Appendix A

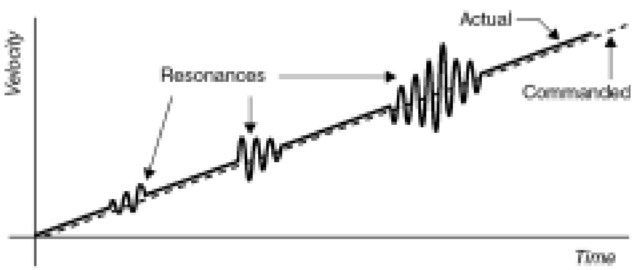
Resonance, Ringing & Damping— Discussion & Theory

In this appendix we will discuss resonance and ringing in step motors. This information will help you configure the ZETA6xxx's damping features—anti-resonance, active damping, and electronic viscosity.

All step motors have natural resonant frequencies, due to the nature of their mechanical construction. Internally, the rotor acts very similarly to a mass suspended on a spring—it can oscillate about its commanded position. Externally, the machine, mounting structure, and drive electronics can also be resonant, and interact with the motor. During a move, two types of problems can arise from these causes: resonance and ringing transients.

Resonance *(Steady State Response)*

Resonance is a *steady state* phenomenon—it occurs when the motor's natural resonant frequencies are excited at particular velocities. It is not caused by transient commands that we give the motor. If you slowly increase your motor's speed from zero to 20 rps, for example, you may notice "rough" spots at certain speeds. The roughness is resonance; it is depicted in the next drawing.



Instead of moving at the commanded velocity, the motor is oscillating between speeds faster and slower than commanded. This causes *error in rotor position*.

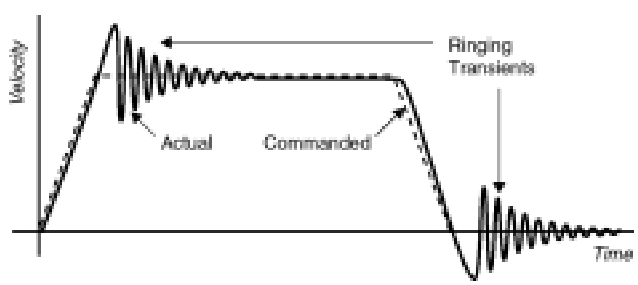
Resonance points can differ in intensity. The drawing shows a typical case—as motor speed increases, resonances of varying levels occur. Usually, the motor can accelerate through the resonance point, and run smoothly at a higher speed. However, if the resonance is extreme, the rotor can be so far out of position that it causes the motor to stall.

Resonance is affected by the load. Some loads are resonant, and can make motor resonance worse. Other loads can damp motor resonance. To solve resonance problems, system designers will sometimes attach a damping load, such as an inertial damper, to the back of the motor. However, such a load has the unwanted effect of decreasing overall performance, and increasing system cost.

The ZETA6xxx has internal electronics that can damp resonance, and *increase* system performance. No external devices are necessary.

Ringing *(Transient Response)*

Inside a step motor, the rotor behaves like a mass on a spring, as mentioned above. When commanded to quickly accelerate to a given velocity, the rotor will "ring" about that velocity, oscillating back and forth. As shown in the next drawing, the ringing *decays*—grows smaller over time—and the rotor eventually settles at the commanded velocity.



Notice that ringing can be caused both by accelerating or decelerating to a commanded velocity, and decelerating to a stop. In any of these cases, ringing causes *error in rotor position*.

Ringing is a *transient* phenomenon (unlike resonance, which occurs during steady state operations). It is a response to a sudden change that we impose on the system, such as “Accelerate to Velocity” or “Stop.”

Several problems are associated with ringing. It can cause audible noise; the motor must have a margin of extra torque to overcome the ringing; and longer settling times can decrease throughput.

To eliminate these problems, system designers use damping to force the ringing to decay quickly. Inertial dampers have been used as components in passive damping methods. Accelerometers, encoders, and tachometers have been used as components in active damping methods. These devices can have the unwanted effect of limiting performance, adding complexity, and increasing cost.

The ZETA6xxx has internal electronics that can damp ringing transients, and cause them to decay quickly. No external devices are necessary.

Damping in the ZETA6xxx

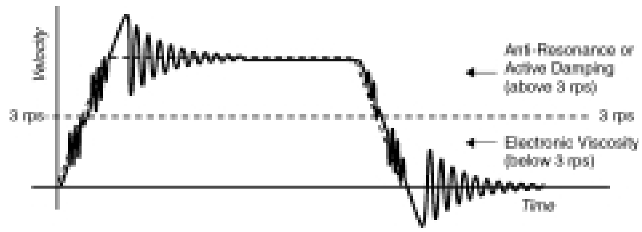
The ZETA6xxx has three different circuits that can damp resonance and ringing.

Anti-Resonance – General-purpose damping circuit. The ZETA6xxx ships from the factory with anti-resonance enabled. No configuration is necessary. Anti-resonance provides aggressive and effective damping.

Active Damping – Extremely powerful damping circuit. The ZETA6xxx ships from the factory with active damping disabled. You must use the Active Damping rotary switch to enable active damping and optimize it for a specific motor size and load (see procedure on page 36).

Electronic Viscosity – Provides passive damping at lower speeds. The ZETA6xxx ships with electronic viscosity disabled. You must use the `DELVIS` command to enable electronic viscosity, and optimize it for a specific application (see procedure on pages 38-39).

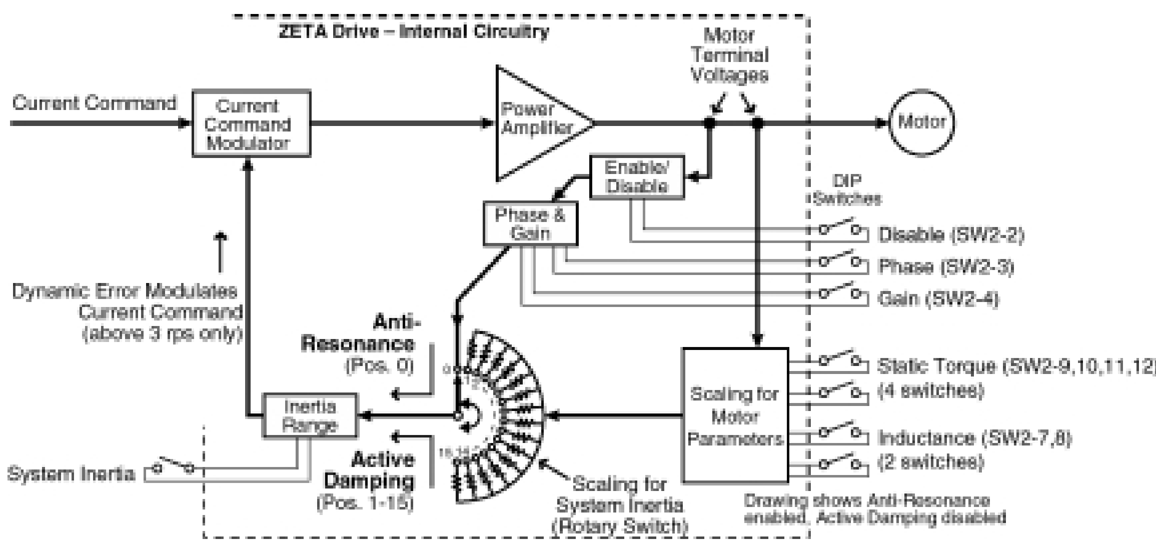
The first two damping circuits—anti-resonance and active damping—work at speeds greater than three revolutions per second (rps). Electronic viscosity works at speeds from rest up to three rps. The ZETA6xxx will automatically switch between the damping circuits, based upon the motor’s speed. The next drawing shows the effective range of each circuit.



Above 3 rps, the ZETA6xxx automatically enables either anti-resonance or active damping—but not both at the same time. They are mutually exclusive.

If active damping is set to zero (AD rotary switch), the ZETA6xxx enables anti-resonance. If the Active Damping rotary switch is set to any setting other than zero, the ZETA6xxx enables active damping. This relationship is shown in the next drawing—notice in the drawing that anti-resonance can also be disabled with a DIP switch setting (SW2-2).

Differences between anti-resonance and active damping are described next; refer to the block diagram below.



Anti-Resonance (AR)

Anti-resonance monitors the ZETA6xxx's motor terminals, and looks at power exchange between the ZETA6xxx and motor. From this, it extracts information about error in rotor position caused by resonance or ringing. It modifies the internal motor current command to correct for the error.

Anti-resonance is a general-purpose circuit. It corrects rotor position error, without knowledge about the system—whether the motor is large or small, or the system inertia is high or low. You cannot modify the circuit's gains, or customize it for a particular application—but, anti-resonance is easy to use. When enabled via DIP switch, SW2-2, it works automatically.

Anti-Resonance Gain

Large rotor motors, or motors driving large inertial loads, may require a reduction in anti-resonance gain. This will be evident if the load becomes too responsive and settles in an overly abrupt manner for your application. SW2-4 should be *off* if the system's inertia is 20 kg-cm^2 or less. SW2-4 should be *on* if system's inertia is greater than 20 kg-cm^2.

Anti-Resonance Phase

This switch allows a broad range of motors to benefit from the anti-resonance damping technique. SW2-3 should be *off* if your mechanical system's resonant frequency is 80 Hz or less. SW2-3 should be *on* if your mechanical system's resonant frequency is greater than 80 Hz, if your motor drives an extremely low inertia load, or if your system has an extremely high torque to inertia ratio.

Active Damping (AD)

Active damping monitors the ZETA6xxx's motor terminals and, like anti-resonance, uses the same current command modulator to modify motor current.

Active damping uses a different method to extract information about rotor position error, however. The circuit's gains are adjustable—you can configure it for your particular system. DIP switch SW2 allows you to scale the circuit for motor inductance and static torque. The AD rotary switch scales the circuit for system inertia.

The active damping circuit uses this information for two purposes:

1. It determines error in rotor position *very* accurately.
2. It adjusts the gains of its feedback loop, based upon how much inertia the system has, and how much torque the motor can produce.

If the rotor rings or vibrates, the active damping circuit will detect the corresponding error in rotor position. It will then modify the motor current command to damp the ringing.

DIP switches on top of the ZETA6xxx set the amount of motor current during normal operations; this current is constant. To damp ringing, the active damping circuit can cause the ZETA6xxx to produce up to twice as much current as is set by the DIP switches. The extra current is only applied during damping oscillations, and lasts a very brief time.

Electronic Viscosity (EV)

The ZETA6xxx uses closed-loop current control to develop and maintain precise currents in the motor phases. When EV is off, the current loops have a bandwidth of approximately 1000 Hz. Because this bandwidth is well beyond the knee of step motor speed-torque curves, the current loop dynamics do not limit the response of the motor.

EV monitors motor velocity, and turns on below 3 rps. It "detunes" the current loop compensation values and brings the bandwidth down to 150 Hz. With this lower bandwidth, the drive electronics become "sluggish." Ordinarily, when the rotor oscillates, it generates current in the motor's coils; but with EV's lower bandwidth, the drive's electronics impede the flow of current caused by oscillations.

The effect on the motor is as if there were a viscous drag on the rotor. At the end of a move, oscillations are damped, and the rotor quickly comes to rest. After accelerating or decelerating to velocities below 3 rps, the rotor quickly settles at the commanded velocity. During moves below 3 rps, EV significantly reduces low speed velocity ripple.

EV is a "passive" circuit. It imposes viscosity on the system, but has no feedback loop to monitor the effect of the viscosity. EV keeps the amount of viscosity the same, regardless of the response of the system.

You can adjust the amount of viscosity by using the `DELVIS` command. This allows you to tailor the circuit for different motor sizes and system inertias, and adapt it to your application.

Current Loop Gain

SW2-5 should be *off* for normal current-loop gain. You can reduce the responsiveness of the current control loop by setting the SW2-5 to the *on* position. This may be necessary when connecting a motor with an extremely low inductance value, on the order of 2 mH. If you hear a high pitched (10kHz) oscillation from the motor, you can decrease or eliminate the oscillation by reducing loop gain. Excessive loop gain may cause motor faults at high loads; reduce loop gain to eliminate this problem.

Recommendations

We recommend that you configure active damping and electronic viscosity. Even if you believe resonance and ringing will not cause problems in your system, you may find that the ZETA6xxx's damping circuits provide increased smoothness, reduced audible noise, and better performance. Refer to the configuration procedures beginning on page 36.

If you choose not to use active damping and electronic viscosity, at least use anti-resonance. The ZETA6xxx is shipped from the factory with anti-resonance enabled (SW2-2 = OFF).