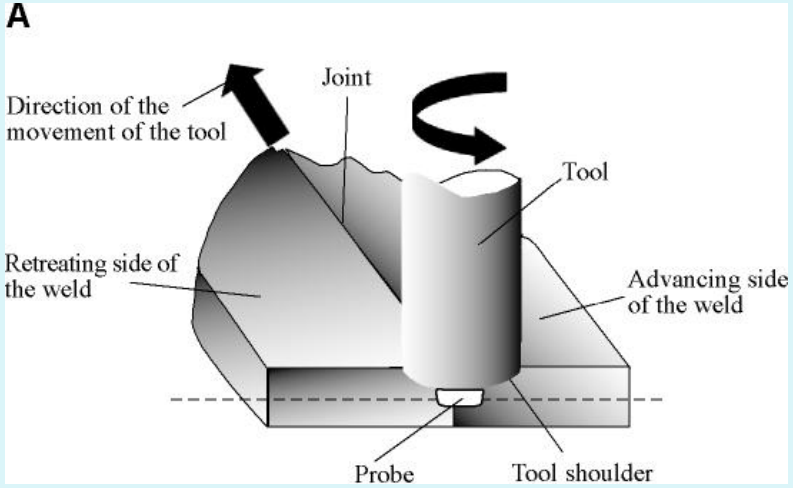
# APM Tutorial with Friction Stir Welding

# Friction Stir Welding Control Overview

- Friction Stir welding is a solid state metal joining process
- A rotating tool creates heat and plasticizes the metal. This allows the metal to be “stirred” around.



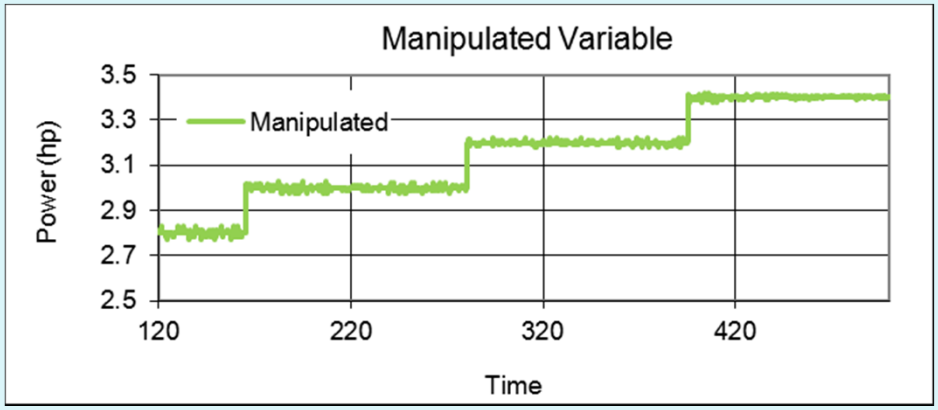

# Friction Stir Welding Applications

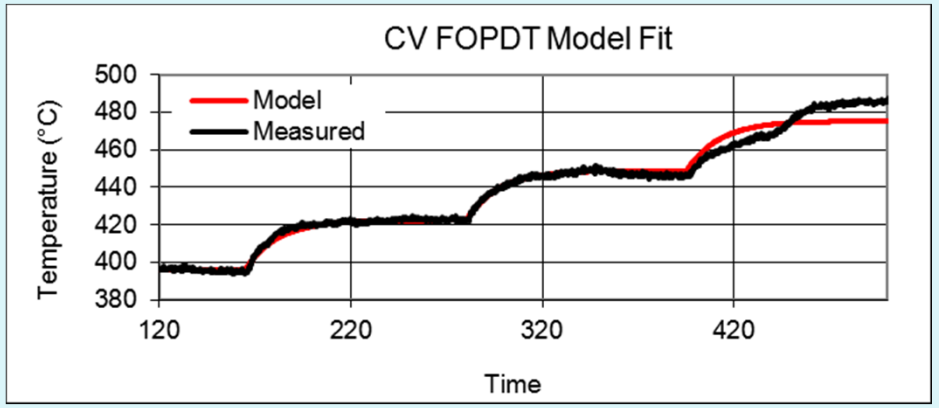
# Tutorial Overview

- Simulation of FSW Process
  - PDE of Tool Heat Transfer
- Estimation with FSW Process Data
  - First order model with variable dynamics
- Temperature Control of FSW
  - Demonstrate in simulation
    - PID (Proportional Integral Derivative Control)
    - MPC (Model Predictive Control)

# FSW Process Model - FOPDT

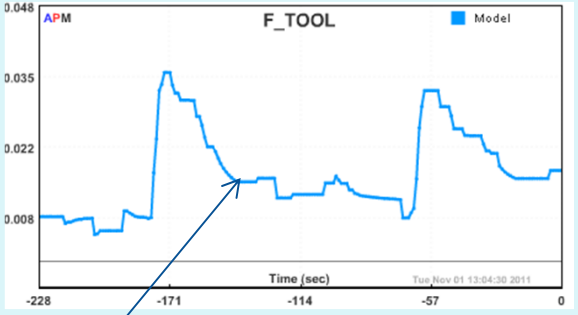
- Model #1 of FSW Process
  - First Order Plus Dead-Time (FOPDT) Model
  - Model predictions on same Aluminum data
  - Gain ($K_p$): 131.7 °C/hp
  - Time Constant ($tau_p$): 16.5 sec
  - Dead-time ($theta_p$): 1 sec

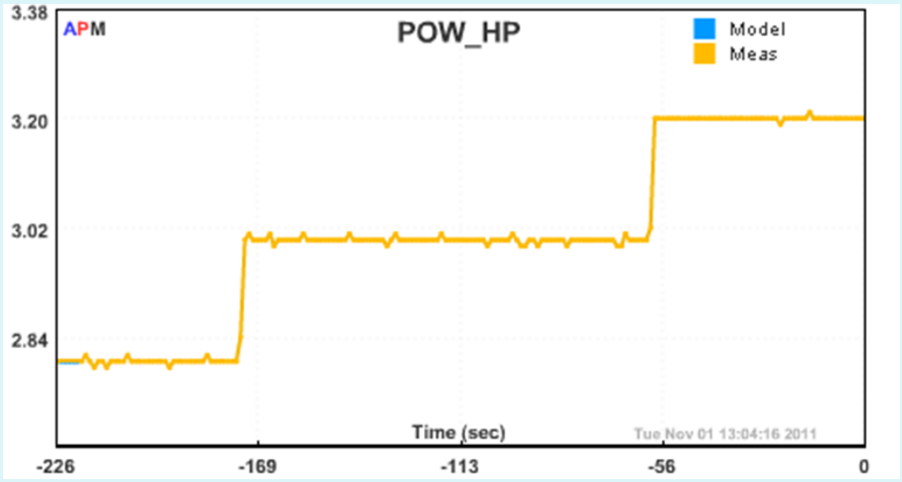


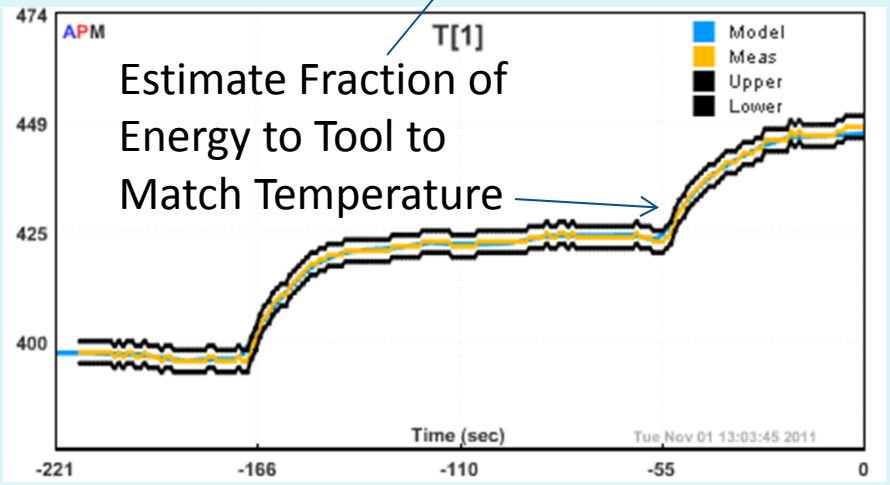



# FSW Process Model – PDE Model

- Model #2 of FSW Process
  - PDE of Tool Heat Transfer
  - Demonstrate model predictions on Aluminum
  - Fit PDE model to process data



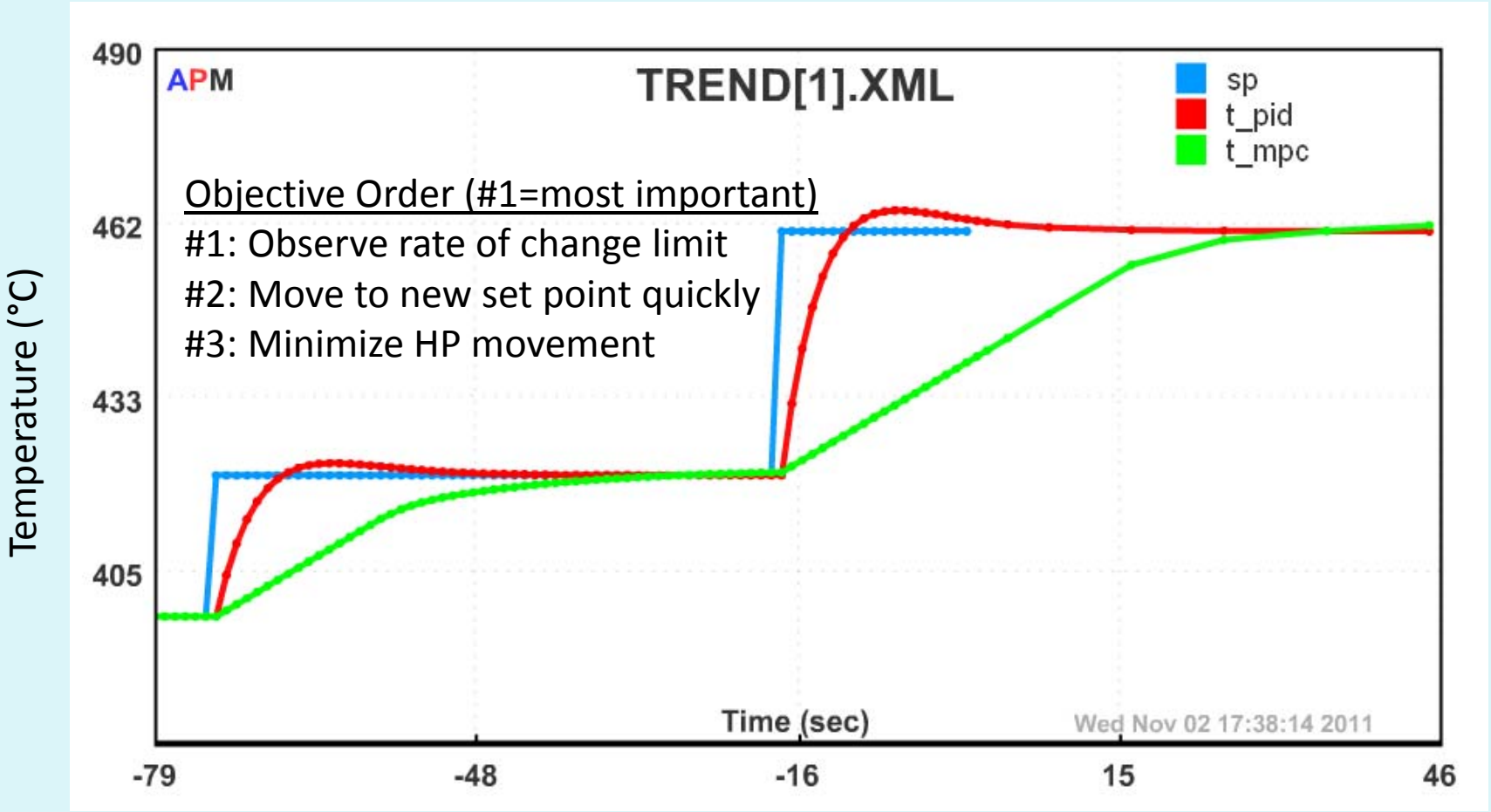




Estimate Fraction of Energy to Tool to Match Temperature

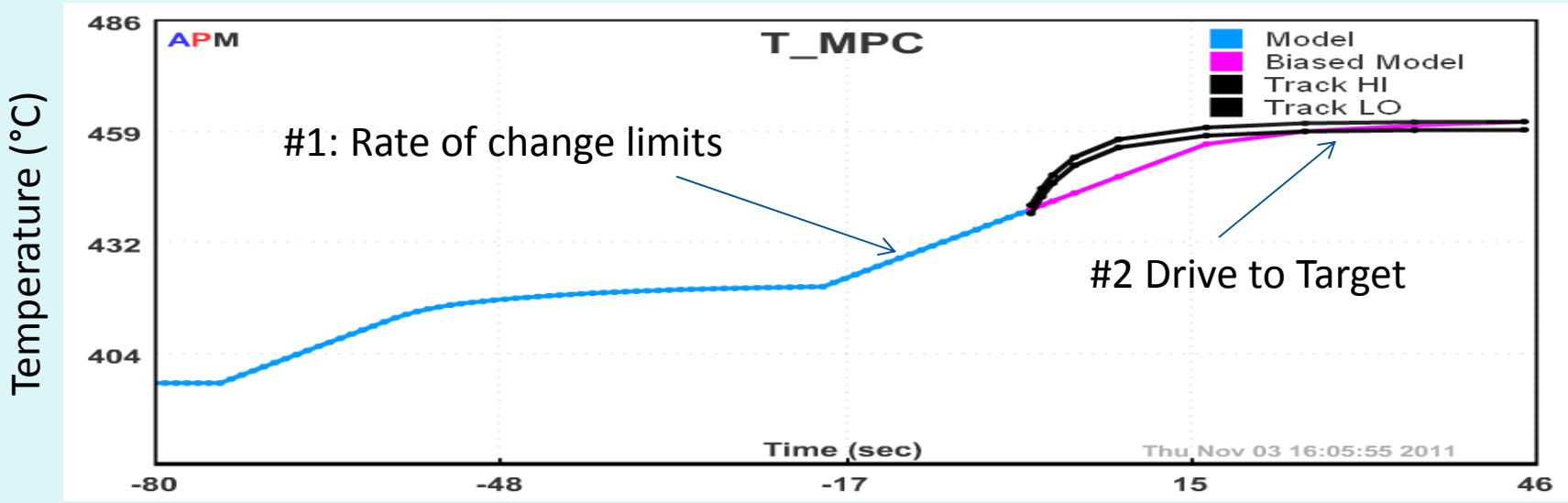
# FSW Temperature Control

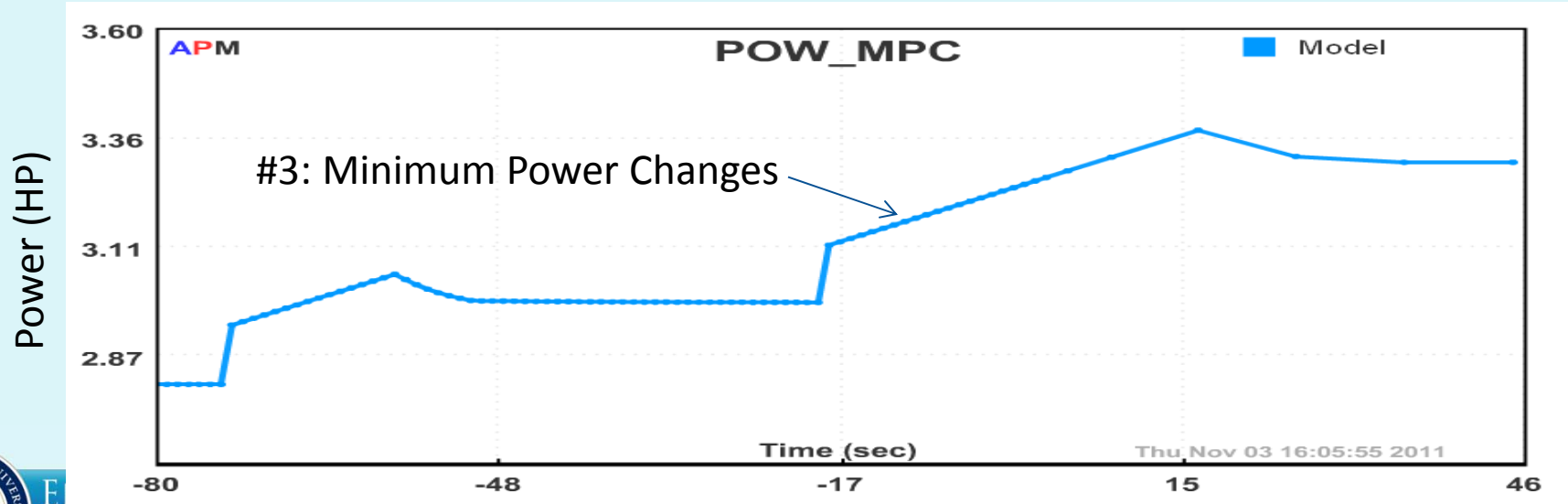
- Current Practice
  - PID Control
  - Start-up procedure
    - Constant rotational speed
    - Manual adjustments to guide temperature
      - Z Axis Force
- Proposed Control Strategy
  - Model based control
  - Automatic control through start-up
    - Limit overshoot
    - Keep process within constraints
      - Rate of change limits for motor power (HP)
      - Rate of change limits for tip temperature

# Comparing PID and MPC

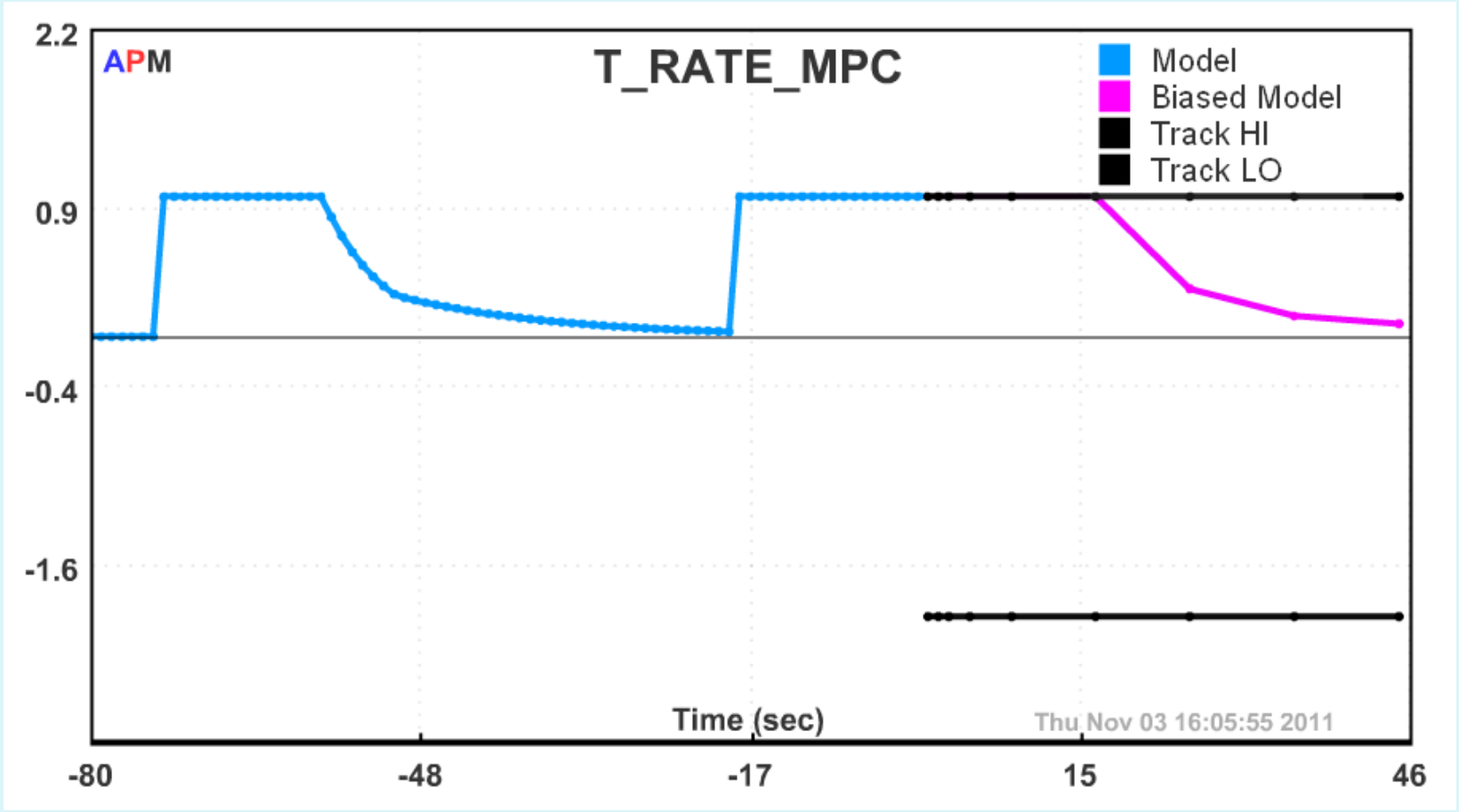


# Model Predictive Control

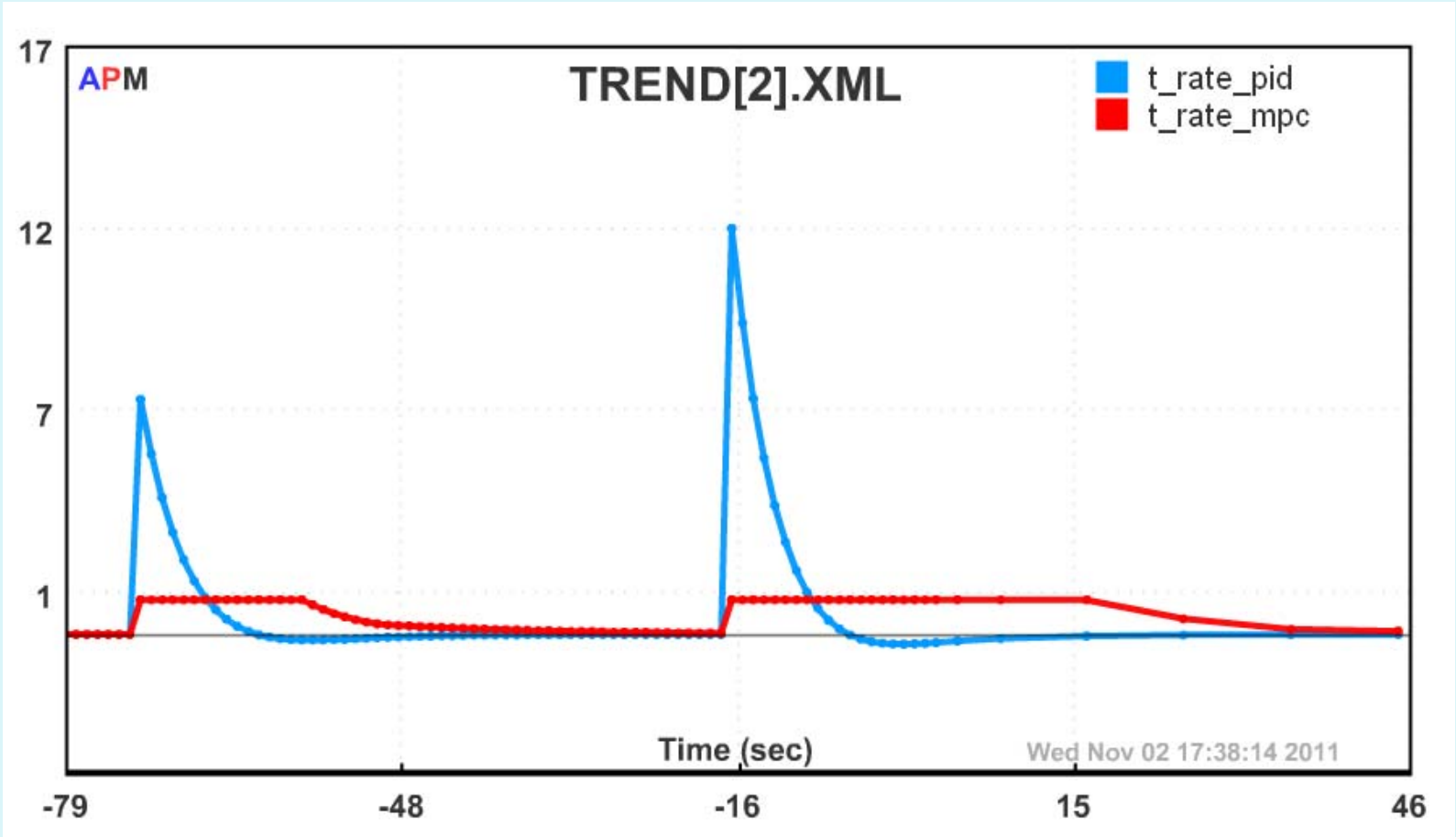


# Operate Within Constraints

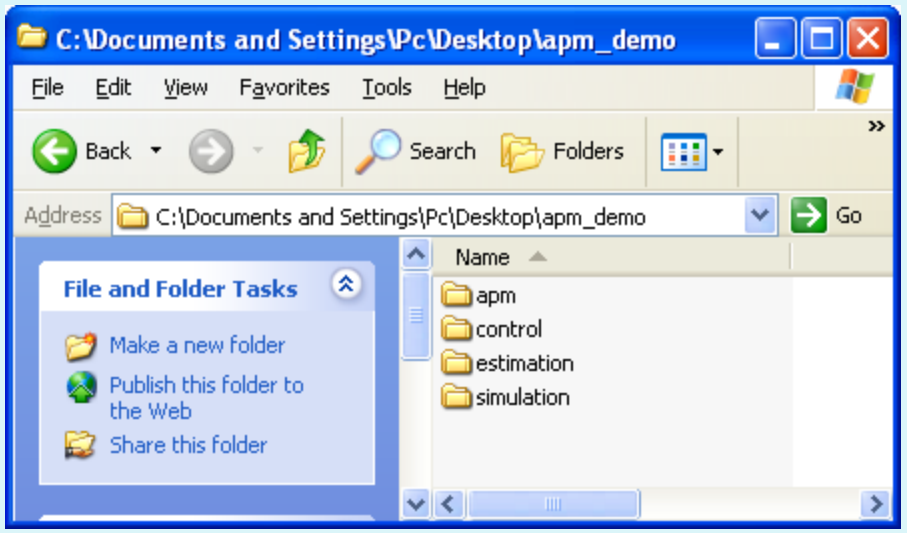


# Rate of Change for PID and MPC



# Download and Run Example Problems

- Simulation
- Estimation
- Control

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