

november 2016

My friend Rodrigo from Escola de Engenharia Mauá in Brazil has been experimenting with a twin-rotor aerodynamic propulsion system. He ran a sequence of open-loop frequency response experiments and obtained the data in Table 1. For ease of data input, the measurements are given in Real-Imaginary format instead of more usual magnitude in dB-phase.

1. Plot the points and sketch an approximate Bode plot for the TWR. Hint: the process is open-loop stable and minimum-phase, that is, all its poles and zeros have negative real part.
2. Obtain a transfer function model for the system. Use any numerical fitting techniques or Matlab toolboxes you want, or just trial-and-error by visual inspection of the graph.
3. Trace the root-locus of the model and its Nyquist plot.
4. Using the root-locus, the Nyquist criterion, and simulations, discuss in qualitative terms the stability and performance of the system in closed-loop.
5. Suggest a possible control scheme to improve the performance: PID, lead-lag compensator, pole-assignment, whatever makes sense.
6. Design and analyze the behavior of the system that incorporates your controller. If necessary change the parameters or pick a different controller structure.
7. You don't really think that the model built using experimental data is very reliable, do you? In fact the real system is nonlinear, multivariable, and controlled in discrete time, as you suspect, though we are going to stick with classical techniques. Change the numbers in the response values a little bit, and check if the controller you designed still works.
8. (Extra credit) It turns out that the process is in fact not minimum phase. The measurements of the gain in several frequencies missed an all-pass factor  $\frac{1-Ts}{1+Ts}$ . Can you say why? Pick a numerical value of  $T$  and redesign your controller as needed.
9. Have fun!

Some Matlab commands I used to create the question are: `bode`; `nyquist`; `rlocus`; `figure`; `frd`; `zpk`; and `tfest`. Transfer function estimation (`tfest`) is part of the System Identification Toolbox, and the command `controlSystemDesigner` opens a graphical user interface to the SISO root locus, Bode, and Nyquist techniques.

Instructions:

- Open book exam. Consult any written sources. Visit the library!
- Internet use allowed, control design software use encouraged.
- First, work on your own. Take as much time as you need, about a week suggested (not full time of course). Write your answers and note how many days you used.
- If you have any questions, please post on Moodle.
- When you are done, feel free to work with colleagues to check, correct, and improve results. Write down changes and improvements, and note how many days you used for the new version.
- No class Friday 11th November.
- Due date is Friday 2nd December. You need to talk to me and show your work on this exam and the project by the due date. If you need more time tell me.

Frequency (rad/s)	Response (Re + Im)
0.01	5.00 - 0.09 i
0.10	4.99 - 0.94 i
0.50	1.78 - 7.18 i
1.00	-1.81 + 0.28 i
2.00	-0.13 + 0.11 i
3.00	-0.02 + 0.01 i
5.00	-0.00 - 0.02 i
6.00	-0.00 - 0.02 i
8.00	0.00 - 0.02 i
10.00	0.00 - 0.01 i
20.00	0.00 - 0.01 i

Table 1: TWR frequency-response.