Step Motor Basics

Introduction

"Conventional" AC and DC motors operate on continuously applied input voltage and most often produce a continuous (steady state) rotary motion. Most commercial type motors are single phase, equipped with two lead wires, or three lead wires, the third lead as a grounding lead. Current flows from one lead wire into the motor and returns through the other lead wire.

Unlike these motors, a Step Motor (also called a stepping motor or a stepper motor) will not produce continuous motion from a continuous input voltage. It will stay at a particular position as long as the power is "on". An electrical phase change is necessary to make a step motor move. This means that no single phase step motor can exist.

A typical three phase step motor has four lead wires. Three of them represent the three phase coils, normally colored brown, red, and orange. The fourth lead is a common lead for current return, commonly colored black or white.

Turning one phase on will hold the rotor in one position (called a detent position). Turning off this phase and turning on the second phase will move the rotor to rest at another detent position. This "on and off" current flow is called a pulse. One pulse into the motor causes the rotor to increment (move) one precise angle. This movement is repeated with each input pulse. When properly applied and controlled, the number of output steps is always equal to the number of input pulses.

The widespread acceptance of the digital approach for overall control of machine and process functions has generated a high demand for mechanical motion devises capable of delivering a discrete incremental motion of known accuracy. The replacement of less dependable (susceptible to wear) mechanical devices, such as clutches and breaks, with step motors, provides considerably greater reliability and consistency.

Step Motor Advantages / Disadvantages

Advantages:

- Can be driven "open loop" (no feedback components necessary)
- Non-cumulative positional error with known limits
- Responds to digital input signals
- Mechanically simpler; requires little or no maintenance
- High reliability
- Can be repeatedly stalled without damage
- Relatively rugged and durable
- Inherently more failsafe than servo motors

Disadvantages:

- Low efficiency, with an ordinary control system
- As friction loads increase, the undetected position error increases (with open loop)
- Rough performance at low speeds unless a microstep drive is used
- Limited power output and size availability
- Limited ability to move large inertia loads

Types of step motors

Variable Reluctance Motors

Variable Reluctance (VR) Motors consist of a magnetically soft iron rotor and a wound stator. VR motors do not use a permanent magnet. As a result, the rotor can move without constraint as it has no detent torque when there is no current flowing in the motor.

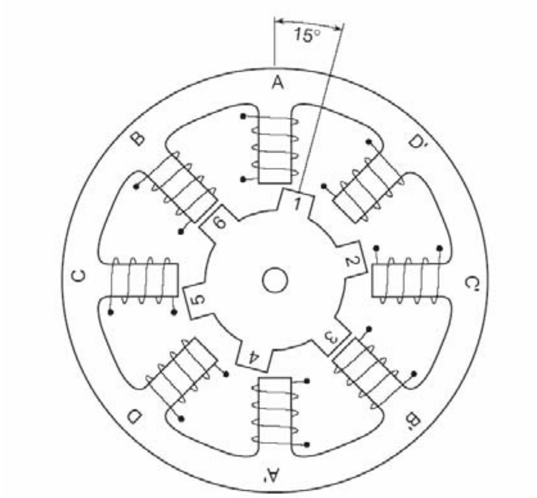

Figure 1: Variable Reluctance Motor 400% @ 40%

The variable reluctance motor in the above illustration (Figure 1) has four sets of stator poles (A, B, C, D) each set containing 2 poles. When phase A is energized, the rotor teeth 1 and 2 line up with the stator teeth of phase A by magnetic attraction. The illustration shows what happens when phase A is turned off and phase B is energized, rotating the rotor clockwise 15 degrees. After that, phase B is turned off and phase C is energized attracting teeth 2 and 5. Then it is phase D's turn before the cycle is repeated. Counter-clockwise rotation is achieved when the phase order is reversed.

Permanent Magnet Motors

Permanent Magnet motors differ from Variable reluctance motors in that the rotor does not have any teeth. These motors have a permanent magnet rotor which is radially magnetized.

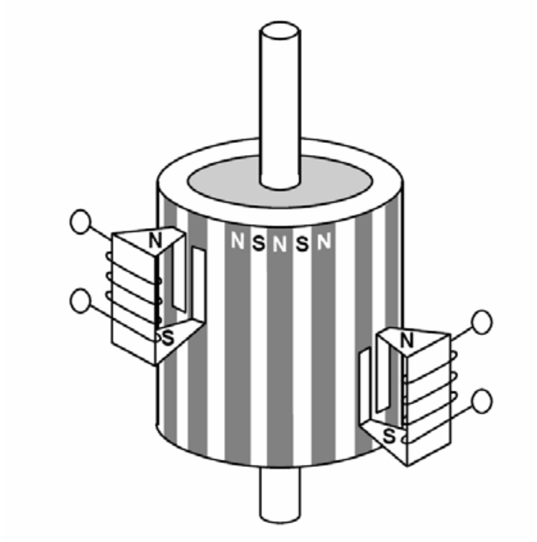

Figure 2: Permanent Magnet Motor

The motor in the illustration (Figure 2) has 4 phases (A,B,C,D) with a 90 degree step angle. Permanent Magnet Motors operate at low speed while providing a relatively high torque. This type of motor provides some holding torque even when the coils are not energized.

Hybrid Motors

A hybrid step motor is the most widely-used step motor in industrial applications. It combines the principles of the variable-reluctance motor and the permanent magnet motor. The rotor consists of two pole pieces. In between the two pole pieces is a concentric permanent magnet, axially magnetized, around the shaft, and surrounding the magnet. The rotor teeth on each end of the magnet must be offset one half of a tooth pitch from each other, so the rotor teeth on both ends of the magnet do not line up with the stator teeth. Hybrid motors have high detent and dynamic torque and can operate at very high step rates.

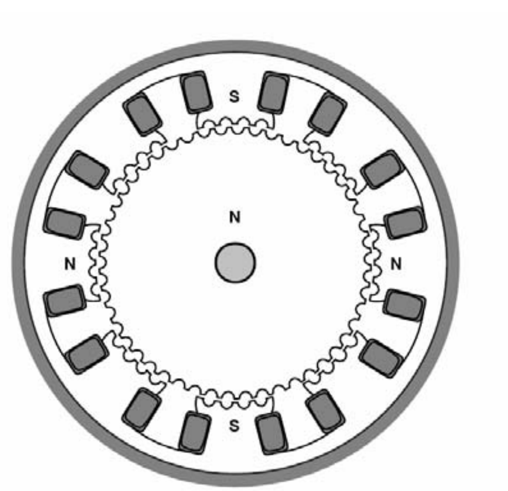

Figure 3: Hybrid Motor

All of our motors here at RMS Technologies are Hybrid motors.

Elements of a Step Motor System

A step motor needs to be part of a step motor system. A Step motor system is made up of 3 basic elements often combined with some form of user interface (computer, dumb terminal, PLC)

Computer/PLC/Terminal – This is used to send commands to the system, for example, spin clockwise for 1000 steps.

Controller/Indexer - A microprocessor that generates the step pulses and direction signals for the driver. The controller typically performs many other sophisticated command functions as well. Most controllers have onboard memory so they can store hundreds, even thousands of commands.

Driver (or Amplifier) - converts the command signals from the controller into the power necessary to energize the motor windings. There are numerous types of drivers, with different current/amp ratings and construction technology. When designing a Motion Control System the driver selection process is critical because not all drivers are suitable to run all motors.

Step Motor - an electromagnetic motor that converts digital pulses into mechanical shaft rotation. A single pulse only moves the motor one rotary increment, or one step, which for our standard motor would only be 1.8 degrees. That is only a portion of a complete rotation. Step motors are low in cost, highly reliable, have high torque at low speeds, and have a simple, rugged construction that operates in almost any environment.

How to select the right step motor for my application?

Choosing the right step motor is entirely application dependant. Ideally the motor should deliver sufficient torque at the highest speed the application requires and no more.

Learn to distinguish the difference between torque and power. High initial torque at low speed does not mean efficient motor utilization. Usually power (torque times speed) output is the more important. It is best to select a motor where you would be utilizing it near its maximum power output level, that way you are making the most efficient use of the motor. Establish a reference for the motor's operating point through power transmission gearing to operate the motor at its maximum power; normally just past its corner frequency.

Here are some requirements one must consider when selecting a step motor for an application:

1. Steps Per Revolution: the number of full steps per revolution for which the motor is designed or wound.
2. Step to Step Accuracy: the percent of the nominal step angle an unloaded step motor may deviate with each step. Normally, it is 1% to 5%. It is always specified as a plus/minus value.
3. Positional Accuracy: the maximum deviation from true position of any step position in a 360 degree rotation of an unloaded step motor.
4. Rotor Inertia: the rotational inertia of the rotor and shaft.
5. Holding Torque: the maximum restoring torque developed by the rotor when one or more phases of the motor are energized. The number of phases on and the energizing current must be specified.
6. Detent Torque: the maximum restoring torque developed by the unenergized rotor. Detent torque applies to permanent magnet and hybrid step motors only; VR step motors have no detent torque.
7. Dynamic Torque: the dynamic (running) torque at a specified speed, usually expressed in steps per second. Sometimes, dynamic torque is specified at several speeds, depending on the customer's application and concerns.
8. Phase Voltage: the normal voltage rating of the motor. Step motors are frequently operated at higher than rated voltage, which requires a current limiting driver system.
9. Phase Current (Steady State): the normal current per phase when static measurements are made.
10. DC phase resistance: the winding (coil) resistance when the motor is at rest at normal room temperature.
11. Phase inductance: the self-induction of the phase winding with the rotor teeth or poles lined up with the stator teeth or poles. The measurement conditions, AC current and frequency must be specified.
12. Ambient Temperature range: The temperature range an operating motor will be subjected to.
13. Lead size, length, and color: the lead wire(s) size, length and colors must be specified as well as exit location (from the motor) and insulation type.
14. Motor outline drawing: a drawing showing the external dimensions and tolerances of the motor. Many times, an outline drawing will have some or all of the above specifications shown on it.

Step Modes

Step motors can have many different “step modes.” They include Full-step, Half-step, and Micro-step. The type of step mode output by the motor is dependant on the driver used.

FULL-STEP
A standard 1.8 degree step motor has 200 full steps per revolution. In full step operation, the motor steps through the normal step angle. There are two kinds of full-step modes. Single phase full-step mode is where the motor is operated with only one phase energized at a time. This mode requires the least amount of power from the driver power supply and should only be used at a fixed speed when load conditions are well defined. Dual phase full-step mode is where the motor is operated with two phases energized at a time. Dual phase full-step, provides about 30 to 40 percent more torque than single phase full-step, but does require twice the power from the driver power supply.

HALF-STEP
Half-step mode is alternating single and dual phase operation resulting in steps one half the full-step size. A motor with 200 full steps per revolution can do 400 steps per revolution with half stepping. This mode provides twice the resolution of full stepping. While there is sometimes a slight loss of torque, this mode results in an increase in smoothness at low speeds and less overshoot and ringing at the end of each step.

MICRO-STEP
In the micro-step mode, a motor's natural step angle can be divided into much smaller angles. For example, a standard 1.8 degree motor has 200 steps per revolution. If micro-stepping is set at 10 then each micro step would move the motor 0.18 degrees and there would be 2,000 steps per revolution. Micro-steps are produced by proportioning the current in the two windings according to sine and cosine functions. This mode is only used when smoother motion or more resolution is required.