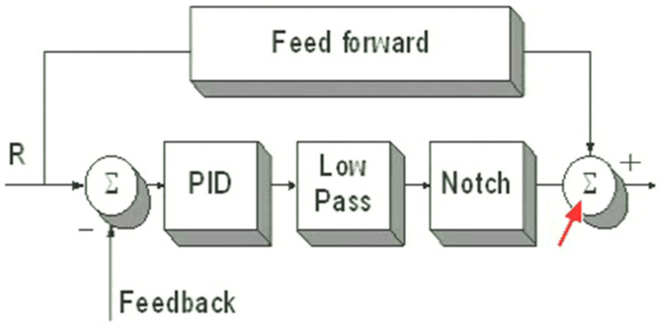
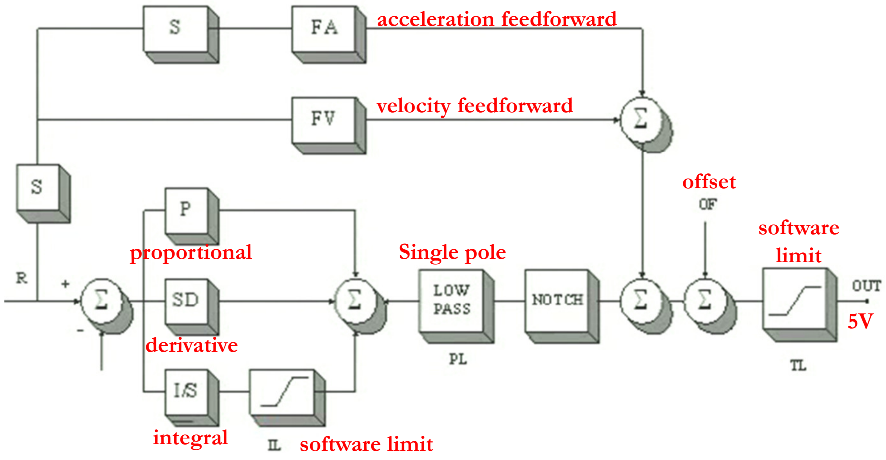
Tuning Servo Systems: Advance Techniques

Advanced Motion Control



Advanced Motion Control



Integrator Design

Limit integrator output

- Twice as big as friction

Enable/Disable I control action appropriately

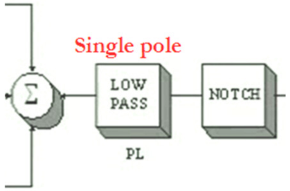
- Integrator action is required at the end of the motion
- Accumulate error at the destination could cause huge overshoots

Low Pass Filter

Limits the gain at high frequency so that the loop won't respond to structural resonances and noise.

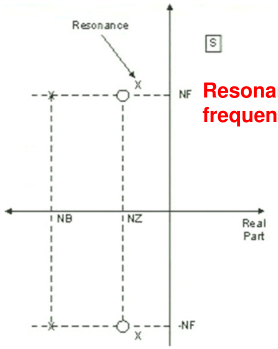
Narrow passband will counter-act the action of the derivative controller. Filter BW should be slightly bigger than system BW.

- Single pole low pass filter.
- Bandwidth set by PL.
- Default PL = 0 implies infinite Bandwidth.
- The Bandwidth, a , equals:
  a = (1/T) ln (1/PL) in rad/s
- Example
  PL 0.8 T = 0.001 a = 223 rad/s



Notch Filter

- Notch filter compensates for resonance.
- Resonance has a pair of complex poles with a real part.
- The larger the real part - The more the resonance attenuation.
- Notch cancels the poles by placing zeros on top of them.
- Notch creates different poles with large real part.



Resonance frequency

Imperfect coupling between motor and load causes the plant to behave as a spring with a certain resonance frequency (two oscillatory poles in plant transfer function). To avoid resonance, the bandwidth can be significantly reduced at the cost of loosing servo performance

NF zeros are accompanied by two new poles. These new poles can be placed on the real axis towards negative direction and away from system poles. Perfect pole-zero cancellation is not a must-have.

Simple Notch Filter Design

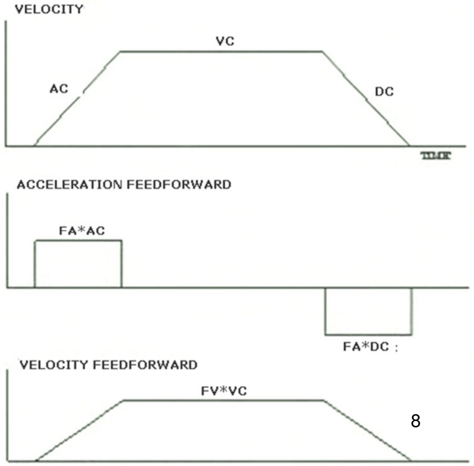
Three parameters of the notch filter NZ, NB, and NF have to be decided

- Estimate resonance frequency.
  (simple observation)
- Set NF to resonance frequency in Hz.
- Set NB = 1/2 NF.
- Set NZ between zero and 5.

simple guess

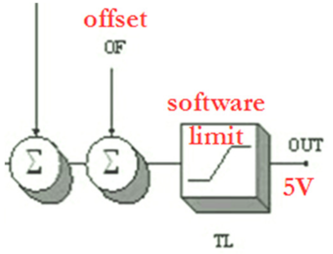
Feedforward Design

- FV - Bias signal proportional to commanded velocity.
- FA - Bias signal proportional to commanded acceleration.
- Feedforward is open loop signal and does not affect stability.
- Since FA is a step signal, it may cause system vibration.
- FA is effective in rigid systems with short motion time.
- FV is effective in reducing velocity following error without using KI.



Offset

- Program open loop commands.
  Fed directly to DAC
- Compensate for offsets in driver.
- Compensate for gravitational force.
- Can create non symmetric FA.
- Troubleshooting.



Torque Limit

Voltage limiter just before it goes to the amplifier

- Motor protection at first power - up.
- Limit the current.
- Limit motor torque/force.

Dual Loop Compensation

Backlash Dilemma

Backlash-The range of positions the motor can move without moving the load.

When the coupling between the motor and the load has a backlash-

Designer choices are:

1. **Place the sensor on the motor**. Resulting system is stable, but load position has an error.
2. **Place the sensor on the load**. Since the backlash becomes a part of the closed loop, it will cause system instability.

delay ⇒ phase loss ⇒ instability

Examples

Gears

Lead Screw

Design Approaches

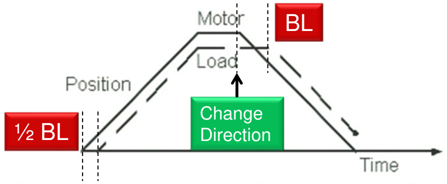
1. Ignore backlash—most common — Have encoder on the motor
2. Avoid backlash—linear motors — get rid of gears/belts ⇒ direct drive happens to be expensive, not found in general applications
3. Open loop compensation
4. Final point correction
5. Dual loop
6. Improved dual loop

} practical methods

Open Loop Compensation

- Assume backlash is ± n counts.
- Motor starts at center of backlash.
- Sensor is placed on motor. **(stable)**
- When motor is driven along the solid line, load follows dashed line

If you know exactly how Much it is, you can compensate for it at the end



Add +n or –n counts to the motor position, according to the direction of commanded motion.

- Common in CNC and machine tools
- Requires knowledge of backlash magnitude **Calibrate regularly**
- Effective when friction is relatively high

In this case, load always lags behind the motor. Low friction could cause oscillations in OLC

Final Point Correction

Typical Example

An antenna is driven by a motor via a 100:1 gear. The objective is to turn the antenna 0° to 90°.

Method: Place encoders on both the motor and the load. Close the position loop with the motor encoder. Initially ignore backlash and drive the motor as needed. After completion of motions, measure the load position and perform a correction.

drive the motor to approximate position ⇒ check error ⇒ drive again ⇒ check error ⇒ drive again ….(multiple error correction)
Need two encoders (expensive)

Final Point Correction cntd..

Advantages:

- Stable system **(sensor is on the motor)**
- Method works regardless of backlash size

Disadvantages

- Correction at endpoint only **error remains along the path - not good for engraving**
- Takes longer time **(+ 20~100ms, may/not be acceptable)**
- Does not compensate for later disturbances

Correction is not part of the feedback loop, but takes place at the end for a given short period of time. Thus, if the load shaft is deflected by an external disturbance, there is no way to correct that error

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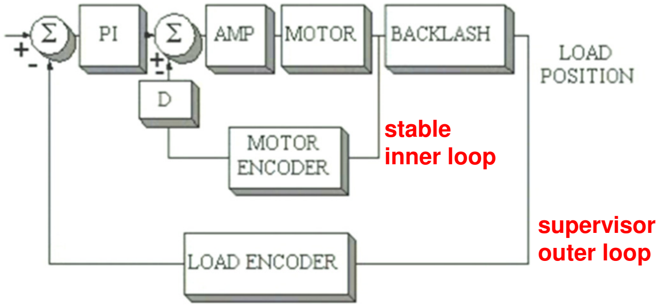
Conventional Dual Loop Control

- Place position sensor on both the motor and load shafts. Controller splits PID operation: PI on the load, and D on the motor



stable inner loop

supervisory outer loop

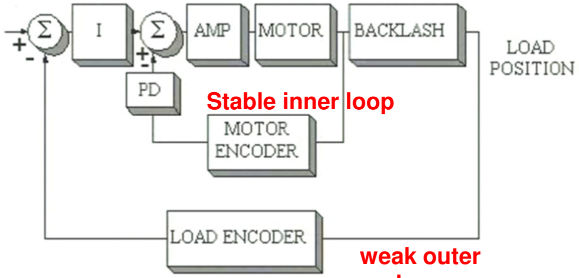
Advantage—continuously compensates the position
Disadvantages—larger backlash degrades stability

backlash↑ ⇒ delay ↑ ⇒ stability ↓

Improved Dual Loop Control

- Reorganize PID operation
- I on load encoder
- PD on motor encoder

Redistribution of PID in an optimal way results in better performance



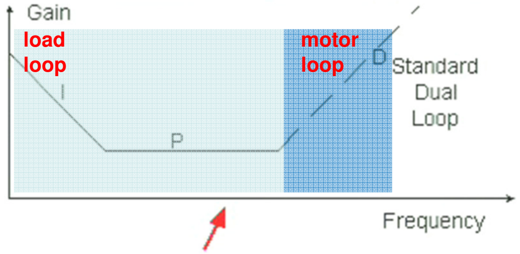
Stable inner loop

weak outer loop

Advantages—more stable than the standard dual loop.

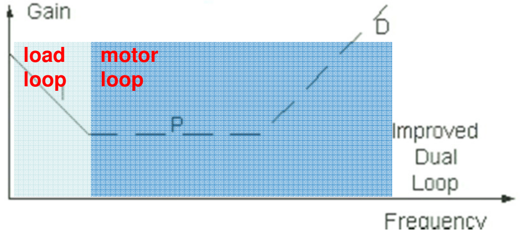
- Motor encoder loop is stable
- Load encoder loop is unstable
- By moving P to the motor encoder loop, we make the stable loop stronger.

Frequency Response of DLC



Conventional:

load loop reacts to a wider range of frequencies. It will react to backlash transients ⇒ undesirable



Improved:

load loop reacts for low frequencies only. It responds only for the steady state errors due to backlash and disturbances

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Performance Comparison

- Backlash between the motor and the encoder is 10 degrees.
- Move motor 90° (1000ct) and measure the time, T, to reach zero error.

Control Method	Single Loop	Dual Loop	Improved Dual Loop
KD	6	200	800
KP	4	9	50
KI	0	1	10
T (ms)	∞	520	142
Bandwidth (Hz)	2	70	280

Single loop: remove integrator to make the system stable, thus, motor never gets to desired position. Low gain ⇒ narrow bandwidth ⇒ long settling time

Dual loop: higher BW ⇒ responds quickly ⇒ short settling time, however, KI has to be low because the integrator reacts to higher frequencies.

Improved dual loop: Integrator is restricted to low frequency, thus, inner loop bandwidth can be increased. This speeds up performance.