Guided Tutorial for Java Control Module V
CHE-4400 Process Control
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In this Java Module, we will learn about the response of different types of processes to various types of input forcing functions and how the time-domain responses are correlated to frequency domain responses. We will also relate the process response through frequency response analysis. Frequency response analysis can be non-intuitive for beginners. However, it gives important insights into performance of a process control system.

The main panel in the java module is divided into three sub-panels: input panel, process panel and output panel. The input and output panels have time and frequency (Fourier transform) plots of the input and output respectively. The central process panel shows step/impulse response plot (top) and bode plot (AR: middle and ?: bottom) of the **process**.

The type of process can be selected in the gray panel to the right. The input forcing function can be selected from the gray panel to the left. In this tutorial, we will analyze time and frequency response for a few instructional cases. Readers are encouraged to try various combinations of transfer functions and process inputs.

Lesson 1: *Learning the physical meaning of Fourier transform* (*frequency response*)

1. On the input panel, choose sinusoidal input "U3: sin(pi*t)" from the dropdown list. Ensure that the checkbox for "Periodic" is checked. Thus, we have a sinusoidal periodic signal. All the energy of this signal is located at a single frequency: the frequency of the sinusoid. Hence the Fourier transform will show a "spike" at this frequency.

2. Now select input "U4: sin(3*pi*t)". You will see the spike shift corresponding to the new frequency.

3. What do you expect if the signal is "U3+U4"?

Lesson 2: *Application: Filters*

4. One of the important applications of frequency response analysis is evident in design of filters. Let us consider an example from Lecture 5-a. Consider a signal composed of sinusoid with random disturbance as input forcing function. In the textbox for input forcing function, type "U3+U5". This is the desired signal. In the process panel, select "G4: Low Pass Filter". You can see that the random noise, which is high frequency data, gets *filtered out* resulting in a sinusoidal filtered output. Next, select "G5: High Pass Filter" and change the "Cut Off Frequency" to 25.0 (type 25.0 in the textbox and click enter). Does the output respond as you expected?

This is one of several uses of frequency domain analysis – a powerful tool for control engineers. We will revisit this lesson towards the end of this tutorial.

Lesson 3: *Understanding Bode plot*

5. Let us switch gears and look at the time and frequency response of first order system. In the drop down list in the bottom-right panel, select the process "G0: 1st-Order". Time constant of this process is shown in text box to be 1.

   The top part of the process panel (i.e. the top-middle plot) shows the finite step response (FSR) or finite impulse response (FIR) of the process. You can toggle between the two by clicking the green button below the plot. The FSR of first order process can be seen in the plot currently. This is the response of first order system to a step input.

   Below this is the bode plot of the system: both AR as well as phase angle plots are shown. Lets see if the bode plot of this system makes sense. Refer to Lecture 5-c (and sec 9.2 of your textbook).

   a. At low frequency, the AR is 1. At high frequencies, the AR decreases linearly. Since it's a first order process, the slope of the AR curve is –1 at high frequencies.

   b. Corner frequency is ? ? 1/? ? 1. Thus, as we can see from the plot, AR curve changes from slope=0 to slope=-1 at the corner frequency (indicated in the plot as "0" as its logarithm is shown).

   c. The phase angle increases akin to arc tan function, from 0 at low frequencies to –90 at high frequencies.

6. Now select second order process by choosing "G1: 2nd order". Corner frequency is 1, and final slope of AR curve at high frequency is –2. The phase angle goes from 0 at low frequencies (you will not see in this plot) to –180^{o} at high frequencies.

   Change the damping coefficient to 0.1, 1, 5 etc. Is the behavior of the system as expected?

7. Select the process to be "G0: 1st order" again. Choose the input forcing function to "G3: sin(pi*t)". The frequency of the sinusoid is 0.5 time^{-1}. We can read the AR and phase change from bode plot to be approximately 0.24 and –70^{o} respectively. As we can see from the output plot, the maximum amplitude is reduced from 1.0 (of the input) to approximately 0.24. The sin wave is also phase-shifted. However, the frequency of sin function is not changed. This can also be seen from the Fourier transform of the output, where the impulse is observed at the same frequency (0.5).

Lesson 4: *Analyzing other transfer functions*

8. Change the process to "G7: time delay". Do the time response pots (FSR plot and process output plot) and bode plots make sense?

   Consider First order plus time delay (FOPTD) system by typing "G0*G7" as the process. Do the plots make sense?

Lesson 5: *Putting it all together: Low Pass Filter Revisited*

In lesson 2, we learnt that low pass filter is useful in filtering out noise from the signal. Noise, we saw was a high frequency component that the filter discards.

In lesson 3, we saw how to use bode plot and what AR and phase angle mean. We will combine the two for noise filtering.

9. As in Lesson 2, item 4, enter the input forcing function as "U3+U5" and choose "G4: low pass filter" as the process. Make the "Cutoff f" to 10 (if it isn't that value already) by entering 10 in the textbox and clicking enter.

   Observe the Fourier transform of the input function. Low frequency component is low. A spike is observed at frequency of 0.5 (which corresponds to the sin wave U3). Then, we have high frequency component due to the random part (U5).

   We want a low pass filter… a filter that will discard high frequency component and retain low frequency component. What that means is that the filter should have an AR of 1 (preferably) at low frequency and AR of 0 (preferably) at high frequency.

   The selected filter is "Low-Pass Filter" has AR=1 below the cutoff frequency of 10 and AR decreases rapidly at higher frequency. Now see the Fourier transform of the output signal. The Fourier transform of the output signal is obtained by multiplication of the Fourier transform of input signal and AR from bode plot; which becomes addition as we use log scale. We can clearly see that the low frequency component is retained, the spike at frequency 0.5 corresponding to sine input is retained, and the amplitude at high frequency is greatly reduced.

   *Thus, when using **log scale**, we can simply add the input and AR curves to get the output curve.*

10. What do you expect if we decrease the cutoff frequency to (say) 0.2? Since the sin wave (U3) is at a higher frequency (=0.5), it gets cut off. In the time plot, we see that the response is nearly constant (note that the scale of axes is reduced to 10^{-3}) – meaning that the signal of interest (sine wave) is lost.