CONTROLLERS, COMPENSATORS, PID CONTROLLER

LAB EXPERIMENT 17

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***Abstract*—This experiment explores the design, tuning, and implementation of a Proportional-Integral-Derivative (PID) controller and a lead-lag compensator using simulation in Python. A second-order system, modeled after a DC motor, was used to evaluate system performance both with and without control strategies. The goal was to achieve improved rise time, reduced overshoot, and enhanced stability. The PID controller significantly improved transient response compared to the open-loop system. A compensator was later introduced to examine its additional impact on system behavior. Results from the simulations confirm the importance of controller tuning and compensator design in shaping control system performance.**

I. RATIONALE

PID controllers are widely used in control systems to improve system performance. This experiment investigates the design and tuning of PID controllers, and the impact of compensators on system behavior.

II. OBJECTIVES

- Design a PID controller for a given system and tune the parameters (Kp, Ki, Kd) to achieve the desired performance.
- Compare the performance of the system with and without the PID controller in terms of rise time, settling time, and overshoot.
- Implement a compensator (e.g., lead-lag) and quantify its impact on system performance.

III. MATERIALS AND SOFTWARE

- Software: Python (with control library)

IV. PROCEDURES

1) Set up a system with feedback control (e.g., DC motor).
2) Design a PID controller for the system and implement it in the feedback loop.
3) Tune the PID parameters (Kp, Ki, Kd) to achieve desired system performance.
4) Compare the system's performance with and without the PID controller.
5) Implement a compensator and observe its effect on system performance.

V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

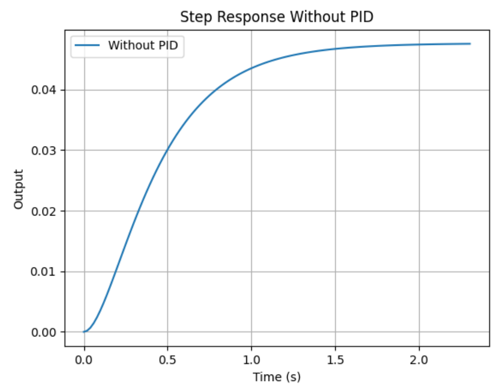

Fig. 1. System Response - Without PID

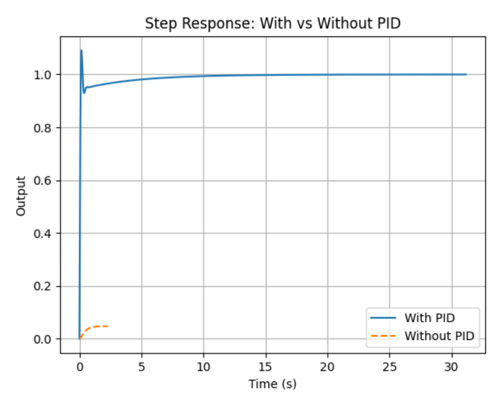

Fig. 2. Step Response - With vs Without PID

https://drive.google.com/drive/folders/1h9li4c94ermsr_kD0qfitS9uE63YK086
Click here to open the Drive

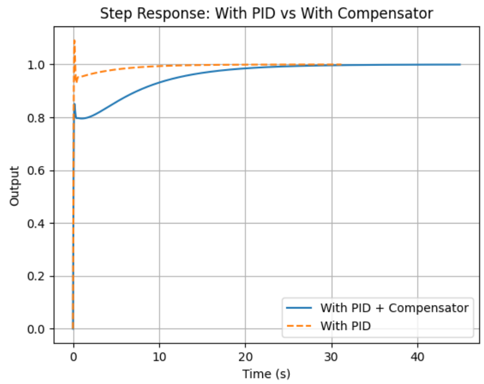

Fig. 3. Step Response - With Compensator

VI. DATA ANALYSIS

The performance metrics obtained from the simulated step responses are summarized below:

System with PID Only

- Rise Time: 0.0838 s
- Settling Time: 4.7486 s
- Overshoot: 9.12%
- Peak: 1.0912
- Steady-State Value: 1.0

System with PID and Compensator

- Rise Time: 7.4834 s
- Settling Time: 18.0292 s
- Overshoot: 0%
- Peak: 0.9997
- Steady-State Value: 1.0

A quick comparison shows that the PID-only system achieved fast response and acceptable overshoot. However, the addition of a compensator significantly suppressed overshoot but at the expense of slower rise and settling times.

VII. DISCUSSION AND INTERPRETATIONS

The results illustrate the trade-offs inherent in control system design. The PID controller enhanced the system's dynamic performance by drastically reducing the rise time to approximately 0.084 seconds and ensuring a quick response with minimal delay. The overshoot of 9.12% remained within acceptable margins for many engineering applications, and the steady-state value was successfully achieved at 1.0.

In contrast, the compensator's primary effect was to completely eliminate the overshoot, stabilizing the system further. However, this came with a cost—rise time ballooned to over 7 seconds and settling time extended to 18 seconds. These values suggest that while the compensator improved robustness and eliminated oscillations, it did so by damping the system more heavily and slowing its responsiveness.

This clearly demonstrates a core concept in control theory: aggressive tuning for speed can introduce instability (overshoot), while conservative tuning or additional compensation can improve stability but at the expense of speed. Thus, tuning must be aligned with specific application requirements—some may prioritize rapid reaction, while others may value precision and damping.

VIII. CONCLUSION

This simulation-based experiment successfully met its objectives by demonstrating the role of PID control and compensators in modifying system dynamics. The PID controller alone was effective in improving rise time and maintaining a relatively low overshoot. The addition of a lead-lag compensator further refined the system's behavior, eliminating overshoot entirely but significantly reducing responsiveness.

Overall, this experiment emphasized the importance of balancing competing control objectives. It also highlighted how simulations, even without physical hardware, can provide powerful insight into the dynamics and trade-offs of control system design. These findings are valuable for future real-world applications, especially where performance tuning is critical.