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## Introduction

### PROBLEM STATEMENT

The Los Alamos Neutron Science Center (LANSCE) is a linear particle accelerator that supports a wide range of critical research and national security missions, including nuclear research, aircraft electronics radiation testing, and medical isotope production for cancer treatment. Maintaining high availability of the accelerator is essential, as unplanned downtime directly impacts these programs. As part of ongoing modernization efforts, the resonance control system has been identified as a recurring source of downtime due to the limitations of its aging analog hardware.

### ABSTRACT

The accelerator's forty-eight RF (radio-frequency) cavities each require precise resonant frequency regulation to guarantee maximum power acceptance from their respective amplifiers. The resonant frequency is related to the size of the cavity, and is dependent on the temperature, so a form of active temperature control is needed. This is done by controlling the input cooling water flow rate. We developed a digital PID controller to replace the existing analog system and a digital twin of the accelerating cavity to confirm controller performance prior to deployment.

### CURRENT RESONANCE CONTROL SYSTEM

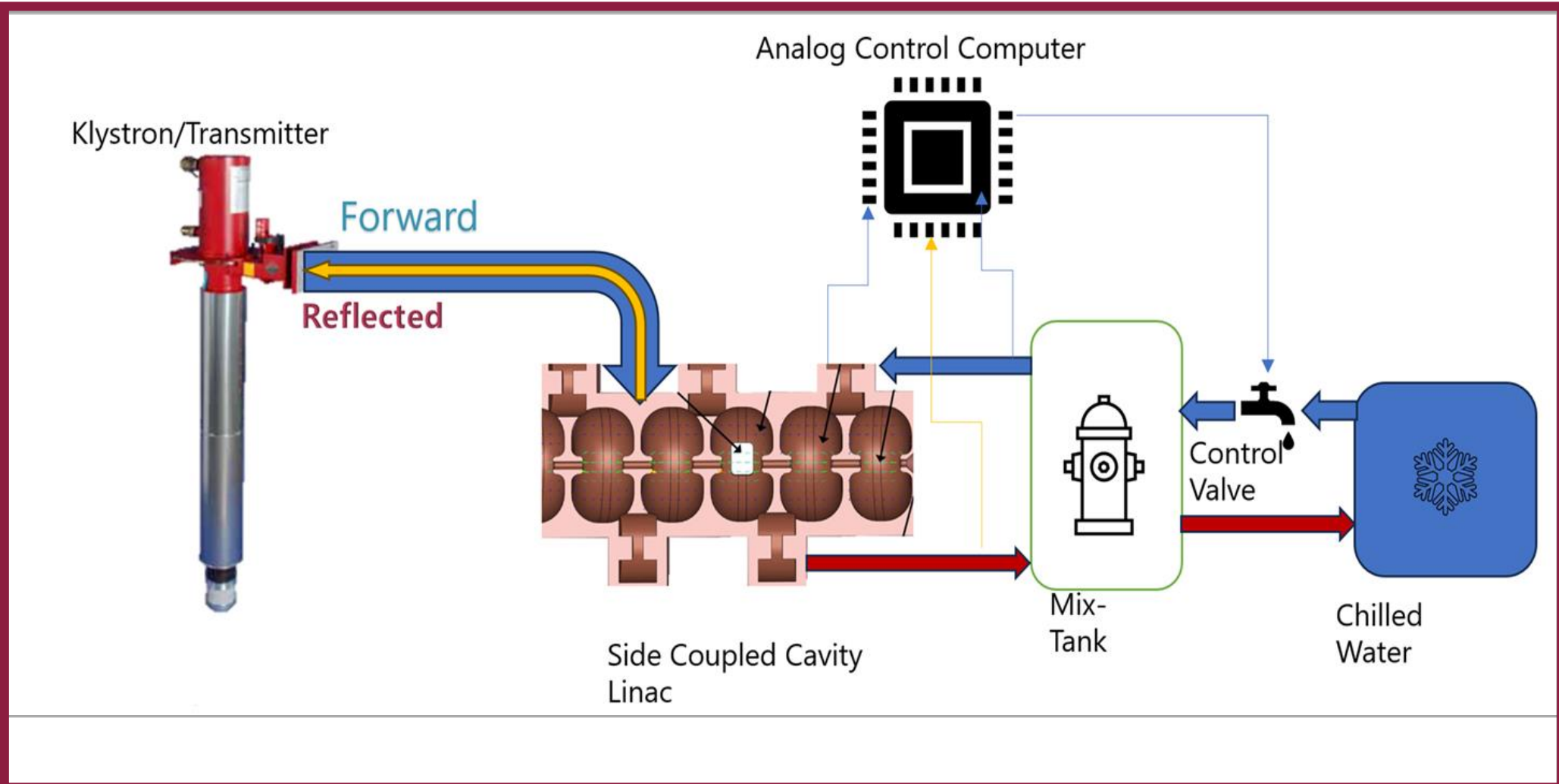


Figure 1: Legacy Resonance Control System at LANSCE

## Digital Twin

### EQUIVALENT CIRCUIT MODEL

- Cavity → Parallel RLC network
- Coupling → Transformer
- Waveguide → Transmission Line

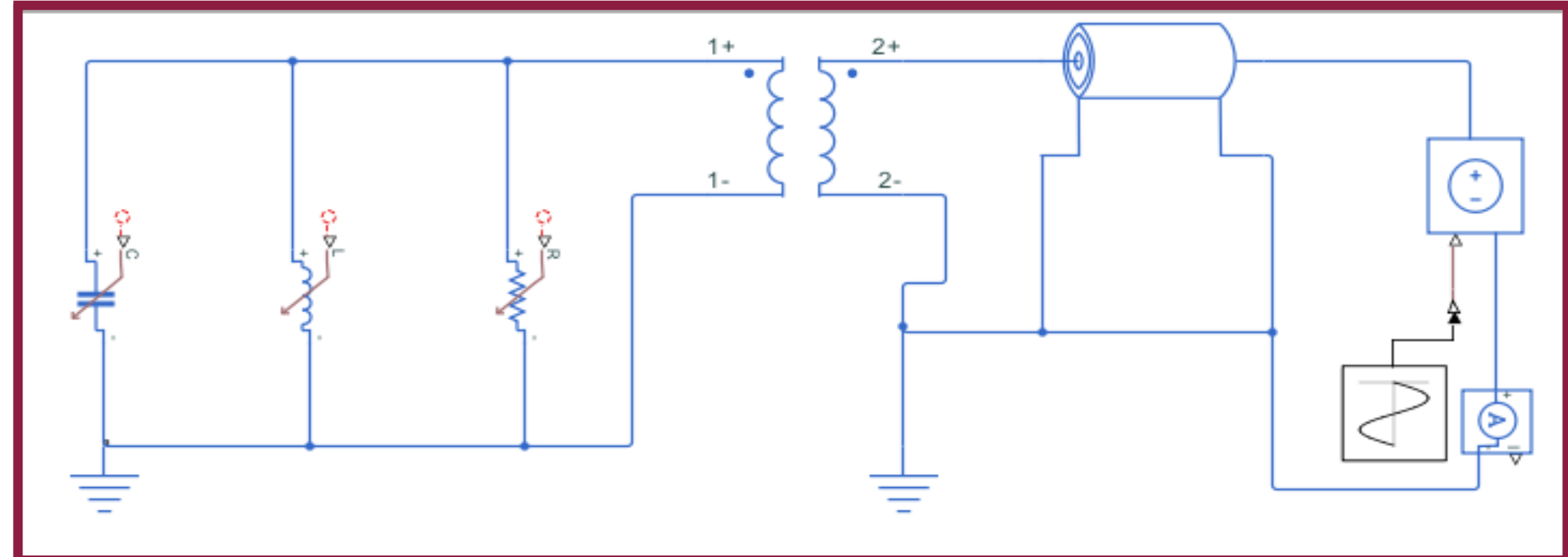


Figure 2: Equivalent Circuit Representation of Accelerating Cavity

### ANSYS

- Validates circuit equivalent model with full wave solutions
- Models electric field distribution at resonance
- Allows for coupling optimization from cavity to waveguide

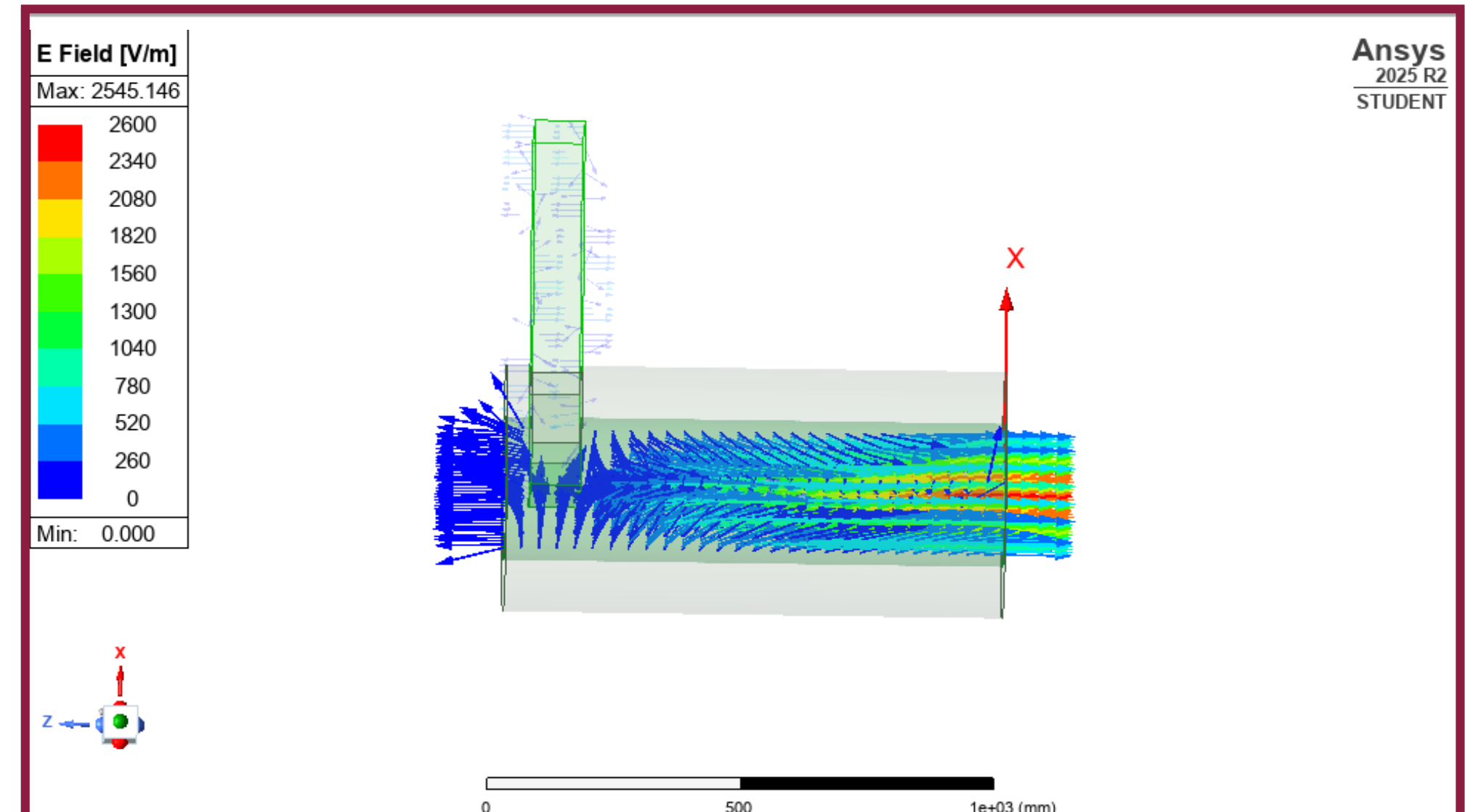


Figure 3: ANSYS HFSS simulation of accelerating cavity and waveguide

## Control System

### PI Control GUI

- Simulated thermal response compared to desired setpoint
- PI controller outputs PWM signal to regulate chilled water valve
- Control algorithm implemented on STM32 microcontroller

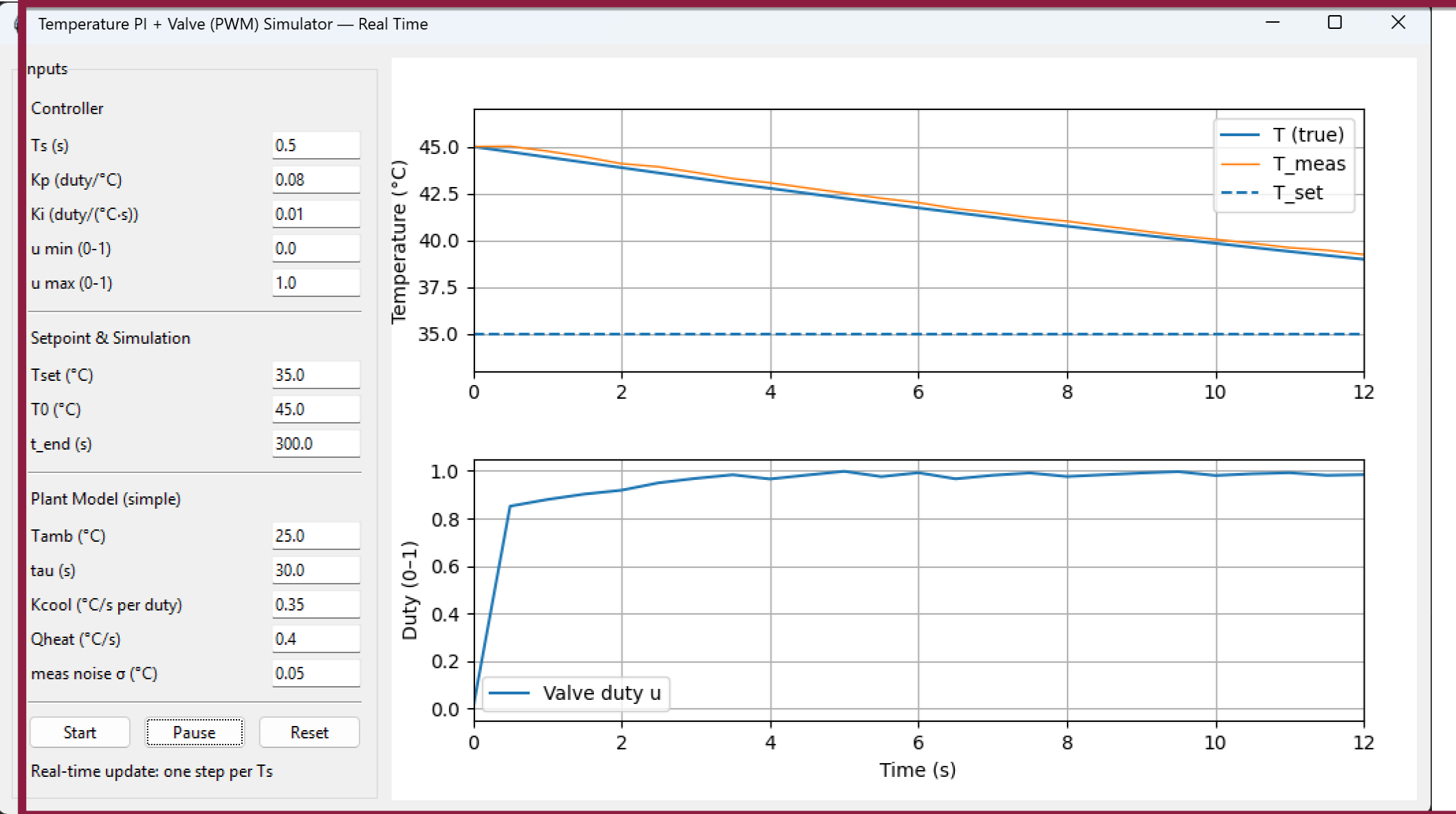


Figure 4: PI GUI showing Temperature Regulation & Duty Output

## Conclusion

### RESULTS

- Tracks temperature, reflection coefficient, and forward power
- PI controller adjusts PWM duty cycle to regulate chilled water valve

### NEXT STEPS

- Validate digital twin against real LANSCE cavity measurements
- Optimize PI controller coefficients to minimize resonance deflections to +/-1%
- Integrate valve mechanism into existing control system
- Extend model to handle beam-loading and multiple cavity coupling