GALIL
WE MOVE THE WORLD

Application Note #5466

High Speed Performance Limitations of Step Motors

Introduction

There are cases where step motors fail at some frequencies. The main causes are resonance and insufficient voltage. Both of these effects will manifest themselves as a loss of position that will go undetected without the benefit of position feedback (usually in the form of an optical encoder).

Background

Step motors operate by switching current through their phase windings in a specific sequence. For each step in the sequence the motor position advances by one step. Because of this step motors may operate in an open loop configuration without the use of position feedback. As long as none of these steps are skipped, loss of position will not occur. This is not always the case however, and steps may be skipped when the load requires a greater torque than the motor can provide.

In general terms, the motor may be driven in one of several basic ways. One may operate the motor by keeping only one winding activated at any given time, or with both windings active (assuming a two phase motor). The position the rotor assumes when two windings are activated is half way between the positions the rotor assumes when only one winding is activated. The motor may then be half stepped by alternately turning one winding on and then turning two windings on in the proper sequence. For example, if a 1.8 degree stepper (200 steps per rotation) is half stepped the step increments will be 0.9 degrees.

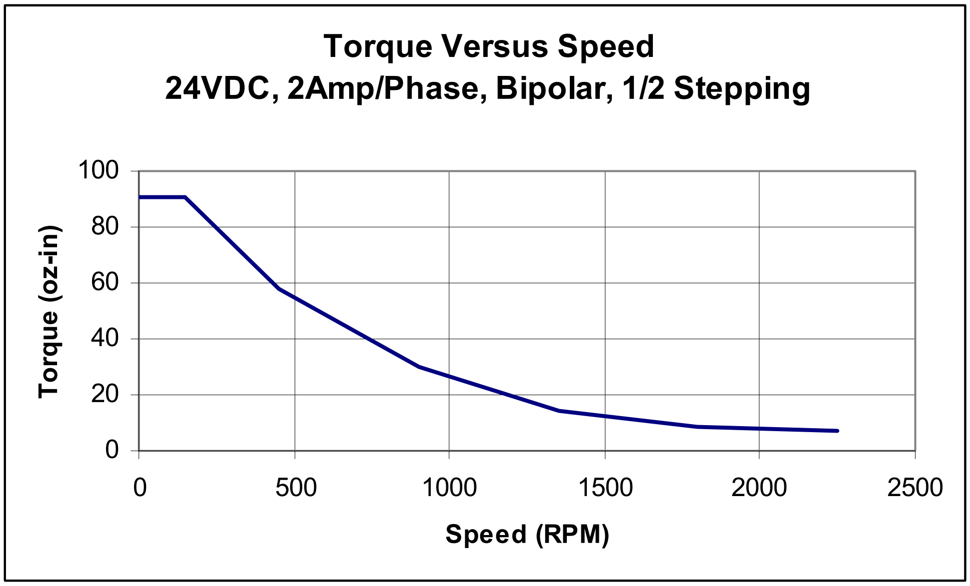
If the currents were to be subdivided into further smaller variations between on and off the motor could assume even more intermediate positions. Step motors are micro-stepped in this way by proportioning the currents in the stepper's windings. This produces a much smoother motion than half stepping as well as a high positional resolution. The more micro steps one adds per full step the closer the currents resemble two sine waves separated by a 90 degree phase shift.

Resonance

Fundamental to the operation of step motors is their inherent vibration caused when they change their position in discrete steps. When the step frequency matches the natural oscillation or resonant frequency of the step motor the amplitude of these vibrations will increase. The resonant frequency depends primarily on the motor and load inertia. The resonant frequency is best determined after the system is connected. If these oscillations become large enough the motor may skip steps and loss of position may occur. Reduction of resonance effects can be made by half stepping, micro stepping or other techniques. Nevertheless resonance and loss of position is still a potential issue.

Required Voltage for Step Motors

Step motors are well suited for applications that require high torque at low speeds. However, as the speed of a step motor increases the available torque rapidly diminishes. The torque speed curve for a Lin Engineering 4118L-01D (1.8°/step) step motor is shown in the figure below. Step motors will typically operate close to their rated torque up to a few hundred RPM. The practical upper limit of step motor operation is less than 1000 RPM. Servo motors are better suited where higher speeds are required.



Typical Torque Speed Curve for Step Motors

Allowing for some physical variation between step motors, the required voltage to operate a step motor at a particular speed can be approximated with the following equation:

$$V = IR + L\frac{dI}{dt} + K_e\Omega \qquad (1)$$

Where:

V is the supply voltage across the phase winding,

I is the instantaneous current in the phase

R is the resistance in the phase

L is inductance per phase

$\frac{dI}{dt}$ is the rate of change of current

K_e is the EMF constant

Ω is the motor speed in radians per second

When micro-stepping a motor I is sinusoidal and consequently $\frac{dI}{dt}$ increases linearly with the speed. $K_e\Omega$ also increases linearly with speed. The resulting torque-speed curve has the general appearance of the Lin Engineering curve shown above.

Analysis:
To select an appropriate amplifier and power supply we need to know the voltage required to operate the step motor at a particular speed. To start out assume that we have a motor with the following known parameters:

R – resistance
L – Inductance
T_h – Holding Torque
I_o – Nominal current for holding torque
N – Number of magnetic cycles per shaft rotation (typically 50 for a 1.8° step motor)

Suppose the user needs to run the motor at a given speed S [rpm] and requires a certain level of current I.

Equation 1 includes 3 terms:

1) IR:
This term is negligible compared to the other terms and will be ignored for this analysis.

2) $L\frac{dI}{dt}$:
Since the current is Isin(ωt) the magnitude of $\frac{dI}{dt}$ is ωI (obtained by substituting Isin(ωt) and using the chain rule when differentiating) where the electrical frequency in radians per second is:

$$\omega = \frac{SN}{60}2\pi$$

Where:
S is the motor speed in RPM
N is the number of magnetic cycles per motor shaft rotation

Then:

$$L\frac{dI}{dt} = \frac{2\pi NSLI}{60} \qquad (2)$$

Galil Motion Control, Inc. • 3750 Atherton Road • Rocklin, CA 95765 USA • 800-377-6329 • Ph: 916-626-0101 • Fax: 916-626-0102 • www.galilmc.com

3) $K_e\Omega$:
This term is more difficult to determine, and depends on the motor design. The value can be approximated as follows:

$$K_e \cong \frac{T_h}{I_o} \quad \text{and} \quad \Omega = \frac{2\pi S}{60}$$

$$\text{then} \quad K_e\Omega \cong \frac{2\pi S T_h}{60 I_o} \qquad (3)$$

Example:

Given a step motor with:
T_h = 180 oz-in/A
I_o = 2.8 A
R = 2.2 Ω
L = 3.6 mH

It is desired to run the motor at 1200 RPM with I = 2A. What is the required voltage?
Using Equation (2):

$$L\frac{dI}{dt} = \frac{2\pi \cdot 50 \cdot 1200 \cdot 3.6 \cdot 10^{-3} \cdot 2}{60} = 44V$$

To find the last term, note that

$$K_e \cong \frac{T_h}{I_o} = \frac{180}{2.8} = 64\frac{\text{oz-in}}{\text{A}}$$

To express K_e in the required mks units we divide this value by 144:

$$K_e = 0.44\frac{V}{\text{rad/s}}$$

Then:

$$K_e\Omega \cong \frac{2\pi S K_e}{60} = \frac{2\pi \cdot 1200 \cdot 0.44}{60} = 56V$$

In other words a total voltage of 44+56 = 100V is required. This voltage is higher than the operating voltage of Galil's SDM-20640 which is from 20 to 60V. When using the SDM-20640 it's suggested that another motor be selected that will allow higher speeds for the given voltage.

In summary it is due to both the inductive effects of the motor windings and the back EMF in the motor that a higher voltage is required to move the motor at speed than is required to maintain the torque while at rest. For these reasons it is better to use a higher voltage power supply if it is desired to run the step motor at higher speeds. Nevertheless, the available torque of step motors still diminishes rapidly as speed increases.