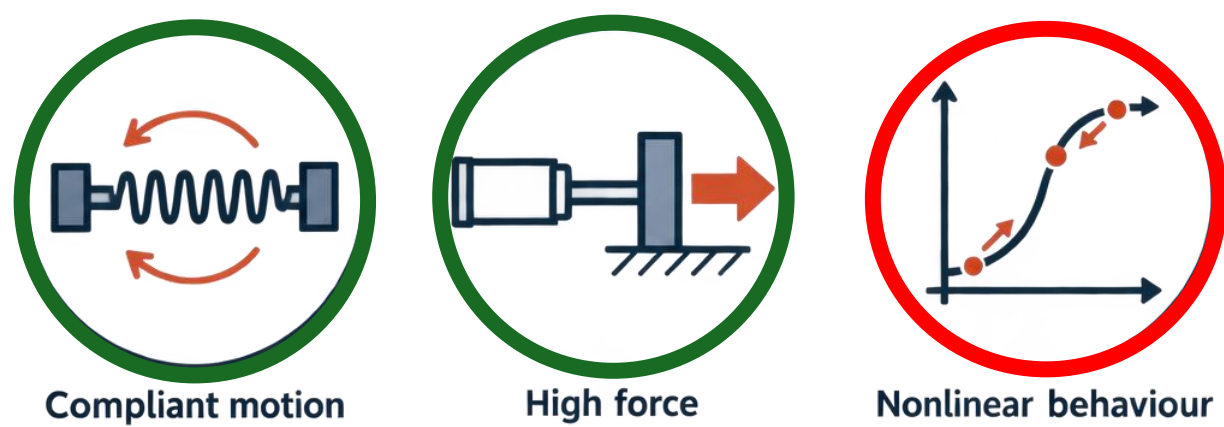


Position Tracking Through Coordinated Chamber-Pressure Control

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Problem & Motivation

- Pneumatic actuators are lightweight, compliant and capable of producing high force.
- Actuator control is challenging because compressed air, friction, valve behaviour, and changing chamber pressure create nonlinear and time-varying motion.
- Predictive control offers a way to anticipate these effects while coordinating actuator inputs and operating limits.

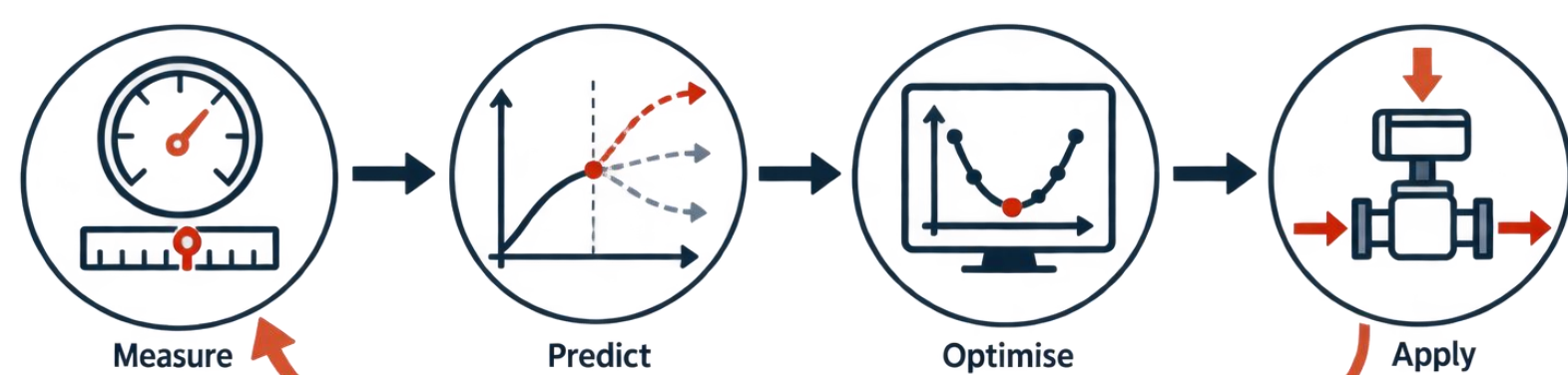


Research Objectives

- Design and test a controller for a double-acting pneumatic cylinder using piston-position and chamber-pressure feedback.
- Use model predictive control to anticipate how valve adjustments will change the chamber pressure and piston motion, allowing the piston to follow a commanded path while staying within safe position and pressure limits.
- Evaluate position-tracking accuracy and chamber-pressure response on the physical system, and investigate how valve and pump energy use can be reduced without sacrificing tracking performance or safe operation.



What is Model Predictive Control?



- Model predictive control (MPC) uses a model of a system to estimate how it will respond over a short future horizon.
- At each update, the controller evaluates possible control actions, chooses the one that best follows the desired motion while respecting operating limits, applies only the first action, and repeats the process using new sensor measurements.

Why it matters

- Pneumatic Actuation is useful where compliance and high force-to-weight ratio are valuable
- Better control can improve repeatability and broaden the use of pneumatic systems in automation and robotics.
- The work connects predictive control theory with sensing, real-time experimentation, and physical system constraints.

Experimental System

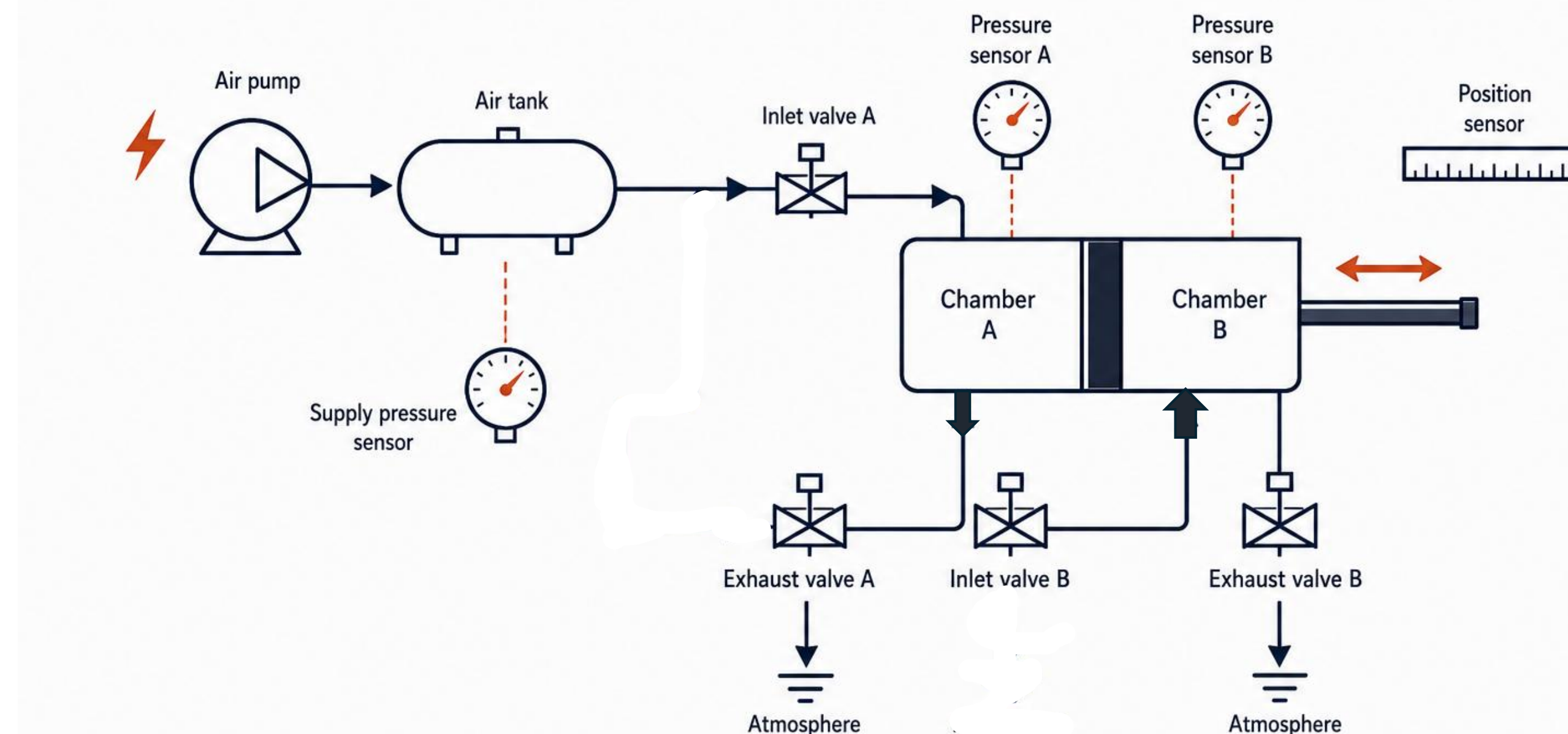


Figure 1. The air pump pressurizes a storage tank, and inlet valves direct compressed air into either cylinder chamber. Exhaust valves release air to the atmosphere. Chamber-pressure sensors and a position sensor measure the actuator's response and provide the feedback needed to control piston motion.

Control Architecture

This cascaded controller uses two connected feedback loops

- The motion and force controller compares the desired and measured piston positions.
- The desired motion is then converted into pressure targets for Chambers A and B.
- The model predictive controller (MPC) uses the desired pressures and the measured chamber pressure to select the ideal valve commands.
- By admitting or releasing compressed air, the valves create the pressure difference needed to move the piston.

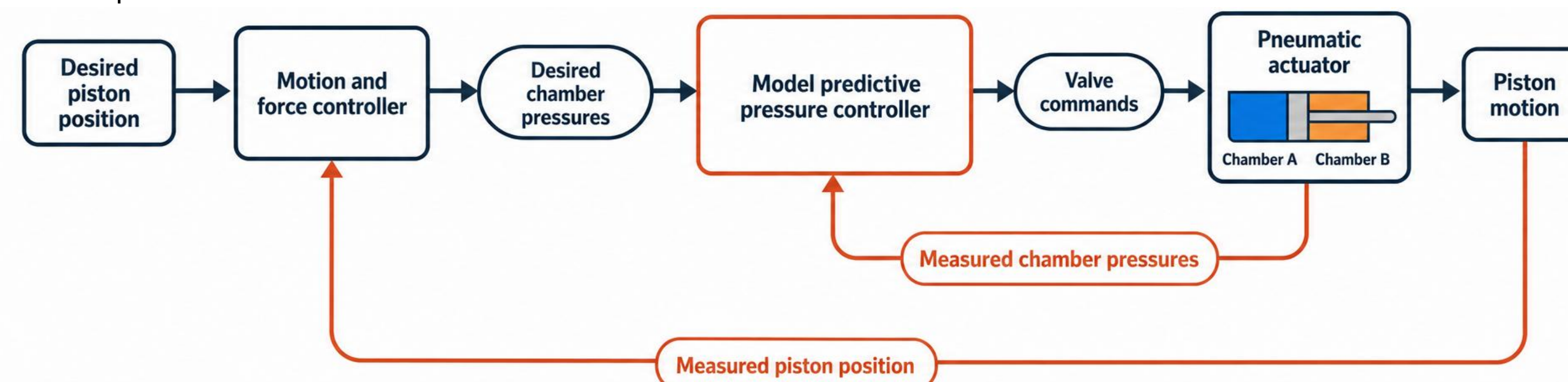
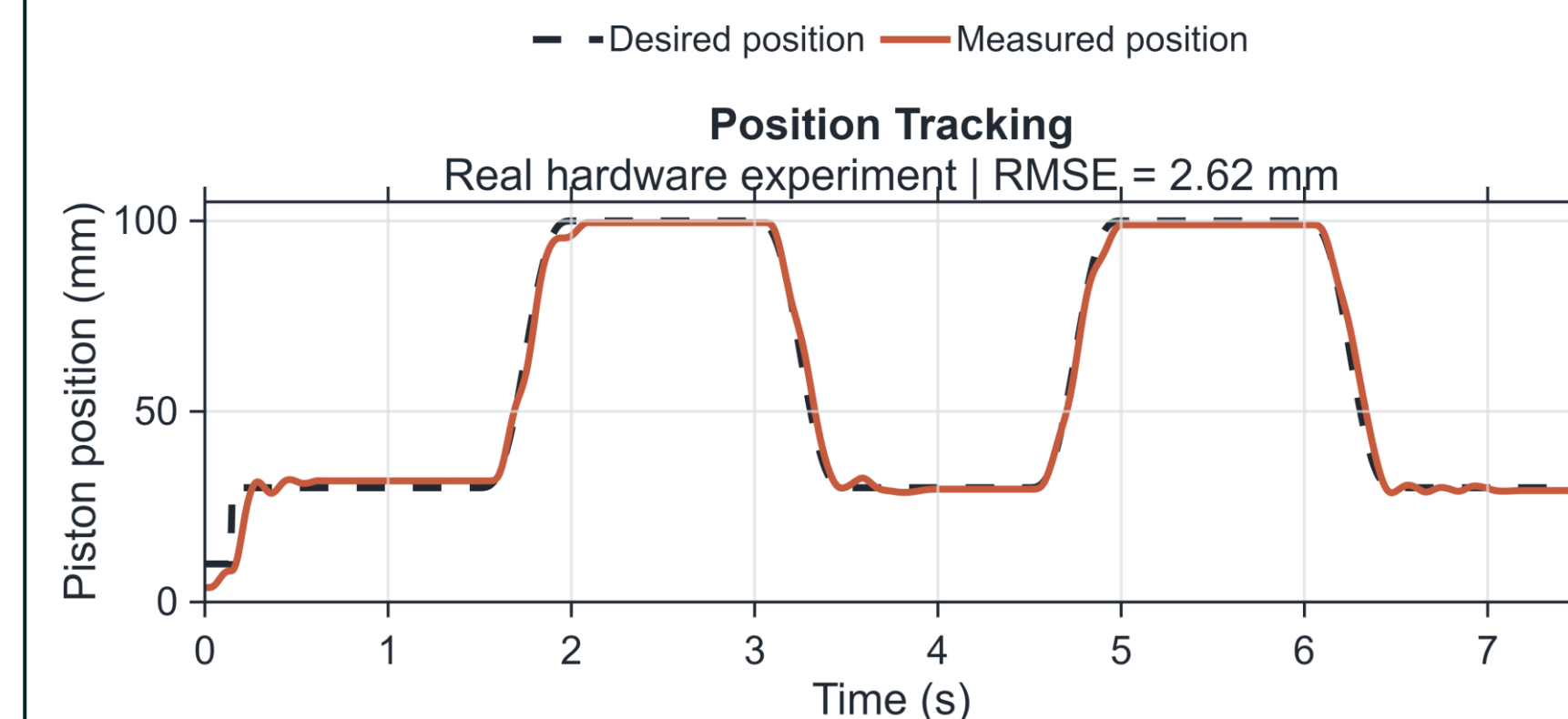


Figure 2. The motion objective is translated into chamber-pressure targets, and model predictive pressure control determines the valve actions.

Results



Tracking RMSE	Mean absolute error	Safety Stops	Valve Electrical energy
2.62 mm	1.55 mm	0	7.48 J

- During the 30 mm and 100 mm holds, the mean absolute tracking error was 1.00 mm and 0.81 mm, respectively.
- The controller required an average computation time of 0.17 ms per sample.

Discussion

- The close agreement between the desired and measured positions during the holds shows that the controller can maintain a requested piston position on the physical system.
- Most of the remaining tracking error occurs during the initial position change and rapid motion transitions. This behaviour is consistent with the delayed response of compressed air and the nonlinear behaviour of the valves and actuator.
- These results are based on one selected trial. Repeated experiments and comparison with a baseline controller are needed to evaluate repeatability and determine whether energy consumption was reduced.

Conclusions & Next Steps

- Experimental nonlinear model predictive control was used to move a double-acting pneumatic actuator through a multi-position trajectory on real hardware.
- Experimental achieved a position RMSE of 2.62 mm and completed without a safety stop, supporting the feasibility of coordinated chamber-pressure control.
- Future work will compare energy consumption against a baseline controller, repeat the experiment across multiple trials, and improve the response during position transitions without increasing oscillation.