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ENGINEERING AND TECHNOLOGY

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Arduino Temperature Control Lab

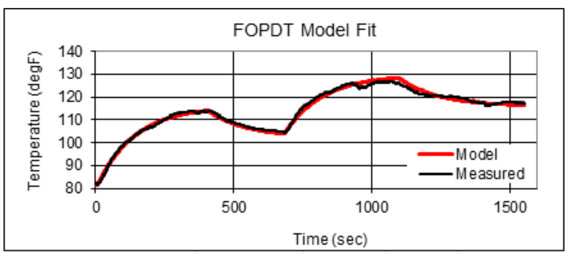
Introduction

An Arduino control board was used in conjunction with a transistor/thermistor system to collect experimental data, build a temperature controller, and develop a first principles model using parameter estimation to describe the system. This experiment demonstrated understanding of process controls principles discussed thus far in the course.

First Order Transfer Function Development

In order to establish parameters for a first order plus deadtime (FOPDT) model of the temperature control system, a doublet test was performed. This experimental data was then used to determine the FOPDT parameters through a minimization of squared error in Excel, resulting in:

K_p = 0.3424 °F/mV
τ_p = 137.8377 seconds
θ_p = 1.7553 seconds



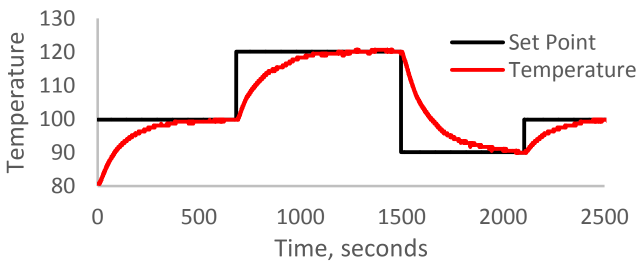
Calculation of Tuning Parameters

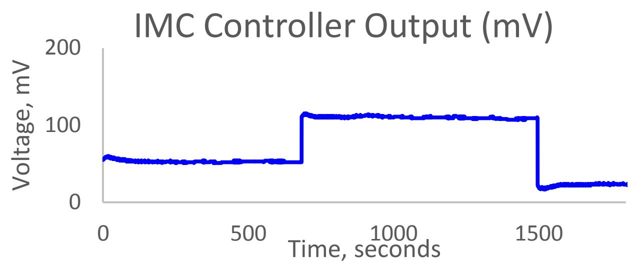
Tuning parameters for a PI controller (K_p and τ_I) were calculated using two tuning methods. The controllers were then tested on the Arduino board, and analyzed for robustness.

IMC for Set Point Tracking:

$$K_c = \frac{0.586}{K_p}\left(\frac{\theta_p}{\tau_p}\right)^{-0.916} \qquad \tau_I = \frac{\tau_p}{1.03 - 0.165\left(\frac{\theta_p}{\tau_p}\right)}$$

K_c = 93.153 mV/°F
τ_I = 134.097 seconds



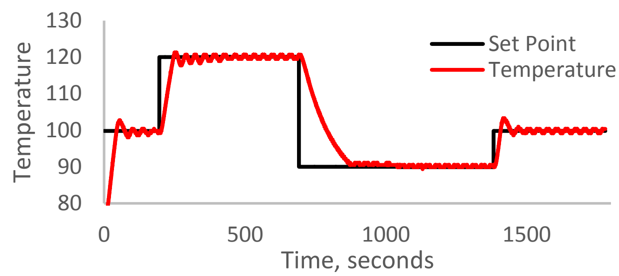


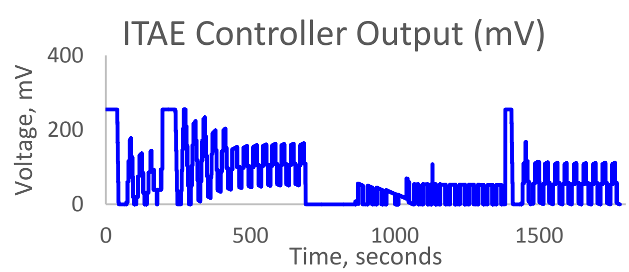
The IMC controller has a rise time of 542 seconds, with an overshoot ratio of 0.28 and very little oscillation in the PV or in the OP. The controller was generally non-aggressive.

ITAE with moderate tuning:

$$K_c = \frac{1}{K_p}\frac{\tau_p}{\theta_p + \tau_c} \qquad \tau_I = \tau_p$$

K_c = 2.884 °F/mV
τ_I = 137.838 seconds





The ITAE controller exhibited a rise time of only 46 seconds, with an overshoot ratio of 0.62. While this controller has a very rapid response, it also showed persistent oscillations in the PV and significant OP movement, even after achieving the set point.

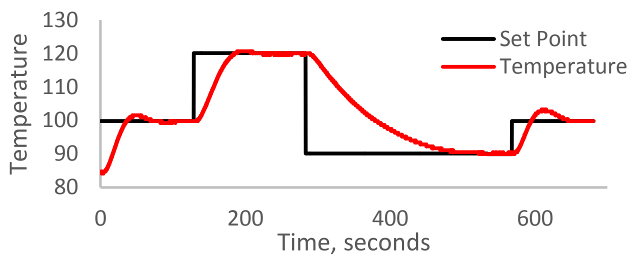
Stability Analysis

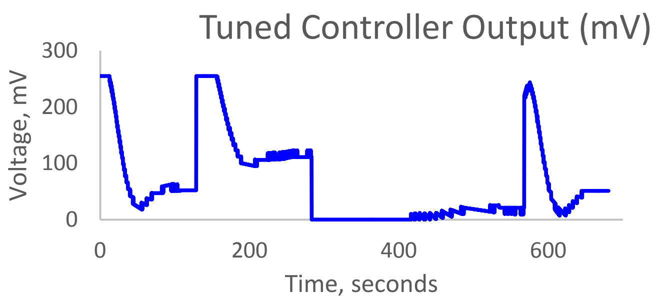
A stability analysis was performed to determine K_c values for which a PI controller would be stable. This was done using a root locus plot. This resulted in a stable K_c range of 1.58 to 464 mV/°F.

Controller Tuning

Using the stability limits and response of ITAE and IMC as guidelines, the PI controller was tuned to balance rise time with oscillatory behavior in both the PV and the OP. The following tuning constants achieved the best response:

K_c = 20 °F/mV
τ_I = 40 seconds





This PI controller resulted in a rise time of only 56 seconds, with an overshoot ratio of 0.028. This response is only 10 seconds slower than the ITAE, but has very little oscillation in the PV or the OP, similar to the IMC.

First Principles Simulation and Parameter Estimation

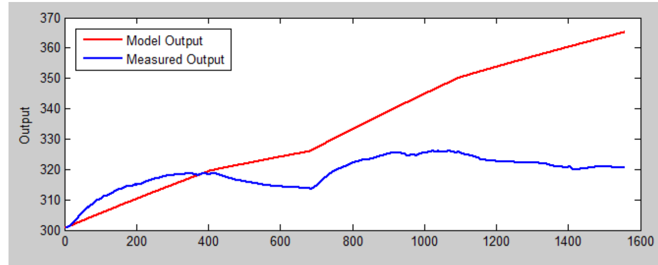
A first principles model was developed to describe the relationship between thermistor temperature and voltage through the transistor.

$$mC_p\frac{dT}{dt} = -hA(T - T_a) + \frac{IV}{1000}$$

In order to simplify the model, the following were assumed to remain constant:

T_a = 80°F = 299.8167 K
A = 6 cm^2 = 0.0006 m^2
I = 1 Amp

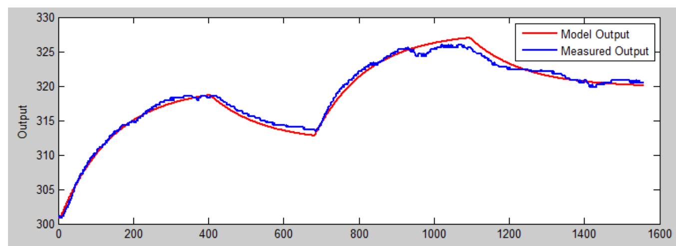
Model inputs of time and voltage resulted in thermistor temperature (T). The model was simulated with guess values of h, m, and C_p.



Using Matlab function fmincon( ), values of h, m and C_p were estimated using the doublet test as measured values.

h = 8.340891 W/m^{2}K
m = 0.001015 kg
C_p = 696.869 J/kgK

The following model fit was achieved:



Comparison of First Principles to Empirical Approach

The first principles model was linearized, and then arranged to a transfer function in the LaPlace domain.

$$\frac{dT'}{dt} = -\frac{hA}{mC_p}T' + \frac{I}{1000mC_p}V' \qquad \frac{T(s)}{V(s)} = \frac{\frac{I}{1000mC_p}}{s + \frac{hA}{mC_p}}$$

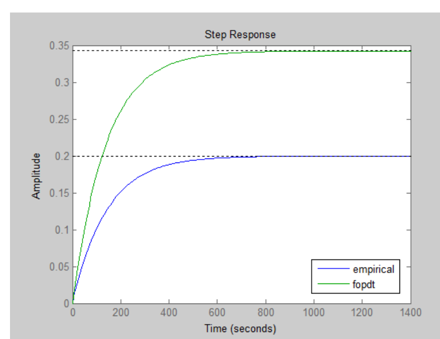
The first principles transfer function was compared with the FOPDT transfer function:

First Principles:

$$\frac{T(s)}{V(s)} = \frac{0.20}{141.34s + 1}$$

Empirical (FOPDT):

$$\frac{T(s)}{V(s)} = \frac{0.34}{137.84s + 1}$$



We see that while there is some discrepancy between the two models, they exhibit the same form, with constants of the same magnitude. The empirical model will better represent the system because of its basis in real data rather than parameter assumptions.