4.8. WAVE WINDING

Wave winding is also sometimes known as *series winding.* In lap winding a coil side under one pole is connected directly to a coil side which occupies a nearly corresponding position under the next pole by means of back connections, and this second coil is then connected back through the commutator segment, to a coil side under the original pole, but removed two or more coil sides from the initial one. But in a wave winding the coil side is not connected back but progresses forward to another coil side, as shown in fig. 4.18 (*e*). In this way the winding progresses, passing successively every N pole and S pole till it returns to coil the side from where it was started. Thus the connections always progress in the same direction around armature instead of moving in alternate directions like that of lap winding. As the winding shape is wavy, the winding is, therefore, called *wave winding.* If after completing one round of the armature, the winding falls in a slot to the right of its starting point it is known as *progressive wave winding* and if it falls in a slot left of its starting point, it is called a *retrogressive wave winding.* The other difference in lap and wave windings is that in a lap winding the number of parallel paths is equal to m times the number of poles where *m* is the multiplicity of the winding but number of parallel paths in wave winding is twice the multiplicity of the winding.

The fact that simplex wave windings always have two parallel paths (*m* being equal to unity) each of which contains conductors more or less uniformly distributed around the entire armature core surface, serve to provide machines wound in this manner with certain unique advantages. In the first place, wave wound machines need have but two sets of brushes (although as many brush sets as poles are frequently employed), while satisfactory operation of simplex lap wound machines is possible only if there are as many brush sets as there are poles; furthermore, in a wave wound machine equipped with as many brush sets as poles, if one or more of the brush sets develop poor contact with the commutator, satisfactory operation is still possible, this is not true in case of lap wound machines.

A second advantage of wave wound machines is that sparkless commutation is more likely to occur than in those wound with lap windings. The reason for this is that each of the two parallel paths contain conductors distributed completely around the entire circumference whereas in lap wound armatures, each of the parallel paths contains conductors lying under two poles only. If the fluxes produced by all the poles are not exactly the same, the voltages generated in both of the paths of the wave wound armature are still exactly equal because the two paths are affected similarly, whereas this is not true in case of lap would armatures and so requires equalizer connections to give sparkless commutation, as already explained in Art. 4.7.2.

Since wave winding gives always two parallel paths irrespective of number of poles and, therefore, for a given number of poles and armature conductors, it gives more emf than the lap winding hence it is used for high voltage and low current machines. For machines of upto 125 kW capacity with voltages that result in total armature current of not more than 500 A, current per path will not exceed 250 A. This value represents a sort of practical upper limit, above which serious commutation difficulties appear. For total current ratings larger than 500 amperes, it becomes necessary to employ armature windings giving more than two parallel paths, that is, windings that are not simplex wave. Simplex lap windings, that give as many parallel paths as poles are customarily employed in such cases, but sometimes in order to retain the advantages of the wave type winding over lap type winding and still keep the current per path within the upper limit indicated above, use of multiplex wave winding is made. Such windings, as already told, give the parallel paths twice the multiplicity of the winding in number, regardless the number of poles. Thus duplex, triplex and quadruplex wave windings give four, six and eight paths in parallel. Such windings, however, have limited use because other operating difficulties have developed. In some cases, the arcing at the commutator that these windings were supposed to correct, appeared another way by causing sparking and blackening at every second, third or fourth segment, a condition that resulted when slight differences existed in the electric circuits.

Important Points Regarding Wave Winding. (*a*) *In simplex wave winding*

1. Both the pitches, back pitch and front pitch must be odd numbers.
2. Back and front pitches must be nearly equal to the pole pitch and may be equal or differ by 2 in which case, they will be one more or one less than average pitch.
3. Commutator pitch, Y_c = Average pitch, Y_{av}
4. The average pitch Y_{av} is given by

$Y_{av} = \frac{Y_b + Y_f}{2} = \frac{Z \pm 2}{P}$ where Z is the number of conductors or coil sides and P is the number of poles. In order that the wave winding may close itself, the average pitch Y_{av} must be a whole number and agree to the above formulae.

In the above formulae ± 2 has been taken due to the reason that after one round of the armature the winding falls short of two conductors from the starting conductor. If it is not done and the average pitch is taken equal to $\frac{Z}{P}$ then after one round of the armature, the winding will come back to the starting conductor or winding will close itself without including all coil sides.

The + ve sign in the above formulae will give progressive winding and –ve sign a retrogressive winding.

Since average pitch Y_{av} should be a whole number, this winding is not possible with any number of coil sides. For example with 28 conductors in a 4-pole machine, since $Y_{av} = \frac{28 \pm 2}{4} = 7\frac{1}{2}$ or $6\frac{1}{2}$ being fractional number, the wave winding is not possible but for 26 or 30 conductors, this winding can be employed since $Y_{av} = \frac{26 \pm 2}{4} = 7$ or 6 and $Y_{av} = \frac{30 \pm 2}{4} =$ 8 or 7.

5. For even number of pairs of poles *i.e.* for 2, 4, 6, or 8 pair pole machine.

(*i*) the average pitch, $Y_{av} = \frac{Y_b + Y_f}{2}$ may be odd or even

(*ii*) the number of coils must be odd

(*iii*) the number of commutator segments must be odd.

For odd number of pairs of poles such as 3, 5, 7

(*i*) the number of coils may be even or odd

(*ii*) the number of commutator segments may be even or odd

(*iii*) if the number of coils is even, average pitch must be odd and if the number of coils is odd, average pitch must be even.

(*b*) *In Multiplex wave Winding.*

1. The relation between the back pitch and the front pitch for multiplex wave winding is also the same as for the multiplex lap winding, so

$$Y_b = Y_f \pm 2m$$

where m is the multiplicity of the winding;
+ ve sign indicates progressive winding and –ve sign indicates retrogressive winding.

2. The average pitch for multiplex wave winding is given as $Y_{av} = \frac{Z \pm 2m}{P}$ and it must be an integer.

3. In a duplex winding having an odd number of pairs of poles, whose average pitch is odd, must have an odd number of commutator segments and coils and one whose average pitch is even must have an even number of commutator segments and coils.

If the duplex winding has an even number of pairs of poles, the number of commutator segments and coils must be even irrespective of whether the average pitch is odd or even.

If in a duplex winding average pitch Y_{av} is odd, the winding will be singly re-entrant and if even, doubly re-entrant.

4.8.1. Dummy Coils. The wave winding is possible only with particular number of conductors but sometimes the standard armature punchings available in armature winding shops do not meet with the requirements of the winding as these may accommodate more than the required number of conductors. In such cases *dummy coil or coils* are employed. (These coils are placed in slots to preserve the balance of machine but are not electrically connected to the rest of the winding.

Say for example it is desired to have a simple wave winding for 16 slots, each slot accommodates two coil sides in a 4-pole machine.

$$Y_{av} = \frac{Z \pm 2}{4} = \frac{32 \pm 2}{4} = 8\frac{1}{2} \text{ or } 7\frac{1}{2}.$$

But the average pitch must be an integer, so the winding is not possible with 32 conductors.

However, if 30 conductors are used, $Y_{av} = \frac{30 \pm 2}{4} = 8$ or 7. Thus two windings are possible, one progressive and other retrogressive, but in both cases two coil-sides or one coil is inactive and hence is called *dummy coil*. The ends of dummy coil are taped and are not connected to the commutator segments.)

Example 4.5. Draw up the winding table for a 4 pole, wave-connected armature having 30 coil sides and give a developed diagram of the winding showing the polarity and position of the brushes, the main poles and the direction of motion of the armature for a dc motor.

Solution: Average pitch, $Y_{av} = \frac{Z \pm 2}{P} = \frac{30 \pm 2}{4} = 8$ or 7;

if Y_{av} is taken odd then back pitch Y_b and front pitch Y_f will be equal to Y_{av} *i.e.* 7.

Ist coil side is connected to 8th coil side at the back, which is connected to 15th coil side through commutator segment no. 7 at the front. The 15th coil side is connected to 22nd coil side at the back and 22nd coil side is connected to 29th coil side through commutator segment no 14 at the front and winding diagram is completed with the help of winding table given below. The developed winding diagram is shown in fig. 4.30.

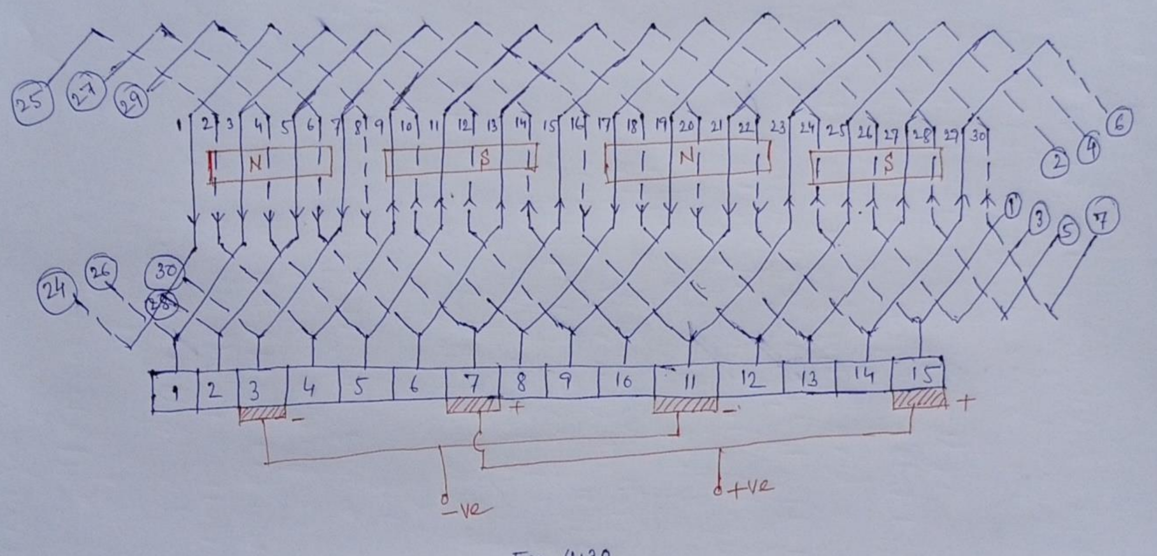
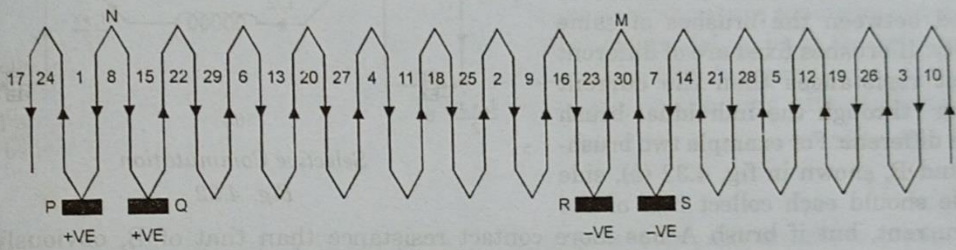


Fig. 4.30

At Back End		At Front End		
Coil Side No.	*Connected to Coil Side No.*	*Coil Side No.*	*Connected to Coil Side No.*	*Through Segment No.*
1	8	8	15	7
15	22	22	29	14
29	6	6	13	6
13	20	20	27	13
27	4	4	11	5
11	18	18	25	12
25	2	2	9	4
9	16	16	23	11
23	30	30	7	3
7	14	14	21	10
21	28	28	5	2
5	12	12	19	9
19	26	26	3	1
3	10	10	17	8
17	24	24	1	15



Equivalent Ring or Spiral Winding
Fig. 4.31

To determine the brush position the ring winding, as shown in fig. 4.31, be drawn. On inserting the direction of emfs according to the actual winding, it is clear that the winding divides itself into two halves between M and P and N and R. The point N is the separating point of the emfs and it corresponds to + ve brush. As it is at the back of the winding and not at commutator end, so the +ve brushes may be fixed at points P and Q on the ring winding or on the junctions of coil side nos. 24 and 1; 8 and 15. Point M is the meeting point of the emfs and, therefore, it corresponds to –ve brush. As it is at the back of the winding and not at commutator end so the – ve brushes may be fixed at points R and S on the ring winding or on junctions of coil side nos. 16 and 23 and of coil side nos. 30 and 7.

Since conductors 24, 1, 8, 15, 16, 23, 30, 7 fall in between the poles, so these conductors have got no induced emf and brushes may be fixed at their respective junction points.

Note: *In generator + ve and – ve brushes should be fixed at meeting and separating points respectively but in motor it is vice-versa.*

Direction of Motion: The direction of motion for a motor is determined by Fleming's left hand rule. The direction has been shown in fig. 4.30.

...f Simplex Wave Winding. From the above winding diagram, the following facts