ME 4232: Fluid Power Control Laboratory

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Lab.20: Modal tracking - Internal model controller

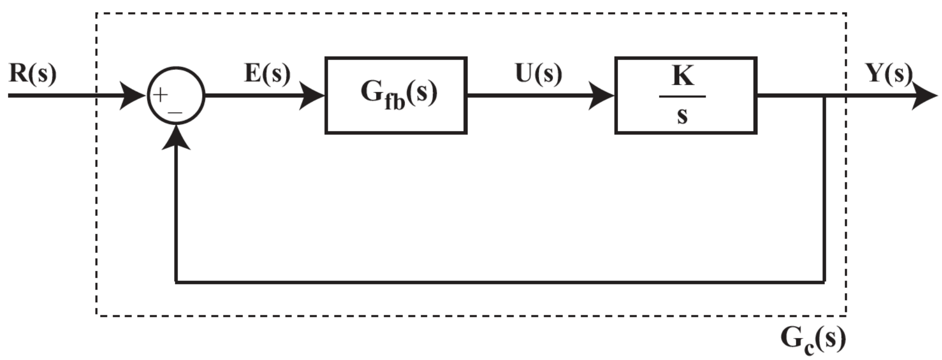
Objective

In this lab, we shall extend the concepts of integral control to the tracking control of signals with specific mode characteristics. Specifically, we shall design a feedback type tracking controller so that the output *y(t)* tracks an input *r(t)* given by:

$$r(t) = \alpha \cdot \sin(\omega_1 t) + \beta \cdot \sin(\omega_2 t)$$

where α and β are not known to the control system designer. Nominally, ω_1 = 5rad/s and ω_2 = 7rad/s. (Your TA will tell you what values are appropriate for your setup).

The approach to accomplishing this is to incorporate modes in the controller that correspond to those of the signal you would like to track. This is a generalization of adding integral terms in the controller when you would like to track steps and ramps. Notice that in integral control, $1/s$, and $1/s^2$ are exactly the modes of the desired outputs of steps and ramps. We say that the controller incorporates an internal model of the signals (steps and ramps) to be tracked. In this lab, the modes are sinusoidal modes so we need to incorporate internal models of the sinusoidal modes of interests.



Specifically, the controller $G_{fb}(s)$ will be of the form:

$$G_{fb}(s) = \frac{a \cdot s^4 + b \cdot s^3 + c \cdot s^2 + d \cdot s + e}{(s^2 + \omega_1^2)(s^2 + \omega_2^2)}$$

Notice that $\frac{\omega_1}{s^2 + \omega_1^2}$ and $\frac{\omega_2}{s^2 + \omega_2^2}$ are the Laplace transform of $\sin(\omega_1 t)$ and $\sin(\omega_2 t)$ respectively.

Pre-lab exercises

1. With the information about the plant and the controller given above, compute the closed loop transfer function in terms of the plant model $G(s) = K/s$ and the controller coefficients *a, b, c, d and e.* Ensure that the transfer function expression is in its most simplified form i.e.,

$$G_c(s) = \frac{Y(s)}{R(s)} = \frac{b_{n-1}s^{n-1} + b_{n-2}s^{n-2} + \ldots b_0}{s^n + a_{n-1}s^{n-1} + a_{n-2}s^{n-2} + \ldots a_0}$$

Thought experiment

Before designing the internal model controller, suppose that someone has designed a feedback system $G_c(s)$ for you already, discuss what criteria you would use to design a feed-forward controller so that the desired signal $r(t)$ in Eq. (1) is tracked.

Procedure

1. What is the Laplace transform of the $r(t)$?

2. Based on the closed loop transfer function $G_c(s)$ you derived in the pre-lab exercise, write down the error transfer function $G_E(s) = E(s)/R(s)$ where $E(s)= R(s)-Y(s)$.

3. Notice the terms in the numerator of your transfer function $G_E(s)$.

4. Assuming that $G_E(s)$ is stable, what is the steady state error $e(t \rightarrow \infty)$? [Use final value theorem].

5. Because of the observation in step 4, you need only determine your controller coefficients *a, b, c, d, e* so that $G_E(s)$ (or $G_c(s)$) is stable. For simplicity you can pick all the poles so that all of them are the same, e.g. -10rad/s (you should iterate this procedure with different poles locations so that the system is stable and have good performance in implementation). What is the D.C. gain of $G_c(s) = Y(s)/R(s)$ and why is this useful?

6. Simulate this system with K of the plant as modeled and with $K \rightarrow K/2$. Does $y(t)$ converge to $r(t)$ in either case ? If you had designed a feed-forward controller, do you think that $y(t)$ would converge to $r(t)$ when $K \rightarrow K/2$?

7. Implement the controller on the experimental hardware and note any discrepancy from your simulations.

8. Modify the simulink diagram to ensure that the controller performs in a satisfactory manner.

9. Vary the poles locations of your closed loop system and note how the system behaviors differ.

10. Notice the transient and the steady state error behaviors.

11. Add a constant bias to r(t) and test if your controller can track the new r(t).

12. Does your controller reject an input disturbance which is: a) a sinusoid with frequency of ω_1 or ω_2, b) a constant? How would you modify your controller so that it can reject these as well?

Report

The report should document your understanding of how to design and implement the internal-model controller. Below are some points (non-exhaustive) that you should consider.

- Comment briefly on the intuition behind choosing the controller of this specific form for this specific signal.
- Show the derived closed loop transfer function
- Apply the final value theorem to determine the value of the steady-state tracking error
- Comment on how to choose the controller coefficients a,b,c,d and e.
- Simulations showing the effectiveness of the controller when the plant is exactly as modeled.
- Simulations showing the performance of the controller when the plant is different from the model used for control design
- Comments about additional steps you had to perform to ensure that the controller worked as expected. (Explanation about control saturation, initial conditions etc.)
- Results from experimental implementation showing good tracking performance.
- The effect of the closed loop pole location. What are the problems with choosing poles that are too fast or too slow ?? If possible support with data you may have collected.
- Comment on any discrepancies between theory and implementation.