Tech Note #1:
Using the Torque Reference Low Pass Filter

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Abstract:

In this Tech Note the implementation of a digital two-pole low pass filter for smoothing the torque reference to a motor's amplifier is described. Some of the I^{2}T motion modules incorporate this filter between the PID filter output and the analog command resulting in a smoothing of the analog output. The most common reason for using this filter is to reduce a low audible noise from the motor resulting from the motor output exciting a high frequency mechanical resonance. However, if the system has a low mechanical frequency then this filter can be used to prevent the system from going into resonance resulting in potential damage to the system.

What is resonance?

Mechanical resonance results from the "springiness" in the power transmission components between the motor and the load. It is the affect were a mechanical system will vibrate at its natural frequency do to an excitation at or near this frequency. In its simplest form the resonance frequency can be calculated using the load and motor inertias and the stiffness of the mechanics coupling them. However, in most cases this calculation is complicated do to multi-staged power transmission components or changing system inertias, and therefore is usually obtained through measurement.

Resonance is rarely a problem when the required performance of the system is low. It is only when the loop gains are increased to improve performance that resonance may occur.

Detecting resonance

A resonance will usually produce a sound that can aid in determining how far the resonance is from the servo systems response rate. When the resonance frequency is very high the sound produced will be a continuous hum that can be removed by the low pass filter with minimal affect to the system response. This would be considered a high frequency resonance, and most likely can be removed with by setting the low pass filter's bandwidth to 600 Hz.

As response of the servo system is increased through tuning this hum may become more unpleasant indicating that the servo system response rate is approaching the resonance frequency providing more energy to excite it. In this scenario lowering the bandwidth of the low pass filter can aid in removing the potential for system damage, however a degradation of servo system response rate will occur. Depending on the performance demands of the system the use of a low pass filter in this scenario can be acceptable. However, if the application requires a faster response rate from the servo system then it may be necessary to make mechanical modifications to the system to increase its natural frequency or to add mechanical dampening.

The low pass filter
The low pass filter used in the I^2T motion module is a two-pole low pass filter in the following form:

$$T(s) = \frac{\omega_N^2}{s^2 + 2 \cdot \zeta \cdot \omega_N \cdot s + \omega_N^2}$$

The poles of this equation are set to:

$$s = -\zeta \cdot \omega_N + \omega_N \cdot \sqrt{1 - \zeta^2} \qquad \text{and} \qquad s = -\zeta \cdot \omega_N - \omega_N \cdot \sqrt{1 - \zeta^2}$$

With ω_N equal to the filter's natrual frequency

And, the filters damping ratio, ζ, set to .707

The resulting bandwidth of this filter can be easily set during system commissioning through the I^2T motion controller setup software. If, however, there is a need to change the filter bandwidth from the application software then this can be performed in either a PLC or PC communicating to the module.

Setting the filter through the Motion modules command set

- Calculate new Coefficients using a desired filter bandwidth
- Disable the filter using Command 2106
- Set Filter A Coefficients using Command 2104
- Set Filter B Coefficients using Command 2105
- Enable the filter using Command 2106

Calculate filter coefficients:
Determine the desired bandwidth for the filter, Fbw. Acceptable range is 30 to 800 Hz.

Calculate the coefficient denominator:

$$D = 4 + .004 * Fbw + .000002467 * Fbw * Fbw$$

Use denominator value to obtain filter coefficients

$$A1 = (-32768 + .02021 * Fbw * Fbw) / D$$

$$A2 = (16384 - 18.195 * Fbw + .01011 * Fbw * Fbw) / D$$

$$B0 = .01011 * Fbw * Fbw / D$$

$$B1 = 2 * B0$$

$$B2 = B0$$

Convert the coefficients to a form to be downloaded
This logic is performed to remove the sign and improve resolution for download to the module. The module will assume that any number less than 32767 is negative and greater than 32767 is positive.
Perform the following logic to A1, A2, B0, B1, and B2

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If A1 < 0 Then A1 = -1 * A1
Else A1 = 65535 – A1
Endif
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Excel Spreadsheet for constant calculations

An Excel spreadsheet that
- Calculates the filter constants
- Graphs the filter output to a Sin wave with user defined frequency

Spreadsheet file name: Low Pass Filter Constants.xls

This spreadsheet can be obtained from the I^2T Internet Site