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Use of describing function in prediction of limit-cycles

In this project you will perform some experiments in order to understand the describing function technique

1.1 System description

This project is based on the paper by Pratt [1]. The file of the paper has been uploaded for your convenience. Please read the paper and then perform the following tasks.

1.2 Problem sets

The problem tasks are as follows (to be submitted by **Thursday 16th of Mordad 1399**). Please note the following:

- You need to present your results in a report. The report should include all your results. **Marks will only be awarded to results which are present in your report**.
- Your report should be typed, **no longer than 30 pages AND 3000 words**.
- All your m-files should also be submitted.
- Please check that your files run correctly and are **compatible with 64-bit MATLAB 2013b**, prior to submission. If your file do not run correctly no marks will be awarded at all.
- You should have **one main m-file from which all other m-files may be run**. Your main m-file should produce figures and results in exactly the same order in which they appear in your report. Failure to do so will result in a loss of marks

1.3 What you need to do

1. Using Simulink, implement the closed-loop system described in the paper (without the relay).
2. Determine the value of K which will cause marginal stability.
3. Using Simulink, implement the closed-loop system described in the paper (this time with the relay). Set the gain to 1.6 and the relay characteristics as in Figure 3(b).
4. Use your simulink model to produce the responses outlined in Figures 4(a-d).
5. Using describing function analysis predict the frequency and amplitude of the prevailing limit cycle. Confirm the results of analysis by plotting the Nyquist diagram of the system and the Describing function. Compare the predicted theoretical value of the limit cycle with the actual values obtained from the simulink simulation.
6. In your simulation model, experiment with difference values for the set-point and determine if the value of the closed-loop set-point has any effect of the frequency or amplitude of the prevailing limit cycles. Present the results of your experiments and state the conclusion from your observation. Does it match with your expectations?
7. In your simulation model, experiment with difference values for d (the dead-band width) and determine if the value of d has any effect of the frequency or amplitude of the prevailing limit cycles. Present the results of your experiments and state the conclusion from your observation. Does it match with your expectations?
8. In your simulation model, experiment with difference values for M (the output level of the relay - default is 5V) and determine if the value of M has any effect of the frequency or amplitude of the prevailing limit cycles. Present the results of your experiments and state the conclusion from your observation. Does it match with your expectations?
9. Change the transfer function of the system to,

$$G(s) = \frac{1.6}{s(1+s)} \tag{1.1}$$

   first using describing function analysis determine if there is going to be a limit cycle. Then using the simulink simulation, observe experimentally if there is a limit cycle. Do the theoretical and experimental results match? if not why? if yes why?
10. Change the pure relay to a relay with hysteresis as in Figure 3(d). Repeat steps 3 to 9 in the same order. For step 7, replace d with h (the width of the hysteresis).

References

[1] R.W. Pratt, A laboratory exercise to illustrate the describing function technique, IEEE TRANSACTIONS ON EDUCATION, **29** (1986), no. 4, 186–189.