Fig. 4.1. Disassembled view of a brushless DC motor: permanent magnet rotor, winding, and Hall element.

Fig. 4.2. Three-phase unipolar-driven brushless DC motor.

Fig. 4.8. DC motor's brushes replaced with mechanical switches or transistors: (a) commutator segment A is touching the positive brush, (b) touching the negative brush. (c) touching neither.
Conventional vs Brushless DC Motors

<table>
<thead>
<tr>
<th>Mechanical structure</th>
<th>Conventional motors</th>
<th>Brushless motors</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Field magnets on stator</td>
<td>Field magnets on rotor</td>
</tr>
<tr>
<td></td>
<td>Windings on rotor</td>
<td>Windings on stator, therefore easier to cool</td>
</tr>
<tr>
<td>Commutation method</td>
<td>Mechanical contact between brushes and commutator added friction, brush debris RFI</td>
<td>Electronic switching using transistors low order harmonics due to ripple</td>
</tr>
<tr>
<td>Detecting method of rotor's position</td>
<td>Automatically detected by brushes</td>
<td>Hall element, optical encoder, etc.</td>
</tr>
<tr>
<td>Reversing method</td>
<td>Reverse terminal voltage</td>
<td>Rearrange logic sequencer</td>
</tr>
<tr>
<td>Distinctive features</td>
<td>Quick response</td>
<td>Long-lasting</td>
</tr>
<tr>
<td></td>
<td>Excellent controllability</td>
<td>Easy, or no, maintenance</td>
</tr>
<tr>
<td></td>
<td>Current limited by brush/commutator interface</td>
<td>Current limited by winding resistance only</td>
</tr>
<tr>
<td></td>
<td>Speed limited by brush bounce</td>
<td>No fundamental high frequency limit</td>
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<td></td>
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<td>Usually more efficient than conventional</td>
</tr>
</tbody>
</table>
Fig. 1.1 Variable-reluctance stepping motor

Fig. 1.2 Permanent-magnet-rotor stepping motor

Fig. 1.3 Hybrid stepping motor

Fig. 2.74. Examples of T/I characteristics: (a) a 1.8° four-phase VR motor; and (b) a 1.8° four-phase hybrid motor. (After Ref. [17].)
Figure 3-16 Single step response characteristics

Fig. 2.75. Dynamic characteristics.

DYNAMIC CHARACTERISTICS OF STEPPING MOTORS

Fig. 4.16. Example of pull-out torque curve with dips and islands.
Figure 7 - Stepper Motor Winding Types

Fig. 2.51. Bifilar winding.

Fig. 2.52. Three fundamental exciting circuits: (a) monofilar winding, unipolar excitation; (b) monofilar winding, bipolar excitation; (c) bifilar winding, bipolar excitation.
Figure 1-6 Appearance of windings and internal wire connections of an Oriental Motor hybrid stepping motor.

Schematic 2 - Motor connections for (a) four-wire and (b) six-wire stepper motors.
BIPOLAR AND UNIPOLAR OPERATION
All Airpax stepper motors are available with either 2 coil bipolar, or 4 coil unipolar windings.

The stator flux with a BIPOLAR winding is reversed by reversing the current in the winding. It requires a push-pull bipolar drive as shown in Fig. 14. Care must be taken to design the circuit so that the transistors in series do not short the power supply by coming on at the same time. Properly operated, the bipolar winding gives the optimum motor performance at low to medium step rates.

A UNIPOLAR winding has 2 coils wound on the same bobbin per stator half. Flux is reversed by energizing one coil or the other coil from a single power supply. The use of a unipolar winding, sometimes called a bifilar winding, allows the drive circuit to be simplified. Not only are half as many power switches required (4 vs. 8), but the timing is not as critical to prevent a current short through two transistors as is possible with a bipolar drive.

For a unipolar motor to have the same number of turns per winding as a bipolar motor, the wire diameter must be decreased and therefore the resistance increased. As a result unipolar motors have 30% less torque at low step rates. However, at higher rates the torque outputs are equivalent.

Fig. 14 Schematic Bipolar and Unipolar Switching Sequence. Direction of Rotation Viewed from Shaft End.
Fig. 2.55. Difference in single-step response between the single-phase (a) and two-phase (b) excitation.

Fig. 2.56. Rotor oscillation in the two-phase excitation.

Fig. 2.2. Block diagram for motor drive system.
Figure 2-13 Diagram of the current rise of a stepping motor

Fig. 5.24. Improving build-up by putting $R_e$ in series with the winding and raising supply potential $E$.

Fig. 4.8. Measured position–time responses on a three-phase VR motor in the two-phase-on excitation mode (after Ref. [1], reproduced by permission of the Institution of Electrical Engineers, and by courtesy of Professor P. J. Lawrenson and Dr A Hughes.)