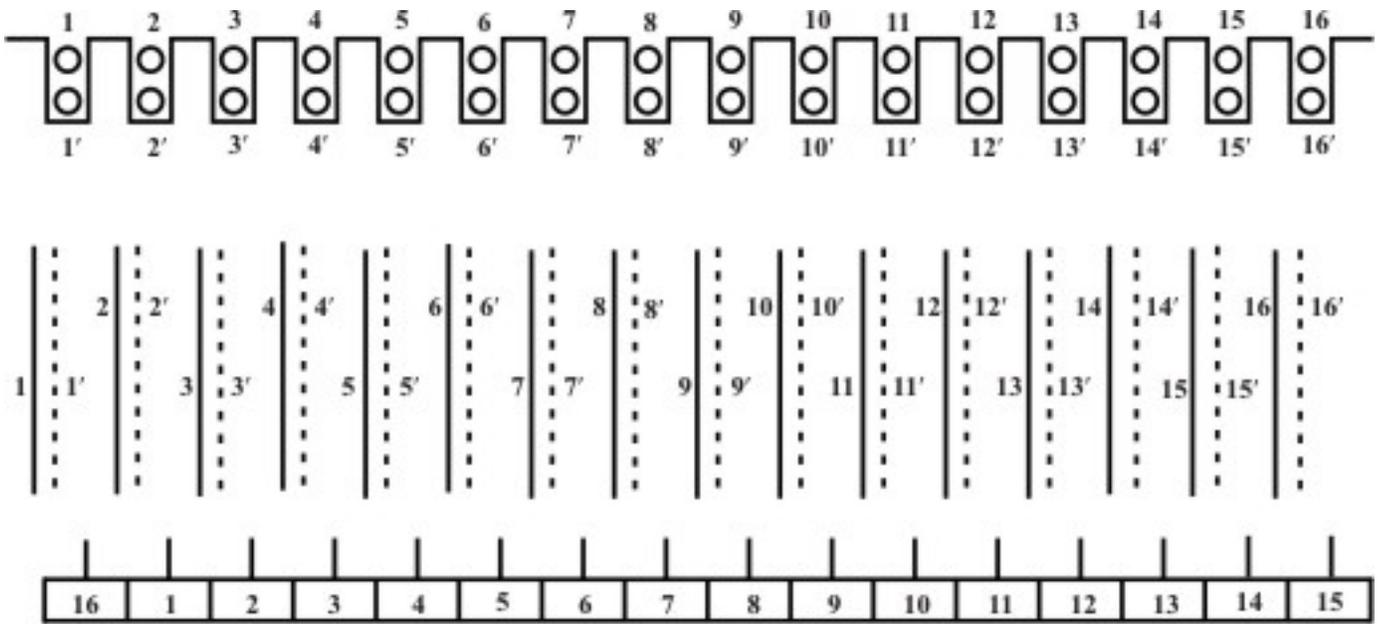


Figure 35.10: Developed diagram of the armature showing slots, coil sides & commutator segments

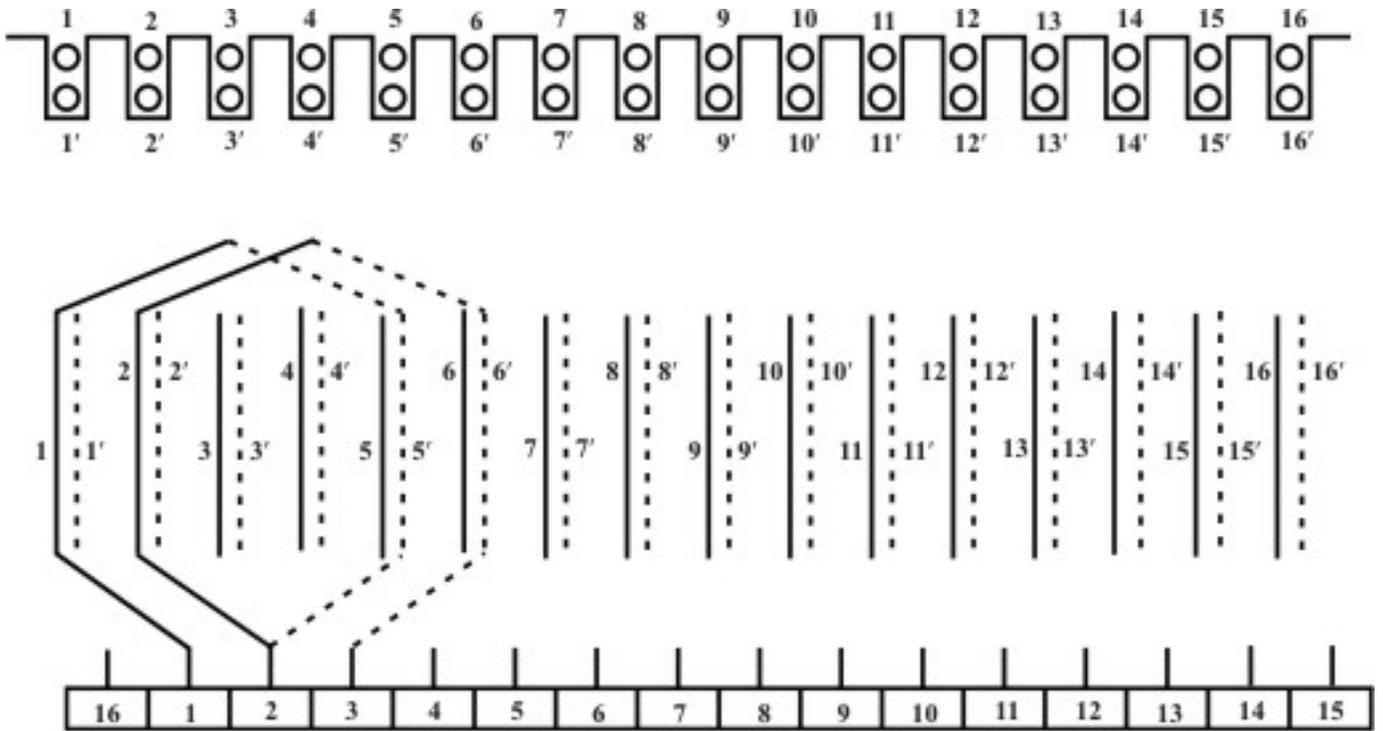


Figure 35.11: Starting a Lap winding

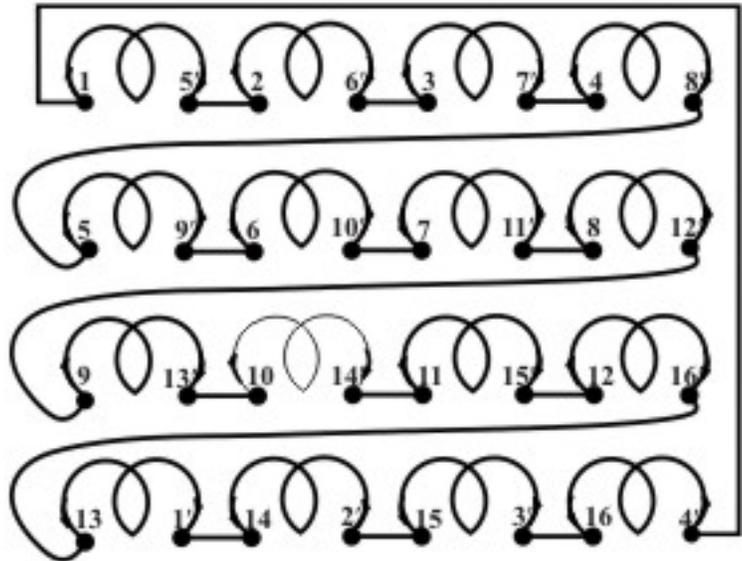
It can be seen that the second coil 2 - 6' is in the lap of the first coil 1 - 5', hence the winding is called *lap* winding. The winding proceeds from left to right due to our assumption that $y_c = +1$. Such a winding is called *progressive simplex lap* winding. It can be easily shown that if y_c is chosen to be -1, the winding would have proceeded from right to left giving rise to a

retrogressive lap winding. One can make first a winding table and then go for actual winding. By now it is clear that to go ahead with winding, two information are essential; namely the number of coil sides of a coil and the number of commutator segments where the free ends of the coil sides will be terminated. In a winding table (look at figure 35.12) these two information are furnished.

The complete progressive lap winding is shown in figure 35.13. To fix up the position of the brushes, let us assume the instant when slots 1,2,3 and 4 are under the influence of the north pole which obviously means slots 5 to 8 are under south pole, slots 9 to 12 are under north pole and slots 13 to 16 under south pole. The poles are shown with shaded areas above the active lengths (coil sides) of the coils. Considering generator mode of action and direction of motion from left to right (i.e., in clockwise direction of rotation of the cylindrical armature), we can apply right hand rule to show the directions of emf in each coil side by arrows as shown in figure 35.13. EMF directions are also shown in the simplified coil connections of the figure 35.12. The emfs in the first four coils (1 - 5', 2 - 6', 3 - 7' and 4 - 8') are in the clockwise directions with 8' +ve and 1 -ve. In the same way, 5 is +ve, 12' is -ve; 16' is +ve and 9 is -ve; 13 is +ve and 4' is -ve. Therefore, two +ve brushes may be placed on commutator segment numbers 5 and 13. Two numbers of -ve brushes may be placed on commutator segment numbers 1 and 9. Two armature terminals A_2 and A_1 are brought out after shorting the +ve brushes together and the -ve brushes together respectively. Thus in the armature 4 parallel paths exist across A_2 and A_1 . Careful look at the winding shows that physical positions of the brushes are just below the center of the poles. Also worthwhile to note that the separation between the consecutive +ve and the -ve brushes is one pole pitch ($16/4 = 4$) in terms of commutator segments.

Coils	Commutator segments where the coil ends terminated
1 - 5'	1, 2
2 - 6'	2, 3
3 - 7'	3, 4
4 - 8'	4, 5
5 - 9'	5, 6
6 - 10'	6, 7
7 - 11'	7, 8
8 - 12'	8, 9
9 - 13'	9, 10
10 - 14'	10, 11
11 - 15'	11, 12
12 - 16'	12, 13
13 - 1'	13, 14
14 - 2'	14, 15
15 - 3'	15, 16
16 - 4'	16, 1

(a) Winding Table



(b) Simplified representation of the coil connection

Figure 35.12: Winding table and coil connections

In fact for a P polar machine using lap winding, number of parallel paths $a = P$. Will it be advisable to put only a pair of brushes in the armature? After all a pair of brushes will divide the armature into two parallel paths.

$$\begin{aligned}
 \text{Let, the total number of slots} &= S \\
 \text{The total number of poles} &= P \\
 \therefore \text{Total no. of commutator segments} &= S \\
 \text{Total no. of coils} &= S \because \text{double layer winding} \\
 \text{No. of coils between two consecutive commutator segments} &= 1 \because \text{simplex lap winding} \\
 \text{Number of commutator segments between consecutive +ve and} & \\
 \text{-ve brushes} &= S/P \\
 \therefore \text{Number of coils between the +ve and -ve brushes} &= S/P
 \end{aligned}$$

If only a pair of brushes is placed, then armature will be divided in to two parallel paths consisting of S/P coils in one path and $(P-1)\frac{S}{P}$ coils in the other path. So current distribution in the paths will be unequal although emf will be same. A little consideration shows another pair of brushes can be put (figure 35.13) producing 4 identical parallel paths. Therefore, in a lap winding number of brushes must always be equal to the number of poles. Lap winding is adopted for low voltage, high current D.C Machines.

35.5.1 Another example of Lap winding

In figure (35.14), a 4-pole, lap winding for d.c machine armature is presented with 8 numbers of slots. Armature winding of a d.c machine is *double layer type* which means that in each slot there will be two coil sides present. The *upper coil sides* are numbered as 1, 2, 3...8 and the *lower coil sides* are marked as 1', 2', 3'8'. Number of commutator segments are 8 and they are also numbered as 1,2,3...8. Since two coil sides make a single coil and each slot is housing two coil sides, number of total coils that can be accommodated is also 8 (= number of slots). It may be noted that coil ends of first, second, third,...eight coils are respectively, 1 - 1', 2 - 2', 3 - 3'...8 - 8'. The spatial distance between two coil sides of a coil should be *one pole pitch* apart.

Now number of slots per pole is $\frac{8}{4} = 2$. Coil side 1 of the first coil is put in slot number 1 and its other coil side 1' is placed in slot number 3. The ends of the first coil 1 and 1' are terminated to commutator segments 1 and 2 respectively. In the same way coil sides 2 and 2' of the second coil are placed in slot numbers 2 and 4 respectively. Also its coil ends 2 and 2' are terminated on commutator segments 2 and 3 respectively. Between commutator segments 1 and 3 we find that first and second coils are present and they are series connected by virtue of the termination of the ends 1' (of first coil) and 2 (of second coil) on the same commutator segment 2. In the same fashion one can complete the connection of the third, fourth, ... eighth coil. End 8' of the eighth coil is finally terminated on commutator segment 1 where one end of the first coil was terminated at the beginning. Thus we see that all the coils are connected in series via commutator segments in a closed circuit.

To fix up the position of the brushes consider an instant when there are two slots under each pole and the armature is rotating in the clock wise direction. By applying right hand rule, we can find out the direction of the emfs induced in the conductors (i.e., \odot or \otimes). In order to show the direction of emfs in the coils more clearly, the coils have been shown spread out off the slots like petals in the figure (35.14). If you start from any of the commutator segments and trace all the coils you will encounter as many clock wise arrows as the number of anti clockwise arrows. Which simply confirms that total emf acting in the loop is zero. Now the question is where to put the brushes? In commutator segments 8 and 4 arrows converge indicating 2 brushes are to be placed there. These two

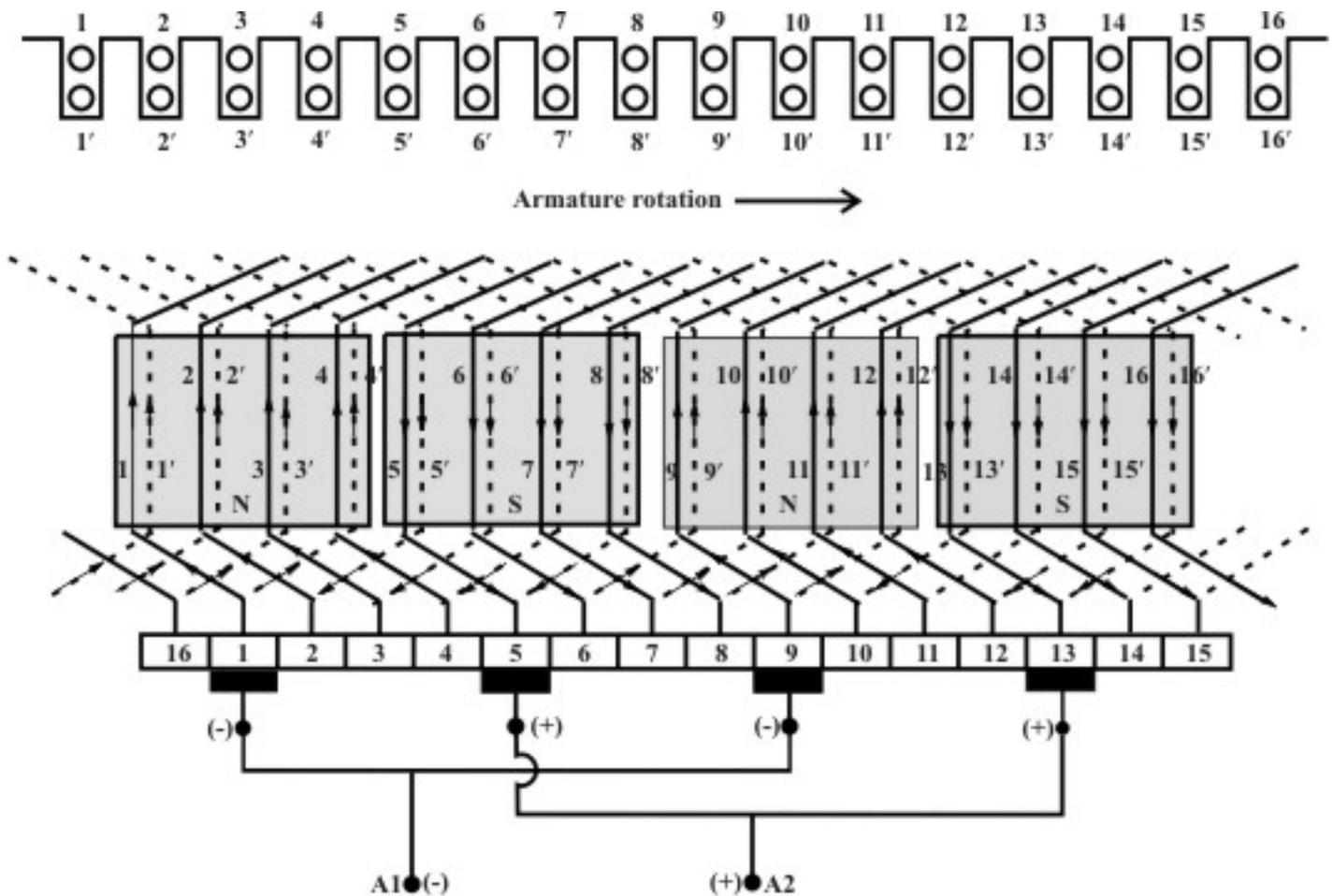


Figure 35.13: Complete simplex progressive lap winding

brushes externally joined together to give +ve armature terminal of the generator. Similarly two brushes should be placed on segments 2 and 6 and joined together to give -ve terminal of the generator. It is quite obvious now that across the armature terminals of the d.c generator 4 parallel paths exist. In general for a p polar machine number of parallel paths a , will be equal to the number poles p . Parallel paths and the coils with polarity of voltages are shown in the simplified diagram in figure (35.15). Since lap winding provides more number of parallel paths, this type of winding is employed for large current and low voltage d.c machines.

For clarity each coil in the armature is shown to have *single turn* in figure (35.14).

35.6 Wave winding

In this winding these coil sides of a coil is not terminated in adjacent commutator segments, i.e., $y_c \neq 1$. Instead y_c is selected to be closely equal to *two pole pitch* in terms of commutator segments. Mathematically $y_c \approx 2S/P$. Let us attempt to make a wave winding with the specifications $S = 16$ and $P = 4$. Obviously, coil span is 4 and $y_c = 8$.

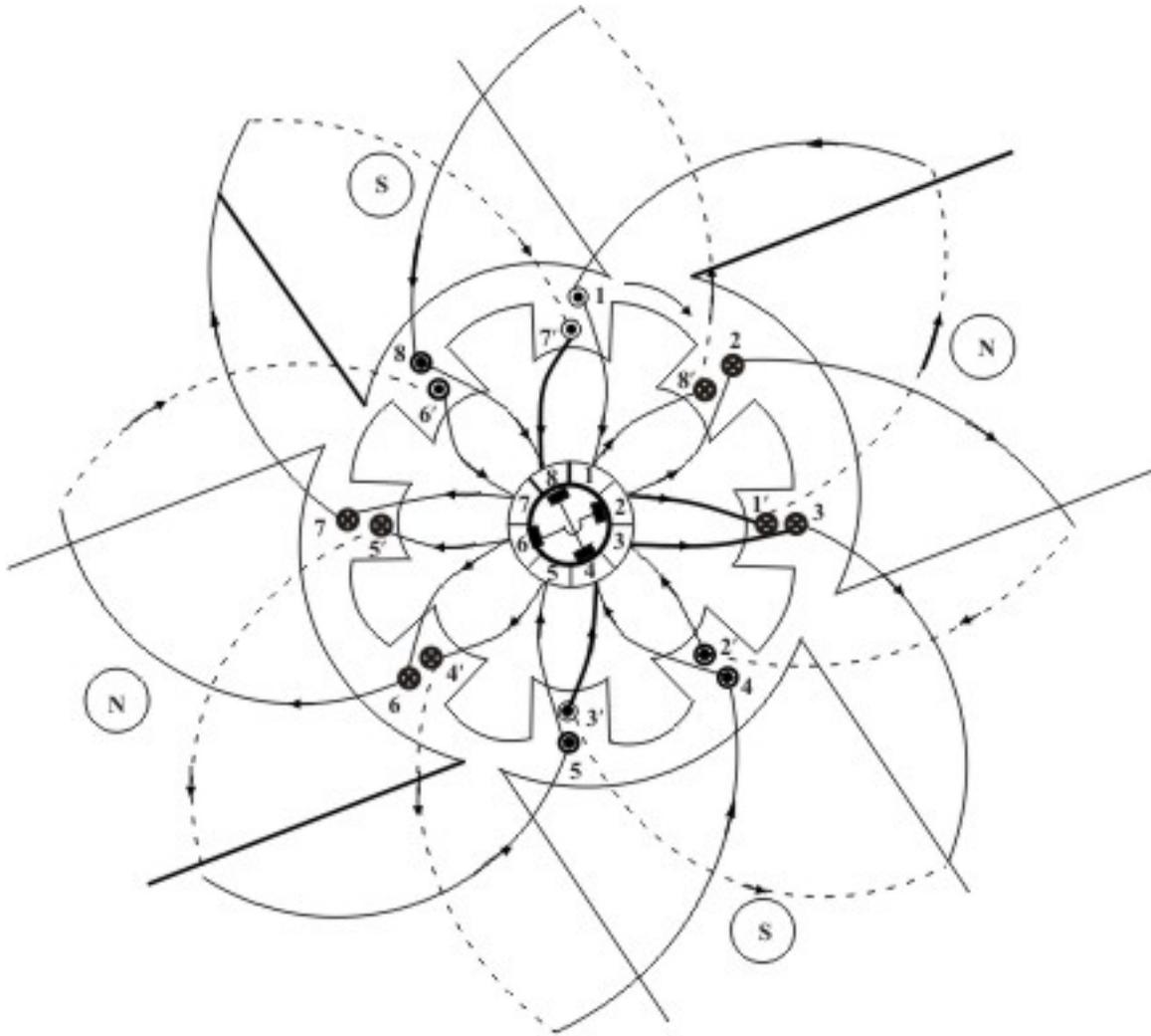


Figure 35.14: Lap winding, polar diagram

The first coil is (1 - 5') and is terminated on commutator segments 1 and 9. The second coil (9 - 13') to be connected in series with the first and to be terminated on commutator segments 9 and 1 (i.e., 17'). Thus we find the winding gets closed just after traversing only two coils and it is not possible to carry on with the winding. Our inability to complete the wave winding will persist if $2S$ remains a multiple of P . It is because of this reason expression for commutator pitch y_c , is modified to $y_c = 2(S \pm 1)/P$. In other words, number of slots, should be such that $2(S \pm 1)$ should be multiple of P . It can be shown that if +ve sign is taken the result will be a *progressive wave winding* and if -ve sign is taken the result will be *retrogressive wave winding*.

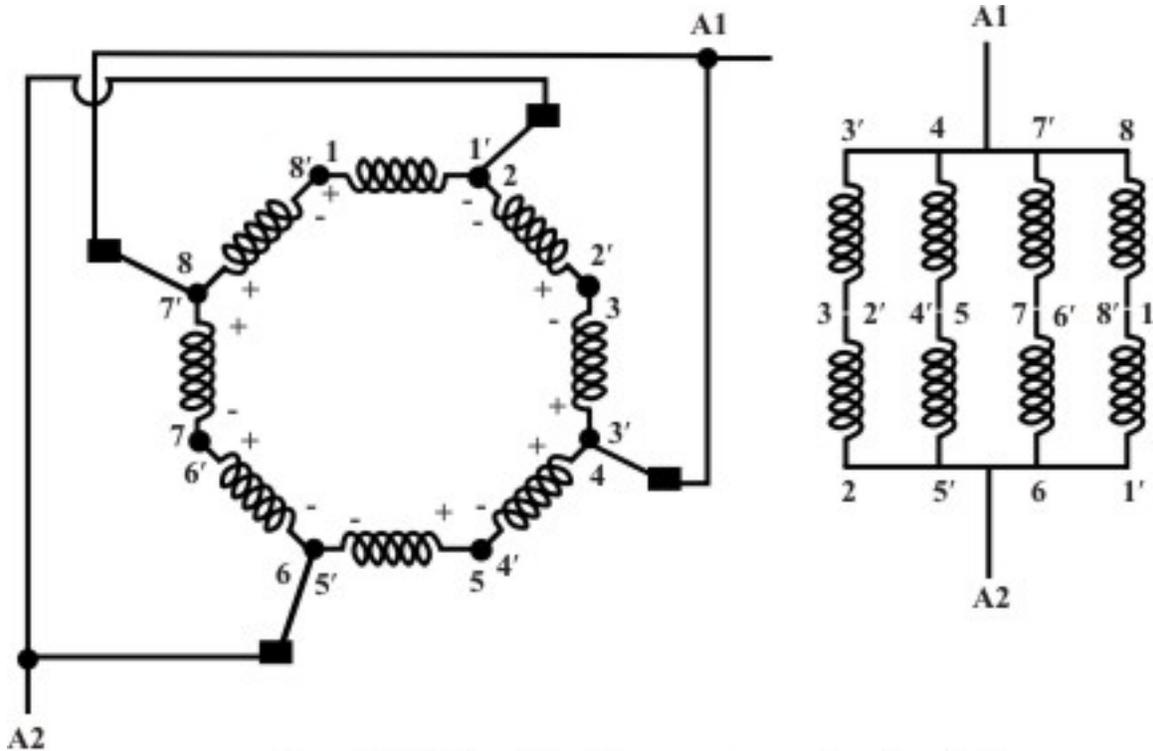


Figure 35.15: Parallel paths across armature terminals

35.6.1 An example

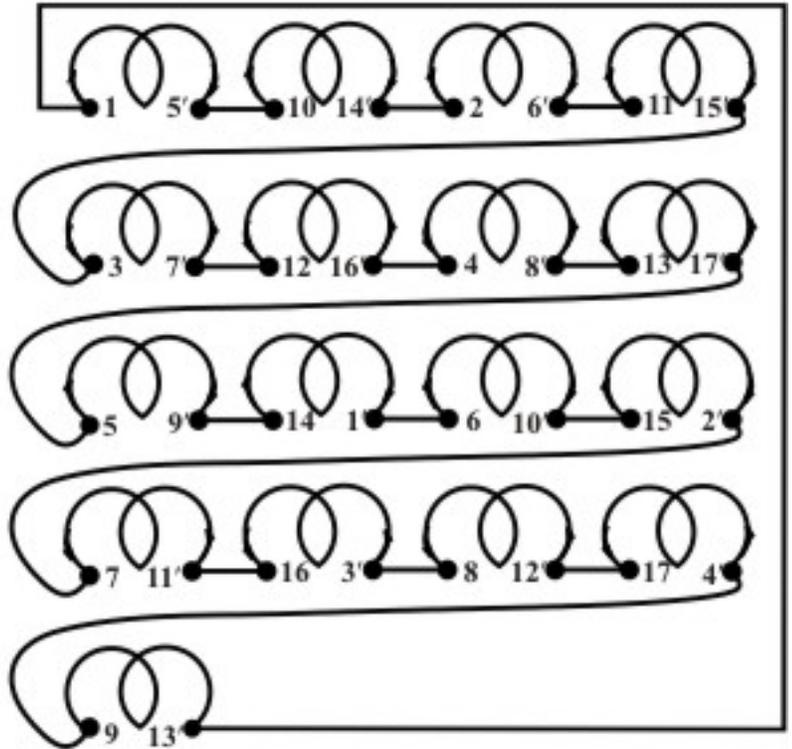
We have seen that for 4-pole wave winding, choice of $S = 16$ is no good. Let us choose number of slots to be 17 and proceed as follows:

$$\begin{aligned}
 \text{No. of poles, } P &= 4 \\
 \text{No. of slots, } S &= 17 \\
 \text{Winding pitch, } y_c &= 2(S+1) / P \text{ choosing } +1 \text{ for progressive winding} \\
 \therefore y_c &= 2(17+1) / 4 = 9 \\
 \text{Coil span} &= S/P \approx 4
 \end{aligned}$$

Once coil span and the commutator pitch y_c are calculated, *winding table*, shown in figure 35.16(a) can be quickly filled up. Series connection of all the coils are also shown in figure 35.16(b). Directions of induced emfs are shown after assuming slots 1 to 4 and 9 to 12 to be under north pole; slots 5 to 8 and 13 to 16 to be under south pole. Since S/P is not an integer slot 17 has been assumed to be in the neutral zone. It is interesting to note that polarity of the induced emf reverses after nearly half of coils are traversed. So number of armature circuit parallel paths are two only. It is because of this reason wave winding is preferred for low current, large voltage d.c machines.

Coils	Commutator segments where the coil ends terminated
1 - 5'	1 , 10
10 - 14'	10 , 2
2 - 6'	2 , 11
11 - 15'	11 , 3
3 - 7'	3 , 12
12 - 16'	12 , 4
4 - 8'	4 , 13
13 - 17'	13 , 5
5 - 9'	5 , 14
14 - 1'	14 , 6
6 - 10'	6 , 15
15 - 2'	15 , 7
7 - 11'	7 , 16
16 - 3'	16 , 8
8 - 12'	8 , 17
17 - 4'	17 , 9
9 - 13'	9 , 1

(a) Winding Table



(b) simplified representation of the coil connections
 +ve brush may be placed on comm. seg. 13 (and/or 5)
 +ve brush may be placed on comm. seg. 9 (and/or 17)

Figure 35.16: Wave winding table and coil connections

In figure 35.17 are shown only two coils to explain how winding proceeds. Important thing to be noted from this figure is that the first coil (1 - 5') starts from commutator segment one and ends on commutator segment 10, where from the second coil (10 - 14') starts and finally gets terminated on commutator segment 2. In other words between any two consecutive commutator segments 2 coils are present. This statement can be generalized as: for a P polar simplex wave winding, *between any two consecutive commutator segments $P/2$ coils will be present*. A look at those two coils suggest that the winding progresses like a wave – hence the name wave winding. Figure 35.18 shows the completed wave winding where the directions of induced emfs in the coil sides are also shown.

That the number of parallel paths in a simplex wave winding is always 2 can be established mathematically as follows.

$$\begin{aligned}
 \text{Let, the total number of slots} &= S \\
 \text{The total number of poles} &= P \\
 \therefore \text{total no. of commutator segments} &= S \\
 \text{Total no of coils} &= S \because \text{double layer winding}
 \end{aligned}$$

No. of coils between two consecutive commutator segments = $P/2$ \therefore simplex wave winding

Number of commutator segments between consecutive +ve & -ve brushes = S/P

\therefore Number of coils between the +ve & -ve brushes = $(S/P) \times (P/2)$
= $S/2$

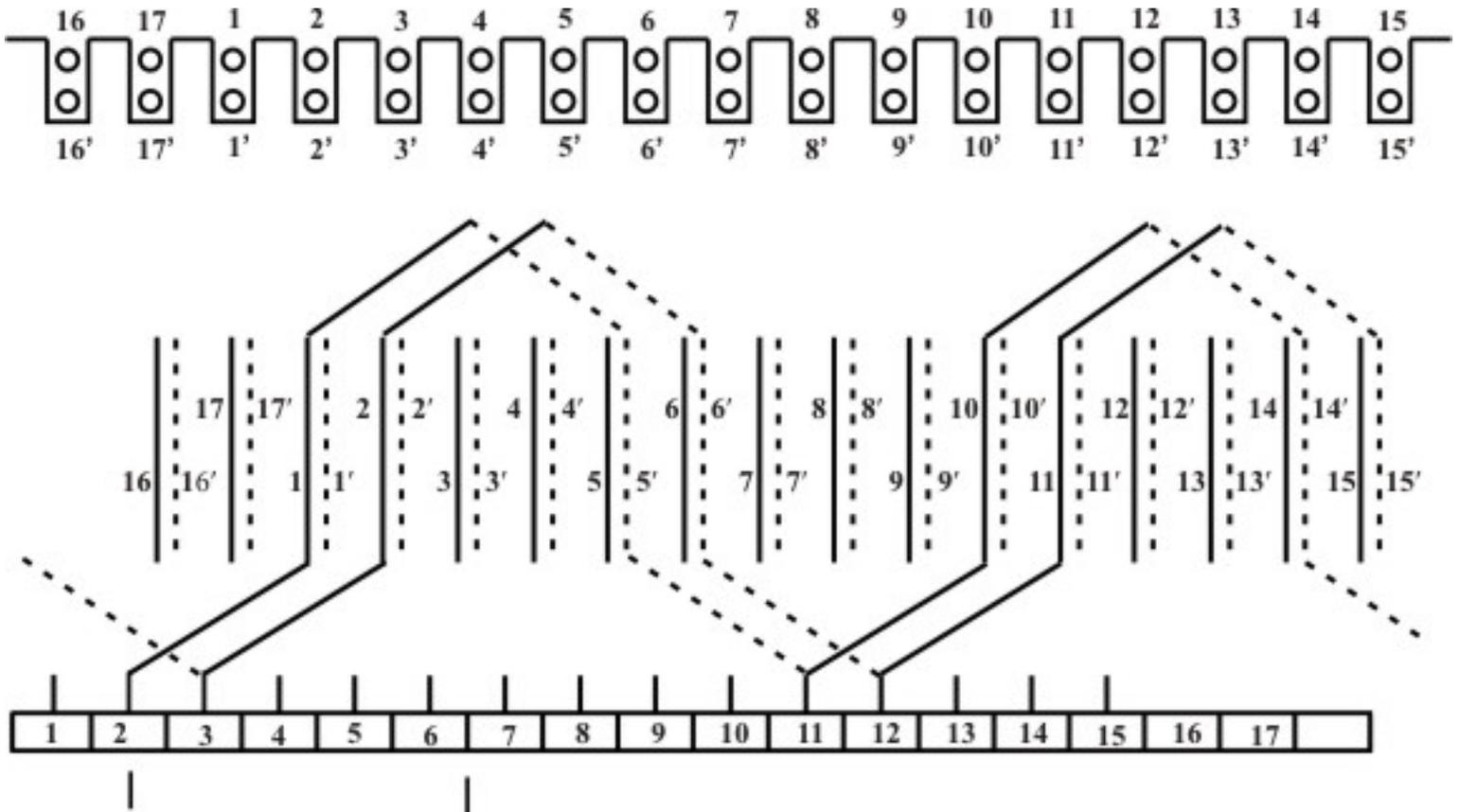


Figure 35.17: Starting a simplex progressive wave winding

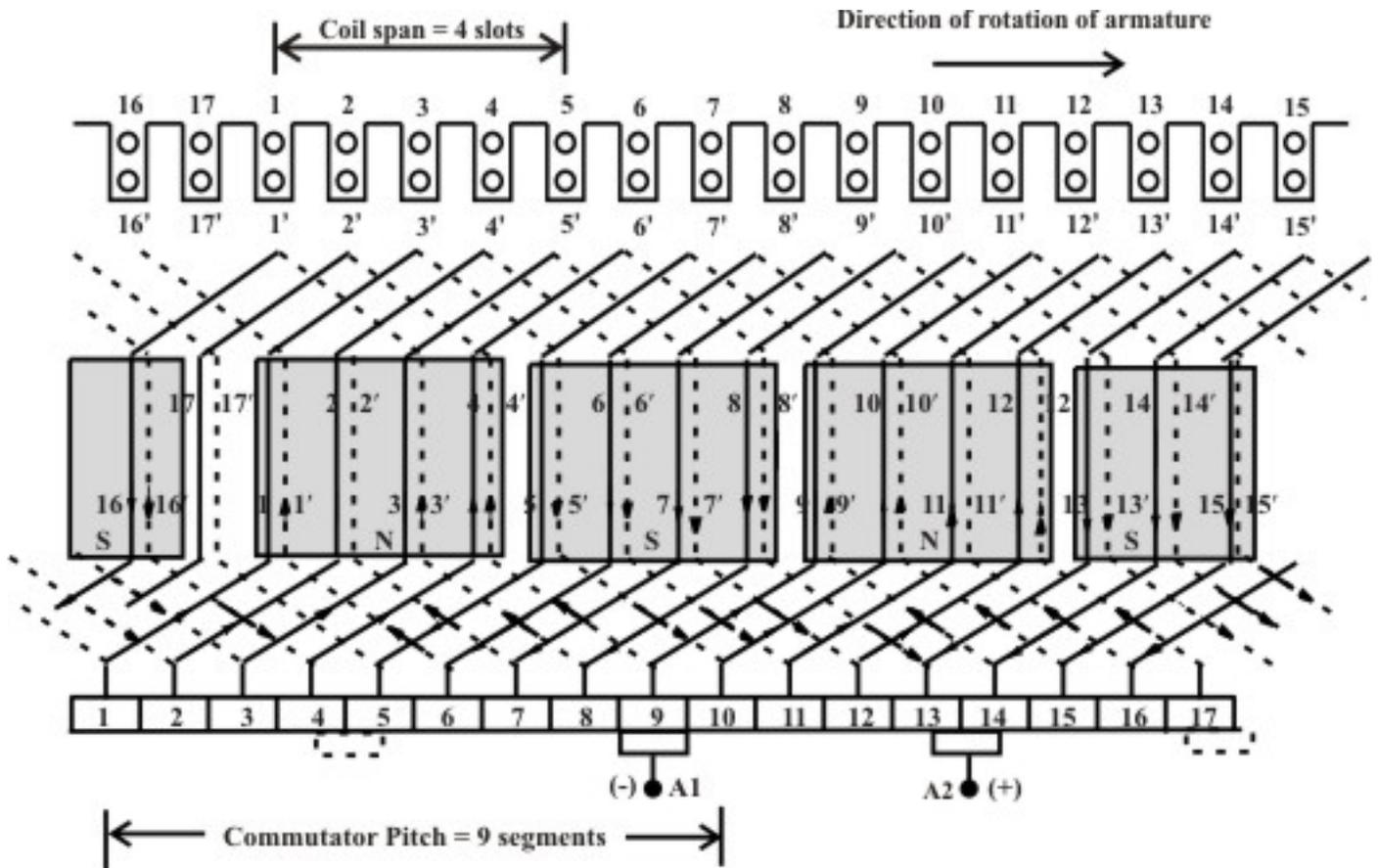


Figure 35.18: Complete simplex progressive wave winding

Thus, a pair of brush divides the armature into two parallel paths. From the direction of emfs –ve brush can be placed on commutator segment 9 and the +ve brush can be positioned touching commutator segments 13 and 14. In a wave winding since number of parallel paths are 2, theoretically a pair of brushes is sufficient for armature independent of the number of poles of the machine. However for relatively large armature current one can put additional brushes such that total number of brushes are equal to P thereby reducing the size of the brushes. For the 4 polar winding that we are considering, additional +ve brush can be placed over commutator segments 4 and 5 and another –ve brush can be placed over commutator segments 17 and 1 as shown with dotted boxes in figure 35.18.

35.7 Answer the following

1. What is the difference between a *single turn coil* and a *multi turn coil*?
2. What type of insulation is used between two consecutive commutator segments?
3. Clearly identify which of the following items are rotating and which of them are stationary.
 - (a) Field coil, (b) armature, (c) commutator segments and (d) carbon brushes.

4. For 6 polar D.C machine armature has 36 number of slots and the type of winding is a double layer simplex lap winding.
 - a. How many coils are present?
 - b. What is the coil span in terms of number of slots?
 - c. If each coil has 4 turns, then what is the total number of armature conductors presents?
 - d. How many parallel paths will be their in the armature?
 - e. Altogether how many brushes will be their?

5. For 4 pole d.c machine armature winding with a double layer progressive simplex wave winding with 23 number of slots answer the following:
 - a. How many coils are present?
 - b. What is the coil span in terms of number of slots?
 - c. What is commutator pitch in terms of commutator segments?
 - d. How many coils are there between two consecutive commutator segments?
 - e. How many parallel paths are present?