



PMAC Servo Loop Tuning

Interactive Tuning





Servo Tuning

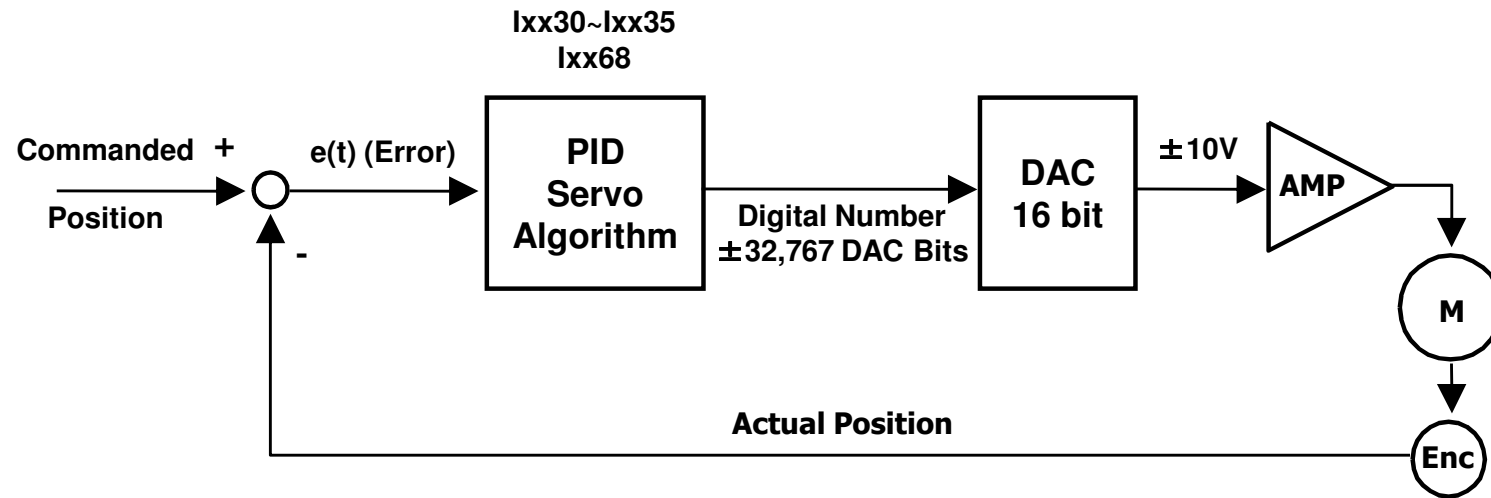
- PMAC's Servo Algorithm must be configured to properly control any given system with motors and amplifiers
- Configuration is done by adjusting I-Variables (Ixx30 through Ixx35) pertaining to the PID gains
- Ixx68 (Friction Feedforward) is also needed
- The process of determining proper values of PID gains is called "Tuning"





PID Servo Loop

Adjust Servo Algorithm parameters for desired position response, including how quickly and accurately the motor can move to a target position



$$e(t) = \text{Commanded Position} - \text{Actual Position}$$

- | | | | |
|---------|---|---------|---|
| ➤ Ixx30 | Proportional Gain (K_p) | ➤ Ixx34 | Integration Mode |
| ➤ Ixx31 | Derivative Gain (K_d) | ➤ Ixx35 | Acceleration Feedforward (K_{aff}) |
| ➤ Ixx32 | Velocity Feedforward (K_{vff}) | ➤ Ixx68 | Friction Feedforward (K_{fff}) |
| ➤ Ixx33 | Integral Gain (K_i) | | |





Steps for Tuning

1. **Perform the DAC Calibration as described in the Motor Setup section**
2. **Set Ixx34 (Motor xx PID Integration Mode) – can be changed on the fly as needed**
 - =1, position error integration is performed only when Motor xx is not commanding a move (when desired velocity is zero)
 - =0, position error integration is performed always
3. **Using the Step Response, tune the following parameters in this order:**
 1. Proportional Gain, K_p (Ixx30)
 2. Derivative Gain, K_d (Ixx31)
 3. Integral Gain, K_i (Ixx33)
4. **Using the Parabolic Move, tune the following parameters, not necessarily in this order:**
 - Velocity Feedforward, K_{vff} (Ixx32)
 - Acceleration Feedforward, K_{aff} (Ixx35)
 - Friction Feedforward, K_{ff} (Ixx68)



Note

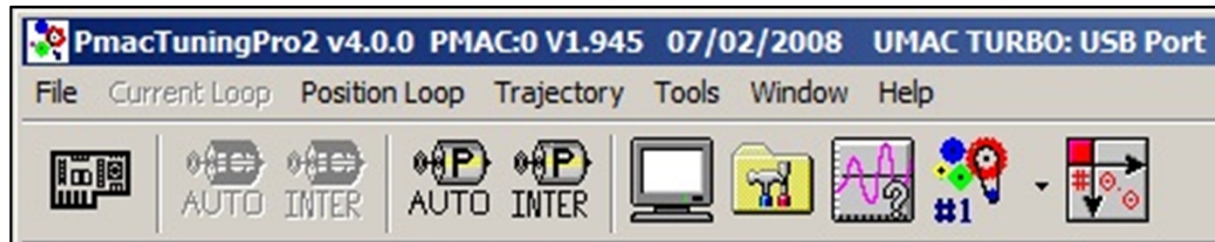
- When tuning the feedforward gains, set Ixx34=1 so that the dynamic behavior of the system may be observed without integrator action.
- Setting $K_{vff} = K_d$ (Ixx32 = Ixx31) is a good place to start when tuning K_{vff} .



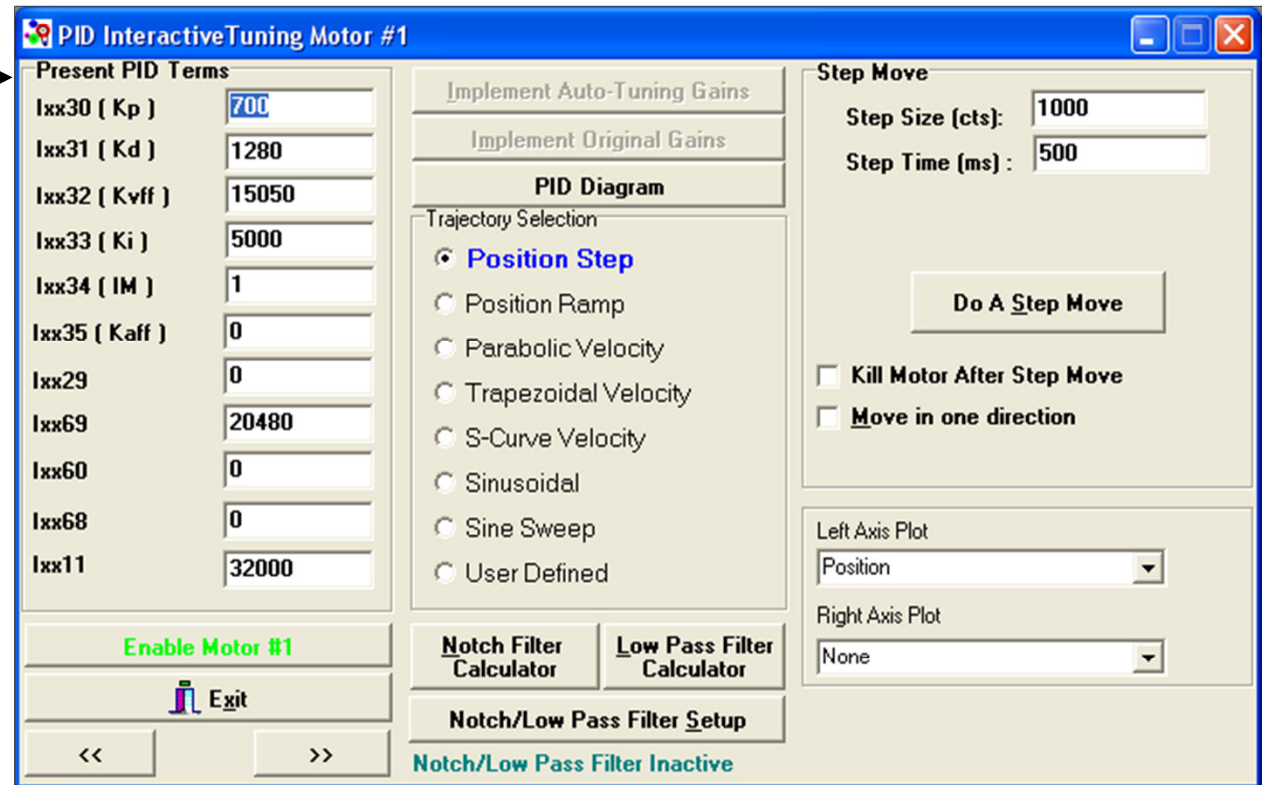


Interactive Tuning

- Interactive Tuning can be accessed in PMAC Tuning Pro2



Interactive Tuning
for Position





- Use the controller gains obtained from Auto Tuning as the starting point for Interactive Tuning
- Change one gain at a time to adjust the response
- Different types of moves are available for tuning purposes

The screenshot shows the 'PID InteractiveTuning Motor #1' window. It is divided into several sections:

- Present PID Terms:** A list of PID parameters with their current values:
 - Ixx30 (Kp) : 700
 - Ixx31 (Kd) : 1280
 - Ixx32 (Kvff) : 15050
 - Ixx33 (Ki) : 5000
 - Ixx34 (IM) : 1
 - Ixx35 (Kaff) : 0
 - Ixx29 : 0
 - Ixx69 : 20480
 - Ixx60 : 0
 - Ixx68 : 0
 - Ixx11 : 32000
- Implement Auto-Tuning Gains / Implement Original Gains:** Two buttons for applying different sets of gains.
- PID Diagram:** A section for visualizing the PID control loop.
- Trajectory Selection:** A list of move types with radio buttons:
 - ☒ Position Step
 - ☐ Position Ramp
 - ☐ Parabolic Velocity
 - ☐ Trapezoidal Velocity
 - ☐ S-Curve Velocity
 - ☐ Sinusoidal
 - ☐ Sine Sweep
 - ☐ User Defined
- Step Move:** A section for configuring a step move:
 - Step Size (cts): 1000
 - Step Time (ms): 500
 - Do A Step Move button
 - ☐ Kill Motor After Step Move
 - ☐ Move in one direction
- Left Axis Plot / Right Axis Plot:** Two dropdown menus for selecting data to plot:
 - Left Axis Plot: Position
 - Right Axis Plot: None
- Notch Filter Calculator / Low Pass Filter Calculator:** Two buttons for filter configuration.
- Notch/Low Pass Filter Setup:** A section for configuring the filters.
- Notch/Low Pass Filter Inactive:** A status indicator.
- Enable Motor #1:** A green button to start the motor.
- Exit:** A button with a motor icon to exit the application.
- Navigation:** Left and right arrow buttons at the bottom.

Annotations with blue arrows point to specific areas:

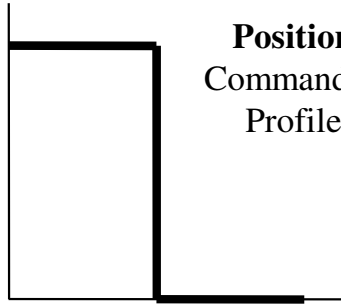
- PID gains:** Points to the 'Present PID Terms' list.
- Move types:** Points to the 'Trajectory Selection' list.
- Filter:** Points to the 'Notch Filter Calculator' and 'Low Pass Filter Calculator' buttons.
- Move size:** Points to the 'Step Size (cts)' field in the 'Step Move' section.
- Data to plot:** Points to the 'Left Axis Plot' and 'Right Axis Plot' dropdown menus.



Step Tuning (Ixx30, Ixx31, Ixx33)

$\frac{1}{2}$ to $\frac{1}{4}$ rev.

Position
Commanded
Profile



Note:

The intent is to operate within the linear range of the system.
This is usually a step size approx. $\frac{1}{2}$ to $\frac{1}{4}$ revolution

Overshoot and Oscillation

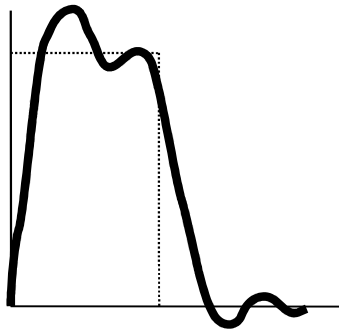
Cause:

Too much Proportional gain or
too little Damping

Fix:

Decrease K_p (Ixx30)

Increase K_d (Ixx31)



Position Offset

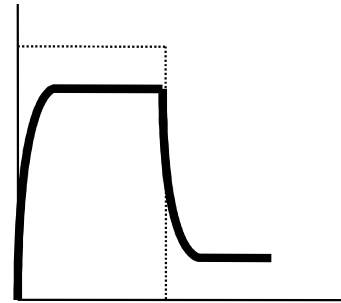
Cause:

Friction or Constant Force

Fix:

Increase K_i (Ixx33)

Increase K_p (Ixx30)



Sluggish Response

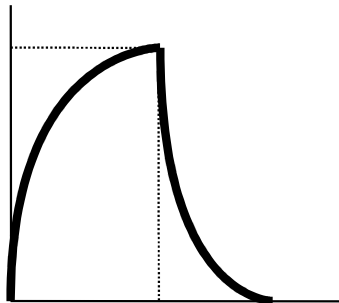
Cause:

Too much Damping or
too little Proportional gain

Fix:

Increase K_p (Ixx30) or

Decrease K_d (Ixx31)



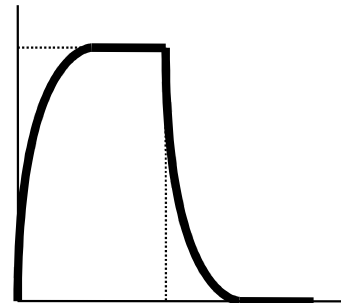
Physical System Limitation

Cause:

Limit of the Motor/Amplifier/Load
and gain combination

Fix:

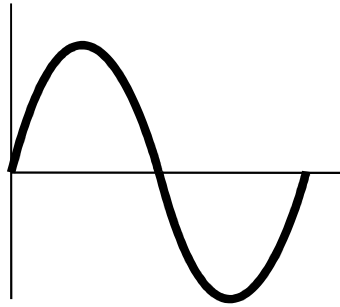
Evaluate Performance and
maybe add K_p (Ixx30)



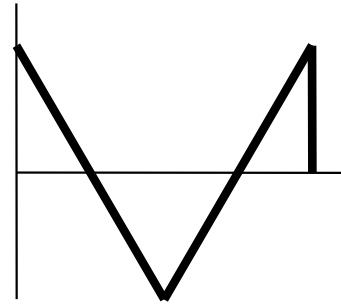


Parabolic Tuning (Ixx32-Ixx35, Ixx68)

**Velocity
Commanded
Profile**



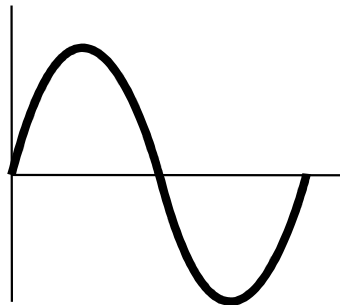
**Acceleration
Commanded
Profile**



Following Error Profile (F.E.)

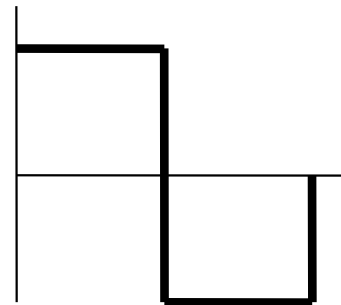
High Vel./F.E. Correlation

Cause: Damping
Fix: Increase K_{vff} (Ixx32)



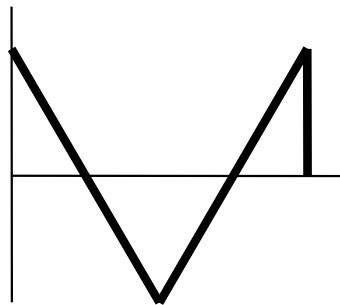
High Vel./F.E. Correlation

Cause: Friction
Fix:
Add Friction Feedforward (Ixx68)
and/or turn on Integral Gain
(Ixx33, Ixx34)



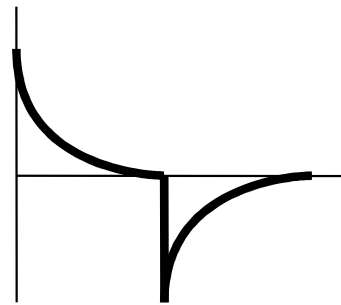
High Acc./F.E. Correlation

Cause: Inertial Lag
Fix:
Increase K_{aff} (Ixx35)



High Acc./F.E. Correlation

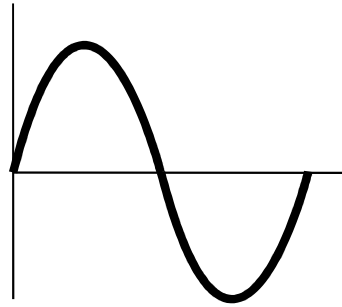
Cause:
Physical System Limitation
Fix:
Use softer acceleration
or add more Ixx68



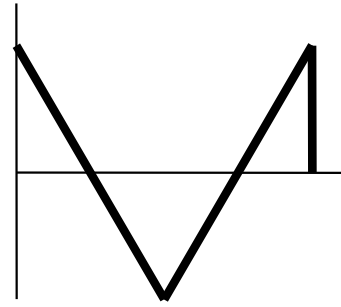


Parabolic Tuning (Ixx32-Ixx35, Ixx68)

**Velocity
Commanded
Profile**



**Acceleration
Commanded
Profile**



Following Error Profile (F.E.)

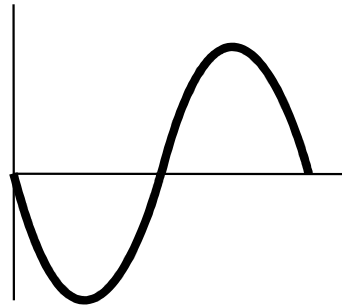
Negative Vel./F.E. Correlation

Cause:

Too much Velocity
Feedforward

Fix:

Decrease K_{vff} (Ixx32)

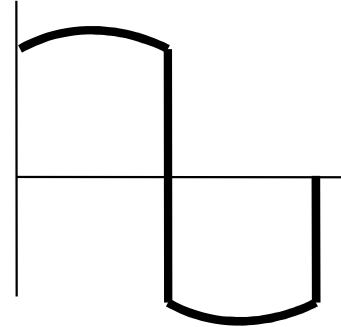


High Vel./F.E. Correlation

Cause: Damping & Friction

Fix:

Increase K_{vff} first (Ixx32)
Possibly adjust Ixx68



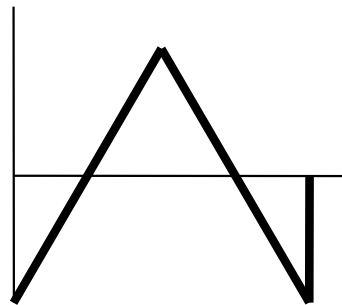
Negative Acc./F.E. Correlation

Cause:

Too much acceleration
Feedforward

Fix:

Decrease K_{aff} (Ixx35)



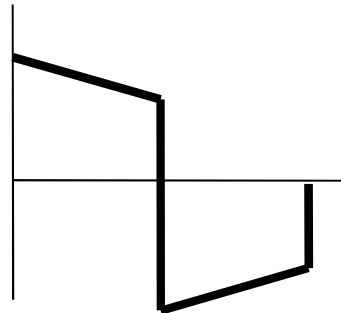
High Vel./F.E. & Acc./F.E. Correlation

Cause:

Inertial Lag & Friction

Fix:

Increase K_{aff} (Ixx35)
Possibly adjust Ixx68





Tuning Exercise

- In the Terminal Window, set lxx30 through lxx39 to 0. This will clear the servo loop tuning for Motor xx.

```
// Reset PID gains of Motor 1 ~ 4  
I130..139=0      ; Set Motor 1 PID gains to 0  
I230..239=0      ; Set Motor 2 PID gains to 0  
I330..339=0      ; Set Motor 3 PID gains to 0  
I430..439=0      ; Set Motor 4 PID gains to 0
```

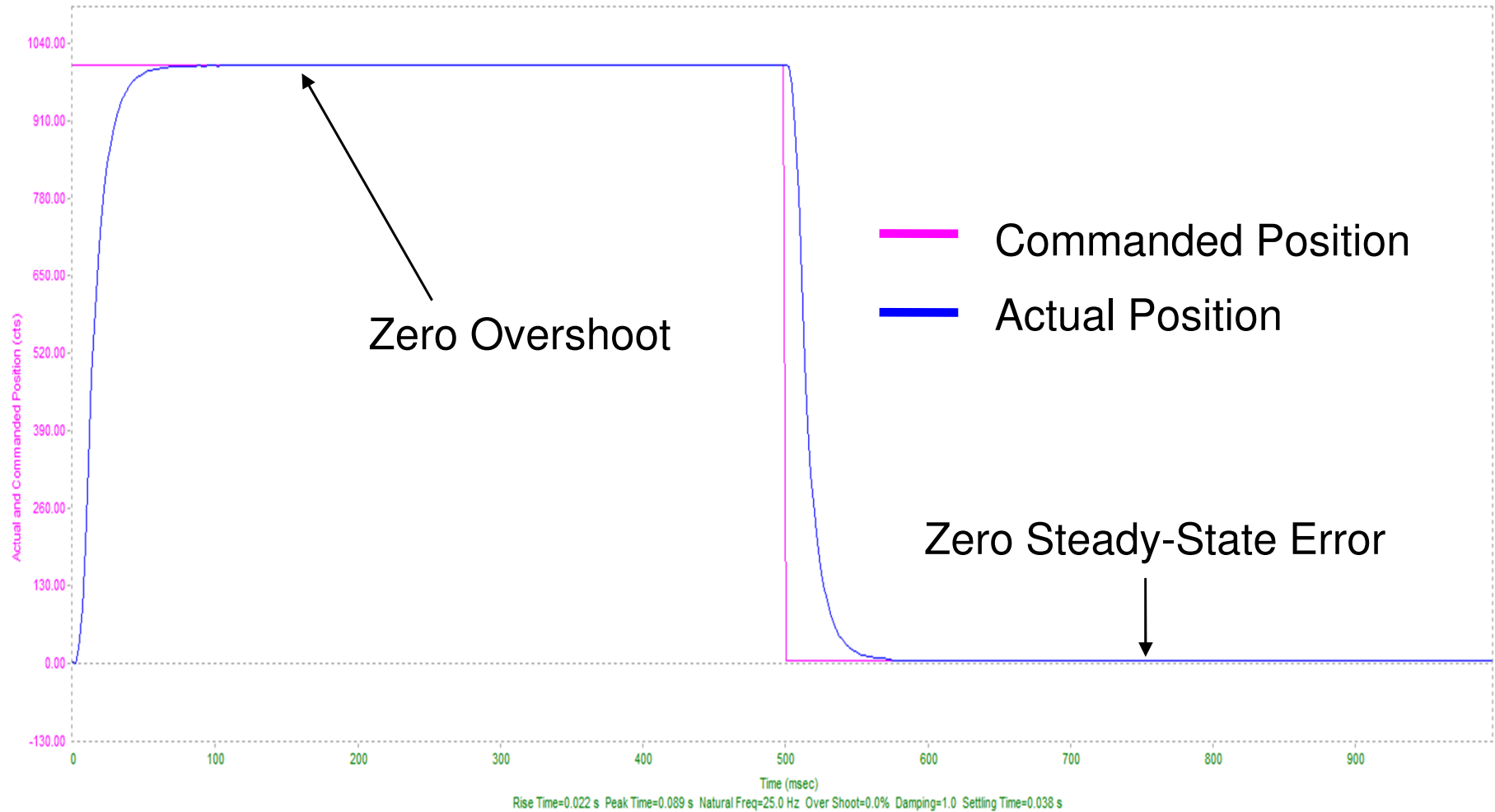
— Turbo PMAC Script —

- Launch PMAC Tuning Pro2 from Tool menu. Tune all available PMAC motors for minimum following error.
- Use previous slides as references to change I-Variables for servo tuning to have better performance.





Well-Tuned Step Response





Well-Tuned Parabolic Move

