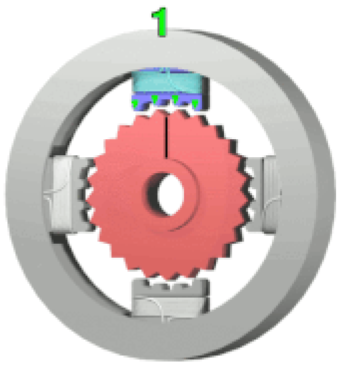
LamaPLC: Stepper motor basic

A stepper motor, also known as step motor or stepping motor, is an electrical motor that rotates in a series of small angular steps, instead of continuously. Stepper motors are a type of digital actuator. Like other electromagnetic actuators, they convert electric energy into mechanical position can be commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is correctly sized to the application in respect to torque and speed.



Switched reluctance motors are very large stepping motors with a reduced pole count, and generally are closed-loop commutated.

Brushed DC motors rotate continuously when DC voltage is applied to their terminals. The stepper motor is known for its property of converting a train of input pulses (typically square waves) into a precisely defined increment in the shaft’s rotational position. Each pulse rotates the shaft through a fixed angle.

Stepper motors effectively have multiple “toothed” electromagnets arranged as a stator around a central rotor, a gear-shaped piece of iron. The electromagnets are energized by an external driver circuit or a micro controller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one. From there the process is repeated. Each of the partial rotations is called a “step”, with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

There are three main types of stepper motors:

1. Permanent magnet stepper motors
2. Variable reluctance stepper motors
3. Hybrid stepper motors

Permanent magnet stepper motors

Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor magnet and the stator electromagnets. Pulses move the rotor clockwise or anticlockwise in discrete steps. If left powered at a final step, a strong detent remains at that shaft location. This detent has a predictable spring rate and specified torque limit; slippage occurs if the limit is exceeded. If the current is removed, a lesser detent still remains, holding the shaft position against spring or other torque influences. Stepping can then be resumed while reliably being synchronized with control electronics.

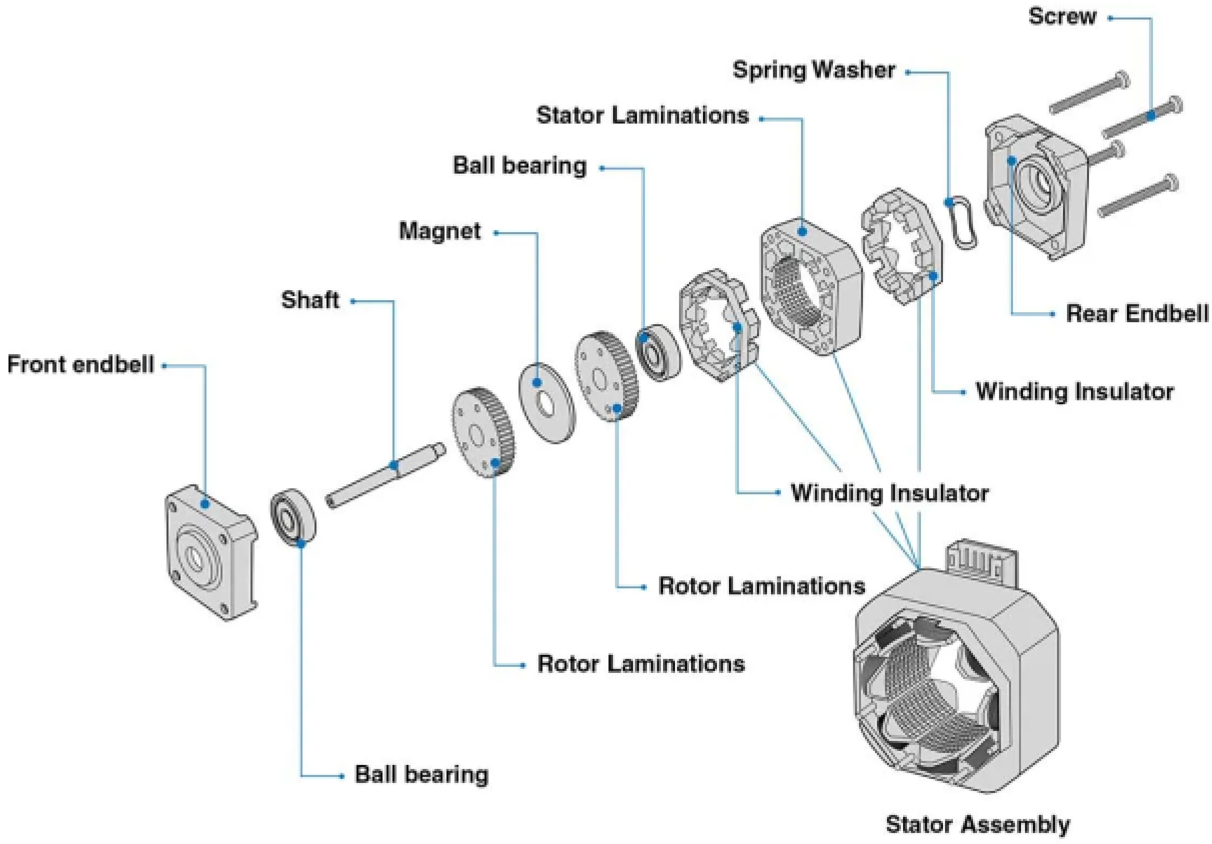
Variable reluctance stepper motors

Variable reluctance (VR) stepper motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

Hybrid stepper motors

Whereas hybrid stepper motors are a combination of the permanent magnet and variable reluctance types, to maximize power in a small size. Variable reluctance motors have detents when powered on, but not when powered off.

Basic structure of stepper motor

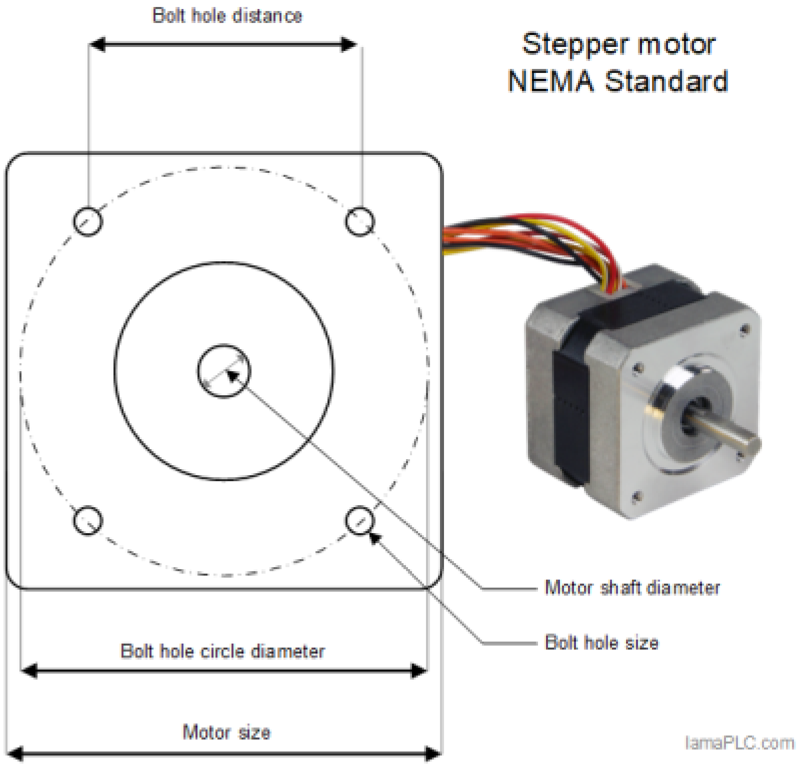


NEMA standard for stepper motors

The US National Electrical Manufacturers Association (NEMA) standardizes various dimensions, marking, and other aspects of stepper motors, in NEMA standard (NEMA ICS 16-2001). NEMA stepper motors are labeled by faceplate size, NEMA 17 being a stepper motor with a 1.7 by 1.7 inches (43 mm × 43 mm) faceplate and dimensions given in inches.

The standard also lists motors with faceplate dimensions given in metric units. These motors are typically referred to with NEMA xx, where xx is the diameter of the faceplate in inches multiplied by 10 (e.g., NEMA 17 has a diameter of 1.7 inches). There are further specifiers to describe stepper motors, and such details may be found in the ICS 16-2001 standard.

Nema Type	**NEMA 8**	**NEMA 11**	**NEMA 14**	**NEMA 17**	**NEMA 23**	**NEMA 34**	**NEMA 42**
Motor Size ≈	20.3 mm (0.79 in)	28 mm (1.10 in)	35.6 mm (1.4 in)	43.2 mm (1.65 in)	58.4 mm (2.3 in)	86.4 mm (3.4 in)	106.7 mm (4.2 in)
Motor shaft diameter	4 mm 0.157 in	5 mm 0.197 in	5 mm 0.197 in	5 mm 0.197 in	6.35mm 0.250 in	9.5 mm 0.375 in	16 mm 0.625 in
Bolt hole circle diameter	22.6 mm 0.891 in	32.5 mm 1.280 in	36.8 mm 1.448 in	43.8 mm 1.725 in	66.7 mm 2.625 in	98.4 mm 3.875 in	125.7 mm 4.950 in
Bolt hole distance (square)	16 mm 0.630 in	23 mm 0.905 in	26 mm 1.024 in	31 mm 1.220 in	47 mm 1.854 in	70 mm 2.744 in	89 mm 3.500 in
Bolt Hole size	3mm 0.118 in	4mm 0.157 in	4mm 0.157 in	4.40 mm 0.173 in	5mm 0.195 in	5.5 mm 0.218 in	5.5 mm 0.218 in



Phase current waveforms

A stepper motor is a polyphase AC synchronous motor, and it is ideally driven by sinusoidal current. A full-step waveform is a gross approximation of a sinusoid, and is the reason why the motor exhibits so much vibration. Various drive techniques have been developed to better approximate a sinusoidal drive waveform: these are half stepping and microstepping.

Wave drive (one phase on)

In this drive method only a single phase is activated at a time. It has the same number of steps as the full-step drive, but the motor will have significantly less torque than rated. It is rarely used. The animated figure shown above is a wave drive motor. In the animation, rotor has 25 teeth and it takes 4 steps to rotate by one tooth position. So there will be 25 × 4 = 100 steps per full rotation and each step will be 360⁄100 = **3.6°**.

Full-step drive (two phases on)

This is the usual method for full-step driving the motor. Two phases are always on so the motor will provide its maximum rated torque. As soon as one phase is turned off, another one is turned on. Wave drive and single phase full step are both one and the same, with same number of steps but difference in torque.

Half-stepping

When half-stepping, the drive alternates between two phases on and a single phase on. This increases the angular resolution. The motor also has less torque (approx 70%) at the full-step position (where only a single phase is on). This may be mitigated by increasing the current in the active winding to compensate. The advantage of half stepping is that the drive electronics need not change to support it. In animated figure shown above, if we change it to half-stepping, then it will take 8 steps to rotate by 1 tooth position. So there will be 25×8 = 200 steps per full rotation and each step will be 360/200 = **1.8°**. Its angle per step is half of the full step.

Microstepping

What is commonly referred to as microstepping is often sine–cosine microstepping in which the winding current approximates a sinusoidal AC waveform. The common way to achieve sine-cosine current is with chopper-drive circuits. Sine–cosine microstepping is the most common form, but other waveforms can be used. Regardless of the waveform used, as the microsteps become smaller, motor operation becomes smoother, thereby greatly reducing resonance in any parts the motor may be connected to, as well as the motor itself. Resolution will be limited by the mechanical stiction, backlash, and other sources of error between the motor and the end device. Gear reducers may be used to increase resolution of positioning.

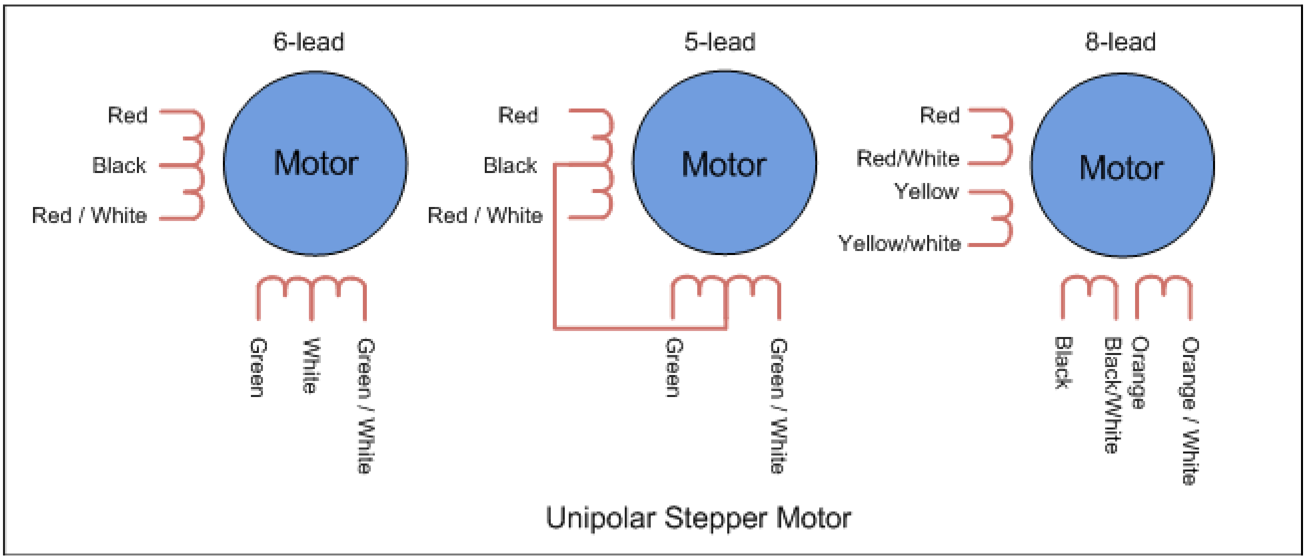
Step size reduction is an important step motor feature and a fundamental reason for their use in positioning.

Two phase stepper motors

There are two basic winding arrangements for the electromagnetic coils in a two phase stepper motor: bipolar and unipolar.

Unipolar stepper motors

A unipolar stepper motor has one winding with center tap per phase. Each section of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the polarity of the common wire, the commutation circuit can be simply a single switching transistor for each half winding.



Typically, given a phase, the center tap of each winding is made common: three leads per phase and six leads for a typical two phase motor. Often, these two phase commons are internally joined, so the motor has only five leads.

Bipolar stepper motors

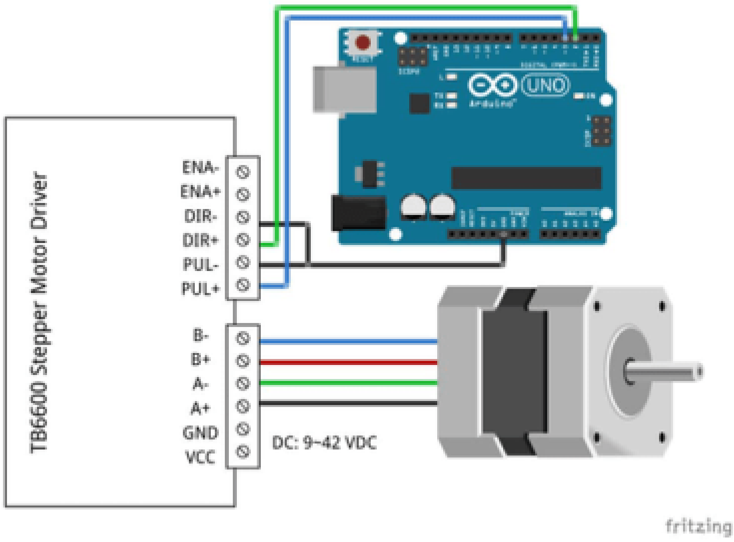
Bipolar motors have a pair of single winding connections per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (however there are several off-the-shelf driver chips available to make this a simple affair). There are two leads per phase, none is common.

A typical driving pattern for a two coil bipolar stepper motor would be: **A+ B+ A− B−**. I.e. drive coil A with positive current, then remove current from coil A; then drive coil B with positive current, then remove current from coil B; then drive coil A with negative current (flipping polarity by switching the wires e.g. with an H bridge), then remove current from coil A; then drive coil B with negative current (again flipping polarity same as coil A); the cycle is complete and begins anew.

Static friction effects using an H-bridge have been observed with certain drive topologies.

Stepper motor drivers

Stepper motor control with Arduino



Sources

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