INTRODUCTION TO STEP MOTORS

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 (see page Z-8)shows a diagram of a conventional permanent magnet rotor step motor. A 2-phase winding is illustrated. Figure 1a (see page Z-8) 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

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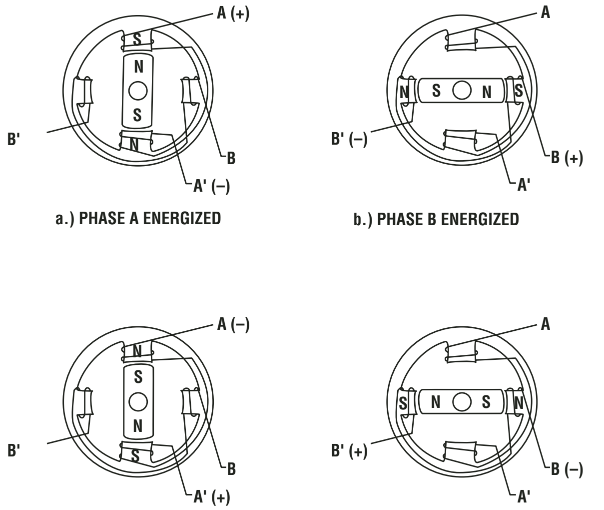
The shaft completes one revolution for each complete revolution of the electromagnetic field in this motor. Figure 2 (see page Z-8) shows the same motor with both windings energized. The important difference here is that the resultant electromagnetic field is between two poles. In Figure 2 (see page Z-8), the field has moved 45° from the field in Figure 1 (see page Z-8). 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 (see page Z-8) with that shown in Figure 2 (see page Z-8). Figure 3 (see page Z-8) shows the diagrams of a motor with half-step rotor motion. The energizing sequence and rotor positions are shown in Table III (see page Z-8).

FIGURE 1



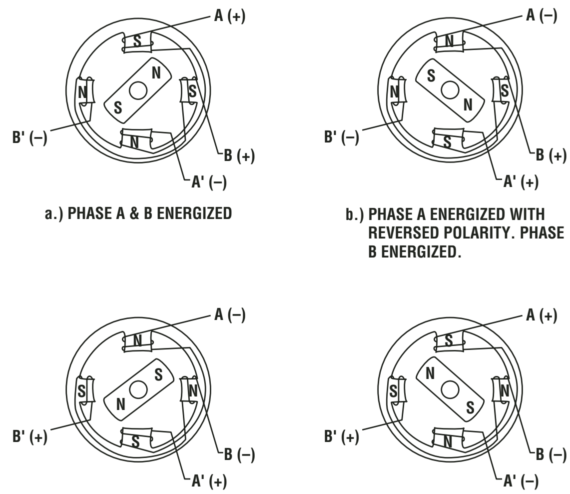
a.) PHASE A ENERGIZED

b.) PHASE B ENERGIZED

c.) PHASE A ENERGIZED WITH REVERSE POLARITY

d.) PHASE B ENERGIZED WITH REVERSED POLARITY

FIGURE 2



a.) PHASE A & B ENERGIZED

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

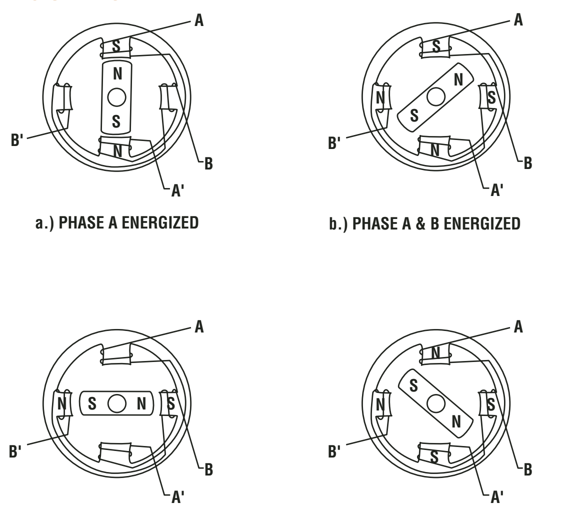
c.) PHASES A & B ENERGIZED WITH REVERSE POLARITY

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

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.

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

FIGURE 3



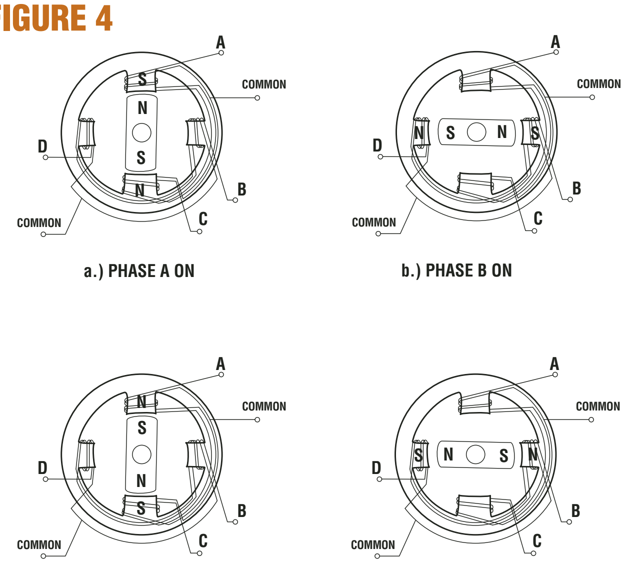
a.) PHASE A ENERGIZED

b.) PHASE A & B ENERGIZED

c.) PHASE B ENERGIZED

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

FIGURE 4



a.) PHASE A ON

b.) PHASE B ON

c.) PHASE C ON

d.) PHASE D ON

PM step motor with half step motion.

A conventional PM step motor with bifilar winding.

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 (see page Z-8) 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 (see page Z-10) 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 (see page Z-10) is shown in Figure 6 (see page Z-10). 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:

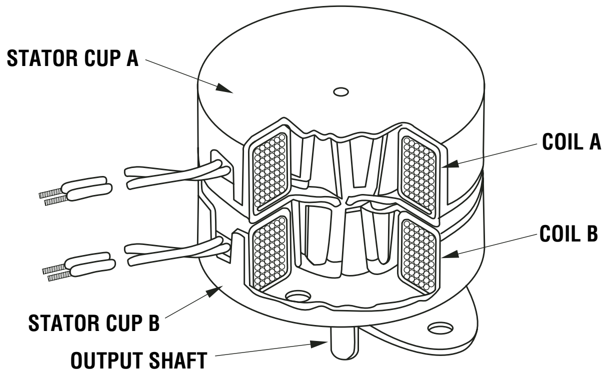
Step Angle Degrees	Steps Per Revolution
1.8	200
3.6	100
3.75	96
7.5	48
9	40
10	36
11.25	32
15	24
18	20
22.5	16
30	12
45	8
90	4

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.

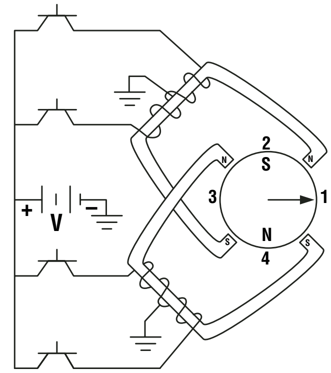
A 3-phase VR motor diagram is shown in Figure 7 (see page Z-10). The motor shown has 12 stator teeth, 8 rotor teeth, and step angle of 15°. The energization sequence is shown in Table V (see page Z-11).

FIGURE 5



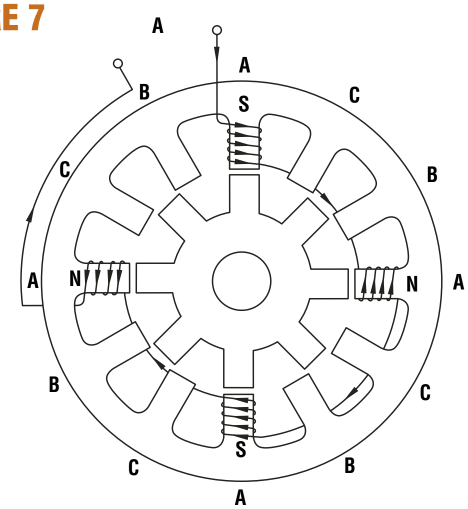
Cut-away view of a PM motor.

FIGURE 6



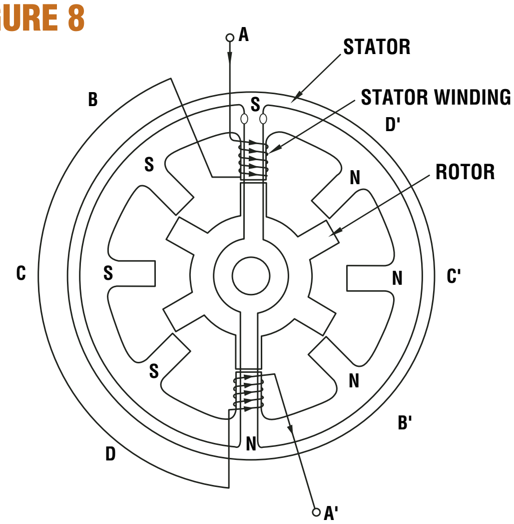
Schematic diagram of a PM motor.

FIGURE 7



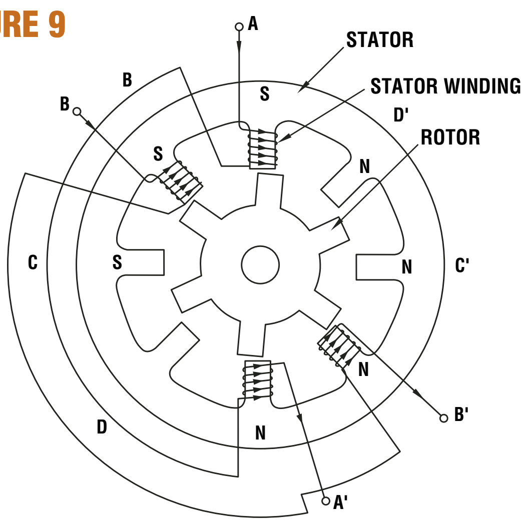
3 phase VR motor.

FIGURE 8



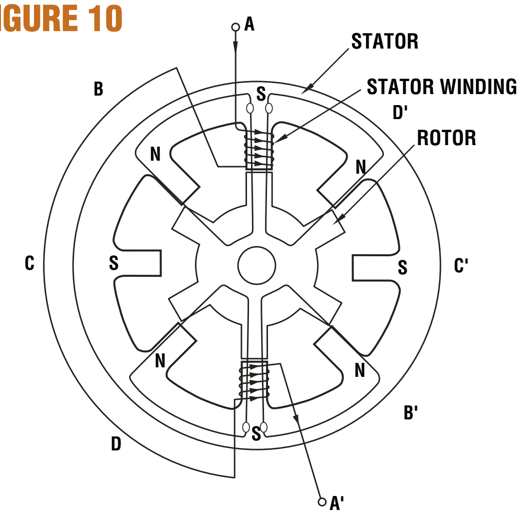
4 phase VR motor with one phase on.

FIGURE 9



4 phase VR motor with two phases on.

FIGURE 10



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

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 (see page Z-10) 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 (see page Z-10) 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 (see page Z-10). The diagrams in Figures 8 and 9 (see page Z-10) illustrate windings connected 4N and 4S. This indicates the magnetic poles as they are energized. The coil hookup shown in Figure 10 (see page Z-10) shows a symmetrical hookup called N-S-NS 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 (see page Z-12) 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 (see page Z-10), the teeth would be slender and difficult to wind. A better method of doing this is shown in Figure 12 (see page Z-12). The number of rotor and stator teeth is increased while the number of stator poles is reduced.

Figure 13 (see page Z-12) 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 (see page Z-12).

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

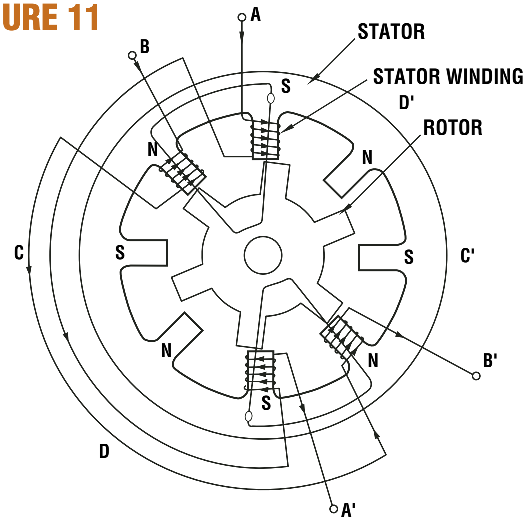
Hybrid

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 (see page Z-12) 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 (see page Z-12) 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 = NR x Ø

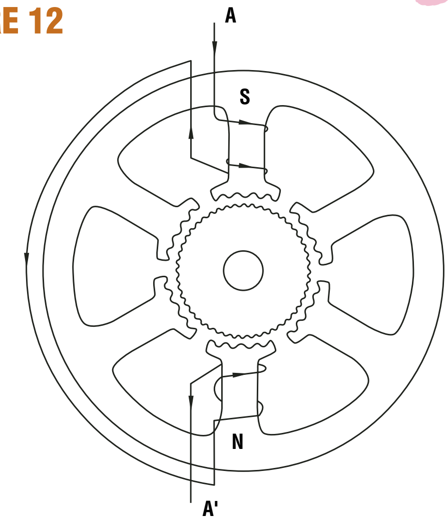
Where: SPR = number of steps per revolution
NR = total number of rotor teeth (total for both yokes)
Ø = number of motor phases
or: NR = SPR/Ø

FIGURE 11



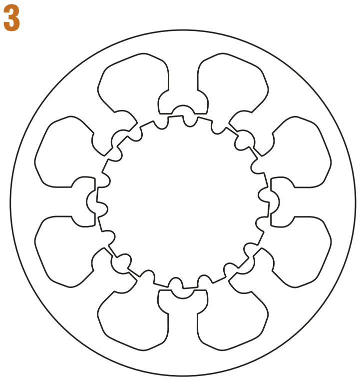
4 phase VR motor with two phases on. Wound for alternate polarity.

FIGURE 12



Stator poles with multiple teeth.

FIGURE 13



5° step angle VR motor.

FIGURE 14

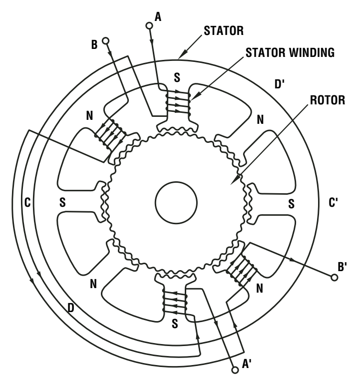
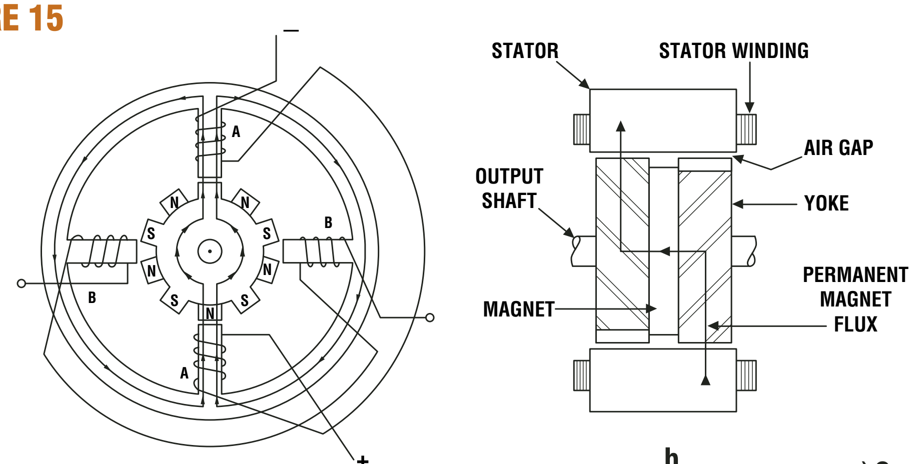


Diagram of 1.8° VR motor.

FIGURE 15



a

b

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

Example: The motor shown in Figure 15 (see page Z-12) 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 (see page Z-12) shows one tooth per pole and a total of 4 teeth on the stator.

Formula: SA = (1/Nst - 1/NRP) X 360N X NSTP

Where: SA = step angle in degrees

NST = number of stator teeth

NRP = number of rotor teeth per pole or yoke

NSTP = 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 (see page Z-12) has 5 teeth on each rotor yoke and one tooth per pole with 4 teeth total.

NA = (¼ – ⅕) x 360 x 1

= (0.25 – 0.20) x 360

= 18°

Figure 16 (see page Z-14) shows the shaft rotation with 2-phase-on. The switching sequence, field rotation and output shaft rotation are shown in Table VII.

TABLE VII

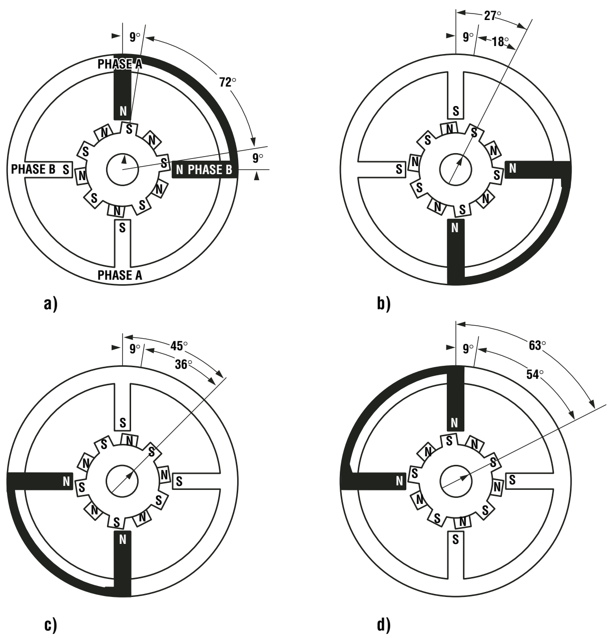
Step	Position Rotor & Shaft	(Mechanical Degrees) Electromagnetic Field	Phases A	Phases B	Figure
0	9˚	45˚	+	+	16a
1	27˚	135˚	—	+	16b
2	45˚	215˚	—	—	16c
3	63˚	305˚	+	—	16d

Figure 17 (see page Z-14) 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 (see page Z-14).

Hybrid step motors are available in the following step angles:

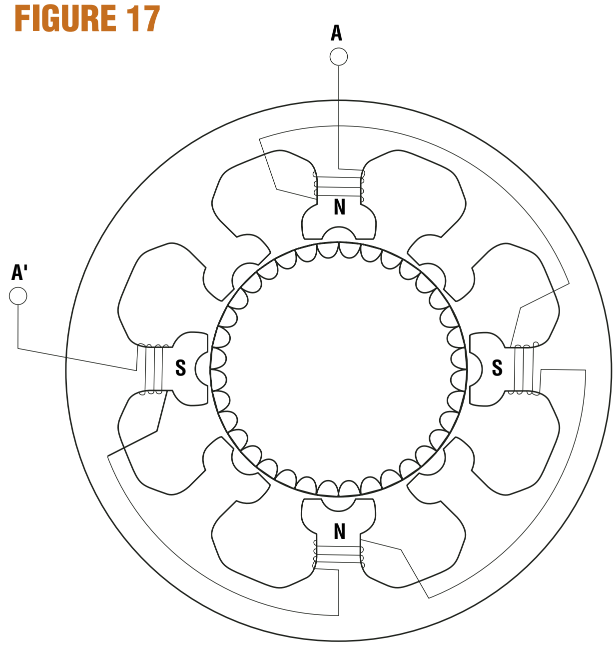
Step Angle Degrees	Steps Per Revolution
0.45	800
0.72	500
0.9	400
1.8	200
1.875	192
2	180
2.5	144
3.6	100
5	72

FIGURE 16



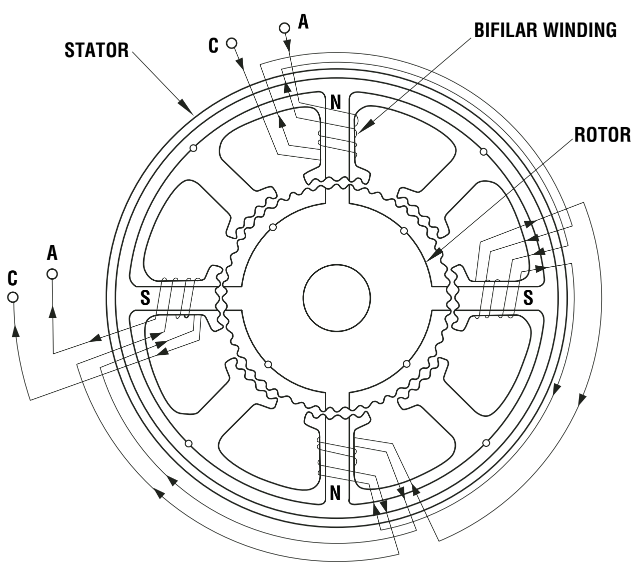
Rotation diagram of 18° Hybrid motor.

FIGURE 17



5° Hybrid motor.

FIGURE 18



1.8° Hybrid motor.

CONVERSION TABLES

Inertia Conversion Tables

To convert from A to B multiply by entry in table.

A \ B	lb•ft²	lb•ft•s² or slug-ft²	lb•in²	lb•in•s²	oz•in²	oz•in•s²	kg•cm²	kg•cm•s²	g•cm²	g•cm•s²
lb•ft²	1	3.108×10^{-2}	144	.373	2.304×10^{3}	5.968	421.40	0.4297	4.214×10^{5}	429.71
lb•ft•s²	32.174	1	4.633×10^{3}	12	7.413×10^{4}	192	1.356×10^{4}	13.825	1.356×10^{7}	1.383×10^{4}
lb•in²	6.944×10^{-3}	2.158×10^{-4}	1	2.590×10^{-3}	16	4.144×10^{-2}	2.926	2.984×10^{-3}	2.926×10^{3}	2.984
lb•in•s²	2.681	8.333×10^{-2}	386.1	1	6.177×10^{3}	16	1.130×10^{3}	1.152	1.130×10^{6}	1.152×10^{3}
oz•in²	4.34×10^{-4}	1.349×10^{-5}	6.25×10^{-2}	1.619×10^{-4}	1	2.59×10^{-3}	0.183	1.865×10^{-4}	182.901	0.186
oz•in•s²	0.168	5.208×10^{-3}	24.13	6.25×10^{-2}	386.088	1	70.616	7.201×10^{-2}	7.0616×10^{4}	72.008
kg•cm²	2.373×10^{-3}	7.376×10^{-5}	0.3417	8.851×10^{-4}	5.467	1.416×10^{-2}	1	1.0197×10^{-3}	1000	1.0197
kg•cm•s²	2.327	7.233×10^{-2}	335.109	0.8679	5.362×10^{3}	13.887	980.665	1	9.807×10^{5}	1000
g•cm²	2.373×10^{-6}	7.376×10^{-8}	3.417×10^{-4}	8.851×10^{-7}	5.467×10^{-3}	1.416×10^{-5}	10^{-3}	1.0197×10^{-6}	1	1.0197×10^{-3}
g•cm•s²	2.327×10^{-3}	7.233×10^{-5}	0.3351	8.680×10^{-4}	5.362	1.389×10^{-2}	.9807	10^{-3}	980.667	1

Example: *Convert a rotor inertia of 90 g•cm² to oz•in•sec²*
The multiplier from the table above is 1.416×10^{-5}
The new inertia = $90 \times 1.416 \times 10^{-5} = 1.27 \times 10^{3}$ oz•in•sec²

Torque Conversion Tables

To convert from A to B multiply by entry in table.

A \ B	lb•ft	lb•in	oz•in	dyne•cm	N•m	mN•m	kg•cm	g•cm
lb•ft	1	12	192	1.356×10^{7}	1.356	1.356×10^{3}	13.825	1.3825×10^{4}
lb•in	8.333×10^{-2}	1	16	1.130×10^{6}	0.113	1.13×10^{2}	1.152	1.152×10^{3}
oz•in	5.208×10^{-3}	6.250×10^{-2}	1	7.062×10^{4}	7.062×10^{-3}	7.062	7.201×10^{-2}	72.01
dyne•cm	7.376×10^{-8}	8.851×10^{-7}	1.416×10^{-5}	1	10^{-7}	10^{-4}	1.0197×10^{-6}	1.0197×10^{-3}
N•m	0.7376	8.851	141.62	10^{7}	1	1000	10.197	1.0197×10^{4}
mN•m	7.376×10^{-4}	8.851×10^{-3}	0.1416	10^{4}	10^{-3}	1	1.0197×10^{-2}	10.197
kg•cm	7.233×10^{-2}	0.8679	13.877	9.8066×10^{5}	9.8066×10^{-2}	98.066	1	1000
g•cm	7.233×10^{-5}	8.680×10^{-4}	1.389×10^{-2}	980.67	9.8066×10^{-5}	9.8066×10^{-2}	10^{-3}	1

Example: *Convert a torque of 53 oz•in to kg•cm.*
The multiplier from the table above is 7.201×10^{-2}
The new value of torque is 53 x 72.01 = 3.816 kg•cm

GLOSSARY

Accuracy (step)

The correctness of the distance a step motor moves during each step. Does not include errors due to hysteresis.

Axial Play

The axial shaft displacement due to a reversal of an axial force on the shaft. (End play)

Bifilar (winding)

Two windings wound (in parallel) on the same pole. This permits magnet polarity reversal with simple switching means.

Bi-level Drive (dual voltage drive)

A driver where two levels of voltage are used to drive a step motor. A high (over drive) voltage is applied to the winding each time it is switched on. The high voltage stays on until the current reaches a predetermined level. The high voltage is turned off after a time period determined experimentally or by sensing winding current. The low voltage maintains the rated or desired current.

Bipolar Drive

A drive which reverses the magnetic polarity of a pole by electronically switching the polarity of the current to the winding (+ or –). Bipolar drives can be used with 4, 6 or 8 lead motors. With 4 and 8 lead motors bipolar drives are usually more efficient than unipolar drives.

Chopper Drive

A step motor drive that uses switching amplifiers to control motor current. Chopper drives are more efficient than L/R or voltage drives.

Controller (step motor)

A system consisting of a DC power supply and power switches plus associated circuits to control the switches in the proper sequence.

Detent Torque

The maximum torque required to slowly rotate a step motor shaft with no power applied to the windings. This applies only to permanent magnet or hybrid motors. The leads are separated from each other.

Driver

An electronic package to convert digital step and direction inputs to currents to drive a step motor.

Duty Cycle

The percentage of ON time vs. OFF time. A device that is always on has a 100% duty cycle. Half on and half off is a 50% duty cycle.

End Play

The axial shaft motion, due to the reversal of an axial force acting on a shaft with axial clearance or low axial preload.

Friction (coulomb)

A resistance to motion between nonlubricated surfaces. This force remains constant with velocity.

Friction (viscous)

A resistance to motion between lubricated surfaces. This force is proportional to the relative velocity between the surfaces.

Holding Torque (static torque)

The maximum restoring torque that is developed by the energized motor when the shaft is slowly rotated by external means. The windings are on but not being switched.

Hybrid Step Motor (HY)

A type of step motor comprising a permanent magnet and variable reluctance stator and rotor structures. It uses a double salient pole construction.

Hysteresis (positional)

The difference between the step positions when moving CW and the step position when moving CCW. A step motor may stop slightly short of the true position thus producing a slight difference in position CW to CCW.

Indexer

An electronic control which converts motion commands from a computer terminal into pulse and direction signals for use by a step motor driver.

Inductance (mutual)

The property that exists between two currentcarrying conductors or coils when magnetic lines of flux from one link with those of the other.

GLOSSARY, CONT.

Inductance (self)

The constant by which the time rate of change of the coil current must be multiplied to give the self-induced counter emf.

Instantaneous Start Stop Rate

The maximum switching rate that an unloaded step motor will follow without missing steps when starting from rest.

L/R Drive

A drive that uses external resistance to allow a higher voltage than that of a voltage drive. L/R drives have better performance than voltage drives, but have less performance and efficiency than a chopper drive.

Maximum Reversing Rate

The maximum switching rate at which an unloaded motor will reverse direction of rotation without missing steps.

Maximum Slew Rate

The maximum pulse rate at which a step motor with no load will run and remain in synchronism.

Microstepping

A technique in which motor steps are electronically divided by the drive into smaller steps. The most common microstep resolutions are 10, 25 and 50 steps per full step, but many resolutions, ranging from 2 to 256 microsteps per full step are available.

Oscillator

A device that is used to produce pulses for driving a step motor at a preset speed. Some A.M.P. drives are available with built in oscillators.

Overshoot

The amount the step motor shaft rotates beyond the commanded stopping position. Usually applies to a single step.

Permanent Magnet Step Motor (PM)

A step motor having a permanent magnet rotor and wound stator.

Positional Accuracy

The maximum error in one revolution of a full step in 360°. Expressed as a percentage of a full step.

Pull-in Rate (response rate)

The maximum switching rate at which an unloaded motor can start without losing step positions.

Pull-in Torque

The maximum torque load at which a step motor will start and run in synchronism with a fixed frequency pulse train without losing step positions.

Pull-out Torque

The maximum torque load that can be applied to a motor running at a fixed stepping rate while maintaining synchronism. Any additional load torque will cause the motor to stall or miss steps.

Pulse Rate

The rate at which successive steps are initiated or the windings switched.

Radial Play

The side to side movement of the shaft due to clearances between the shaft and bearing, bearing to housing, and bearing internal clearance for ball and roller bearings. (Side play)

Response Rate (pull-in rate)

The switching rate an unloaded motor can follow from a standing start without missing steps.

Settling Time

The elapsed time starting the instant the rotor reaches the commanded step position and the oscillations settle to within a specified displacement band about the final position, usually ±3 to ±5 percent.

Stall Torque (holding or static torque)

The maximum restoring torque that is developed by the energized motor when the shaft is slowly rotated by external means. The windings are not switched.

Step Angle

The nominal angle through which the step motor shaft rotates between adjacent step positions.

GLOSSARY, CONT.

Step Rate (speed)

The number of steps a shaft rotates during a specified time interval.

Step-to-Step Accuracy

The maximum error that occurs between any adjacent step, expressed as a percentage of one full step.

Switching Amplifier

A device that switches a high voltage on and off to control current. Some amplifiers (PWM types) switch at a constant frequency and adjust duty cycle to control current. Other types have a fixed off time and adjust the frequency.

Switching Sequence (energizing sequence)

The sequence and polarity of voltages applied to the coils of a step motor that result in a specified direction of rotation.

Thermal Resistance

The resistance to the flow of heat between two surfaces of the same body or different bodies. Thermal resistance = Winding temperature/Watts in the winding = °C/Watt.

Thermal Time Constant

The time required for the motor winding to reach 63.2% of its final temperature.

Torque Displacement Curve

The holding (restoring) torque plotted as a function of rotor angular displacement with the motor energized.

Torque Gradient (stiffness)

The ratio of the change in holding torque for a particular change in shaft position when the motor is energized.

Unipolar Drive

The motor phase winding current is switched in one direction only. The polarity of the applied voltage to each winding is always the same. Unipolar drives require 6 or 8 lead motors.

Variable Reluctance Step Motor (VR)

A step motor having a wound stator or stators with salient poles working with a soft iron rotor having salient poles on the periphery.

Viscous Damping

A damper which provides a drag or friction torque proportional to speed. At zero speed the drag torque is reduced to zero.

Viscous Inertia Damper

A damper with an inertia coupled to the motor shaft, through a film of viscous fluid, usually silicone oil to minimize viscosity variations due to temperature changes. This damper only responds when the velocity between the damper inertia and motor shaft changes. At steady state speed there is no effect from the damper.

Voltage Drive

A drive operated at the minimum voltage required to safely limit motor current. Motors used with voltage drives produce less torque at higher speeds than when used with L/R or chopper drives.

Wave Drive

Energizing the motor phases one at a time. Driving the motor one phase or winding on at a time.

STANDARD DESIGN FEATURES

Mechanical, Electrical & Environmental Specifications

	SIZE 14	SIZE 16	SIZE 17	SIZE HT17	SIZE 23	SIZE HT23	SIZE 34
SHAFT RUN-OUT (inches)	.0005	.0005	.0005	.0005	.001	.002	.002
RADIAL PLAY (inch/Lbs.)	.0004 max @ 1 Lb.	.0008 max @ 1 Lb.	.001 max @ 4.4 Lbs.	.0008 max @ 1 Lb.	.001 max @ 1 Lb.	.001 max @ 1 Lb.	.001 max @ 1 Lb.
END PLAY (inch/Lbs.)	.0004 max @ 2 Lb.s	.0006 max @ 3 Lbs. .002 min @ 8 Lbs.	.001 max @ 6.6 Lbs.	.003 max @ 2.2 Lbs.	.001 max @ 9 Lbs.	.003 max @ 2.2 Lbs.	.001 max @ 15 Lbs.
PERPENDICULARITY	.003	.003	.003	.003	.003	.003	.003
CONCENTRICITY (inches)	.002	.002	.002	.002	.002	.003	.002
OPERATING TEMPERATURE RANGE	-20°C to 50°C	-20°C to 50°C	-20°C to 50°C	-20°C to 50°C	-20°C to 50°C	-20°C to 50°C	-20°C to 50°C
INSULATION CLASS	130°C Class B	130°C Class B	130°C Class B	130°C Class B	130°C Class B	130°C Class B	130°C Class B
LEAD WIRE GAUGE	26 AWG	26 AWG	26 AWG	26 AWG	26 AWG	22 AWG	18 AWG
MAXIMUM RADIAL LOAD	5	5	5	5	15	15	25
MAXIMUM THRUST LOAD	3	3	3	3	25	25	50

Design Tips

- Series connect lead wires for best torque at low speeds
- Center tap to end or parallel connect lead wires for best torque at higher speeds
- Keep motor case temperature below 100°C. This can be achieved by lowering the motor current or limiting the duty cycle
- Allow sufficient time to accelerate load
- Size motor with 100% safety factor for required torque @ speed
- Do not disassemble motors. A significant reduction in motor performance will result
- Do not machine shafts without consulting Applied Motion Products
- Do not disconnect motor from drive while in operation
- Do not use holding torque/detent torque of motor as fail safe brake

Motion Installation Tips

- Mount the motor securely against a surface with good thermal conductivity such as steel or aluminum
- Properly align the motor with the load using a flexible coupling
- Protect the motor shaft from excessive thrust, overhung and shock loads