Applied Motion Products

404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

A ***STEP MOTOR IS DEFINED AS*** a device whose normal shaft motion consists of discrete angular movements of essentially uniform magnitude when driven from sequentially switched DC power supply.

A step motor is a digital input-output device. It is particularly well suited to the type of application where control signals appear as digital pulses rather than analog voltages. One digital pulse to a step motor drive or translator causes the motor to increment one precise angle of motion. As the digital pulses increase in frequency, the step movement changes into continuous rotation.

Types Of Step Motors

There are three basic types of step motors in common use:

- Active rotor: permanent magnet (PM)
- Reactive rotor: variable reluctance (VR)
- Combination of VR and PM: Hybrid(HY)

These are brushless electrical machines which rotate in fixed angular increments when connected to a sequentially switched DC current. When alternating current is used, the rotation is essentially continuous.

Permanent magnet: This type of step motor has a permanent magnet rotor. The stator can be similar to that of a conventional 2- or 3-phase induction motor or constructed similar to a stamped motor. The latter is the most popular type of step motor.

a.) Conventional permanent magnet type. Figure 1 shows a diagram of a conventional permanent magnet rotor step motor. A 2-phase winding is illustrated. Figure 1a shows Phase A energized with the "A" terminal positive. The field is at 0˚. With the coil wound as shown, the north seeking pole of the rotor is also at 0˚. The motor steps as shown in Table I.

TABLE I

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Energization phase A A'	phase B B'	Figure
0	0	0	+ —	off off	1a
1	90	90	off off	+ —	1b
2	180	180	— +	off off	1c
3	270	270	off off	— +	1d

The shaft completes one revolution for each complete revolution of the electromagnetic field in this motor.

Figure 2 shows the same motor with both windings energized. The important difference here is that the resultant electromagnetic field is between two poles. In figure 2, the field has moved 45˚ from the field in figure 1. Table II shows the energization sequence and rotor positions.

TABLE II

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Energization phase A A'	phase B B'	Figure
0	45	45	+ —	+ —	2a
1	135	135	— +	+ —	2b
2	225	225	— +	— +	2c
3	315	315	+ —	— +	2d

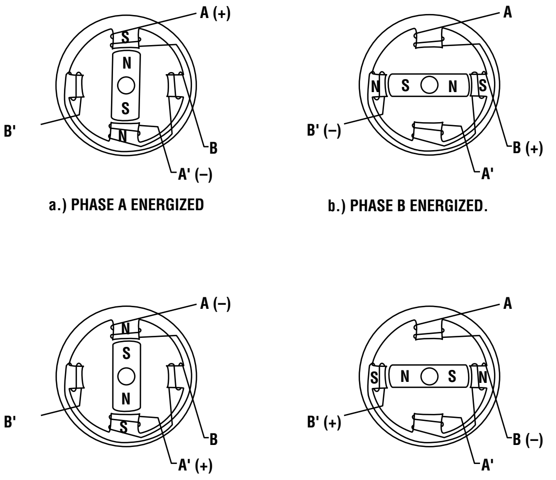
As in the one-phase-on energizing scheme, the shaft completes one revolution for each complete revolution of the electromagnetic field.

It should be evident that this motor can half step; i.e., step in small step increments. This is possible by combining the energization shown in Figure 1 with that shown in Figure 2. Figure 3 shows the diagrams of a motor with half-step rotor motion. The energizing sequence and rotor positions are shown in Table III.

Applied Motion Products

404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

FIGURE 1



a.) PHASE A ENERGIZED

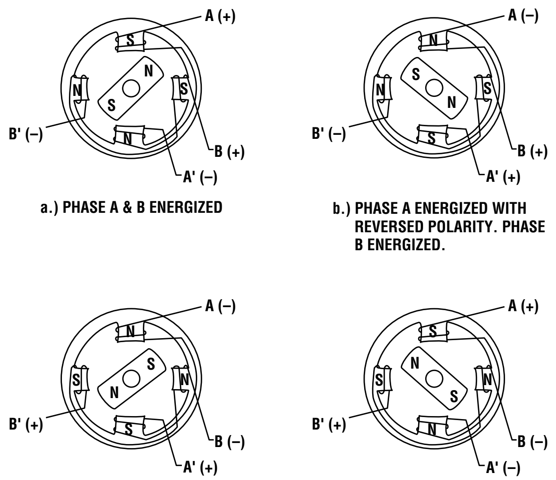
b.) PHASE B ENERGIZED.

c.) PHASES A ENERGIZED WITH REVERSE POLARITY.

d.) PHASE B ENERGIZED WITH REVERSED POLARITY.

Conventional permanent magnet step motor shown with one phase energized with a bipolar drive. The electromagnetic field rotates in 90° increments. The rotor rotates in 90° increments.

FIGURE 2



a.) PHASE A & B ENERGIZED

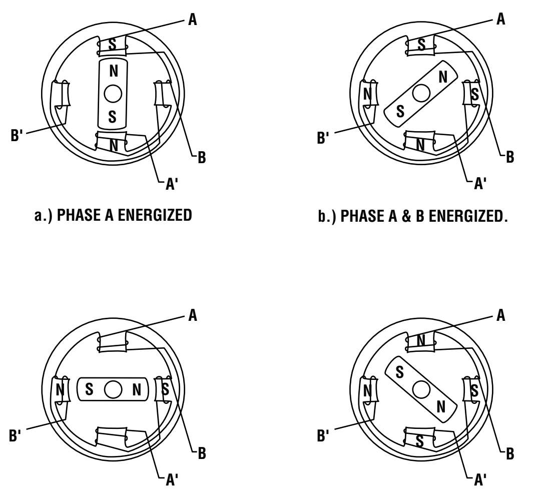
b.) PHASE A ENERGIZED WITH REVERSED POLARITY. PHASE B ENERGIZED.

c.) PHASES A & B ENERGIZED WITH REVERSE POLARITY.

d.) PHASE A ENERGIZED. PHASE B ENERGIZED WITH REVERSED POLARITY.

Permanent magnet step motor shown with two phases energized with a bipolar drive.

FIGURE 3



a.) PHASE A ENERGIZED

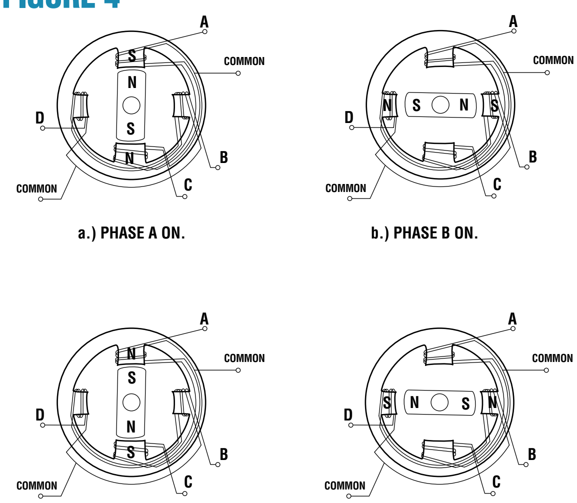
b.) PHASE A & B ENERGIZED.

c.) PHASE B ENERGIZED.

d.) PHASE B ENERGIZED. PHASE A ENERGIZED WITH REVERSED POLARITY.

PM step motor with half step motion.

FIGURE 4



a.) PHASE A ON.

b.) PHASE B ON.

c.) PHASE C ON.

d.) PHASE D ON.

A conventional PM step motor with bifilar winding.

Applied Motion Products
404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

TABLE III

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Energization phase A A'	phase B B'	Figure
0	0	0	+ —	off off	3a
1	45	45	+ —	+ —	3b
2	90	90	off off	+ —	3c
3	135	135	— +	+ —	3d

As in the previous diagrams, the rotor and shaft move through the same angle as the field. Note that each step resulted in a 45˚ rotation instead of 90˚ in the previous diagram.

A permanent magnet step motor may be wound with a bifilar winding to avoid the necessity of reversing the polarity of the winding. Figure 4 shows the bifilar winding while Table IV shows the energization sequence.

TABLE IV

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Energization phase A C	phase B D	Figure
0	0	0	on off	off off	4a
1	90	90	off off	on off	4b
2	180	180	off on	off off	4c
3	270	270	off off	off on	4d

Bifilar windings are easier to switch using a transistor controller. Fewer switching transistors are required.

b.) Stamped or can stack permanent magnet step motor. The most popular type of permanent magnet step motor is the so called stamped type, claw tooth, sheet metal, tin can or simply low cost motor. This motor is difficult to illustrate clearly because of the way it is constructed. The cutaway in Figure 5 is an attempt to show how this type of PM step motor looks. The motor is shown with both phases energized. The rotor is shown with 12 poles resulting in 24 steps per revolution with a 15˚ step angle. A schematic diagram of a PM step motor of the type illustrated in Figure 5 is shown in Figure 6. This motor has a pair of coils surrounding a permanent magnet rotor. The coils are enclosed in a soft iron housing with teeth on the inside reacting with the rotor. Each coil housing has the same number of teeth as the number of rotor poles. The housings are radially offset from each other by one-half the tooth pitch.

PM step motors are available with the following step angles:

Step Angle Degrees	Steps Per Revolution
1.8	200
3.6	100
3.75	96
7.5	48
9	40
10	36
11.25	32
15	24
18	20
22.5	16
30	12
45	8
90	4

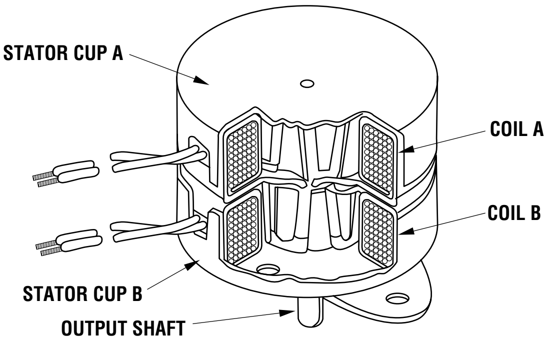
Variable Reluctance Type: This type of step motor has an electromagnetic stator with a magnetically soft iron rotor having teeth and slots similar to the rotor of an inductor alternator. Whereas PM motors are basically 2-phase machines, VR motors require at least 3 phases. Most VR step motors have 3 or 4 phases although 5-phase VR motors are available.

A 3-phase VR motor diagram is shown in Figure 7. The motor shown has 12 stator teeth, 8 rotor teeth, and step angle of 15˚. The energization sequence is shown in Table V.

Applied Motion Products

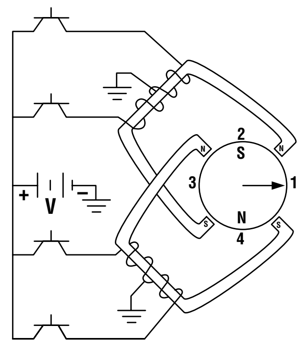
404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

FIGURE 5



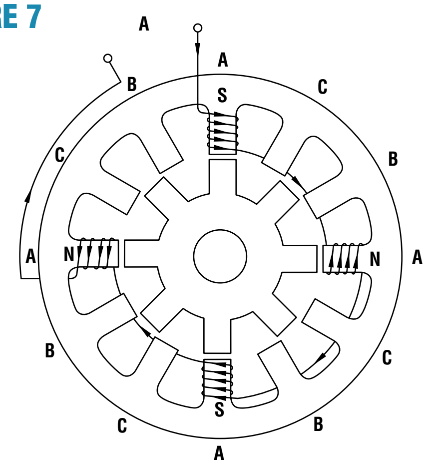
Cut-away view of a PM motor

FIGURE 6



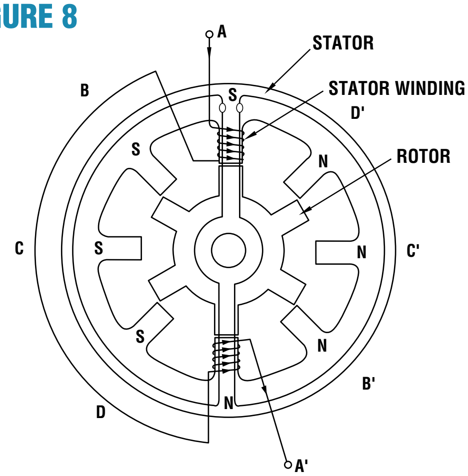
Schematic diagram of a PM motor.

FIGURE 7



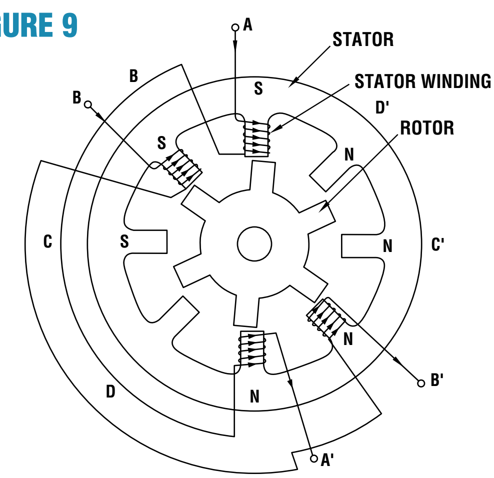
3 phase VR motor.

FIGURE 8



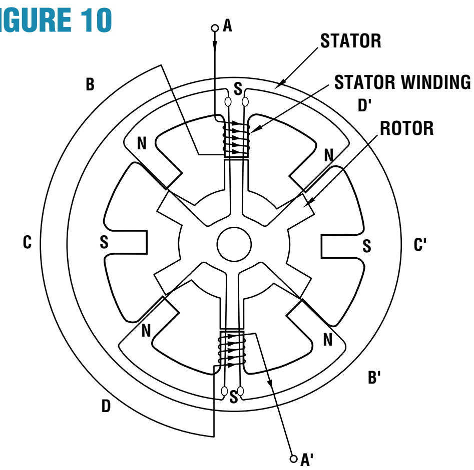
4 phase VR motor with one phase on.

FIGURE 9



4 phase VR motor with two phases on.

FIGURE 10



4 phase VR motor with one phase on. Wound for alternate polarity.

Applied Motion Products
404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

TABLE V

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Energization Phase A	B	C
0	15	60	on	off	off
1	30	120	off	on	off
2	45	180	off	off	on
3	60	240	on	off	off

In a VR step motor, the field moves at a different rate than the rotor.

Figure 8 shows a diagram of a 4-phase 15˚ step angle motor with one phase energized. The energization diagram is shown in Table VI.

TABLE VI

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Phases A	B	C	D
0	15	-45	on	off	off	off
1	30	-90	off	on	off	off
2	45	-135	off	off	on	off
3	60	+135	off	off	off	on

Note the rotation of the electromagnetic field. The field takes a big jump in rotation between steps 2 and 3. This is characteristic of a motor connected this way. Figure 9 shows this motor with two phases energized at a time. The rotation of the field remains the same. A way to correct this is shown by the diagram in Figure 10. The diagrams in figures 8 and 9 illustrate windings connected 4N and 4S. This indicates the magnetic poles as they are energized. The coil hookup shown in Figure 10 shows a symmetrical hookup called N-S-N-S because of the coil polarity. Note that Phase A coil has two south poles and no north poles for a flux return path. You may rest assured that there will be one. The flux will return through the path of least reluctance, namely through the pole pairs which are nearest to two rotor teeth. This varies with rotor position. The flux induces a voltage in the coils wound on the pole. This induces a current in the winding slowing the rotor. The amount of current is determined by the voltage across the coil. A diode-clamped coil will have more current than a resistor diode or zener diode-clamped winding. Figure 11 illustrates the diagram of a 4-phase VR step motor with N-S-N-S hookup and two phases energized. Note the short flux path between poles.

It is frequently necessary to make the step angle smaller without using gearing. One method is to double the number of rotor and stator teeth. If the motor was constructed as shown in Figure 7, the teeth would be slender and difficult to wind. A better method of doing this is shown in Figure 12. The number of rotor and stator teeth is increased while the number of stator poles is reduced.

Figure 13 shows a diagram of a 5˚ per step variable reluctance step motor. A 1.8˚ per step VR step motor diagram is shown in Figure 14.

Variable reluctance step motors are available in the following step angles:

Step Angle Degrees	Steps Per Revolution
1.8	200
5	72
7.5	48
15	24

Hybrid: This type of motor is frequently referred to as a permanent magnet motor. It uses a combination of permanent magnet and variable reluctance structure. Its construction is similar to that of an induction motor. Figure 15 shows a simplified type of hybrid motor to illustrate its construction. The rotor has two end pieces (yokes) with salient poles equally spaced but radially offset from each other by one-half tooth pitch. A circular permanent magnet separates them. The yokes have essentially uniform flux of opposite polarity. The stator is formed from laminated steel. The motor shown in Figure 15 has 4 coils arranged in two groups of 2 coils in series. One coil pair is called Phase A and the other Phase B. For the motor illustrated, each pole has one tooth. The number of full steps per revolution may be determined from the following formula:

$SPR = N_R \times Ø$

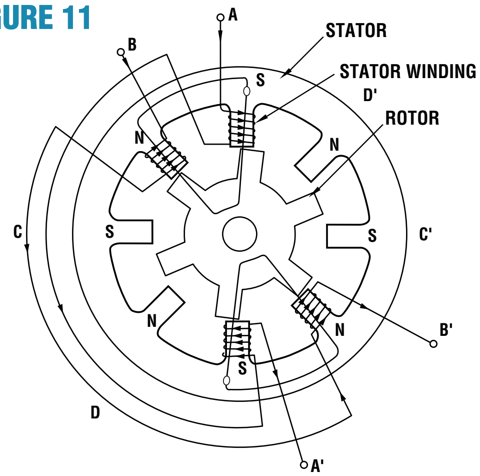
Where: SPR = number of steps per revolution

N_R = total number of rotor teeth (total for both yokes)

Ø = number of motor phases

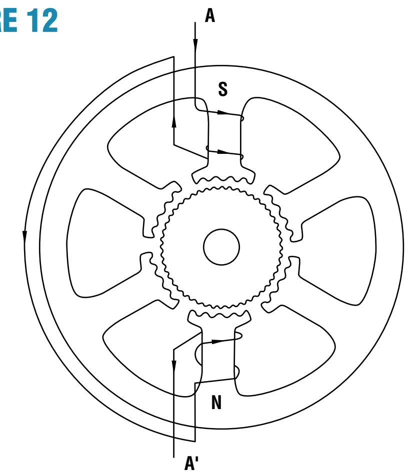
or: $N_R = SPR/Ø$

FIGURE 11



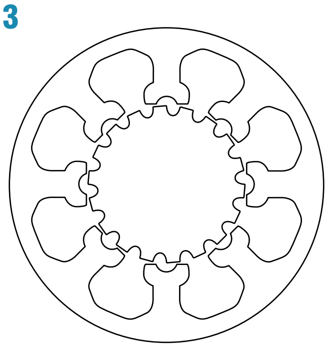
4 phase VR motor with two phases on. Wound for alternate polarity.

FIGURE 12



Stator poles with multiple teeth.

FIGURE 13



5° step angle VR motor.

FIGURE 14

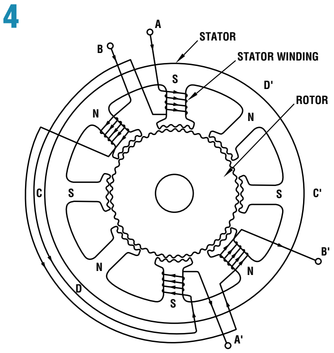
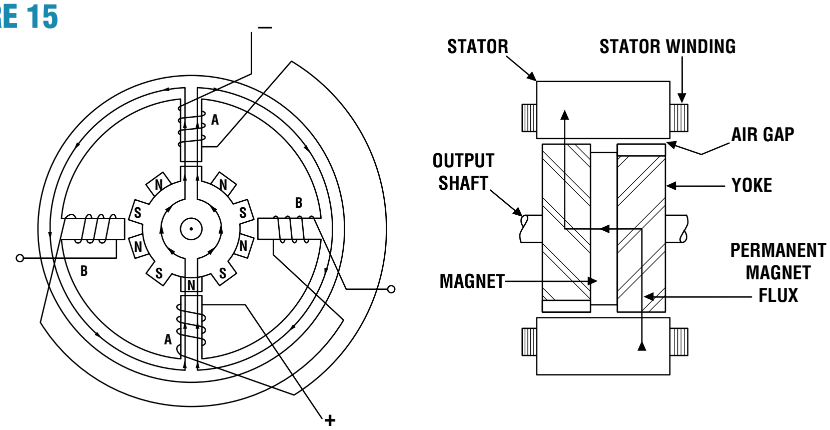


Diagram of 1.8° VR motor.

FIGURE 15



a b

a.) Cross section, phase A energized.
b.) Axial view.

Applied Motion Products

404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

Example: The motor shown in Figure 15 has a 2 Ø winding and a rotor with 5 teeth per yoke for a total of 10 teeth. Calculate the number of steps/rev.

SPR = 10 X 2 = 20 steps/rev.

The step angle may be found from the following formula:

SA = 360/SPR

Where: SA = the step angle in degrees
SPR = steps per revolution

Example: Calculate the step angle for the above motor.

SA = 360/20 = 18°

The step angle may be calculated directly without knowing the number of phases if the number of stator teeth and teeth per pole are known. Figure 15 shows one tooth per pole and a total of 4 teeth on the stator.

Formula: $SA = (1/N_{st} - 1/N_{RP}) \times 360^N \times N_{STP}$

Where: SA = step angle in degrees
N_{ST} = number of stator teeth
N_{RP} = number of rotor teeth per pole or yoke
N_{STP} = number of stator teeth per pole

Note that motors are frequently built with one or two teeth between each pole left out to facilitate winding the motor and reduce flux leakage between poles. This formula requires that the theoretical number of teeth be used.

Note that here, too, the theoretical number of teeth must be used. It is usually easy to visually determine if a tooth or two has been left out between poles.

Example: The motor in Figure 15 has 5 teeth on each rotor yoke and one tooth per pole with 4 teeth total.

NA = (1/4 - 1/5) x 360 x 1
= (.25 - .20) x 360
= 18˚

Figure 16 shows the shaft rotation with 2-phase-on. The switching sequence, field rotation and output shaft rotation are shown in Table VII.

TABLE VII

Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Phases A	Phases B	Figure
0	9˚	45˚	+	+	16a
1	27˚	135˚	—	+	16b
2	45˚	215˚	—	—	16c
3	63˚	305˚	+	—	16d

Figure 17 shows a 5˚ hybrid step motor. Note that the rotor has 18 teeth on each yoke for a total of 36 teeth. The commonly available 1.8˚ hybrid diagram is shown in Figure 18.

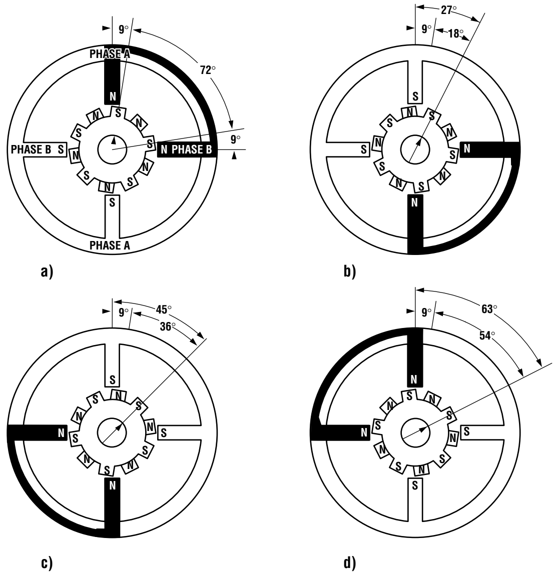
Hybrid step motors are available in the following step angles:

Step Angle Degrees	Steps Per Revolution
0.45	800
0.72	500
0.9	400
1.8	200
1.875	192
2	180
2.5	144
3.6	100
5	72

Applied Motion Products

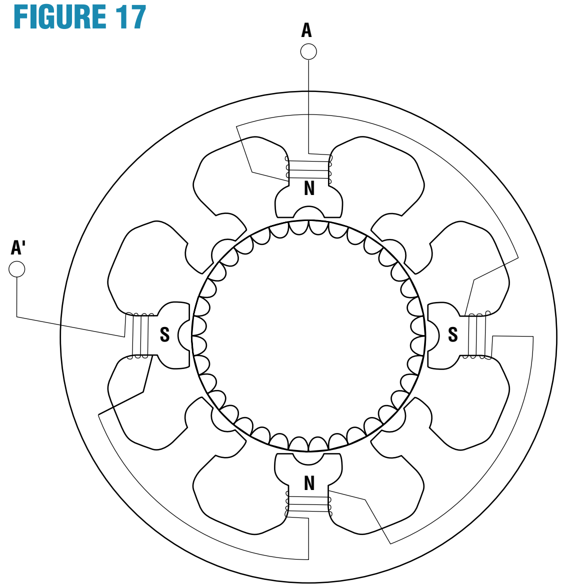
404 Westridge Dr. • Watsonville, CA 95076
831/761-6555 • 800/525-1609 • FAX 831/761-6544
www.applied-motion.com

FIGURE 16



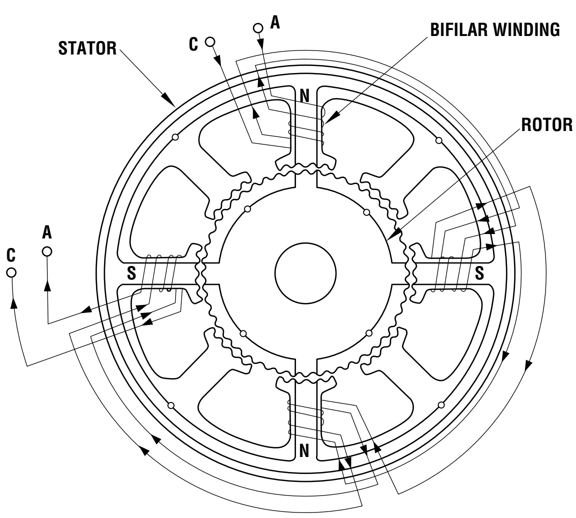
Rotation diagram of 18° Hybrid motor.

FIGURE 17



5° Hybrid motor.

FIGURE 18



1.8° Hybrid motor.