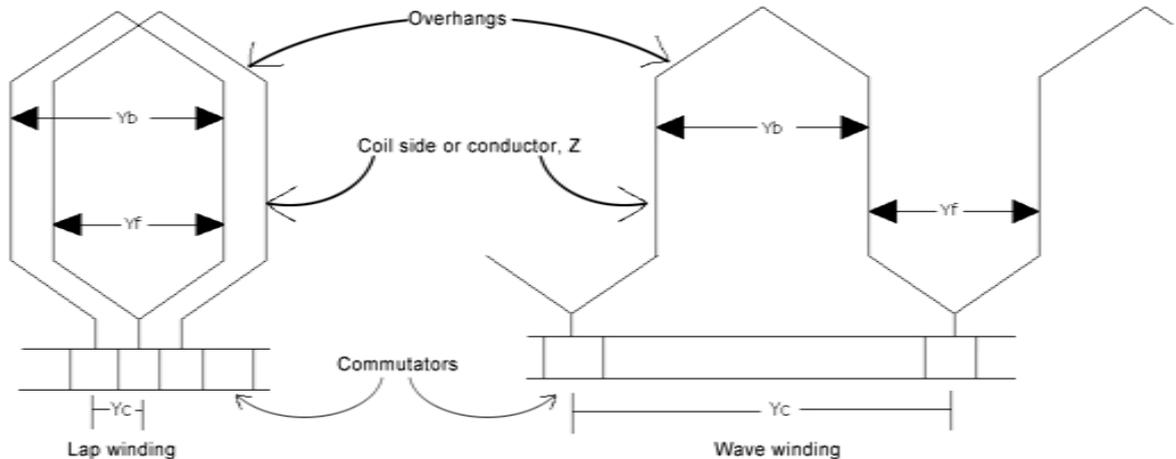


# Electrical Drawing

## DC Winding

DC windings can be classified as –

- Lap or Wave
- Single layer or double layer
- Simplex or multiplex
- Progressive or retrogressive



$Y_b$  – Back pitch. Distance between conductors of one coil

$Y_f$  – Front pitch. Distance between two conductors connected to same commutator segment

$Y_c$  – Commutator pitch. Distance between the two ends of a coil

A coil ( $C$ ) can be single turn or multi-turn. The active length of the coil under the poles ( $P$ ) is called a Conductor ( $Z$ ), that is, coil sides

Number of coils = number of commutator segments

In a single layer winding,  $Z=2C$

In a double layer winding,  $Z=C$

Coil pitch is the number of slots the coil will cover

Pole pitch =  $Z/P$       -- conductors per pole

If coil pitch < pole pitch, it is short chorded coil

If coil pitch > pole pitch, it is over chorded coil

Single layer: One conductor in one slot

Double layer: Two conductors in one slot

Multiplex windings:

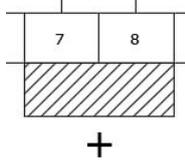
When more number of parallel paths is required, multiplex windings are used.

Degree of re-entrancy or closure of a winding indicates the number of independent closed circuits on the armature.

a. Singly re-entrant: If degree of re-entrancy is one, it is singly re-entrant winding. All simplex windings are singly re-entrant. Multiplex windings can be singly or doubly re-entrant. In short, if a winding returns to its starting point after passing through all the conductors, it is a singly re-entrant winding.

b. Doubly re-entrant: If degree of re-entrancy is two, it is doubly re-entrant winding. From starting, if only half the active conductors are encountered before returning to the starting point, it is doubly re-entrant. There are two separate windings and two winding tables.

For singly re-entrant winding, brush width equals commutator segment width  
 For doubly re-entrant winding, brush width equals two segment widths



Degree of re-entrancy is got by the highest common factor between the multiplicity and the number of coils.

For ex:

i. Duplex winding with 26 conductors

$Z=26$ ,  $m=2$ . No. of coils is 13

HCF between 13 and 2 is 1. So it is a singly re-entrant winding, that is, there is only one winding, though it is mentioned as duplex. Simply, it is a simplex winding.

ii. Duplex winding with 36 conductors

$Z=36$ ,  $m=2$ . No. of coils is 18

HCF between 18 and 2 is 2. It is a doubly re-entrant winding with two windings and two winding table. Simply, it is a duplex winding

### Lap Winding

If end of one coil is connected via commutator segment to the start of the next coil under the same pole, it is called lap winding. Adjacent coils *overlap* each other.

Back pitch,  $Y_b = Z/P + m + K$

Front pitch,  $Y_f = Z/P - m + K$

$K$  is a number added or subtracted to make the pitches odd number.

$m$  is called multiplicity that tells if the winding is simplex, duplex or multiplex

### **1. Draw a developed lap winding diagram of DC machine with 20 conductors and 4 poles. The winding is single layer and simplex**

*a. Calculations:*

Conductors,  $Z = 20$

Poles,  $P = 4$

Multiplicity,  $m = +1$  (simplex and progressive)

Pole pitch,  $Y_p = Z/P = 20/4 = 5$

Back pitch,  $Y_b = Z/P + m = 20/4 + 1 = 6$

Front pitch,  $Y_f = Z/P - m = 20/4 - 1 = 4$

$Y_b$  and  $Y_f$  must always be odd.

Therefore,  $Y_b = 5$  or  $7$ , and  $Y_f = 3$  or  $5$ . Take  $K = -1$

Then  $Y_b = 5$ ,  $Y_f = 3$

*b. Winding table:*

Can be written in either ways

$Y_b = +5$	$Y_f = -3$
1+5=6	6-3=3
3+5=8	8-3=5
5+5=10	10-3=7
7+5=12	12-3=9
9+5=14	14-3=11
11+5=16	16-3=13
13+5=18	18-3=15
15+5=20	20-3=17
17+5=22 (2)	22-3=19
19+5=24 (4)	24-3=21 (1)

OR

1	6
3	8
5	10
7	12
9	14
11	16
13	18
15	20
17	2
19	4
1	6

Notes

- a. Number of columns in the table =  $Z/2m$ , i.e.  $20/(2*1) = 10$
- b. Each row progresses by  $+2m$ , i.e. 6, 8, 10, 12... or 3,5,7,9....

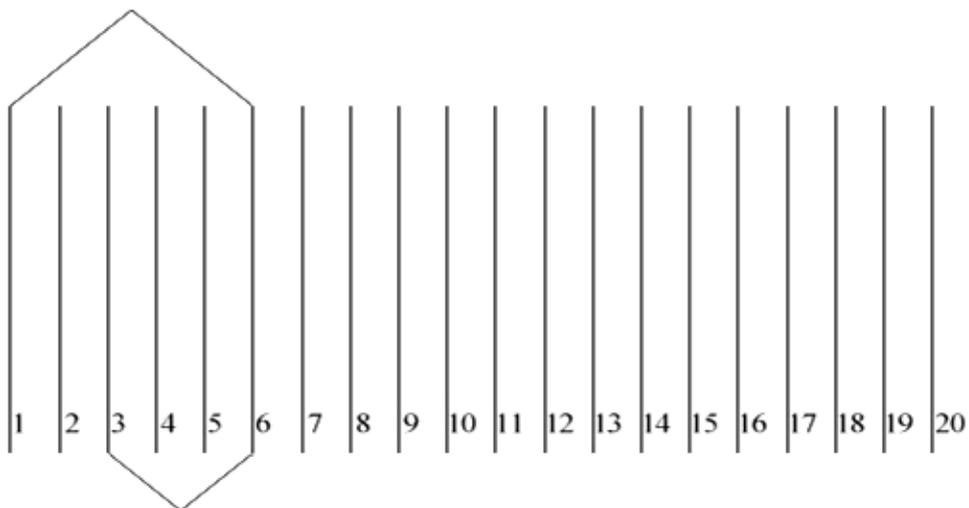
*c. Winding diagram*

c1. Draw 20 vertical lines

c2. Number them

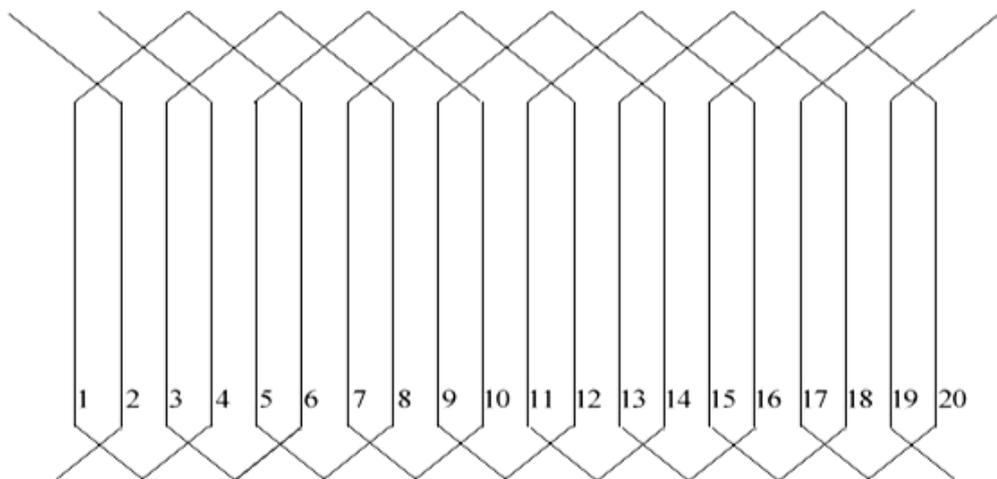
c3. Draw the top overhanging lines (back pitch) and bottom overhanging lines (front pitch) as given by the winding table

Here,  $1+5=6$ , that is, 1<sup>st</sup> conductor is connected to 6<sup>th</sup> on top  
 $6-3=3$ , that is, at the bottom, 6<sup>th</sup> conductor is connected to 3<sup>rd</sup>.



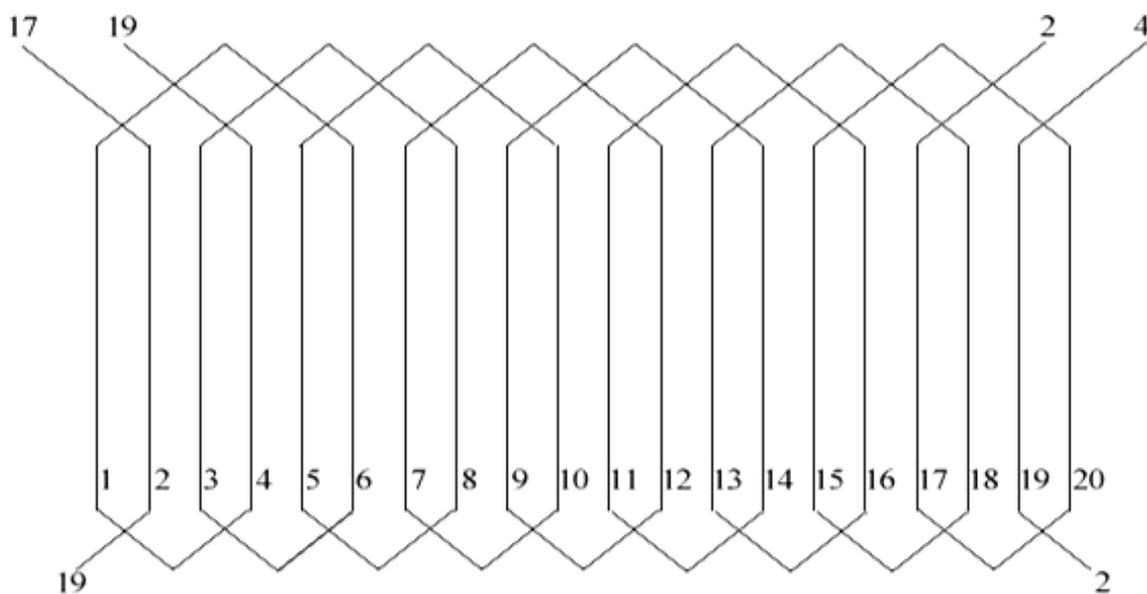
c4. Continue drawing the overhanging lines on top and bottom.

Note that all odd numbered conductors tilt towards the right, and all even numbered conductors tilt towards left, on both top and bottom.



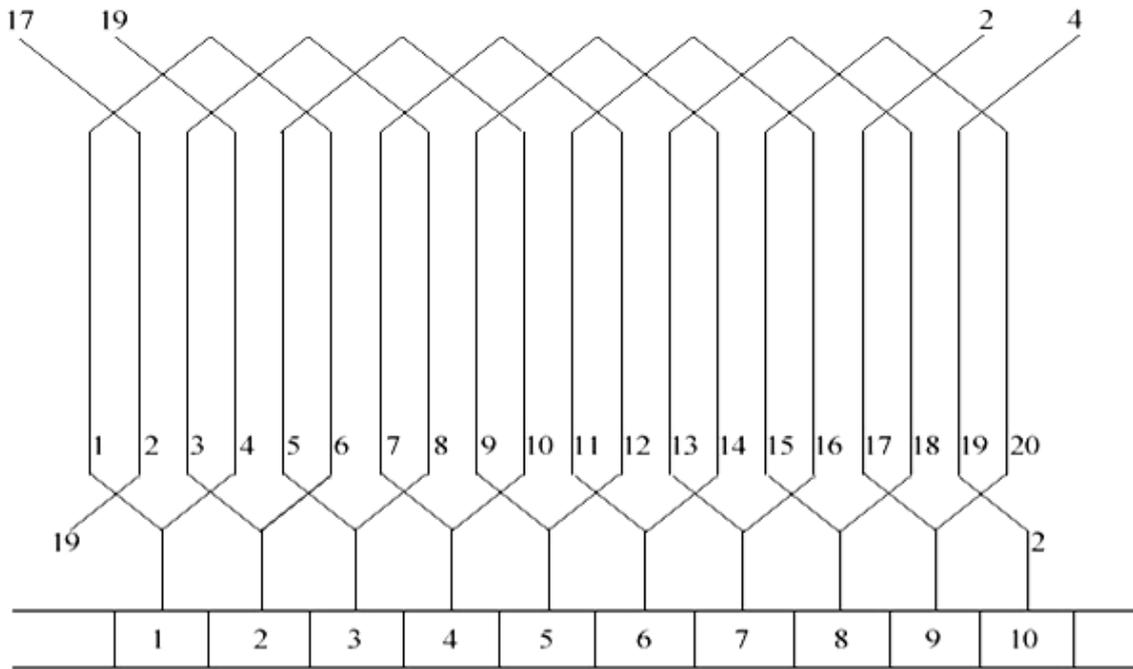
c5. Number the overhangs that are left unconnected.

Note that 17 is connected to 2, 19 is connected to 4 on top. At the bottom, 19 gets connected from 2. Number accordingly



c6. Draw commutator segments, and number them

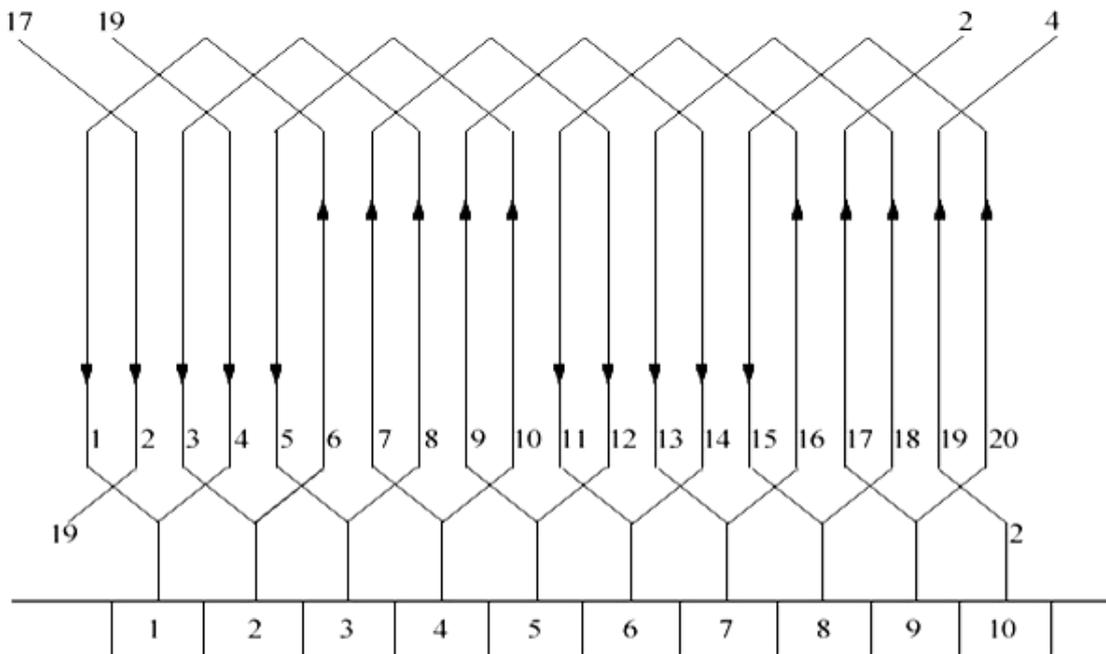
Note that there are  $Z/2 = 20/2 = 10$  commutator segments



c7. Draw direction of current

Assume downward direction for conductors under North Pole, upward direction for conductors under South Pole

Pole pitch is 5. That is, first 5 conductors have down arrows; next 5 have up arrows and so on

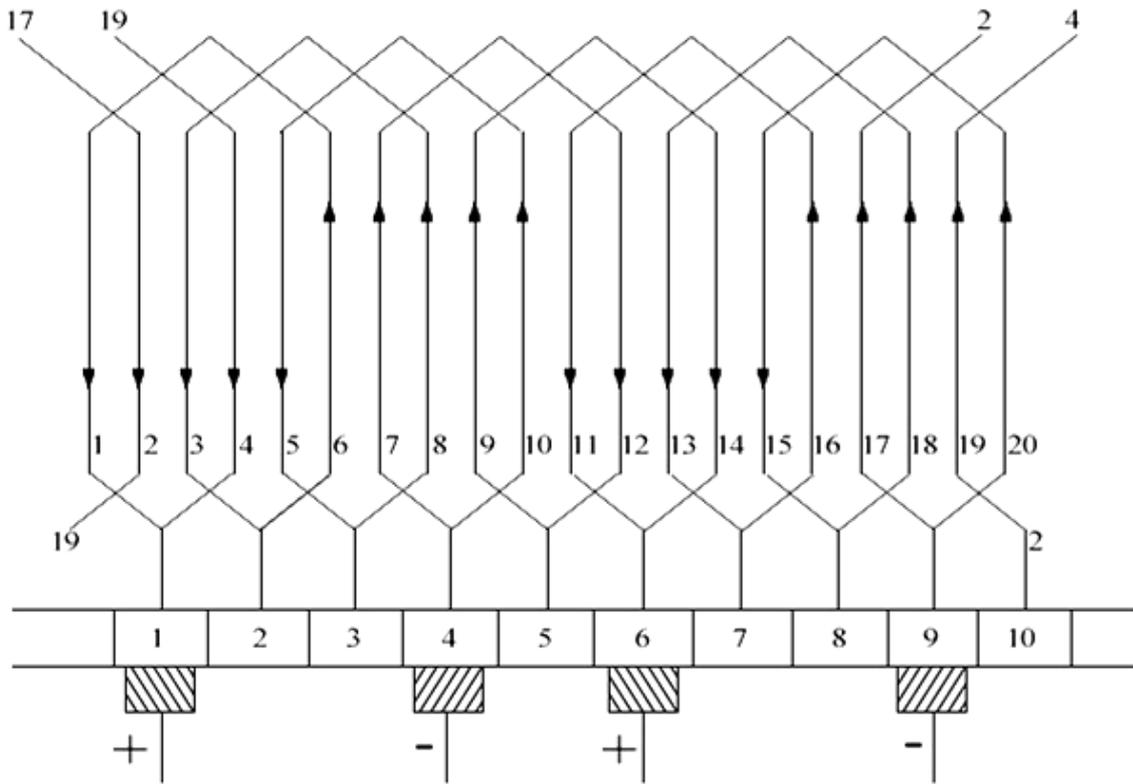


c8. Place the brushes according to the direction of current.

a) The conductors (1 and 4) connected to 1st commutator segment have currents in same direction. Place a brush here. Currents go out of a positive brush

b) Conductors (7 and 10) connected to 4th segment also have currents in same direction, i.e. up. Place a negative brush as currents enter the machine through this brush

c) Similarly, positive brush at 6th segment, and negative brush at 9th segment



Direction of current and brush position can be found from the table or sequence diagram also  
 c9. Table method of finding brush position:

	19	4	
	1	6	
$Y_p/m=5$	3	8	
	5	10	
	7	12	
	9	14	
	11	16	
	13	18	
	15	20	
	17	2	
	19	4	
	1	6	

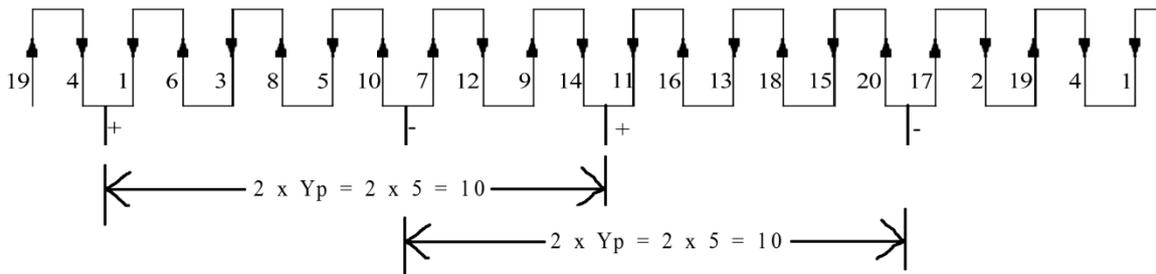
- i. The first positive brush is connected to the conductor 1. So it is between 1 and 4
- ii. Next +ve brush after  $Y_p/m$  rows, ie., at the 5<sup>th</sup> row after 1, which is conductor 11. The second +ve brush is between 11 and 14
- iii. One negative brush always connected to highest even numbered conductor, 20, that is, -ve brush between 20 and 17
- iv. Next -ve brush at 5<sup>th</sup> from 20, ie., conductor 10. This -ve brush between 10 and 7

Current direction given by the brushes

	Commutator			Commutator	
	10	19	4	1	↓
↓	1	1	6	2	↑
↓	2	3	8	3	↑
↓	3	5	10	4	↑
↑	4	7	12	5	↓
↑	5	9	14	6	↓
↓	6	11	16	7	↑

↓	7	13	18	8	↑
↓	8	15	20	9	↑
↑	9	17	2	10	↓
↑	10	19	4	1	
	1	1	6	2	

c10. Sequence diagram method of finding brush position and current direction:



### Equaliser rings:

If there are inequalities in the poles, air gaps, conductors, there is imbalance in the emfs produced. This causes unequal currents, overloading and sparks. Equaliser rings are provided to bypass and short circuit the circulating currents. They are required only in lap windings as the number of parallel paths are more, equal to number of poles. Not required in wave windings as they have only two parallel paths, and the difference in emfs is negligible. There are no circulating currents in a simplex wave winding as the parallel paths are distributed over all poles, so all parallel paths are affected equally by the asymmetry in the magnetic circuit.

Number of equaliser rings,  $n = \text{coil sides/poles} = Z/2/P = Z/2P$

Total number of tappings =  $nP/2$

No. of tappings for each ring =  $P/2$

Distance between two tappings of same ring =  $Z/P$

Distance between two adjacent tappings =  $Z/nP$

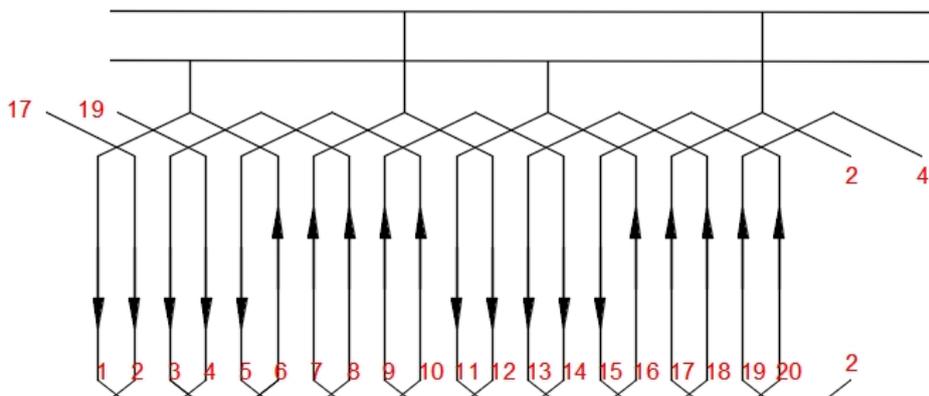
For  $Z=20, P=4$

$n = Z/2P = 20/2 \cdot 4 = 2.5 \sim 2$

Total tappings =  $nP/2 = 2 \cdot 4/2 = 4$

Distance between two tappings on same ring =  $Z/P = 20/4 = 5$

Distance between two adjacent tappings =  $Z/nP = 20/2 \cdot 4 = 2.5 \sim 2$  and  $3$



**2. Draw a winding diagram of lap wound machine, with 18 slots, 6 poles. It is double layer, duplex wound machine**

A duplex winding means there are two separate windings. The first starts from 1<sup>st</sup> conductor, the second winding starts from the 3<sup>rd</sup>. If it is a triplex winding, there will be three separate windings, the third one starts from 5<sup>th</sup> conductor

*a. Calculations*

$Z = 36$  Since it is double layer, number of conductors is 18 slots x 2. A double layer means there are two conductors in one slot

$P = 6$

$m = 2$  (Duplex)

Pole pitch,  $Z/P = 36/6 = 6$

Back pitch,  $Y_b = Z/P + m = 6+2=8$

Front pitch,  $Y_f = Z/P - m = 6-2=4$

As  $Y_b$  and  $Y_f$  have to be odd, assume  $K=-1$ . Therefore  $Y_b = 7, Y_f = 3$

Note:  $Y_b - Y_f = 2m = 2*2=4$

*b. Winding table*

Winding 1

1	8
5	12
9	16
13	20
17	24
21	28
25	32
29	36
33	4
1	8

Winding 2

3	10
7	14
11	18
15	22
19	26
23	30
27	34
31	2
35	6
3	10

Note: i) A duplex winding will have two tables, one for each winding

ii) Number of rows in each table is given by  $Z/2m$ . Here, there will be 9 rows

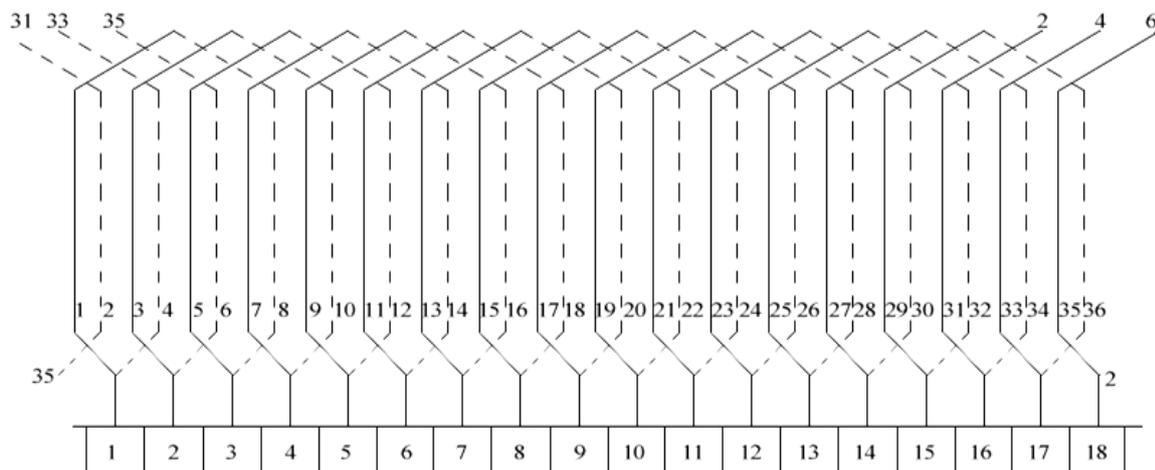
iii) Each row progresses by  $2m$ , i.e., 4

*c. Winding diagram*

c1. Draw 36 vertical lines. Since this a double layer, draw alternate solid and dotted lines. Note that top conductors (solid) must be connected to bottom (dotted) conductors

c2. Draw commutator segments, and numbers them

There are 36 conductors. Number of commutator segments given by  $Z/2 = 36/2=18$



*d. Brush position and current direction*

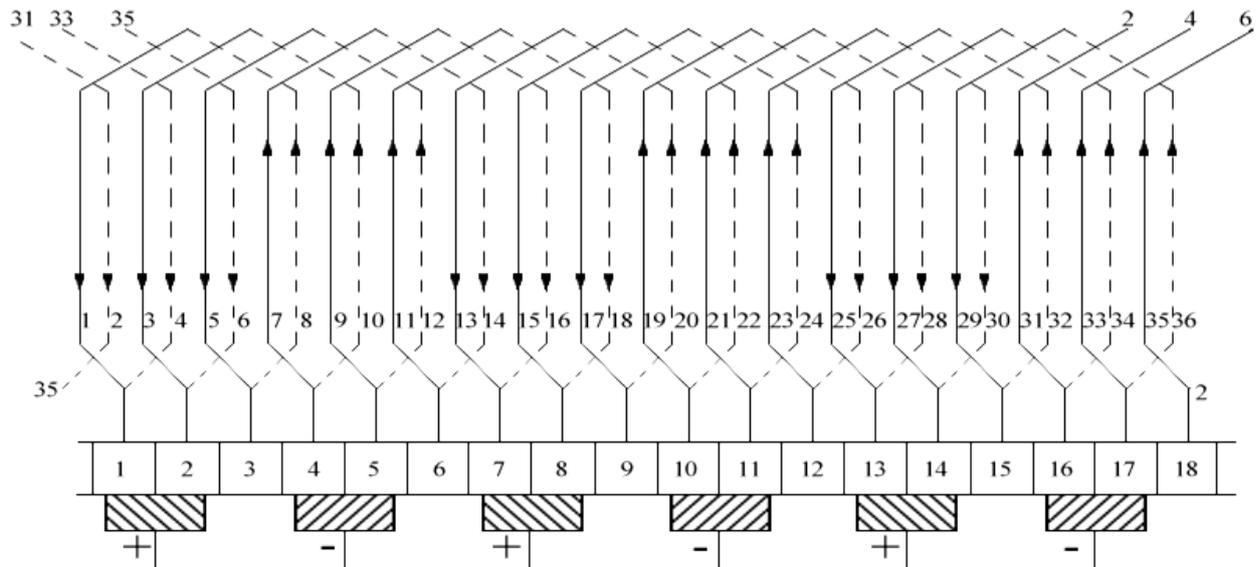
First brush between 1 and 4. Next +ve brush after  $Y_p/m = 6/2 = 3$  rows, ie., at conductor 13, then at 25. Last -ve brush at highest even numbered conductor, 36. Next -ve brush after 3, ie., at 24, next at 12. Same method for the second table. Here highest even number is 34

Winding 1

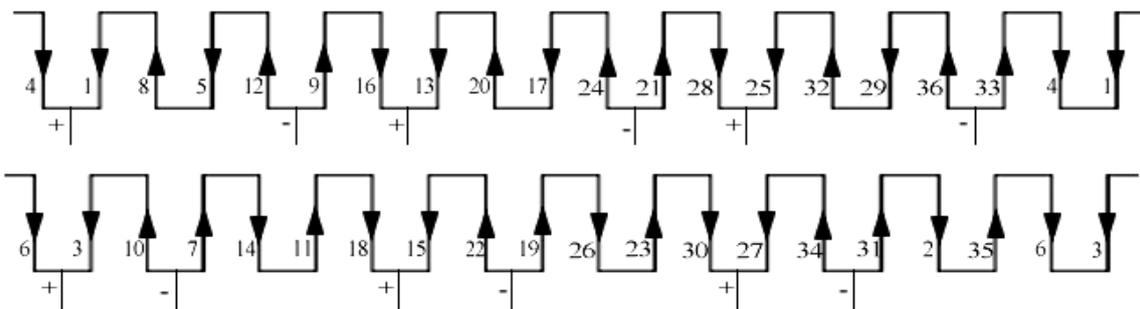
		Com		Com		
		17	33	4	1	↓
	↓	1	1	8	3	↑
$Y_p/m=3$	↓	3	5	12	5	↑
	↑	5	9	16	7	↓
	↓	7	13	20	9	↑
	↓	9	17	24	11	↑
	↑	11	21	28	13	↓
	↓	13	25	32	15	↑
	↓	15	29	36	17	↑
	↑	17	33	4	1	
		1	1	8	3	

Winding 2

		Com		Com		
		18	35	6	2	↓
	↓	2	3	10	4	↑
$Y_p/m=3$	↓	4	7	14	6	↑
	↑	6	11	18	8	↓
	↓	8	15	22	10	↑
	↓	10	19	26	12	↑
	↑	12	23	30	14	↓
	↓	14	27	34	16	↑
	↓	16	31	2	18	↑
	↑	18	35	6	2	
		2	3	10	4	



Brush position and current directions can also be found from sequence diagram. A duplex winding has two sequence diagrams



Note: In duplex windings, brushes span two commutator segments

**3. Draw developed winding diagram for a lap connected machine with 24 slots, 6 poles. It is double layer, duplex, progressive winding**

a. Calculations:

$$Z=24*2$$

$$P=6$$

$$m=2$$

$$\text{Pole pitch, } Y_p = 48/6 = 8$$

$$\text{Back pitch, } Y_b = 8+2 = 10 \rightarrow 9$$

$$\text{Front pitch, } Y_f, 8-2 = 6 \rightarrow 5$$

b. Winding table, brushes and current directions

	45	6	↓
↓	1	10	↑
↓	5	14	↑
↑	9	18	↓
↑	13	22	↓
↓	17	26	↑
↓	21	30	↑
↑	25	34	↓
↑	29	38	↓
↓	33	42	↑
↓	37	46	↑
↑	41	2	↓
↑	45	6	
	1	10	

	47	8	↓
↓	3	12	↑
↓	7	16	↑
↑	11	20	↓
↑	15	24	↓
↓	19	28	↑
↓	23	32	↑
↑	27	36	↓
↑	31	40	↓
↓	35	44	↑
↓	39	48	↑
↑	43	4	↓
↑	47	8	
	3	12	

For duplex windings, distance two positive (or negative) brushes is  $Y_p/2$

One brush is at conductor 1, at 4<sup>th</sup> row, at 17

c. Equaliser rings

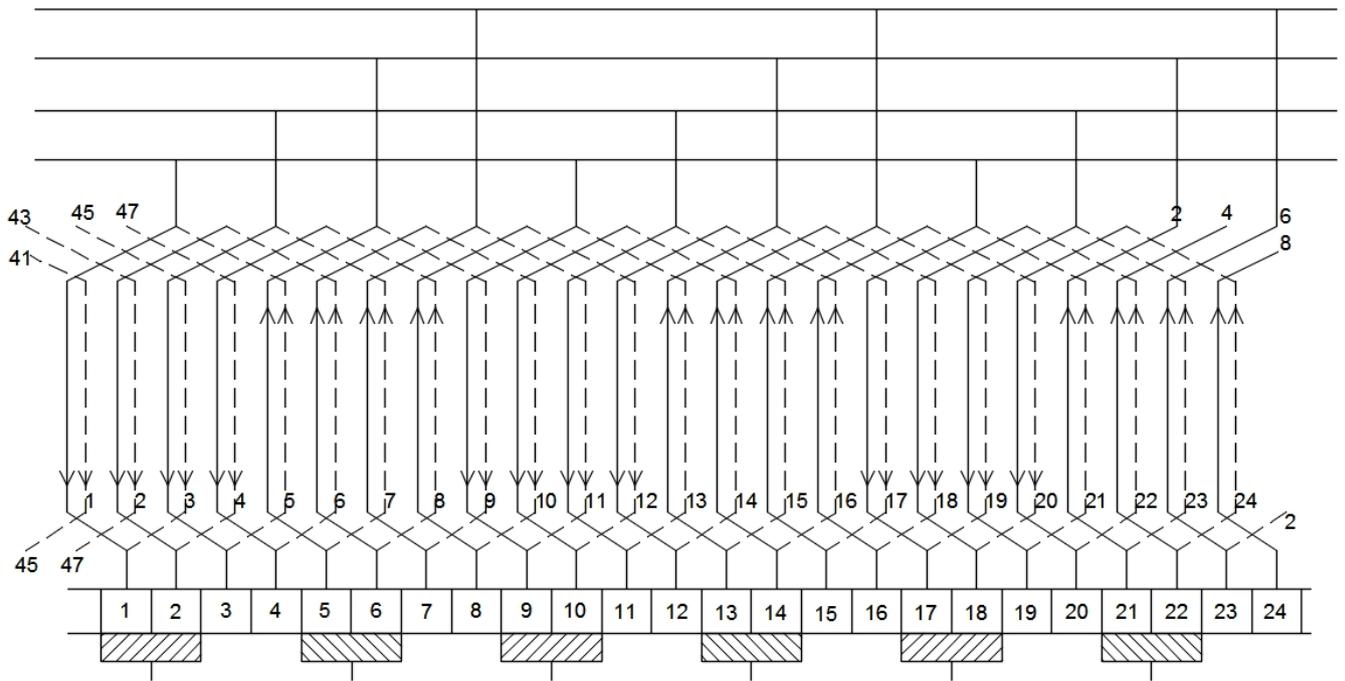
$$Z=48, P=6$$

$$n=Z/2P = 48/2*6 = 4, \text{ ie., 4 rings}$$

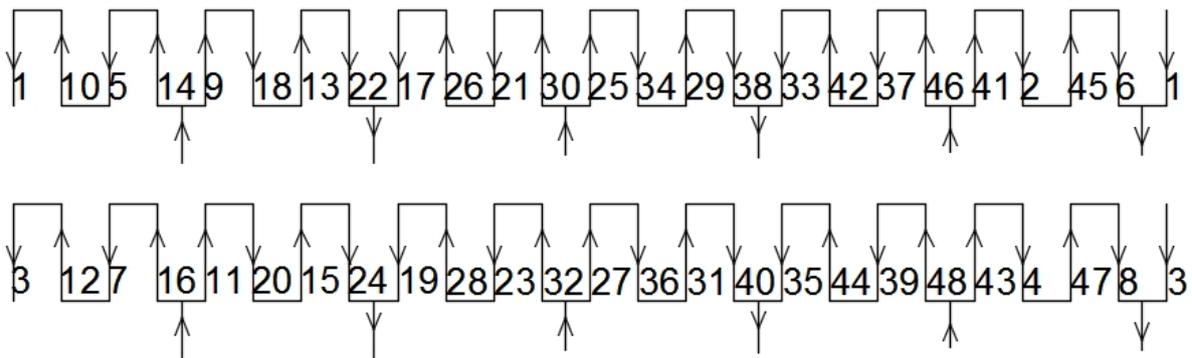
$$\text{Total tappings} = nP/2 = 4*6/2 = 12$$

$$\text{Distance between two tappings on same ring} = Z/P = 48/6 = 8$$

$$\text{Distance between two adjacent tappings} = Z/nP = 48/4*6 = 2$$



Sequence diagrams



**4. Draw developed lap winding diagram for a 30 conductor, 4 pole, single layer, simplex machine**

a. Calculations:

$Z=30 \times 1$

$P=4$

Pole pitch,  $Y_p=30/4 = 7.5$

Back pitch,  $Y_b=7.5+1=8.5, \rightarrow 7$

Front pitch,  $Y_f, 7.5-1=6.5, \rightarrow 5$

b. Winding table, brushes and current directions

	29	6	↓
↓	1	8	↑
↓	3	10	↑
↓	5	12	↑
↓	7	14	↑
↑	9	16	↓
↑	11	18	↓

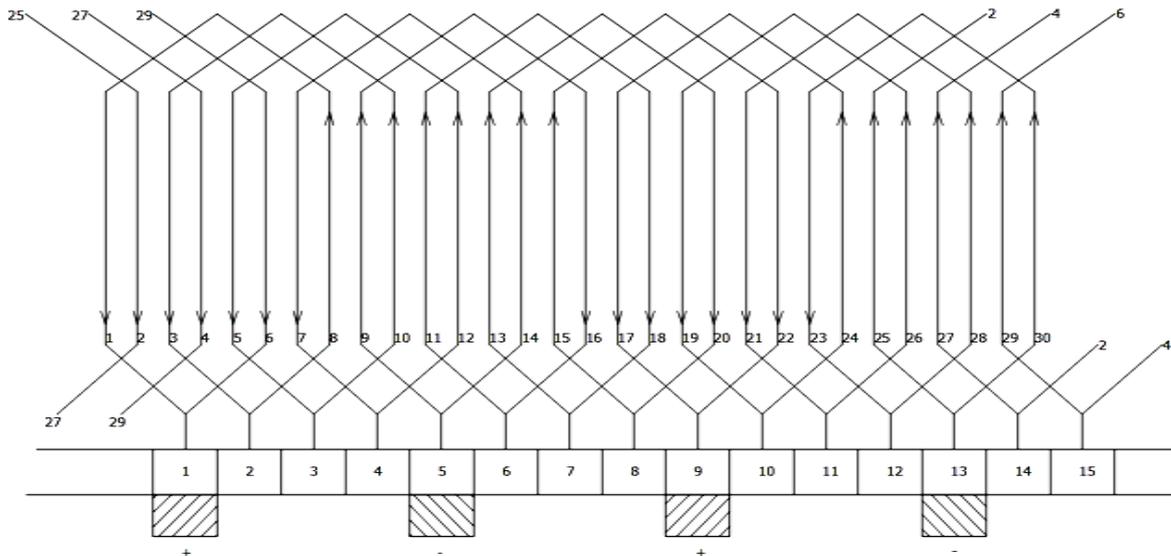
There are  $30/2=15$  rows

Distance between two positive or two negative brushes is  $Y_p=7.5$ . Go to the next higher number, 8.

One +ve brush at 1, next +ve brush at 17, after 8 rows.

Similarly for the negative brushes, at conductors 30 and 14

↑	13	20	↓
↑	15	22	↓
↓	17	24	↑
↓	19	26	↑
↓	21	28	↑
↓	23	30	↑
↑	25	2	↓
↑	27	4	↓
↑	29	6	↓
	1	8	



## Wave Winding

In wave windings, end of one coil is connected to start of another coil under the next pole

$$\frac{Y_b + Y_f}{2} = \frac{Z \pm 2m}{P}$$

Average pitch is given by

If average pitch is odd number,  $Y_b = Y_f$

If average pitch is even number,  $Y_b \sim Y_f = 2m$

Wave is progressive if ending of  $P/2$  coils in series gets connected with a commutator segment which is *ahead* of the starting segment to which the starting of the  $P/2$  coil in series is connected.

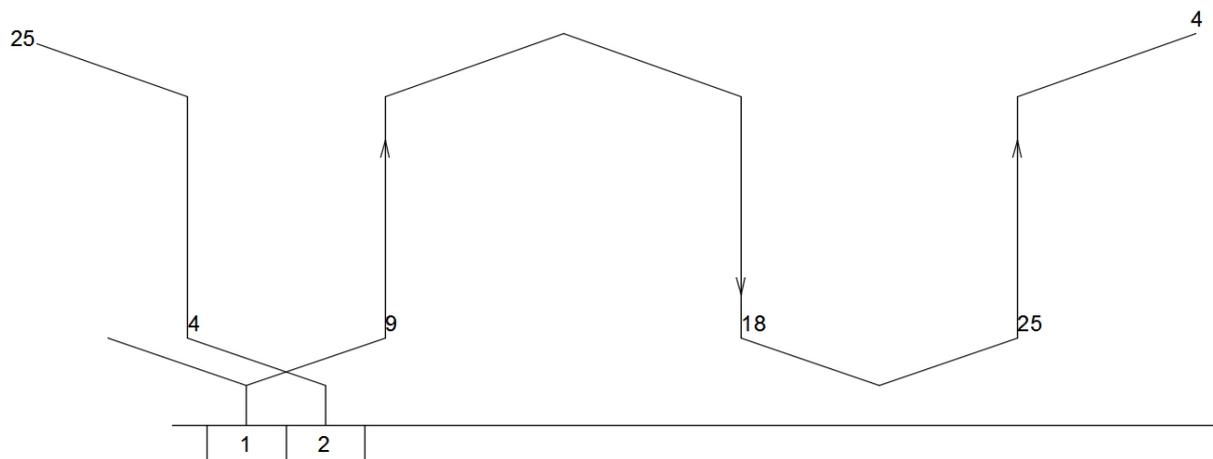
Wave is retrogressive if ending of  $P/2$  coils in series gets connected with a commutator segment which is *behind* the starting segment to which the starting of the  $P/2$  coil in series is connected.

In simple words, if a coil starts at segment 1 –

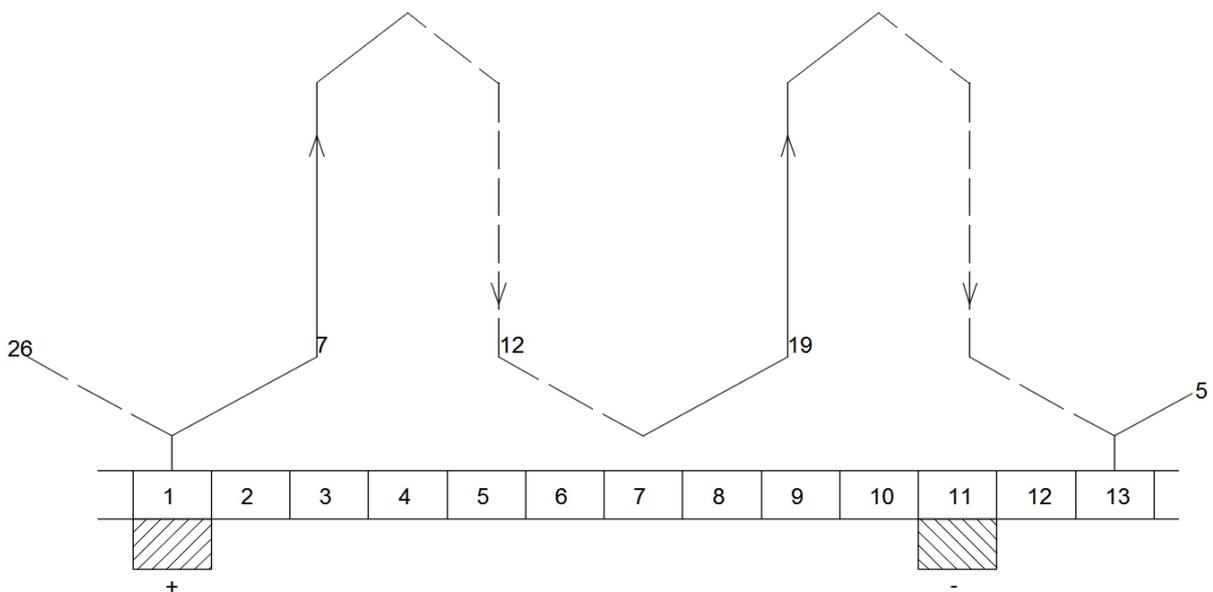
- it has to end at segment 2 for the winding to be progressive

- it has to end at last segment (behind segment 1) for the winding to be retrogressive

The winding starts from commutator segment 1 and ends at segment 2. So it is progressive wave.  $Y_b=9$ ,  $Y_f=7$



The winding starting from commutator segment 1 and ends at the last segment 13. So it is retrogressive wave.  $Y_b=5$ ,  $Y_f=7$



### 1. Draw a double layer wave winding of a DC machine with 17 slots and 4 poles

a. Calculations

Conductors,  $Z = 17 \times 2 = 34$

Poles,  $P = 4$

Multiplicity,  $m = +1$  (simplex and progressive)

$$(Y_b + Y_f)/2 = (Z + 2m)/P = (34 + 2)/4 = 9$$

So,  $Y_b + Y_f = 18$

Assume  $Y_b = Y_f$ . So  $Y_b = 9$  and  $Y_f = 9$

Note: Either  $Y_b = Y_f$ , or  $Y_b - Y_f = 2m$

*b. Winding table*

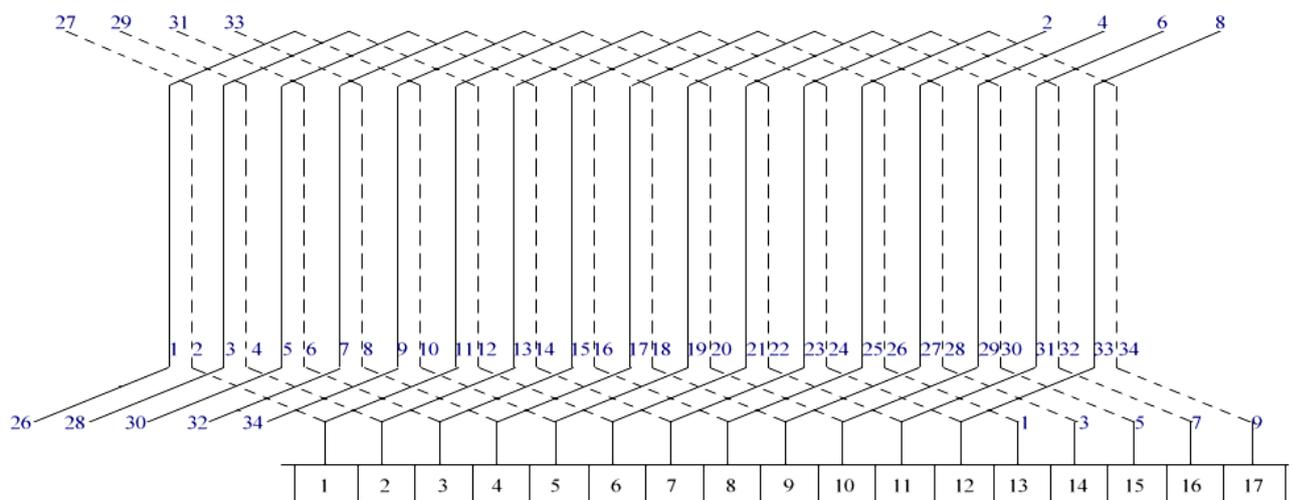
1	10
19	28
3	12
21	30
5	14
23	32
7	16
25	34
9	18
27	2
11	20
29	4
13	22
31	6
15	24
33	8
17	26
1	10

Note:

a. There are  $Z/2m$  rows, that is 17 rows

b. Every alternate row moves up by 2 (decreases by 2 if retrogressive)

*c. Winding diagram*



*d. Brush position and current direction*

Normally, wave winding has two brushes only, as there are only two parallel paths, irrespective of the number of poles. But more number of brushes (4, 6, etc...) can be included. Here, only two brushes are enough

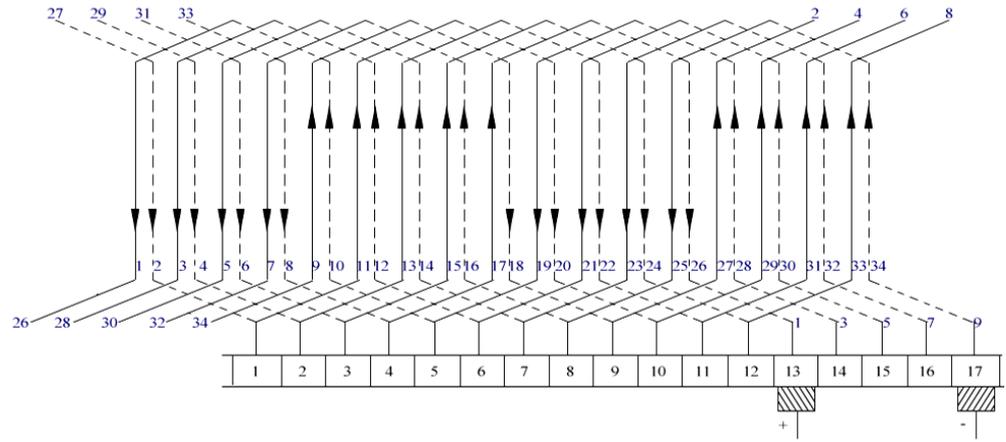
a. A positive brush can be placed at the point **before** the **1<sup>st</sup>** conductor, i.e., between 1 and 26

b. A negative brush can be placed at the point **after** the **last** conductor (highest even numbered), i.e., between 34 and 9

c. At a positive brush, current flows out of the winding. So, conductors 1 and 26 have current in downward direction

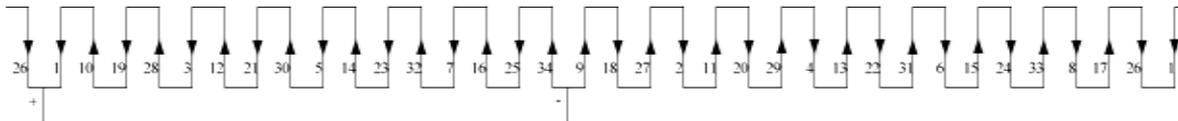
d. At a negative brush, current flows into the winding. So, conductors 34 and 9 have current in upward direction

	17	26	↓
↓	1	10	↑
↓	19	28	↑
↓	3	12	↑
↓	21	30	↑
↓	5	14	↑
↓	23	32	↑
↓	7	16	↑
↓	25	34	↑
↑	9	18	↓
↑	27	2	↓
↑	11	20	↓
↑	29	4	↓
↑	13	22	↓
↑	31	6	↓
↑	15	24	↓
↑	33	8	↓
↑	17	26	
	1	10	



Note: The segment numbers may change if the commutator segments are started from other coils. Since a rotating machine is cylindrical, it does not matter from where the segments start.

If Sequence diagram is used to find current direction-



## 2. Draw developed wave winding diagram for a 22 slot, 4 pole, double layer winding

### a. Calculations

Conductors,  $Z = 22 \times 2 = 44$

Poles,  $P = 4$

Multiplicity,  $m = +1$  (simplex and progressive)

$$(Y_b + Y_f)/2 = (Z + 2m)/P = (44 + 2)/4 = 11.5$$

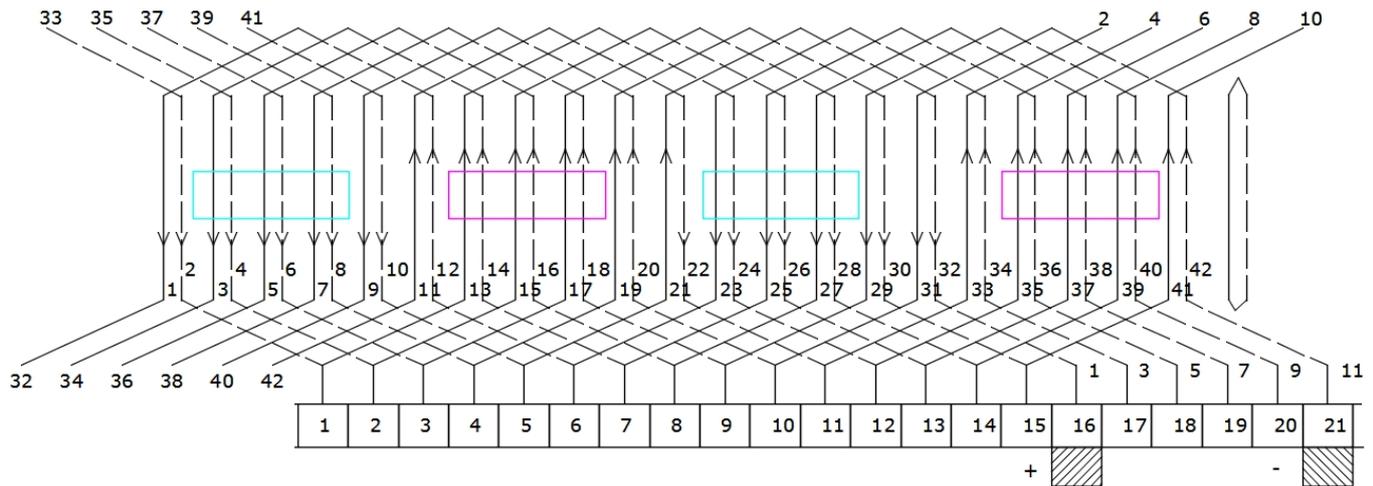
Since this is not a whole number, one full coil is removed. If 2 conductors are removed,  $Z = 42$

$$(Y_b + Y_f)/2 = (Z + 2m)/P = (42 + 2)/4 = 11 \text{ which is a whole number}$$

So,  $Y_b + Y_f = 22$

Assume  $Y_b = Y_f$ . So  $Y_b = 11$  and  $Y_f = 11$

Note: Either  $Y_b = Y_f$ , or  $Y_b - Y_f = 2m$



The 43<sup>rd</sup> and 44<sup>th</sup> conductors form a dummy coil, which is placed only for mechanical balance and are not connected to the commutators

Winding table is created only for 42 conductors, not 44

Dummy coil:

Sometimes with a certain number of coils, it is not possible to get a whole number for average pitch. Then one or more coils have to be removed from the armature circuit. But the coil is still kept in the slots for mechanical balance. They are usually used in small machines only. They are also called as forced windings.