TND6197/D

Stepping Motors and Stepping Motor Control System

ON Semiconductor®

TECHNICAL NOTE

Abstract

This tutorial covers the basic principles of stepping motors and stepping motor control systems, including both the physics of steppers, the electronics of the basic control systems, and software architectures appropriate for motor control.

Introduction

Stepping motors can be viewed as electric motors without commutation. Typically, all windings in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material. All of the commutation must be handled externally by the motor controller, and typically, the motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other. Most steppers, as they are also known, can be stepped at audio frequencies, allowing them to spin quite quickly, and with an appropriate controller, they may be started and stopped "on a dime" at controlled orientations.

Stepper motors are predominantly used for positioning applications, but they aren't the only game in town for that task. So let's start by pulling the camera way back and checking your overall choices.

Below is basic information on common motor choices for positioning motor applications. Note that there are a few other possible choices, such as AC Induction motors or Piezo motors, but these three listed motor types represent the huge majority of applications in use today for general purpose motion control.

1. *Stepper Motors* – These motors are self-positioning, and therefore simple to use. They do not require an encoder to maintain their position nor do they require a servo control loop. Their main drawbacks are vibration and noise, and limited speed range. Like brushless DC motors they must be "commutated" externally using a multi-phase drive.

2. *DC Brush Motors* – These motors require a position encoder for feedback and are stabilized using a PID (Proportional, Integral and Derivative) controller or other position loop controller. These motors do not require external phasing – give them some current and off they go. However, the mechanical brushes inside the motor which accomplish commutation may eventually wear out and fail.

3. *Brushless DC Motors* – These motors require servo control with an encoder for feedback as well as external electronic commutation. They have no brushes however, and they provide high torque over a large speed range. Compared to DC Brush motors, brushless DC motors today offer the 'go to' choice in servo control applications because their historically higher costs have come way down.

For some applications, there is a choice between using servomotors and stepping motors. Both types of motors offer similar opportunities for precise positioning, but they differ in a number of ways. Servomotors require analog feedback control systems of some type. Typically, this involves a potentiometer to provide feedback about the rotor position, and some mix of circuitry to drive a current through the motor inversely proportional to the difference between the desired position and the current position.

In making a choice between steppers and servos, a number of issues must be considered; which of these will matter depends on the application. For example, the repeatability of positioning done with a stepping motor depends on the geometry of the motor rotor, while the repeatability of positioning done with a servomotor generally depends on the stability of the potentiometer and other analog components in the feedback circuit.

Stepping motors can be used in simple open-loop control systems; these are generally adequate for systems that operate at low accelerations with static loads, but closed loop control may be essential for high accelerations, particularly if they involve variable loads. If a stepper in an open-loop control system is over-torque, all knowledge of rotor position is lost and the system must be reinitialized; servomotors are not subject to this problem.

Introduction to Stepper Motor Types

Stepper motors come in two varieties, *permanent magnet* and *variable reluctance* (there are also *hybrid* motors, which are indistinguishable from permanent magnet motors from

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the controller's point of view). Lacking a label on the motor, you can generally tell the two apart by feel when no power is applied. Permanent magnet motors tend to "cog" as you twist the rotor with your fingers, while variable reluctance motors almost spin freely (although they may cog slightly because of residual magnetization in the rotor).

You can also distinguish between the two varieties with an ohmmeter. Variable reluctance motors usually have three (sometimes four) windings, with a common return, while permanent magnet motors usually have two independent windings, with or without center taps. Center-tapped windings are used in unipolar permanent magnet motors.

Stepping motors come in a wide range of angular resolution. The coarsest motors typically turn 90 degrees per step, while high resolution permanent magnet motors are commonly able to handle 1.8 or even 0.72 degrees per step. With an appropriate controller, most permanent magnet and hybrid motors can be run in half-steps, and some controllers can handle smaller fractional steps or micro steps.

For both permanent magnet and variable reluctance stepping motors, if just one winding of the motor is energized, the rotor (under no load) will snap to a fixed angle and then hold that angle until the torque exceeds the holding torque of the motor, at which point, the rotor will turn, trying to hold at each successive equilibrium point.

Variable Reluctance

This type of motor does not use a permanent magnet. As a result, the rotor can move without constraint or 'detent' torque. This type of construction is the least common and is generally used in applications that do not require a high degree of torque, such as the positioning of a micro slide.

Permanent Magnet

Also referred to as a 'canstack' or 'tincan' motor, this device has a permanent magnet rotor. It is a relatively low speed, low torque device with large step angles of either 45 or 90 degrees. The simple construction enables these motors to be produced at low cost, making them the ideal choice for low power applications.

Hybrid Stepper

This version of a Stepper Motor is a clever combination of the variable reluctance and permanent-magnet types.

Stepper Motor Fundamentals

Features of Stepper Motors

- Rotation angle is proportional to number of input pulses
- Rotational speed is proportional to the frequency of input pulses
- Open loop system with no position feedback required
- Excellent response to acceleration, deceleration and step commands
- Non-cumulative positioning error ($\pm 5\%$ of step angle)
- Excellent low speed and high torque characteristics without need for gear reduction
- Holding torque when energized

- Inherent detent torque
- Bi-directional operation
- Can be stalled without motor damage
- No brushes for longer trouble free life
- Precision ball bearings (depending on brand/type)

Drawbacks of Stepper Motors

- Resonances can occur if not properly controlled
- Not easy to operate at extremely high speeds
- If over torqued, all knowledge of position is lost and system must be reinitialized
- Produces much less torque, for a given size than the equivalent DC/AC motor

Winding Connections

Stepper motors are produced in a number of different lead configurations. The most popular are:

- 4 Lead – Bipolar
- 5 Lead – Unipolar
- 6 Lead – Unipolar, Bipolar (series connected)
- 8 Lead – Unipolar, Bipolar (series connected) & Bipolar (parallel connected)

Stepper Modes

The stepper motor can be driven in a number of different sequences. The most common of these are:

- **Wave Drive**
  In this mode only one phase is energized at any given time. For unipolar motors this means only 25% of the available windings are Utilized or 50% utilization for bipolar motors.
- **Full Step Drive**
  In this mode two phases are energized at any given time. For Unipolar motors this means 50% of the available windings are utilized, or 100% utilization for bipolar motors.
- **Half Step Drive**
  In this mode the sequences of the wave and full-step drives are interleaved to enable the rotor to be aligned in half steps. For unipolar Motors this means 37.5% of the available windings are utilized (on average) or 75% utilization for bipolar motors

Applications

- **Industrial Machines**
  Stepper motors are used in automotive gauges and machine tooling automated production equipments. Robotics in MFG, Inspection and Process Flow.
- **Security**
  New surveillance products for the security industry. Including Security Cameras PAN/ZOOM/TILT.
- **Medical**
  Stepper motors are used inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators and blood analysis machinery.

- **Consumer Electronics**
  Stepper motors in cameras for automatic digital camera focus and zoom functions.
- And also have business machines applications, computer peripherals applications.

ON Semiconductor Stepper Motor Driver Solutions

With increased focus on Security, Medical and industrial Applications, as well as reducing cost of System Level design and assembly, every Manufacturer turned to higher levels of integrations as well as the cost down overall. High level of Integration in the Digital World is nothing new, every 18 month the speed doubles and size of Integrated Circuits reduced to close to 50%. In Power Analog World that Motors usually located in it's not as easy as it seems. Motor Horse Power, Heat Dissipation during Motor Drive and Stray Currents needs to be accounted for and driver has to be efficient, small and easy to integrate into an Analog Motor World.
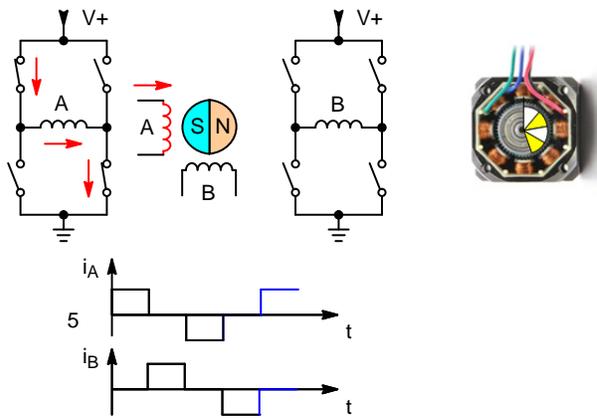
With emphasis on cost, accuracy and ease of use the World has turned to a Stepper Motor Applications. As stated in earlier paragraphs, In Theory, a Stepper motor is a marvel in simplicity. It has no brushes or contacts. Basically it's a synchronous motor with the magnetic field electronically switched to rotate the armature magnet. It converts digital pulses into mechanical shaft rotation so in other words it's a "Digital Motor".

Controlling the Current in Stepper Motor

Controlling the current in the 2 motor coils using H-bridges – Voltage mode.

Figure 1. Voltage Mode
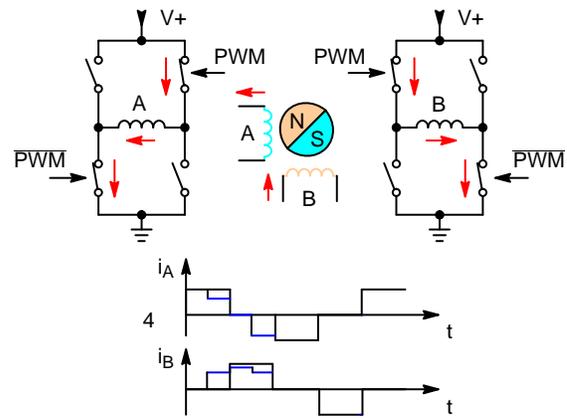
Figure 2. PWM Mode – Microstepping

The Stepper Motor Driver has to Depend on the Following Key Factors

Torque/Torque Efficiency:

Torque is the force to rotate an object around an axis. To generate Torque Two Elements are required – Rotor Filed generated by Permanent Magnet and Stator Field generated by Stator Current. Torque will be MAX when the Fields have Opposite Direction – at $\theta = -\pi/2$ and $\theta = \pi/2$. Torque will increase by increasing the coil current and MAX Efficiency when the MAX delivered torque equals the Load. Key Point – MAX Torque is delivered at the edge of the stable region and if not taken care of in the Driver Logic, will risk to stall the Motor.

Load Angle:

Load angle δ is the angle between stator and rotor field. It is the equilibrium "p" between generated torque and load. With increasing load the load angle δ will increase also.
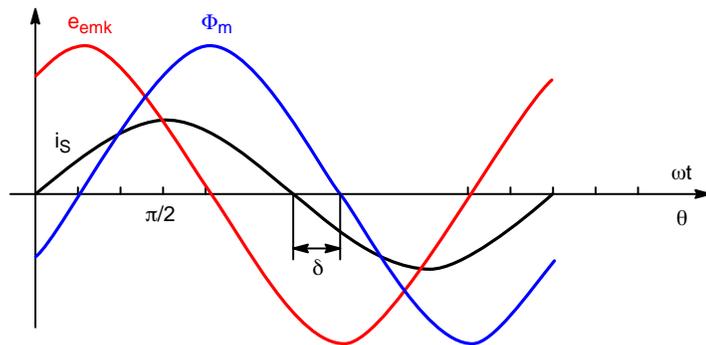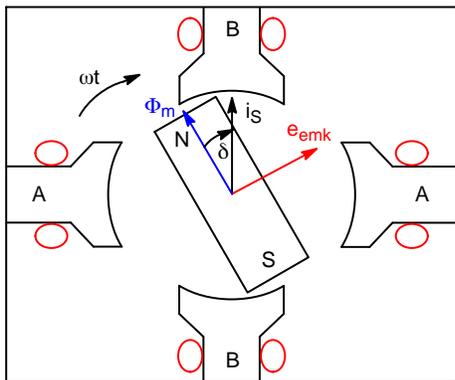

Figure 3. Load Angle

Current Control:

By using Pulse Width Modulation (PWM) and switching H-Bridge the Votlage4 will be chopped across the coil, winding of the Motor. When The Voltage develops across the Coil the Current will increase. When the Coil is shorted, the current will decrease, also called "DECAY".
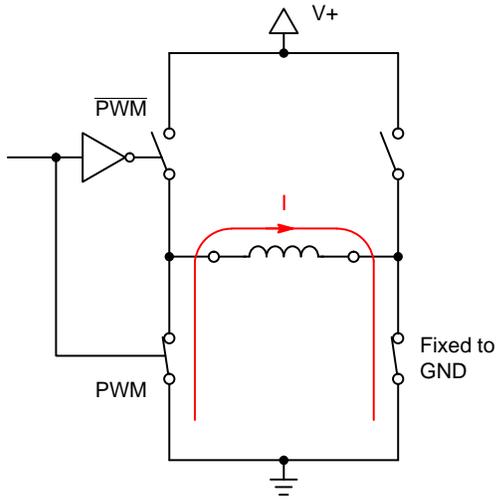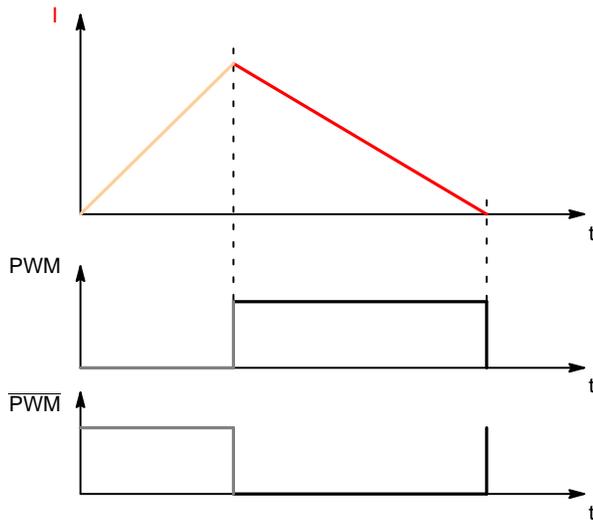

Figure 4. Current Control

The Key Issues Facing Stepper Motor Drivers and Applications

Security Cameras

With Security becoming Number One concern World Wide the use of IP Security Cameras has quadrupled over the last five years. With Digital Cameras and taking the forefront of technology the biggest drawback is increased use of low cost CMOS and CCD Image sensors. The Video quality highly depends on the Sensor Resolution and "Digital Artifacts", Video Distortion, can be seen clearly when Camera Pans or Tilts. Originally this issue was taken care with expensive Analog Motor Drivers with high resolution Servo Feedback based on the Shaft encoder quality. Use of such Drivers was very expensive and different approach had to be introduced for increase Video Quality as well as reduced cost and complexity.

**Introduce ON Semiconductor LV8714A
(Highly Integrated, Dual Channel, PWM Constant, Current Control Stepper Motor Driver)**

With Full Quad H-Bridge Power Switches housed internally with Driver, PWM Logic, LV8714A can driver Two Stepper Motors or Four DC Brushed Motors, if such need arises. With LV8714 any Designer can go from Zero to Full Design of a Pan/Tilt Sec Camera in weeks and not months. With LV8714A both Motors can be driver simultaneously due to Reference Voltage Input avail for each H-Bridge. With wide Input Voltage range of 4–16.5 V it is perfect for any of the following camera applications:

- PoE Sec Camera
- PoE Point of Sales Terminal
- Document Scanners
- Assembly line Quality Control
- Flatbed scanner and Multifunction Printers

Multitude of Safety Factors is built in. Such as:
1. Single Supply Voltage for more reduced cost.
2. High Efficiency and lower Power consumption due to Low Rds(on) internal FET's.
3. Internal Current Sense resistors for reduced components count and further reduction in Power Dissipation. Bringing Power Consumption down by 35% over the competition.
4. Complete Safety Design with Over-current and Thermal Shutdown without use of external components.

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Figure 5. Schematic

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