Exercise 4

Design for performance

Install the student version of the design tool ShapeIt on your computer:

- Download `shapeit_student_version.zip` from the ShapeIt homepage: `http://cstwiki.wtb.tue.nl/index.php?title=Home_of_ShapeIt`
- Unzip the files into a directory e.g. `$matlabroot\toolbox\shapeit`
- Open Matlab, go to this directory and run: `shapeit_setup_runonce.p`

In case you encounter problems with ShapeIt, see the online FAQ first:
`http://cstwiki.wtb.tue.nl/index.php?title=FAQ_of_shapeit`

4.1 Load feedback with constraints

Download `modl.mat` from OASE. It contains an actual measurement of a CD-player, stored in a frequency vector and a complex response vector.

- Load `modl.mat` and make a stable model for the measurements (`hz,fr_l`) using `frsfit.m`; in case of problems, a model is also provided (`al,bl,cl,dl`).

- Make a stabilizing controller for this model with a high as possible bandwidth (0db of open-loop) using just a lead filter and a gain (no notch), satisfying the robustness margin $|S| < 6$dB. What part of the plant is limiting your bandwidth? Explain why.

- Show stability of your closed loop by drawing a Nyquist plot and simulating a closed loop step response.

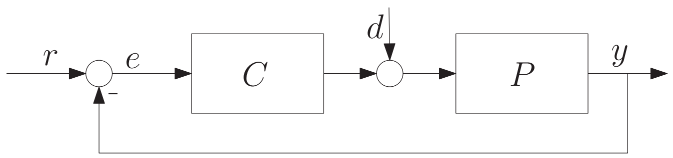
- Now include a notch filter and design a controller which achieves a 20 Hz bandwidth. Again prove closed loop stability by showing Nyquist and a step response.

- Suppose the measurement (and thus your model) denotes a transfer from a voltage [V] to a translation [mm]. Assume the actuator (which is in the plant) can not handle voltages higher than 10V. Design a controller with a high as possible bandwidth, with the constraint that the maximum control signal u due to a step reference $r = 1$mm may not exceed this 10V limit. Verify your results by making time plots.
  Hint: what is the transfer from r to u? Determine its initial and steady-state output from the Bode diagram. What are thus the trivial constraints on this Bode diagram? Can a lowpass filter help to better the performance?

4.2 Non-collocated plant !!⋆!!

Start ShapeIt and select “2 mass non-collocated” as plant (load feedback).

- Design a stabilizing controller with bandwidth of approximately 10 Hz.
- Save your controller to a `.mat` file, and load this file in your workspace. Your data can be found in the structure `shapeit_data`:
  - The controller parameters are stored in `shapeit_data.C.block`; `type` denotes its building blocks (analogous to ShapeIt: 1=gain, 2=integrator, 3=lead/lag, etc.) and `param` contains the corresponding parameter choices. A transfer function (`sys`-object) of C is stored in `shapeit_data.C_tf`.
  - A `sys`-object of the plant P is given in `shapeit_data.P.sys`
- Suppose a sine (cosine) wave disturbance of amplitude 1 and with frequency 2 Hz is applied to the system, between controller and plant:

  What is the transfer function between d and e?
- Construct this transfer with the `sys`-objects of P and C, and apply the defined disturbance to it (e.g. using `lsim.m`). What is the response and can you explain this?

Redesign and improve the controller to achieve the disturbance rejection specification: **error less then 0.01 within 0.5 sec**. Assume, due to uncertainties and measurement noise, that the bandwidth may not be higher than 100Hz. Show the improved transfer from d to e and the new response. What would you have to do to let the error **converge to zero**? Show your obtained controller and time response, and comment on them.

4.3 Wafer stage exercise

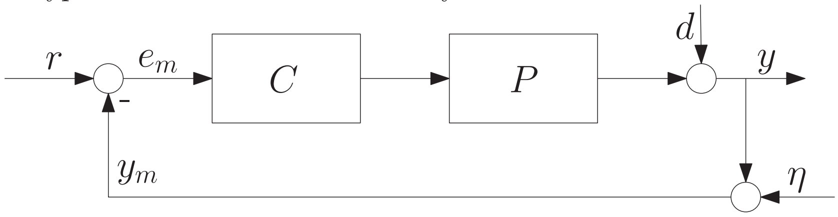
For this exercise you will need the ShapeIt-toolbox installed. The ShapeIt-toolbox can be downloaded for free from the CSTwiki http://cstwiki.wtb.tue.nl. You also need to download `waferstage.mat` from OASE.

1. Load `waferstage.mat` in your workspace. It contains a specific FRF-measurement (`hz,frf`) of a wafer stage.

2. Use `frsfit.m` to make a model of this measurement. Make an appropriate estimation of `struc = [nden,nnum,nint]` beforehand and use an inverse weighting function.

3. Use either your model or the FRF-measurements in ShapeIt to design a controller (and answer the questions) in the following steps:

   - Try to obtain a high as possible bandwidth (400Hz should be possible!), maintaining a robustness margin $|S| < 10$dB, phase margin over 30° and gain margin of at least 6dB.
   - A typical control scheme for this system is shown below:

     The goal of controller design is usually to minimize $e = r - y$ ($\neq e_m$). With this the influence of the various input signals can be derived:

     $$e = r - y = r - CPe_m - d = r - CP(e - \eta) - d$$

     Which transfer function thus denotes the influence of the measurement error η?
   - Assume that this measurement error contains frequencies of 100Hz and higher. These frequencies should thus be suppressed (smaller than 0dB) by the transfer function of the previous question. Is your high-bandwidth controller capable to do so? Why (not)?
   - Again design a controller with a high as possible bandwidth, but now also suppressing measurement errors of 100Hz and higher.

Play around with ShapeIt and try to get used to the toolbox. Try to import your own systems, design different controllers and compare them, export your controller to Simulink, etc. Convince yourself that ShapeIt can save you time, especially during the experiments.
