

Application Note

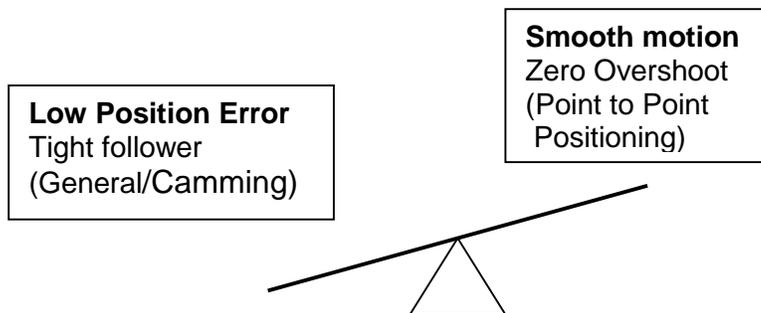
Applying Auto-tune feature for M02AE

Purpose

Most systems can be auto-tuned with the load attached. However, some cases require manual adjustment of some of the parameters to achieve optimal performance while other cases cannot be auto-tuned with the load attached. This document serves as a guide to:

- Manually adjust system gains after a successful, albeit, sub-optimal auto-tune.
- Manually tune an axis that cannot be auto-tuned when coupled to the load.

These are general recommendations. Since each machine application is unique, special consideration should be made on a per machine basis.



After a successful auto-tune procedure is run, you must decide which performance is acceptable: decreasing position error or one that moves smartly to a position without jerking the load. If you decide in favor of low position error, then your system is subject to fast Maximum Acceleration and Deceleration, and will possess high jerk rates. If you opt for smoother moves, then you have lower Maximum Acceleration and Deceleration values and less jerk, but increased position error. Just like in some new cars you can adjust their parameters to run in “Sport Mode” for optimal driving conditions or “Winter Mode” for harsh conditions or “Normal Mode” for balanced operation, you should strive for a balance between all out performance and smoothness in tuning your system.

Issue Definition:

Case 1: The axis can be auto-tuned coupled to the load, but the performance is not optimal.

You can configure the M02AE to interface with either an *external torque servo drive* or an *external velocity servo drive*, based on the External Drive Configuration. Since the recommended tuning procedures depend on the external drive's configuration, each drive type is addressed separately.

In interfacing with a ***torque servo drive***, both the velocity and position loops are closed within the M02AE. This is, generally, the preferred configuration since it gives us direct control access to all the servo gain parameters and eliminates the need to tune the drive separately. In a torque servo drive system, adjusting for load inertia requires just one parameter, Torque Scaling (aka Output Scaling in pre-V9 releases).

In interfacing with a ***velocity servo drive***, only the position loop is closed in the M02AE. The velocity loop is closed in the drive. In this configuration the velocity servo drive must first be tuned using the manufacturers recommended tuning procedure. Then you can apply the auto-tune to the M02AE's position loop.

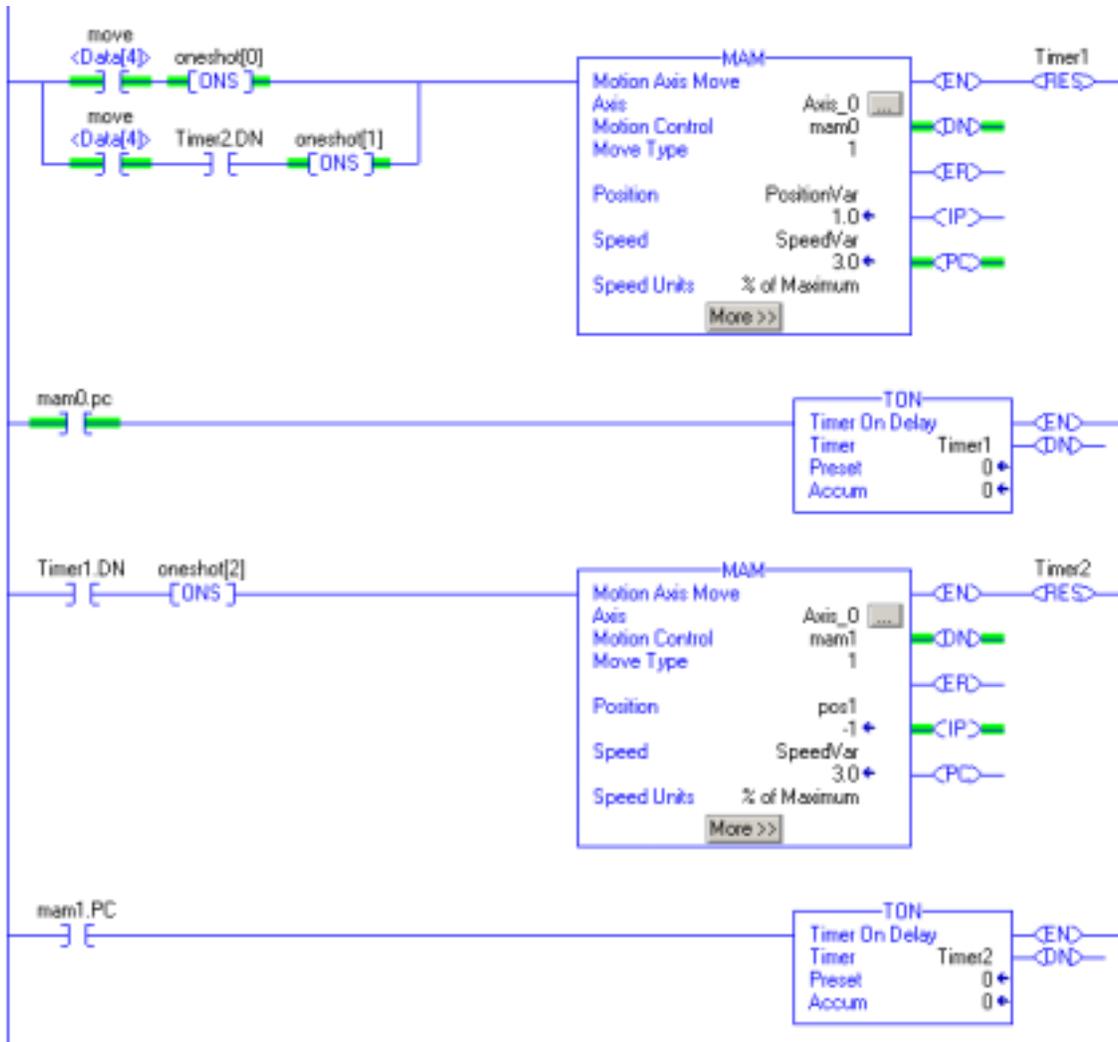
Regardless of the External Drive Configuration, in most cases you can connect the load, and perform the auto-tune, and the system should automatically set gains that result in acceptable servo operation. However, this is not always the case. For example the motor could be coupled to a load that has a high inertia mismatch or lots of compliance. Such systems frequently require manual adjustment to achieve optimal performance.

There are two cases to consider where the auto-tune is sub-optimal:

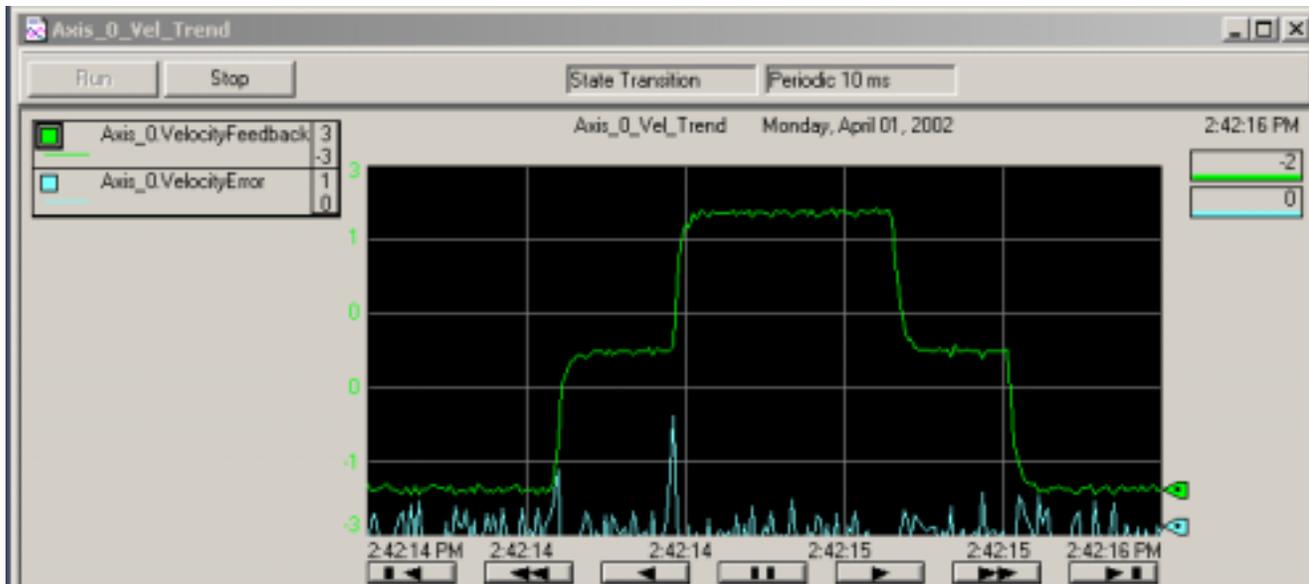
1. Auto-tuned axis is too sluggish. Need to squeeze more bandwidth out of the system.
2. Auto-tuned axis is tuned "too hot". Need to back off the servo bandwidth to achieve a more damped response.

The manual tuning procedure is the same for either case. In this procedure we use the Torque Scaling gain as a convenient real-time handle to adjust the bandwidth of the servo loop.

If your axis can be moved back and forth, a good method to determine the performance of the system is a battery box program. Some use an oscilloscope to watch the velocity profiles, but we have found that the Trending included in RSLogix 5000 works well to provide a visual reference.



This trend profile shows Velocity Feedback, and Velocity Error. This axis has a high inertia mismatch, and shows some overshoot, and unsteadiness. Two of the more critical values to trend are: Velocity Command and Velocity Feedback. You may also wish to trend Position Feedback and Position Error.



The Knobs and Adjustments (The fun stuff):

Integral Gain: The higher the Velocity I gain value, the faster the axis is driven to the zero Velocity Error condition. Unfortunately, I Gain control is intrinsically unstable. Too much I Gain results in axis oscillation and servo instability. If you have a torque mode system you can add I gain to the Velocity loop or the Position loop. If you are using I gain in both loops they tend to fight each other, we typically recommend adding I gain in the Velocity loop only.

Velocity Feedforward Gain: This gain scales the current Command Velocity and adds it as an offset to the velocity servo command input. Hence, the Velocity Feedforward Gain allows the following error of the servo system to be reduced to nearly zero when running at a constant speed.

Acceleration Feedforward Gain: This gain scales the current Command Acceleration and adds it as an offset to the Servo Output generated by the servo loop. Hence, the Acceleration Feedforward Gain allows the following error of the servo system to be reduced to nearly zero when running at a constant acceleration.

Note: Acceleration Feedforward Gain is not applicable for applications employing velocity loop servo drives. Such systems would require the Acceleration Feedforward functionality to be located in the drive itself.

Torque Servo Drive Tuning Method:

1. Tune system coupled
2. Note Torque Scaling value after tuning.
3. Note Velocity and Position P gains

4. At this point if low position error is the goal, try adding Velocity Feedforward gain. This value is typically 100%, but you can manually crank it up or down to suit your application.
5. If the system is a little sluggish getting off the line, add Acceleration Feedforward. This value is typically 100%, but you can manually crank it up or down to suit your application.
6. Hint for changing overall gains performance: during the autotune one of the popup dialog boxes reports the position and velocity bandwidth, change both of these by the same factor to maintain parity between the loops.

Velocity Servo Drive Tuning Method:

1. Using the drives tuning method, tune the drive with the motor coupled. This establishes the velocity gains within the drive. Typically, Velocity I gain is added into the system at the drive.
2. Using RSLogix 5000 tune the axis coupled. This tunes the position loop within the M02AE.
3. Do NOT adjust Output Scaling in velocity loop mode.
4. In velocity loop mode, the “handle” is the position loop Proportional gain. By increasing the Position Proportional gain value, the system position loop bandwidth is increased. This tightens the positioning performance of the system.

Note: Velocity and Position I gains should be considered mutually exclusive. Do not add Position I gain if you are using Velocity I gain at the drive.

Issue Definition:

Case 2 - The axis **cannot** be auto-tuned coupled:

This is usually an application that has high inertia. We will discuss a method of determining the percentage of measured inertia mismatch and attempt to apply that to the system. It must be noted that motor to load sizing should have been done beforehand to select a suitable motor and drive combination for the application.

Method:

Torque Servo Drive method of determining needed bandwidth adjustment:

1. Using auto tune in RSLogix 5000 tune the motor uncoupled.
2. Take note the Torque (Output) Scaling value after tuning.
3. Observing all safety precautions, connect the load to the motor and enable the axis. Exercise the axis to determine overall system performance.
4. Leaving the gains as they are, Crank up (or down) the Torque Scaling. Increasing this value has the effect of stiffening position performance. In torque mode, the “handle” for

measuring the overall gain of the system is to maintain the necessary relationships between the loops is the Torque Scaling value. By increasing the Torque Scaling value, the system bandwidth is increased, and conversely lowering the Torque Scaling value decreases the bandwidth of the system.

5. Note the Torque Scaling value after cranking it.
6. Use the formula:

Initial Torque Scaling / Cranked Torque Scaling = Percent of Bandwidth Change.

The next step is critical to proper scaling and system performance!

7. Set the Torque Scaling to the Initial Torque Scaling value.
8. Multiply your Velocity and Pos P gains by the Percent of Bandwidth Change calculated in step 6.
9. Change your I gain by the Percent of Bandwidth Change Squared.

External Velocity Loop Tune

1. Using the drives tuning method, tune the drive with the motor uncoupled. This establishes the velocity gains within the drive. Typically, Velocity I gain is added into the system at the drive.
2. Using RSLogix 5000 tune the axis uncoupled. This tunes the position loop within the M02AE.
3. Do NOT adjust Output Scaling in velocity loop mode.
4. Connect the load and retune the drive.
5. In velocity loop mode, the “handle” is the position loop Proportional gain. By increasing the Position Proportional gain value, the system position loop bandwidth is increased, and has the effect of tightening the positioning performance of the system.

Note: Velocity and Position I gains should be considered mutually exclusive, do not add Position I gain if you are using Velocity I gain at the drive.

Fine Tuning a Velocity Servo Drive

The system is nervous.

In this case the gains are too hot. Backing off on any particular gain could cause instability in the system. Care must be taken to reduce the gains of the velocity loop in the drive and the position loop in RSLogix. In a velocity mode system, when the axis is acting gnarly it is typically a drive velocity loop problem. If you drop the P gain by a factor then you must also drop the I gain by the square of that factor.

The servo response is sluggish.

This may be a time to crank up the P and I gains of the velocity loop in the drive,

When velocity mode is selected, the velocity loop in the drive compensates for the inertia. Connecting the load allows tuning of the velocity component of the system. Once this is achieved, the position loop is tuned with the M02AE.

Other considerations:

Integral Gain: In the velocity loop configuration, Integral Gain is generally added in the drive. If you have a torque servo drive system you can add I gain to the Velocity loop or the Position loop. If you are using I gain in both loops they tend to fight each other.

Servo Sizing Tip: Inertia!

What is inertia? Inertia is the measure of a body's resistance to changes in velocity whether the body is at rest or moving at a constant velocity. The velocity can be either linear or rotational. The inertia of an object varies according to the fourth power of its diameter. Therefore, an object with a two-inch diameter has 16 times (2^4) the inertia of a similar one-inch diameter object.

Typical inertia units: in * lb * sec² or oz * in * sec², or kg * sec².

For maximum power transfer, it is best to match the inertia of the load (when reflected to the motor shaft) to that of the motor. This inertia ratio of 1:1 (load to motor) is often difficult to achieve, and in practice, any ratio of 1:1 or less works fine. As the inertia ratio exceeds 5:1, the response or bandwidth of the servo amplifier must be increased so that when a change in velocity is required, the system is able to generate enough torque to overcome the load inertia and follow the velocity command. The penalties for increased bandwidth are small velocity disturbances (voltage spikes due to noise on the command lines, etc.) which would otherwise be ignored now cause a motor response. This results in a "nervousness" of the system, which causes a high current (torque) ripple. This ripple results in excessive motor heating, position dither, and machine vibration or buzzing. All of which are undesirable.

Many factors can affect this situation, including the system static (breakaway) and running friction, the servo update rate of the motion controller, and the position resolution. Although some systems can operate successfully with inertia ratios of 10:1 or more. Determining if a system will be stable before it is built is difficult because many of these factors cannot be predicted. Rockwell Automation's Motion Analyzer (Motion Book) provides the user with a system modeling tool that can assist in determining the system inertia. The user can input (model) the mechanical system, describing the load type, the transmission type, and the machine cycle. In addition to providing inertia data, it assists the user in selecting the proper components to match the system requirements.

Use a gearbox to improve system performance by reducing the reflected inertia and required torque. When a gearbox is used, the system inertia reflected to the motor decreases by the square of the gear ratio. For example, adding a 2:1 gearbox reduces the reflected load inertia to a quarter ($1 / 2^2$) of its previous value! In addition, adding the gearbox reduces the torque requirements of the motor--a win-win situation! The required motor torque is reduced by the gear ratio (a 2:1 gearbox cuts the required torque in half), as is the maximum load speed.

If you need to verify a particular application, contact Technical Support at (603) 443-5419.

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