

#10: Understanding Motor Voltage Modes in Servo Amplifiers

A big problem in today's servo technology is understanding the different requirements for operating a servo motor amplifier when set up in the current or voltage modes. There are not many designers who give any consideration to these requirements, even through they have that understanding. Generally, when the axis under consideration is to be tuned, the problems begin, and hindsight engineering takes over. The purpose of this tech tip is to give enough information about how the servo system will react to the current and voltage modes of motor operation, in order to prevent future tuning and stability problems.

Motor Amplifier Modes of Operation:

There are only two primary modes of operation for any motor amplifier package—current mode and voltage mode. The difference between these two modes needs to be completely understood in order for the servo gain algorithm to function properly. If misunderstood, they can, and probably will, produce havoc when motion is called for.

Current Mode:

The current mode of operation in the motor amplifier has a gain rating in Amps/Volt. This implies that a current will be sent to the motor with a specific relationship to the input signal voltage. In other words, if the motor amplifier has a current gain rating of two amps per volt of signal input, the motor will receive 4.0 amps of driving current if the input signal is set at 2.0 volts.

Voltage Mode:

The voltage mode of operation in the motor amplifier has a gain rating in terms of voltage out to the motor relative to the input signal voltage. However, since the voltage out to the motor is directly proportional to the motor's speed, the gain rating found most often is in motor RPM per volt of signal input. In other words, if the motor has a rating of 2000 RPM with a voltage constant, K_e , of 100V/krpm, and the motor amplifier has a gain of 20 volts of output per volt of input, then the motor will turn at 400 RPM if the input signal voltage is 2.0 volts.

Note that in the case of current mode, an unloaded motor will run at its maximum RPM with only a small value of DAC (Digital to Analog Converter) voltage applied (enough to overcome its friction, windage, and other internal losses commonly called viscous damping). In the voltage mode, however, the signal input must reach its maximum value for the motor to run at its top RPM.

What about Torque Mode?

The torque mode is a method of control. If the controlling device puts out a voltage without any feedback correction taking place and the motor amplifier is in the current mode, then the system is operating in the torque mode. The motor will produce a maximum torque based on its torque constant, K_t , and the current being sent to it by the amplifier. The current is limited only by the signal-voltage at the motor amplifier input (assuming no direct current-limiting by the motor amplifier has taken place).

Once a feedback device is incorporated into the operation, velocity, and position corrections, can take place. The operation is transferred from torque

mode to current mode. Therefore, current mode incorporates feedback information to adjust the motor current in order to maintain a given operating parameter such as RPM (velocity).

Thus if the load on the motor exceeds the torque the motor is capable of generating with the given current output [(motor K_t) times (motor Amps)], then the slow down in the motor RPM will be sensed by the servo controller via the encoder (or another feedback device), and the servo controller will then adjust the input signal voltage (via the DAC) to the power supply to return the motor to the required RPM.

Voltage Mode Control:

Voltage mode is similar to current mode only in one way. It has a feedback device used to supply motion information to the motion controller. The motion controller will then correct for any deviation in motor RPM. This is done by changing the motor amplifier input signal, which will then alter the motor's terminal voltage.

If a feedback device is not used in the control system, then the mode of operation changes from a voltage mode to a velocity mode (i.e., simple speed control via a potentiometer).

The easiest way to think about a motor amplifier operating in voltage mode is as a constant voltage power supply. The output voltage is controlled by an input signal voltage (or a control potentiometer). The power supply output current simply "comes along for the ride" and changes according to the load resistance presented (Ohm's Law).

When the motor rotates, it generates what is known as a counter EMF force (Electro Motive Force counter-voltage to that causing it to rotate). If the motor slows down, the counter EMF (or impedance) goes down, and the current passing through will increase (assuming the power supply's terminal voltage has not changed). The increase in current will give the motor more power [(motor K_t) times (motor Amps)] to overcome the load variation that caused it to slow down. So, in order to maintain a requested RPM, load variations will be automatically corrected for by the power supply (or motor amplifier). The input control signal will not have to change.

Open Loop Control:

At this point, it should be apparent that there are two motor amplifier modes, and four servo control modes. Depending on system use of a feedback device, such as an encoder, the servo controller may be working as an open-loop control, or in a closed-loop mode.

If the servo is operating open-loop (which can be done by writing directly to the DAC output), the responsibility for system stability (speed or torque) is transferred to the motor amplifier. The motor amplifier controls motor RPM (or torque) based on its ability to interpret the feedback information given to it by the motor, its internal gain structure, its bandwidth, and the system electrical and mechanical time constants. The open-loop mode of operation does not require critical tuning operations, but does require the motor amplifier to be calibrated to ensure the output is doing what the input driving signal (the servo controller) thinks it is.

Closed Loop Control:

If the servo is operating in a closed-loop mode, a different set of rules apply. Depending on which of the two motor amplifier modes used, amplifier gain, bandwidth, and other factors can hamper the ability to stabilize the system.

When using servo control with the motor amplifier in current mode, all of the stability control responsibility is given to the servo controller directly. The servo controller gain formula can use almost any available format, such as feedforward, feedback, PID (or parts of the PID), and others, to obtain a variety of following-error conditions (from near zero, to leading or lagging). Because of the flexibility allowed in the following-error dimension with this style of control, it is well suited for special operations such as master/ slave, registration control, and various interpolation routines.

However, when using a closed-loop servo control with the motor amplifier in the voltage mode, only part of the responsibility for stability control is given to the servo controller. The motor amplifier has also been given this task. The following discussion is intended to show why voltage mode is more difficult to handle than other modes discussed.

The problem in voltage mode occurs when selecting the system encoder. The actual DAC output, used to drive the motor amplifier is produced by the controller gain formula (algorithm). In plain English, the DAC output is:

$$\text{DAC} = (\text{Gain Scaling})(\text{Following Error})$$

If we were operating in current mode, the motor amplifier would care nothing about RPM, only current (torque). The entire burden of maintaining a stable velocity would be placed on the servo controller. Thus, the DAC output is allowed to vary in order to maintain velocity (or following error) by adjusting the motor current. So, not only will the encoder have a direct bearing on the DAC output, but so would the gain-scaling values. The DAC can be 0.05 volts one moment, and 7.5 volts the next in order to accommodate shifts in position tracking due to load changes, friction differences, and a host of other mechanical situations. Yet, motor RPM could easily remain within 0.1% even though the voltage swing is wide.

In the voltage mode, however, the DAC must remain at a fixed value for any given velocity requirement. In order to maintain that velocity, load variations are going to be handled by the motor amplifier. The amplifier will note a change in voltage feedback and adjust the motor current without any outside help. However, if the controller also notices that motor velocity is changing, it too will try to accommodate the change, by adjusting the DAC output.

We now have two controllers trying to compensate for load changes using two different ways: DAC control by the servo controller, and current control via voltage feedback by the motor amplifier. The problem is that both devices will not necessarily be able to maintain a proper phase relationship to each other (depending on the band width of the motor amplifier package, servo controller, and the system time constants). The bottom line is that it's usually the system stability that loses, and the designers are left holding the bag, wondering why.

Resolving the Problem

Does all of this mean that the voltage mode motor package cannot be used on today's controllers? No, there are only a few things to consider when planning to use the voltage mode. Since we know that the Voltage/RPM relationship of a motor (its Kv) cannot be changed and that the motor amplifier will be the prime factor in controlling the motor's speed, we simply need to rethink the servo control requirements.

If you were operating a master/slave system, it is doubtful that you would set up the slave axis to respond to variations in the master axis at a rate slower than the master is changing. You would not be able to maintain good phase control between the two systems, if any phase control at all. If you think of the voltage mode as a master/slave situation, the servo controller must not operate beyond the response capability of the motor amplifier package.

So, solutions for this type of operation (voltage mode) would be either: to reduce the amount of correction applied to the motor amplifier during any update period of the servo controller, or to increase the update time period allowing the motor amplifier to keep up with the servo controller (i.e., going from 256 microseconds to 1 or 2 milliseconds). In real-world, voltage-mode operation, the servo controller must allow the motor amplifier time to respond, otherwise, the system is being overcontrolled and will produce unstable results.

Discussion

Previously, we discussed a method for selecting an optimum encoder count value. Looking back at the relationship:

$$\text{DAC} = (\text{Gain_Scaling})(\text{Following_Error})$$

It should be apparent that if you were to use a PID gain structure in the servo controller, the term Ki could not be used when operating with a voltage mode motor amplifier since a fixed DAC output requirement calls for a fixed following-error value at any given velocity, and the prime purpose of the Ki term is to pull out (or close up) the following error (i.e., make it as small as possible— theoretically zero) thereby changing the

DAC output as the move progresses, which this mode of operation cannot tolerate.

How do we get good control stability via the servo controller, and maintain the voltage mode of operation within the motor amplifier? If there is no ability to properly scale the motor amplifier gain algorithm to coordinate with the servo controller gain structure—we don't!

In order to maintain a stable system, only one of the two independent controllers must do the work: the servo controller, or the motor amplifier. If the burden of effort is to be placed on the servo controller, then the ability of the motor amplifier to control the motor must be reduced or eliminated. The reverse holds true if the motor amplifier is to be in control. Determine what the situation calls for before you purchase the equipment. Finally, get a good understanding of the specific gain formulas found in the servo controller and motor amplifier that you want to team up. If possible, develop a simplified BASIC level program to plot out what will happen to stability as commanded motion not only moves along, but meets motion discontinuities along the way (i.e., friction tools).

Selecting the motor and amplifier package can be a good experience, or a nightmare. Being informed is the key. ■

About the Author:

In his more than two decades in the industry, **Chuck Raskin, PE, CMCS**, has contributed to many industry publications, including *Motion, Motion Control, & PCIM*, and is currently working on the fourth edition of the *Designing with Motion Handbook*. Chuck is currently the manager of technical services for Technology 80 and a board member of the American Institute of Motion Engineers (AIME).

