Stepper motor

A **stepper motor** (or **step motor**) is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application.

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

Fundamentals of operation

DC brush motors rotate continuously when voltage is applied to their terminals. Stepper motors, on the other hand, effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, first, one electromagnet is given power, which makes the gear's teeth magnetically attracted to the electromagnet's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. So when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one, and from there the process is repeated. Each of those slight 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.
Types

There are four main types of stepper motors:[1]

1. Permanent magnet stepper (can be subdivided into 'tin-can' and 'hybrid', tin-can being a cheaper product, and hybrid with higher quality bearings, smaller step angle, higher power density)
2. Hybrid synchronous stepper
3. Variable reluctance stepper
4. Lavet type stepping motor

Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets. Variable reluctance (VR) 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 are named because they use a combination of PM and VR techniques to achieve maximum power in a small package size.

Two-phase stepper motors

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

Bipolar motor

Bipolar motors have a single winding 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 are common.

Static friction effects using an H-bridge have been observed with certain drive topologies.[2] Dithering the stepper signal at a higher frequency than the motor can respond to will reduce this "static friction" effect.

Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the windings. A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available). Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips means this is much less difficult to achieve.

An 8-lead stepper is wound like a unipolar stepper, but the leads are not joined to common internally to the motor. This kind of motor can be wired in several configurations:

- Unipolar.
- Bipolar with series windings. This gives higher inductance but lower current per winding.
- Bipolar with parallel windings. This requires higher current but can perform better as the winding inductance is reduced.
- Bipolar with a single winding per phase. This method will run the motor on only half the available windings, which will reduce the available low speed torque but require less current.
**Higher-phase count stepper motors**

Multi-phase stepper motors with many phases tend to have much lower levels of vibration,[3] although the cost of manufacture is higher. These motors tend to be called 'hybrid' and have more expensive machined parts, but also higher quality bearings. Though they are more expensive, they do have a higher power density and with the appropriate drive electronics are actually better suited to the application, however price is always an important factor. Computer printers may use hybrid designs.

**Stepper motor drive circuits**

Stepper motor performance is strongly dependent on the drive circuit. Torque curves may be extended to greater speeds if the stator poles can be reversed more quickly, the limiting factor being the winding inductance. To overcome the inductance and switch the windings quickly, one must increase the drive voltage. This leads further to the necessity of limiting the current that these high voltages may otherwise induce.

**L/R drive circuits**

L/R drive circuits are also referred to as constant voltage drives because a constant positive or negative voltage is applied to each winding to set the step positions. However, it is winding current, not voltage that applies torque to the stepper motor shaft. The current I in each winding is related to the applied voltage V by the winding inductance L and the winding resistance R. The resistance R determines the maximum current according to Ohm's law I=V/R. The inductance L determines the maximum rate of change of the current in the winding according to the formula for an Inductor dI/dt = V/L. Thus when controlled by an L/R drive, the maximum speed of a stepper motor is limited by its inductance since at some speed, the voltage U will be changing faster than the current I can keep up. In simple terms the rate of change of current is L / R (e.g. a 10mH inductance with 2 ohms resistance will take 5 ms to reach approx 2/3 of maximum torque or around 24 msec to reach 99% of max torque). To obtain high torque at high speeds requires a large drive voltage with a low resistance and low inductance. With an L/R drive it is possible to control a low voltage resistive motor with a higher voltage drive simply by adding an external resistor in series with each winding. This will waste power in the resistors, and generate heat. It is therefore considered a low performing option, albeit simple and cheap.

**Chopper drive circuits**

Chopper drive circuits are referred to as constant current drives because they generate a somewhat constant current in each winding rather than applying a constant voltage. On each new step, a very high voltage is applied to the winding initially. This causes the current in the winding to rise quickly since dI/dt = V/L where V is very large. The current in each winding is monitored by the controller, usually by measuring the voltage across a small sense resistor in series with each winding. When the current exceeds a specified current limit, the voltage is turned off or "chopped", typically using power transistors. When the winding current drops below the specified limit, the voltage is turned on again. In this way, the current is held relatively constant for a particular step position. This requires additional electronics to sense winding currents, and control the switching, but it allows stepper motors to be driven with higher torque at higher speeds than L/R drives. Integrated electronics for this purpose are widely available.
Phase current waveforms

A stepper motor is a polyphase AC synchronous motor (see Theory below), 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

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 than rated torque. It is rarely used.

Full step drive (two phases on)

This is the usual method for full step driving the motor. Two phases are always on. The motor will have full rated torque.

Half stepping

When half stepping, the drive alternates between two phases on and a single phase on. This increases the angular resolution, but the motor also has less torque (approx 70%) at the half 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.

Microstepping

What is commonly referred to as microstepping is often "sine cosine microstepping" in which the winding current approximates a sinusoidal AC waveform. Sine cosine microstepping is the most common form, but other waveforms can be used [4]. Regardless of the waveform used, as the microsteps become smaller, motor operation becomes more smooth, 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 repeatability is an important step motor feature and a fundamental reason for their use in positioning.

Example: many modern hybrid step motors are rated such that the travel of every full step (example 1.8 Degrees per full step or 200 full steps per revolution) will be within 3% or 5% of the travel of every other full step; as long as the motor is operated within its specified operating ranges. Several manufacturers show that their motors can easily maintain the 3% or 5% equality of step travel size as step size is reduced from full stepping down to 1/10 stepping. Then, as the microstepping divisor number grows, step size repeatability degrades. At large step size reductions it is possible to issue many microstep commands before any motion occurs at all and then the motion can be a "jump" to a new position.
Theory
A step motor can be viewed as a synchronous AC motor with the number of poles (on both rotor and stator) increased, taking care that they have no common denominator. Additionally, soft magnetic material with many teeth on the rotor and stator cheaply multiples the number of poles (reluctance motor). Modern steppers are of hybrid design, having both permanent magnets and soft iron cores.

To achieve full rated torque, the coils in a stepper motor must reach their full rated current during each step. Winding inductance and reverse EMF generated by a moving rotor tend to resist changes in drive current, so that as the motor speeds up, less and less time is spent at full current — thus reducing motor torque. As speeds further increase, the current will not reach the rated value, and eventually the motor will cease to produce torque.

Pull-in torque
This is the measure of the torque produced by a stepper motor when it is operated without an acceleration state. At low speeds the stepper motor can synchronize itself with an applied step frequency, and this pull-in torque must overcome friction and inertia. It is important to make sure that the load on the motor is frictional rather than inertial as the friction reduces any unwanted oscillations.

Pull-out torque
The stepper motor pull-out torque is measured by accelerating the motor to the desired speed and then increasing the torque loading until the motor stalls or misses steps. This measurement is taken across a wide range of speeds and the results are used to generate the stepper motor's dynamic performance curve. As noted below this curve is affected by drive voltage, drive current and current switching techniques. A designer may include a safety factor between the rated torque and the estimated full load torque required for the application.

Detent torque
Synchronous electric motors using permanent magnets have a remnant position holding torque (called detent torque or cogging, and sometimes included in the specifications) when not driven electrically. Soft iron reluctance cores do not exhibit this behavior.

Stepper motor ratings and specifications
Stepper motors nameplates typically give only the winding current and occasionally the voltage and winding resistance. The rated voltage will produce the rated winding current at DC: but this is mostly a meaningless rating, as all modern drivers are current limiting and the drive voltages greatly exceed the motor rated voltage.

A stepper's low speed torque will vary directly with current. How quickly the torque falls off at faster speeds depends on the winding inductance and the drive circuitry it is attached to, especially the driving voltage.

Steppers should be sized according to published torque curve, which is specified by the manufacturer at particular drive voltages or using their own drive circuitry.
Applications

Computer-controlled stepper motors are a type of motion-control positioning system. They are typically digitally controlled as part of an open loop system for use in holding or positioning applications.

In the field of lasers and optics they are frequently used in precision positioning equipment such as linear actuators, linear stages, rotation stages, goniometers, and mirror mounts. Other uses are in packaging machinery, and positioning of valve pilot stages for fluid control systems.

Commercially, stepper motors are used in floppy disk drives, flatbed scanners, computer printers, plotters, slot machines, image scanners, compact disc drives, intelligent lighting.

Stepper Motor System

A Stepper Motor System consists of three basic elements, often combined with some type of user interface (Host Computer, PLC or Dumb Terminal):

- Indexers - The Indexer (or Controller) is a microprocessor capable of generating step pulses and direction signals for the driver. In addition, the indexer is typically required to perform many other sophisticated command functions.
- Drivers - The Driver (or Amplifier) converts the indexer command signals into the power necessary to energize the motor windings. There are numerous types of drivers, with different voltage and current ratings and construction technology. Not all drivers are suitable to run all motors, so when designing a Motion Control System the driver selection process is critical.
- Stepper Motors - The stepper motor is an electromagnetic device that converts digital pulses into mechanical shaft rotation. Advantages of step motors are low cost, high reliability, high torque at low speeds and a simple, rugged construction that operates in almost any environment. The main disadvantages in using a stepper motor is the resonance effect often exhibited at low speeds and decreasing torque with increasing speed.

References


External links

- Control of Stepping Motors - A Tutorial (http://www.cs.uiowa.edu/~jones/step/) – Douglas W. Jones, The University of Iowa
- Stepping 101 (http://www.stepcontrol.com/stepping101.html)