System Identification

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Abstract. The abstract should briefly summarize the contents of the paper in 15–250 words.

Keywords: First keyword · Second keyword · Another keyword.

1 System Introduction

This semester, we are going to control a Galvanometer scanner system to track a 400 Hz triangular trajectory. The system block diagram is shown in Fig. 1. Treating the internal closed-loop plant as an open-loop stable system, denoted as G, including servo driver, Galvo actuator, and position sensor. The input u of G is the position command, and the output y is the system response. The sampling rate of G is 20kHz. In Lab01, as a practice, we try to control the Galvanometer scanner system to track a 400Hz sine wave and follow the "DAVI" steps.

This report is organized as follows. Section 2 includes system identification of the system G. Section 3 elaborates on how we design a controller to track the 400Hz sine wave. In the last section, we tidy up some questions we faced in Lab01.

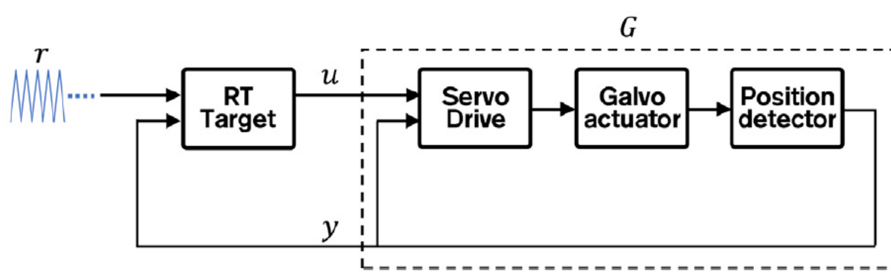


Fig. 1: System block diagram

2 System Identification

In this part, we injected sinewaves with 0.08 amplitude and 12 different frequencies, (10,20,30,50,100,200,300,500,1000,2000,3000,5000), into the system G for 1 second and collected the inputs and outputs to do the system identification.

2.1 Methodology

We implement two methods to obtain our system transfer function. The first one is the **"complex curve fitting"** method provided by Prof. Yu-Hsiu Lee in the system identification course. The second one is using Matlab toolbox **"tfest()"** directly.

Complex Curve Fitting
Considering the standard discrete-time system $G(z)$ can be represented as the Eqn. 1

$$G(z) = \frac{B(z)}{A(z)} = \frac{b_1 z^{-1} + \cdots + b_n z^{-n}}{1 + a_1 z^{-1} + \cdots + a_n z^{-n}} \tag{1}$$

It follows that the frequency response data (FRD) is related to $A(e^{j\omega})$ and $B(e^{j\omega})$ by Eqn.1

$$A(e^{j\omega})G(e^{j\omega}) = B(e^{j\omega}) \tag{2}$$

$$\Rightarrow (1 + a_1 z^{-1} + \cdots + a_n z^{-n})G(e^{j\omega}) = (b_1 z^{-1} + \cdots + b_n z^{-n}) \tag{3}$$

Eqn.3 can be rearranged in the following form:

$$\left[-G(e^{j\omega})e^{-j\omega}, \cdots, -G(e^{j\omega})e^{-jn\omega}, e^{-j\omega}, \cdots, e^{-jn\omega}\right] \begin{bmatrix} a_1 \\ \vdots \\ a_n \\ b_1 \\ \vdots \\ b_n \end{bmatrix} = G(e^{j\omega}) \tag{4}$$

We injected 12 kinds of sinewave with different frequencies into the system G so that we got 12 FRD. Eqn. 4 can be further represented as follows:

$$\underbrace{\begin{bmatrix} -G(e^{j\omega_1})e^{-j\omega_1}, & \cdots, & -G(e^{j\omega_1})e^{-jn\omega_1}, & e^{-j\omega_1}, & \cdots, & e^{-jn\omega_1} \\ \vdots, & \vdots, & \vdots, & \vdots, & \vdots, & \vdots \\ -G(e^{j\omega_{12}})e^{-j\omega_{12}}, & \cdots, & -G(e^{j\omega_{12}})e^{-jn\omega_{12}}, & e^{-j\omega_{12}}, & \cdots, & e^{-jn\omega_{12}} \end{bmatrix}}_{Y} \underbrace{\begin{bmatrix} a_1 \\ \vdots \\ a_n \\ b_1 \\ \vdots \\ b_n \end{bmatrix}}_{\theta} = \underbrace{\begin{bmatrix} G(e^{j\omega_1}) \\ \vdots \\ G(e^{j\omega_{12}}) \end{bmatrix}}_{X} \tag{5}$$

X and Y are complex-valued vector. Theoretically, θ should be a real-valued vector. However, due to the effect of noise, θ would be a complex-valued vector. To deal with this problem, separating the X and Y into real parts and complex parts is a common technique. So far, we can obtain θ by using linear least square.

The system order we choose is 5 (n = 5), inspired by Ta's transfer function. The identification result is Eqn.7:

$$G_{ccf}(z) = \frac{1.146z^4 - 1.807z^3 + 0.8332z^2 - 0.3896z + 0.05047}{z^5 - 4.886z^4 + 12.18z^3 - 19.04z^2 + 17.41z - 6.836} \tag{6}$$

And the bode plot is shown in Fig.2

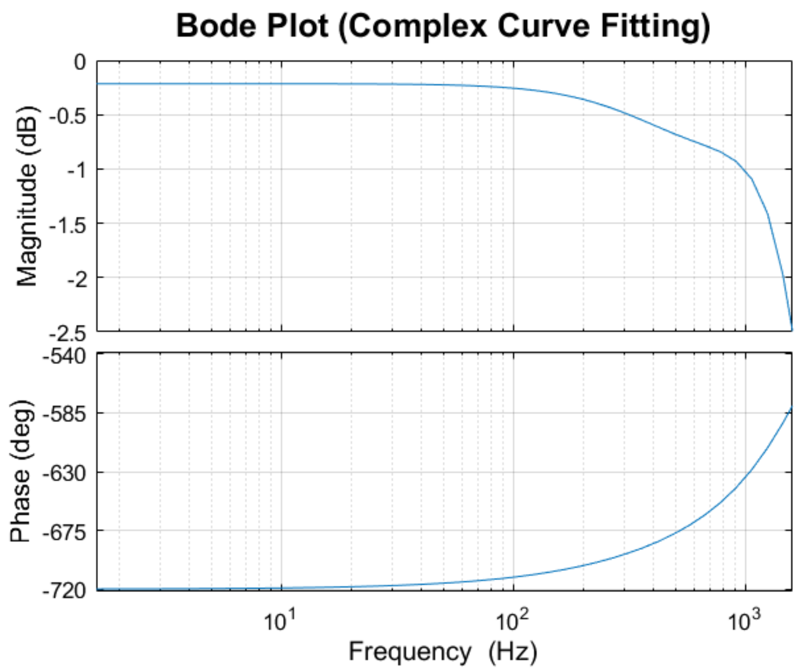


Fig. 2: Bode plot by using complex curve fitting

Matlab Toolbox : tfest()

This is an off-the-shelf Matlab function. The identification result is Eqn.7:

$$G_{tfest}(z) = \frac{-0.01418z^4 + 0.06346z^3 - 0.1069z^2 + 0.08036z^1 - 0.02274}{z^5 - 4.658z^4 + 8.711z^3 - 8.179z^2 + 3.856z - 0.7305} \tag{7}$$

And the bode plot is shown in Fig.3

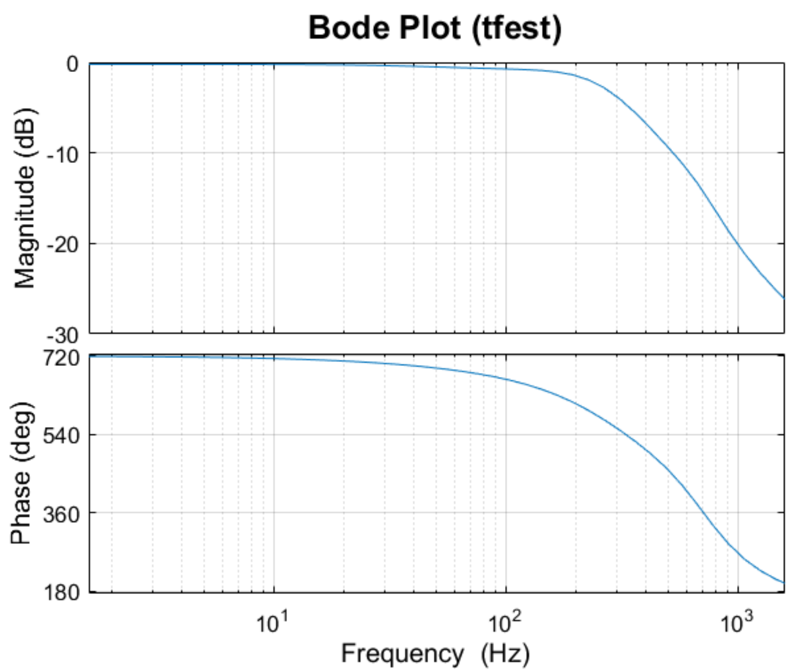


Fig. 3: Bode plot by using tfest

2.2 Comparison

Ta's transfer function is

$$G_{TA}(z) = \frac{0.03017z^4 - 0.05174z^3 + 0.1719z^2}{z^5 - 1.842z^4 + 1.691z^3 - 1.041z^2 + 0.4366z^1 - 0.08933} \tag{8}$$

the bode plot is shown in Fig.4 Next, we will compare the step response and

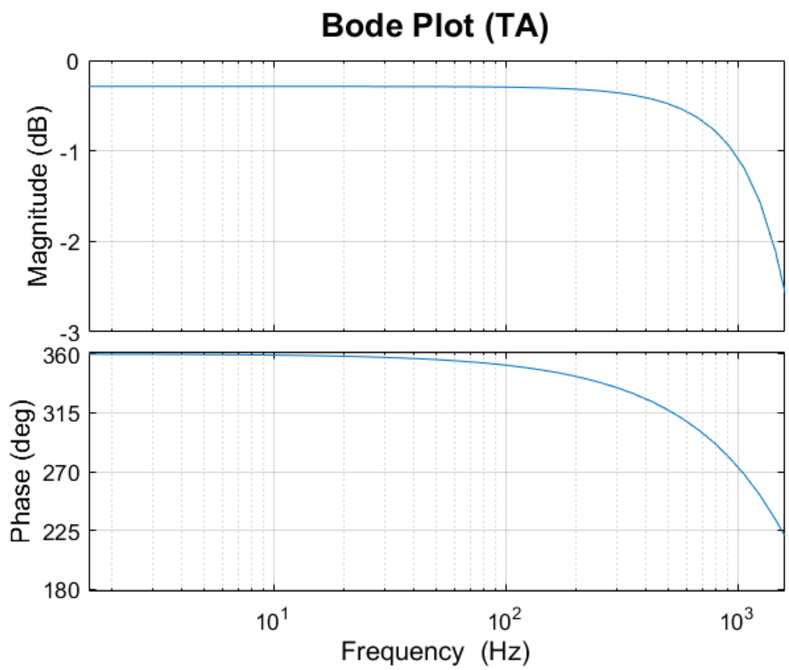
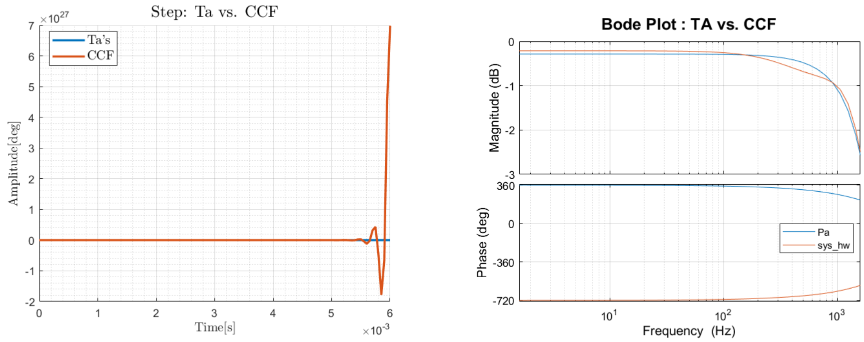


Fig. 4: Bode plot by TA

frequency response between TA's TF, TF by tfest, and TF by CCF.

TA vs. CCF
The result is shown in Fig.5. The TF by CCF is unstable, however, the magnitude part is similar to TA's TF.

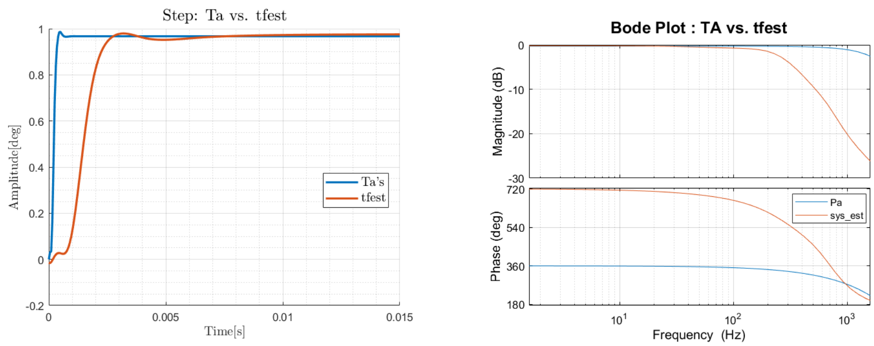
TA vs. tfest
The result is shown in Fig.6. Instead, the result by using tfest is far away from TA's.



raw data show

(a) step response (b) frequency response

Fig. 5: Ta vs. Complex curve fitting



(a) step response (b) frequency response

Fig. 6: Ta vs. tfest

3 Controller Design

The design goal for tracking a 400 Hz sinus wave can be defined as the system having a frequency shift of 0° or a multiple of 360°. We aim to achieve this by increasing the bandwidth of the system for example with a lead or lag compensator

$$\frac{Y}{X} = \frac{z - zero}{z - pole}. \tag{9}$$

To ensure stability a gain and phase margin should be set. Sensitivity???.

4 Discussion

1. The bode plot and the Transfer function on the paper do not match. don't ask!
2. How to ensure the system ID result is correct? experience

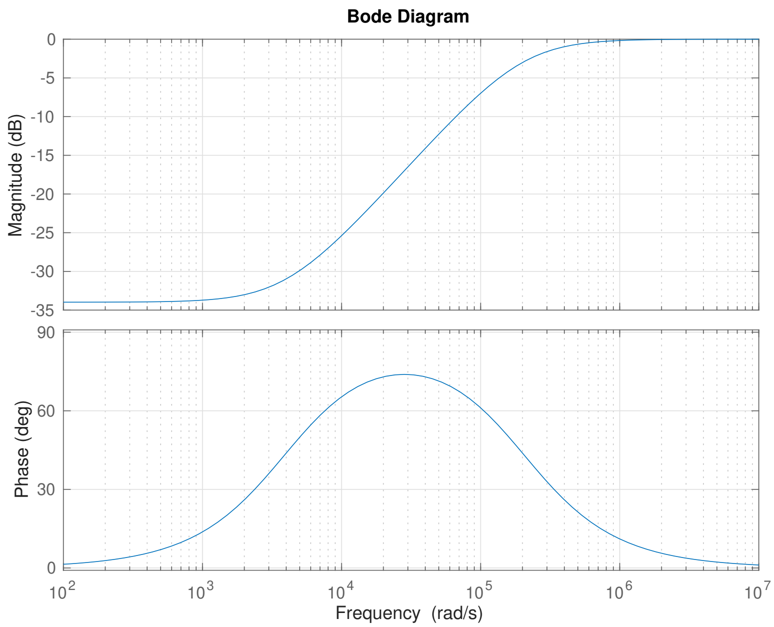


Fig. 7: Continuous frequency domain lag compensator bode plot. Middle frequency around 3 kHz

3. Even if we set up specs for the system, how do we tune the PID value from rlocus? (see Fig.9) find the dominant pole (tune)

References

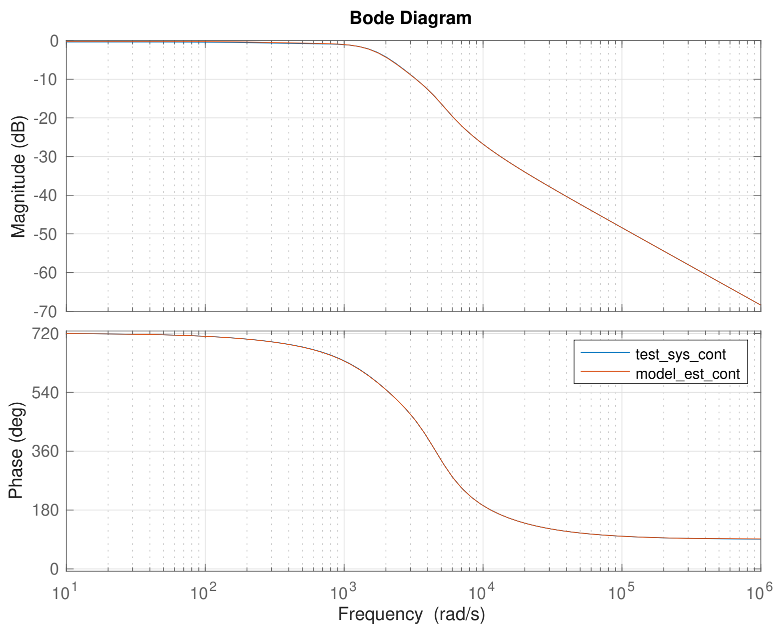


Fig. 8: Continuous system model and feedback system with lag compensator.

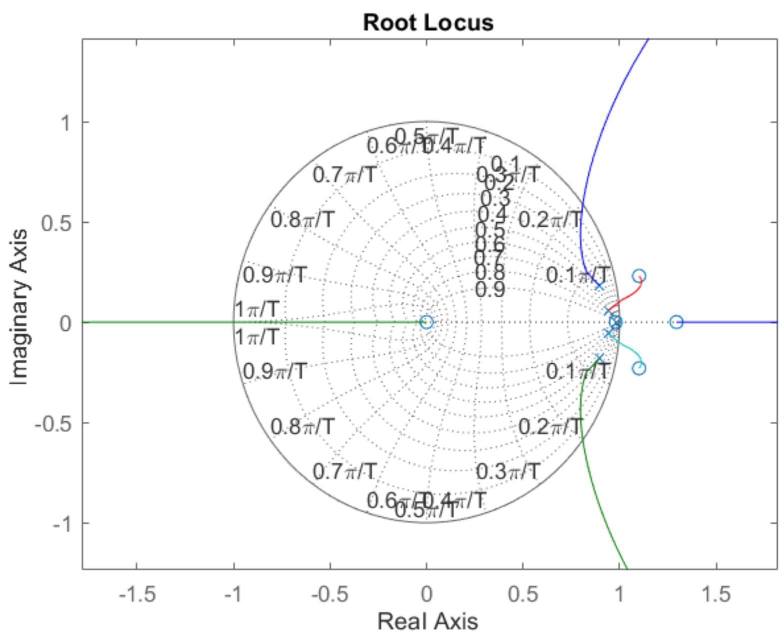


Fig. 9: rlocus of the open loop system by tfest