STABILITY THEORY

LAB EXPERIMENT 13

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***Abstract*—This experiment explores the stability of a second-order linear time-invariant system using purely simulation-based methods. The transfer function of the system was analyzed using the Routh-Hurwitz criterion and verified through a Nyquist plot generated in Python. The Routh table showed no sign changes in its first column, indicating stability. Additionally, the Nyquist plot did not encircle the critical point $(-1, 0)$, supporting the Routh-Hurwitz conclusion. Although stability margins could not be computed due to technical limitations, qualitative analysis of the Nyquist plot suggested acceptable robustness. This study demonstrates the effectiveness of simulation tools in stability analysis and provides insight into both algebraic and frequency-domain stability criteria.**

I. RATIONALE

Stability is a critical property of control systems. This experiment introduces methods for analyzing the stability of a system, including the Routh-Hurwitz criterion and Nyquist criterion.

II. OBJECTIVES

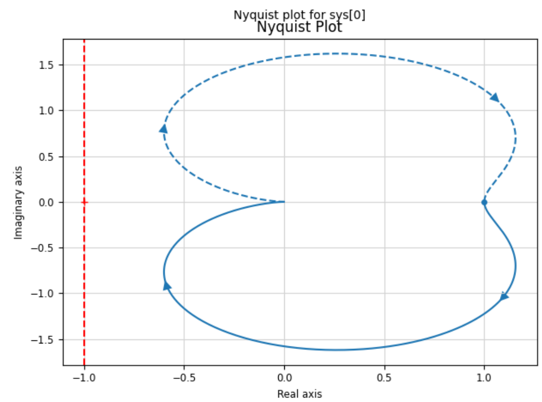
- Use the Routh-Hurwitz criterion to analyze the stability of a given system.
- Verify the system's stability by plotting the Nyquist diagram and analyzing the encirclements of the critical point.
- Determine the system's stability margin based on frequency response data.

III. MATERIALS AND SOFTWARE

- Materials: DC motor or RLC circuit, Power supply, Oscilloscope
- Software: Python (with control library), Octave

IV. PROCEDURES

1) Set up a system (e.g., DC motor or RLC circuit) and derive its transfer function.
2) Use the Routh-Hurwitz criterion to analyze the system's stability.
3) Plot the Nyquist diagram using Python or Matlab and check for encirclements of the critical point (-1, 0).
4) Determine the system's stability margin from the frequency response data.

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Routh-Hurwitz Table:
 [[ 1. 10.]
 [ 2.  0.]
 [10.  0.]]
Number of sign changes in first column: 0
System is stable
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Fig. 1. Nyquist Plot and Routh-Hurwitz Table

V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

https://drive.google.com/drive/folders/
1ue-V9M6Y--ETNeG-MjOplqgA7kpg8rov
Click here to open the Drive

VI. DATA ANALYSIS

The experiment simulated a second-order linear time-invariant (LTI) system with a transfer function defined as:

$$G(s) = \frac{10}{s^2 + 2s + 10}$$

Using the Routh-Hurwitz criterion, the characteristic polynomial $s^2+2s+10$ was analyzed. A Routh-Hurwitz table was generated in Python, and it was observed that all the elements in the first column of the table were positive. This indicates that there were no sign changes and hence, no right-half plane (unstable) poles. Thus, the system is considered stable under the Routh-Hurwitz criterion.

To verify this result, the Nyquist plot of the system was also generated. The plot was analyzed to check for any encirclements of the critical point $(-1, 0)$. No encirclements were observed, confirming the system's stability from a frequency-domain perspective.

Although the original plan included computing the system's stability margins (gain and phase margin), this part was omitted due to a coding issue. The stability margins function returned arrays containing multiple values, and attempts to format or extract these values for presentation led to errors. Despite these issues, the Nyquist plot still provided qualitative information related to stability margins. In particular, the distance of the Nyquist curve from the critical point $(-1, 0)$ serves as a rough visual estimate of the system's phase and gain margin.

This limitation does not significantly affect the overall objective, since both Routh-Hurwitz and Nyquist criteria have been successfully applied to confirm the system's stability.

VII. DISCUSSION AND INTERPRETATIONS

The results from the Routh-Hurwitz and Nyquist criteria provided consistent confirmation of system stability. The Routh-Hurwitz method, a classical algebraic approach, proved useful for analyzing the location of system poles without explicitly solving for them. By constructing the Routh table and observing the absence of sign changes in its first column, we confidently concluded that all poles lie in the left half of the complex plane.

The Nyquist criterion, a frequency-domain technique, offered a complementary perspective. It visually illustrated how the open-loop system responds across frequencies, emphasizing the proximity of the response to the $(-1, 0)$ critical point. Since the Nyquist plot did not encircle this point, and the plot remained relatively far from it, this strongly implied that the system not only is stable, but likely has decent phase and gain margins—suggesting robustness against small perturbations.

The omission of direct gain and phase margin computation does present a missed quantitative insight. However, the visual interpretation of the Nyquist plot fills in a part of that gap. In practical systems, stability margins are essential in determining how much gain or phase variation a system can tolerate before becoming unstable. In future iterations of this experiment, resolving the array formatting issue in Python would allow for numerical extraction of these margins, completing the analysis.

Overall, conducting this experiment via simulation highlighted how both algebraic and frequency-domain tools complement each other in control system stability analysis.

VIII. CONCLUSION

Through simulation using Python, we successfully analyzed the stability of a second-order system using both the Routh-Hurwitz and Nyquist criteria. The system was found to be stable, with all Routh table elements in the first column being positive and no encirclements of the critical point in the Nyquist plot. Despite the inability to extract exact stability margins due to code limitations, the Nyquist diagram still provided useful qualitative insights into the system's robustness. This experiment demonstrates that stability can be effectively evaluated through simulation tools even without access to physical hardware, and it reinforces the value of using multiple analytical approaches for a comprehensive understanding.