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A Look at What's Hot in the Electric Motor & Drive Industry

Determining Current Limiting Resistors For Stepper Motor L/R Drives

Preview the Motor & Drive Systems 2004 Conference on February 3-4 in Ft. Lauderdale, Fla.

- see insert

Determining Current Limiting Series Resistors For L/R Drives: Two Approaches

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The inclusion of a series resistor in each phase of a stepper motor is commonly employed for two different reasons.

- · Performance Enhancement - increasing the voltage while simultaneously limiting the current to the rated value.
- · Safely driving the motor at a higher voltage than it is rated for.

Performance can be significantly enhanced because the electrical time constant is reduced and the back EMF of the motor makes up a smaller percentage of the applied voltage. This will increase the maximum pull out speed and increase the torque available at any speed.

The compromise is additional power dissipation in the two series resistors needed for bipolar operation, cost, circuit board space and possibly larger power supply. ARSAPE motors are relatively low power devices so dissipation may often not be a practical issue. As an example the diminutive 6 mm diameter AM0620, the world's smallest commercial two phase stepper motor, at rated current with two phases on consumes less than 1 watt.

On the practical side, the smaller a motor gets the more difficult it is to wind it for higher voltages. This is due to the limitation on how small a diameter wire can be economically wound, which inherently limits the number of turns a winding can have. The more turns, the higher the voltage. Additionally, the packing factor becomes less in small diameter wires since the insulation becomes an increasingly higher percentage of the cross sectional area, further limiting performance. In order to perhaps avoid a separate, lower voltage power supply for the motor, a series resister nicely solves the problem.

Introduction

There may be occasions where it is desired that an ARSAPE stepper operate at higher voltages than the winding is rated for or at a voltage where no winding exists. An example of the former could be a customer that normally uses a 12 volt winding but suddenly has a requirement for operating it at 24 volts. Another and sometimes more compelling reason is to improve motor performance and simultaneously insure that the motor will remain within its rated current levels.

Solution - L/R Drive Technique - Employing a Current Limiting Resistor

Simply insert a Resistor in series with each of the motor phases, whose value is easily calculated. This is the antithesis of what you would normally want to do for a DC motor but this will actually improve stepper motor performance.

What is the reason? The electrical time constant will be reduced, so performance will improve. This is called an L/R drives (L over R) and was popular in the old days before current drives were affordable. The motor gets the same current, but the current rises in the winding faster. Remember that the electrical time constant is:

$$T_{elec} = L / R_{total}$$

$$R_{total} = R_{series} + R_{Phase}$$

Where,

L	Phase inductance
R_{series}	Current limiting series resistor
R_{total}	Resistance in Ohms Total, Phase plus Series Resistor

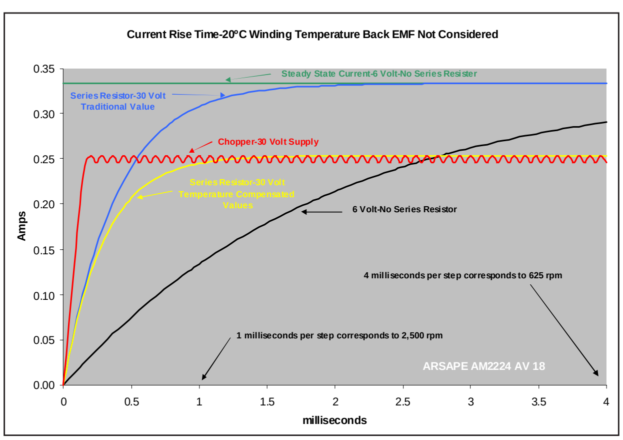

Figure 1.

The downside is additional power dissipation in the two series resistors needed (for bipolar operation), cost, circuit board space and possibly larger power supply required.

Another concern that has to be addressed is the steady state winding temperature. In some cases we must insure that the steady state current is the same both without a series resistor at nominal voltages and with a series resistor at elevated voltages.

Two Different Rationals to Determine Resistor Value

One must decide if the value of the series resistor will be selected to limit the current to the rated value at a "cold" winding or to limit the current to the rated value at a "hot" or maximum winding temperature.

The phase windings are copper wires having a temperature coefficient of approximately 0.393 percent per degree C. Power resistors, on the other hand, ideally have no thermal coefficient. Make sure to utilize a power resistor with low inductance. The goal is to lower the electrical time constant, not increase it.

Resistor Selection - Intermittent Operation - No Compensation for Maximum Thermal Limits

This is normally the technique that is used for the selection of a series resistor. While this technique is fine for intermittent operation there is the danger of overheating the motor for continuous or high duty cycle operation.

Figure 1 illustrates this quite effectively. At 20°C winding temperature the traditional resistor limits the current to the same value as the motor operated at a lower rated voltage without series resistors. Notice too that, ignoring the back emf of the motor, even at 625 rpm the simple 6 volt drive does not have the current built up to nominal value after 4 milliseconds. This figure also shows that the temperature compensated series resistor has a lower current than the traditional one. Lower current values mean lower torque with a "cold" winding.

The chopper is the real champ, with fast rise time and no dissipation in series resistors. The downside of the chopper is that the continuous current is at a lower value. Besides the I squared R losses, the current ripple of the chopper induces eddy currents in the motor which increase heating. The motor is therefore typically rated at a lower continuous current value for a chopper. That correlates to lower continuous torque also. This is particularly true for a "cold" winding since the value of the rated current is such that the motor does not overheat when it is at maximum winding temperature.

Figure 2 illustrates the potential danger in using the traditional approach. With the windings at 120°C the current using the traditional approach exceeds the rating. The motor would actually overheat if driven on a continuous basis. The compensated series resistor, on the other hand, nicely limits the current to the rated value. This is the way to select the series resistor if the motor must be operated continuously or for a long period of time where the thermal time constant is not going to help limit the winding temperature.

If the motor is driven one phase on the voltage and current are increased by $\sqrt{2}$, while torque remains the same. One benefit of driving with one phase on is that when the motor is de-energized it is at a stable equilibrium position and will not move. With two phases on motion of plus/minus up to a half step can occur when the motor is de-energized.

Traditional Resistor Selection

$$R_{SC} = (V_S / I_{RC} - R_{\varnothing C})$$

Where:

I_{RC}	Rated Phase Current -20 °C Winding Temperature	*Amps*
R_{SC}	Series Resistor Needed So Current to Phase(s) is equal to rated or desired current at 20 °C	*Ohms*
$R_{\varnothing C}$	Phase Resistance, 20 °C	*Ohms*
V_S	Power Supply Voltage Available to Winding	*Volts*

Impact on Electrical Time Constant

Without Series Resistor

$$T_E = L_{\varnothing} / R_T$$

$$R_T = R_{\varnothing C}$$

$$T_E = L / R_{\varnothing C}$$

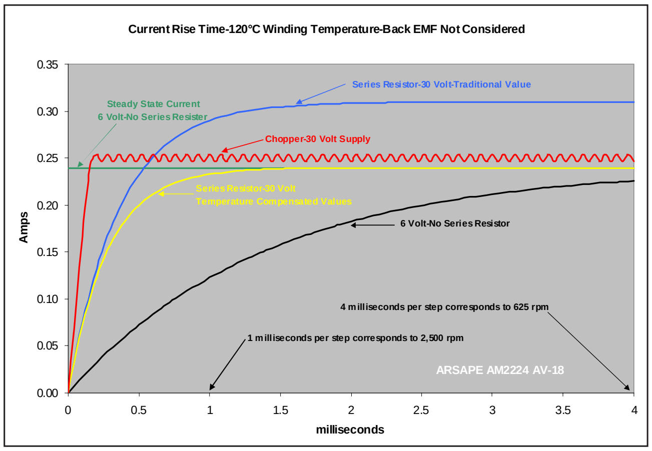

Figure 2.

With Series Resistor

$$R_T = R_{ØC} + R_{SC}$$

$$T_E = L_Ø / (R_{ØC} + R_{SC})$$

Where:

$L_Ø$	Phase Inductance	*Henry*
T_E	Electrical Time Constant	*Seconds*
R_{SC}	Series Resistor Needed So Current to Phase(s) is equal to rated or desired current at 20 °C	*Ohms*
$R_{ØC}$	Phase Resistance, 20 °C	*Ohms*
R_T	Phase Resistance plus Series Resistor	*Ohms*

Compensated Resistor Selection

$$R_{SH} = (V_S / I_{RH} - R_{ØH})$$

$$R_{ØH} = R_{ØC} (1+0.00393 (T_H - 20°C))$$

Where:

I_{RH}	Rated Phase Current-maximum winding temperature	*Amps*
$R_{ØH}$	Phase Resistance, at maximum winding temperature	*Ohms*
R_{SH}	Series Resistor Needed So Current to Phase(s) is Equal to rated or desired current at maximum winding temperature	*Ohms*
T_H	Maximum Winding Temperature	*°C*
V_S	Power Supply Voltage Available to Winding	*Volts*

Conclusion

Introducing a series resistor in each phase of a stepper motor improves performance. Performance improvements include an increase in the maximum speed the motor will operate at and an increase in the utilizable torque at higher speeds. This additional torque results from the reduction in the electrical time constant of the motor, allowing current to build up faster. Additionally, the back EMF of the motor represents a smaller percentage of the total voltage applied, further improving performance.

Additionally it potentially could simplify stocking requirements for customers that want to use the identical motor in applications that have different voltage sources.

Selection of the series resistor value depends on whether the motor will be used intermittently or continuously. Depending on choice either maximum torque will be available with a "cold" winding or maximum recommended torque will be available at maximum winding temperature. Care, of course, has to be taken to insure that the resistor is capable of dissipating the power and that it is of a low inductance type.

Regardless of drive technique utilized testing is absolutely essential. Rating system of stepper motors vary wildly by manufacturer. The thermal realities of every design differ. With proper thermal management you may be able to extract more performance from a motor while retaining a sound, safe, engineering design.

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