Digital Servo Amplifier Basics

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Digital Servo Amplifier Basics

Servo Basics
1. What is a Servo?
2. Input Command
3. Amplifier Operation

Amplifier Power
1. Input Types
2. Regeneration
3. DC Bus Sharing

Digital Control Loops
1. Function
2. Examples
3. Types
4. Bandwidth
5. Tuning Process
6. Tuning Filters

Installation Infrastructure
1. Input Power
2. Noise Filter
3. EMI
4. Heat Loads
Servo Basics – What is a Servo?

- Servo: a device that produces motion in response to a command, regulating the output based on feedback

Source: Yaskawa America Inc. YouTube video “Servo Basic Concepts” eLV.ServoMotion.01.BasicConcepts
Servo Basics – What is a Servo?

- The “servo” is both the servomotor and servo amplifier
- Servo Amplifier: A device which controls the torque, speed and/or the position of a motor
  - by comparing command and feedback signals
  - and making corrections to the command to eliminate the error
- Servo = Amplifier = Amp = Drive
Servo Basics – Input Command

- Servos interface with a variety of host controllers, including motion controllers, CNC’s, indexers, and PLC’s
- Host controller signal – low voltage (±10v typical) analog or pulses
Servo Basics – Input Command

- Fieldbus Networks Common to Servos
  - Mechatrolink
  - EtherCAT
  - Profinet
  - Powerlink
  - Sercos
  - 20+ others

- Fieldbus Advantages
  - Simplified wiring
  - Data transfer between amplifier and controller
Servo Basics – Amplifier Operation

- Control Circuit
  - Performs the “thinking” functions of the amplifier
  - Interface to motion controller
    - Inputs: Digital, analog, encoder
    - Outputs: Digital, analog, pulse
  - Closes control loops
    - Key Performance Indicator: velocity loop frequency response, range from 250Hz to 3200Hz
  - Control circuit may be very complex with many features, or may be a very simple “Dumb Amp”
Servo Basics – Amplifier Operation

- Digital Control Circuit
  - The control circuit of a “digital” servo amplifier is digital instead of analog
  - Values for speed, torque, etc. are stored as digital values rather than voltage levels
  - Same result – command current to the motor

Analog Circuit. Source: learn.sparkfun.com

Digital Circuit. Source: learn.sparkfun.com
Servo Basics – Amplifier Operation

- Typical Power Circuit (Simplified Diagram)
Servo Basics – Amplifier Operation

- Pulse Width Modulation (PWM)

Digital Signals

Carrier Wave

Current Signal

High Voltage (DC bus)

DC Bus Voltage at motor terminals

PWM Output

Current Amplitude
- Commands Motor Torque
- Current Frequency
  - Follows Motor Speed

Resultant Current Waveform on one motor phase
Servo Basics – Amplifier Operation

- Pulse Width Modulation (PWM)
Servo Basics – Amplifier Operation

- Commutation Types
  - Trapezoidal
    - Trap Drive
    - Trapezoidal commutation based on Hall Effect sensor feedback
    - Cost Effective
  - Sinusoidal
    - AC Drive
    - Sinusoidal commutation based on encoder feedback
    - Significant reduction in torque ripple ➔ smooth motion at low speed

Commutation signal from “Trap Drive” (above) and Sinusoidal
Servo Basics – Servo ON

- PWM is active
- Servo “Enable” or “Power”
- Control circuit is active
- Current amplitude may be very low
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• Function and architecture of digital control loop
  • **Command** is compared to **Feedback**
  • The difference is **Error**
  • **Gain** amplifies **Error**
  • **Output Command** is the amplified **Error**

Q: Why close the loop?
  • A: Minimize and eliminate ERROR
Digital Control Loops - Examples

- Examples of closed loop systems

  - Cruise Control

- Furnace with “smart” thermostat
• Types of control loops: Torque/Velocity/Position
  • Output of one loop is the input of the next
  • Torque loop only - “dumb” amp
  • Some amplifiers add speed loop and position loop modes
  • Match to signal from motion controller
Bandwidth is the usable range of frequencies for a control loop - when the output amplitude reduces to -3dB (70.7%) of the input.
Digital Control Loops - Bandwidth

- Control Loop Bandwidth
  - Bandwidth determined by tuning parameters
  - Maintain stable bandwidth ~ 4x separation between loops

- Causes of tuning instability
  - Control loop bandwidth separation – adjust parameters
  - Mechanical compliance – apply filters

\[ f_P = \frac{P_n 102}{2\pi} \]
\[ f_V = P_n 100 \]
\[ f_C \approx \frac{15,900}{P_n 401} \]

Output Amplitude (dB)

-3 dB

~100 Hz Position \((f_P)\)  ~400 Hz Speed \((f_V)\)  ~1600 Hz Torque \((f_C)\)

Frequency (Hz)
Digital Control Loops – Tuning Process

- Tuning = adjust error response
- Three Control Loops
  - Torque
  - Speed
  - Position
- General Tuning Process
  - Minimize mechanical compliance
  - Torque loop tuning to the motor and torque loop filters
  - Speed loop gains
  - Position loop gains
  - Auto-Tuning

Remember – when control loops exist outside the amplifier (in the controller) they must also be tuned.
Digital Control Loops – Tuning Filters

- Low Pass Filter
- Notch Filter
- Advanced filters for lower frequencies
- Measurement can reveal problem frequencies caused by mechanical compliance
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Amplifier Power – Input Types

- Amplifier Power Input Types
  - DC – Power Supply
  - AC – 100V, 200V, 400V internal power supply

- Considerations
  - Available Power
  - Servo Capacity – higher capacity available in higher voltages
  - Current rating drives the cost of an amplifier

<table>
<thead>
<tr>
<th>Rotary Servo Motor Model</th>
<th>Rated Power</th>
<th>Rated Torque</th>
<th>Peak Torque</th>
<th>Rated Speed</th>
<th>Max Speed</th>
<th>Rotary Inertia</th>
<th>SGDV-24/48VDC</th>
<th>SGD7S-100VAC</th>
<th>SGD7S-200VAC</th>
<th>SGD7W-200VAC</th>
<th>SGD7-400VAC</th>
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<td>SGMMV-B3E</td>
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<td>0.0105</td>
<td>0.0263</td>
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<td>6000</td>
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<td>2R1F</td>
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<td>2R1F</td>
<td>2R1F</td>
</tr>
</tbody>
</table>

SGMMV
Low Inertia
Ultra-Small Capacity

| SGMV-7A-A5A              | 50W         | 0.159        | 0.557       | 3000        | 6000      | 0.0217         | R70F           | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-01A              | 100W        | 0.318        | 1.11        | 3000        | 6000      | 0.0337         | R90F           | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-C2A              | 150W        | 0.477        | 1.67        | 3000        | 6000      | 0.0458         | 2R1F           | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-02               | 200W        | 0.637        | 2.23        | 3000        | 6000      | 0.039         | 2R1F           | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-04               | 400W        | 1.27         | 4.46        | 3000        | 6000      | 0.216          | 2R8F           | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-06               | 550W        | 1.75         | 6.69        | 3000        | 6000      | 0.315          | N/A            | N/A            | N/A            | N/A            | N/A           |
| SGMV-7A-08               | 600W        | 1.91         | 8.36        | 3000        | 6000      | 0.775          | 5R5A           | 5R5A, 7R6A     | N/A            | N/A            | 3R5D          |
| SGMV-7A-10               | 1.0kW       | 3.18         | 11.1        | 3000        | 6000      | 0.971          | 120A           | N/A            | N/A            | N/A            | 3R5D          |

SGMV-7A
Low Inertia
Small Capacity
“Regeneration” means that the motor is generating energy rather than using energy.

This happens during deceleration because the load forces the motor to move in the direction opposite to that in which torque is being applied.

Factors that Increase Regen:
- High Speed
- High Inertia
- High Deceleration Rate
- Vertical Applications
- Low Friction
Amplifier Power – DC Bus Sharing

- Handling Regeneration Energy
  1. Burn off through a regeneration resistor
  2. DC bus sharing
     - Energy released by one servo is used by the other

*Figure 2:* A 6-pulse diode rectifier is used for common bussing multiple drives. Regenerating drives/motors can power motoring ones, all while reducing overall wiring.
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Installation Infrastructure – Power Wiring

- Input Power
  - Noise Filter
  - Contactor
  - Main Power
  - Control Power

- Peripheral Devices
  - Regeneration Resistor
• Noise Filter
  • Protect other devices on the AC power line from the electrical noise created by the amplifier PWM
Installation Infrastructure – EMI

- Electromagnetic Interference (EMI)
  - Radiated
  - Conducted

- Good wiring practices
  - Single point “star” grounding
  - Isolate earth ground from DC power supply output
  - Physical separation of power cables and signal cables
  - Shielded cable
  - Twisted pairs
Installation Infrastructure – Heat Loads

- Heat Loads / Cooling
  - Mounting separation specification
  - Flat, vertical mounting surface for heat conduction and convection
  - Amplifier generates heat from power loss
Thank You!

- Fundamentals of digital servo amplifiers still apply
- Advancements in Technology ➔
  - Better performance
  - More Options
  - New Applications
Speaker Contact Details

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