Creating Systems Using Servo Motors

By Juan Aguilar

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Abstract

- This lab focused on developing two systems consisting of a rotating disk and a cart driven by a lead screw. Using video reference data, control theory, and software, a successful model was created. The cart successfully moved past the disk's fixed position during each stop. The disk consistently completed full rotations before its stop and showed little instability. Results show that the PI controllers implemented stability for the entire system during its .5-second test window. The project confirms that effective systems can be built with limited information.

Introduction

- This project aims to replicate and analyze two systems using control theory, MATLAB, and Simulink. The systems are designed to operate together with precise timing.
- Both systems consist of an AC servo motor attached to an external object, where the mass and inertia play a big role in determining how the system needs to be adjusted to the desired goal.

Introduction (Continued)

- The first system has an AC servo motor connected to a rotating disk, where the disk stops for 50 milliseconds periodically. It is important to create a consistent stop during each period to ensure the second system flows correctly.
- The second system will make use of an AC servo motor driving a lead screw, which helps move a cart in linear fashion. On the surface of the cart is a rod that must pass through the disk during its 50-millisecond window.

Objectives

- Model and simulate two systems using MATLAB and Simulink based on a provided video demonstration.
- Design a control system for an AC servo motor to rotate a disk with a 50-millisecond stop during each period.
- Model a system using an AC servo motor driving a lead screw that controls the position of a cart.
- Account for mechanical influences such as inertia from the disk, cart, and lead screw into the system models.

Objectives (Continued)

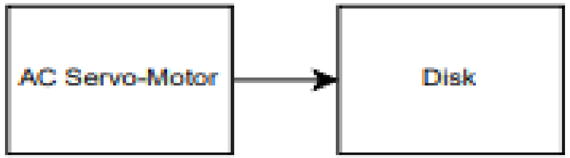
- Sync both systems to ensure the rod on the cart passes through the disk correctly.
- Verify the overall system through simulation and data analysis.

List of Materials

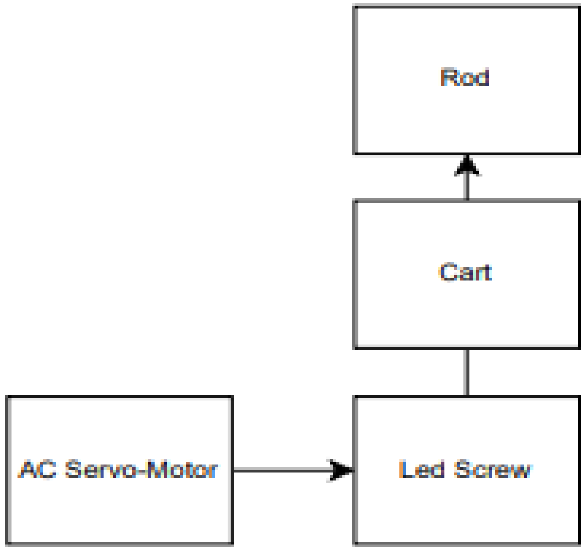
- Two AC-Servo Motors; with the specifications provided by Teknic [Teknic. (2025)]
- One 1018 Carbon Steel Precision Acme Lead Screw, 2"-2 Thread Size, 3 Feet Long, .5” travel distance per turn [McMaster-Carr. (2025)].
- Cart with mass of .145 kilograms.
- Disk with mass of .1 kilograms and .0047-meter radius
- Rod with mass of .05 kilograms.

List of Materials (Diagram)

System 1



System 2



Procedure (Disk System)

- Given the transfer function model for a position tracking DC-servo model, the specifications found from the CPM-MCPV-2310P-RLN [Teknic. (2025)].
- servo are used to better resemble a realistic system.
- Calculate total inertia by combining the inertia of the disk with the servo motor's inertia (total: 1.12×10^{-4} kg·m^2).
- Implement the system in MATLAB and Simulink by using a square pulse as input (amplitude = 2π radians, period = 0.1s).
- The input goes to a PI controller and the modified servo motor model, with negative feedback to stabilize the system. The PI controller is tuned so that the output matches the system input.

Procedure (Cart System)

- Calculate the inertia by the cart, screw, and servo motor.
- Use the output of the disk system as the input for the cart system. A gain block is inserted to increase the signal to allow enough rotations such that the cart moves a meaningful distance. A delay is implemented to avoid collision with the disk.
- Apply a PI controller and servo motor with feedback to stabilize the system. The output then goes through a conversion transfer function to translate rotational motion to linear position.
- Analyze the disk and cart systems to ensure they don’t get close to a collision

Procedure (System Functionality)

- The first system rotates a disk, stopping for a moment to allow the cart with the rod to pass through.
- The second system controls the position of the cart, ensuring it only goes through the disk during its short stop.
- In combination, the systems should create a system that is stable.

Data and Observations (Raw Data)

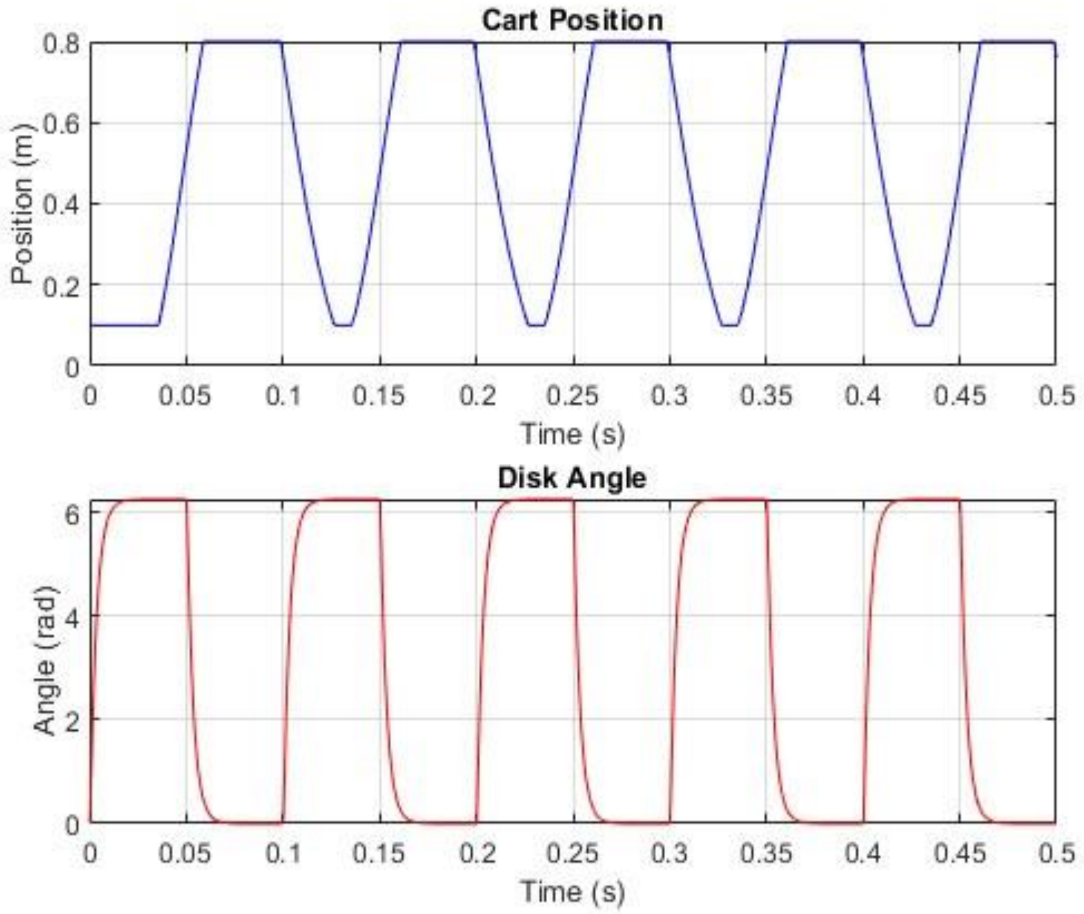
Parameter	Value
Disk Rotation Period	100 milliseconds
Disk Stop Duration	50 milliseconds
Lead Screw Pitch	.0127 meters
Max Linear Travel	.9 meters
PI Values for Disk System	P = 200, I = 20
PI Values for Cart System	P = 30, I = 10
Cart System Gain	100
Cart System Delay	¼ * Signal Amplitude
Disk System Total Inertia	1.12×10^{-4} $kg \cdot m^2$
Cart System Total Inertia	.0047 $kg \cdot m^2$
Saturation Block Limits	Lower limit = 0.1, Upper Limit = 0.8
AC Servo Motor Parameters	Km = 0.8, Ra = 1.5, B = Kb = 0.25, La = 0

Data and Observations (Continued)

- A gain block of 100 was utilized to ensure the cart system could travel its entire distance.
- A delay block was introduced in the second system to offset the cart's movement just after the disk begins its motion. This allows the disk to have time to stop before the cart can get near it.
- The travel distance of the second system is about .9 meters, so a saturation block is placed to ensure the range is limited.
- The disk system used a high proportional gain to ensure the output matched its input to provide accurate rotations. Thus, the cart system used a much smaller value to prevent overshoot.

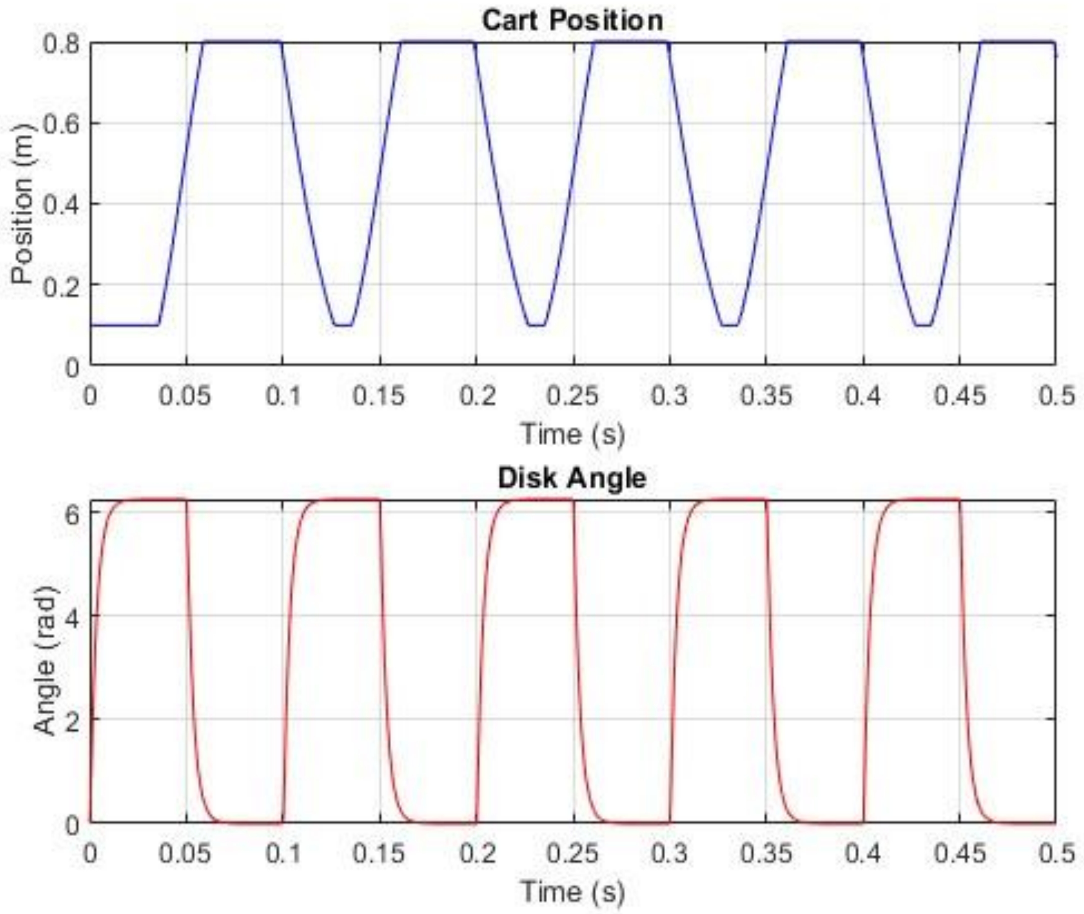
Results

- The processed data show the cart's position ranging from 0.1 meters to 0.8 meters over time. The disk is placed on the 0.4-meter position. The PI values chosen prove that the system remains stable during this 0.5 second test.



Results (Continued)

- From the position data, it is seen that the cart never stops at the .4-meter mark, confirming that the cart does not sit under the disk when the disk is in rotation. The constant rotation of 0 to 2π demonstrates that the PI controller values chosen lead to a stable system.



Analysis

- It was expected that the system would show signs of instability after the first iterations of cart traversal. However, the results demonstrate that the system successfully drives the cart past the disk position during each disk stop, maintaining stability.
- The disk consistently completes a full rotation before stopping for 50 milliseconds, during the cart’s adjusting period.
- The behavior indicates the PI controllers for both systems are handling stability well, despite the high P value of the disk system.
- The synchronization between the two systems suggest that under stressful conditions, it can be a useful system for other intervals.

Discussion

- A challenge faced during the experiment was ensuring the cart and disk systems were synchronized, since the input's amplitude could hardly drive the cart system by itself. It was expected to see the gain block drive the cart system to instability, but the PI controller proved to not need much tuning.
- The disk system did require heavy PI tuning, since it required a high proportional gain to maintain stability. This could be due to dynamics such as motor friction, backlash, or delays in the system.

Discussion (Continued)

- Uncertainties in the experiment may come from dynamic properties not accounted for, noise, latency, and other mechanical discrepancies.
- The cart position may have delays compared to other intervals, especially in small periodic testing. These uncertainties are estimated to be within 0.015 meters for cart position and .055 radians for disk angle.
- The experiment showed that both systems reach a stability quickly, even under stressful conditions. Though a fully detailed theoretical model is not present, the expectations for PI tuning proved to be a challenge.

Conclusion

- The experiment demonstrated the disk and cart system, controlled via PI controllers, reached a stable condition. The cart successfully moved past the disk’s position during its stops.
- The disk managed to maintain a full rotation between pauses, confirming the system successfully reached the desired dynamics for the 100-millisecond period.
- This project addressed the problem of modeling and controlling two systems, based on a reference video and control theory. The results confirm that the dynamic considerations and modeling approach are effective. Thus, with minimal data, a functional system can be built.

Conclusion (Continued)

- Future considerations can involve a full theoretical model to compare with experimental data. Involving more mechanical influences can also lead to more insightful results and may explain the high PI values utilized in the project.

References

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- Teknic. (2025). *ClearPath Motor Model: CPM-MCPV-2310P-RLN*. https://teknic.com/model-info/CPM-MCPV-2310P-RLN/?model_voltage=75VDC
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