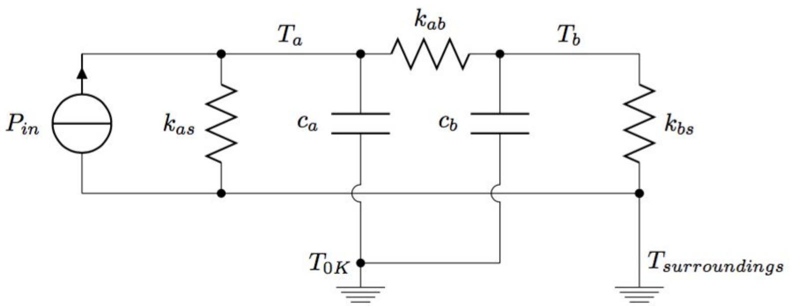
IPB Reactor Calibration

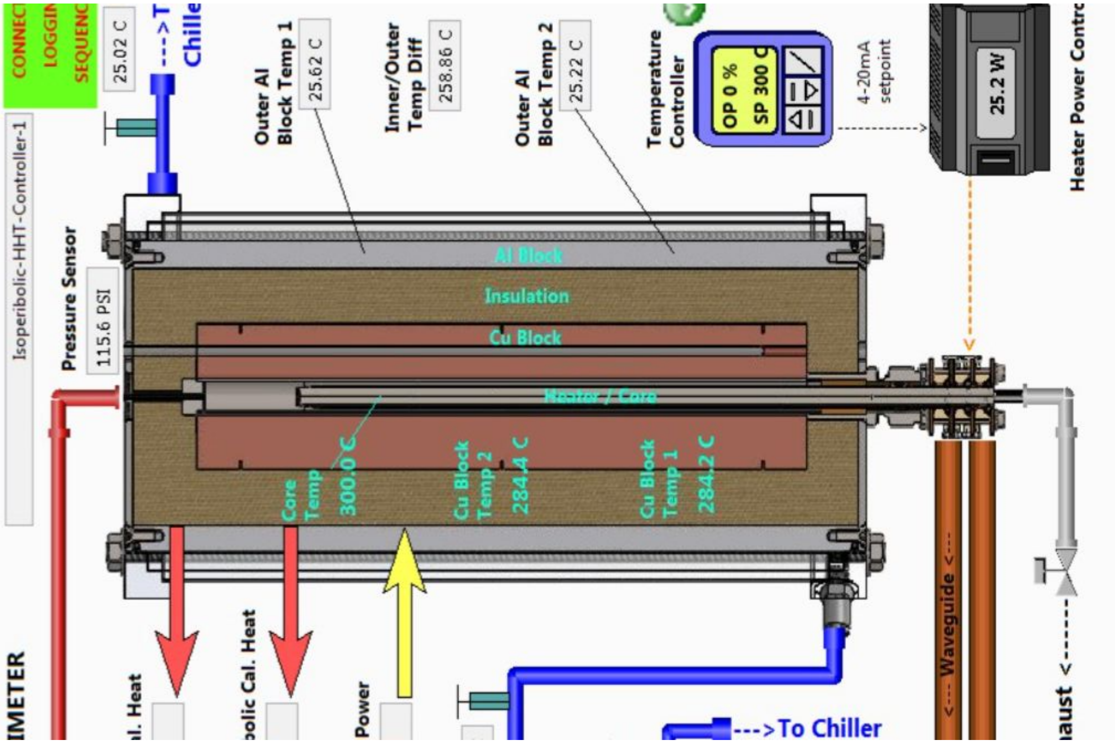
For discussion purposes only
November 2, 2106

Objectives for calorimeter analysis

- **Prepare any claimed result for rigorous review**
  - An error bar on every data point; quantified uncertainty on every claim
  - Employ methods that others with comparable expertise will accept
  - Document the methods and the thread of reasoning from raw data to conclusion
- **During exploration, discover in the data what a human might miss**
  - Use structured model based machine learning to understand the apparatus
  - Avoid the human foible of observer bias
  - During calibration learn the system behavior very well so that during experiments deviations from model predictions can be trusted as significant
- **Specific to this project**
  - Test the hypothesis that COP ~ 1.3 by measuring energy COP to better than +/- 0.03
  - Replicate any significant claim many times
  - Any verified positive result shall include access to apparatus during setup and data acquisition

Proposed equivalent circuit: physical comparison





Proposed equivalent circuit

Two inputs:

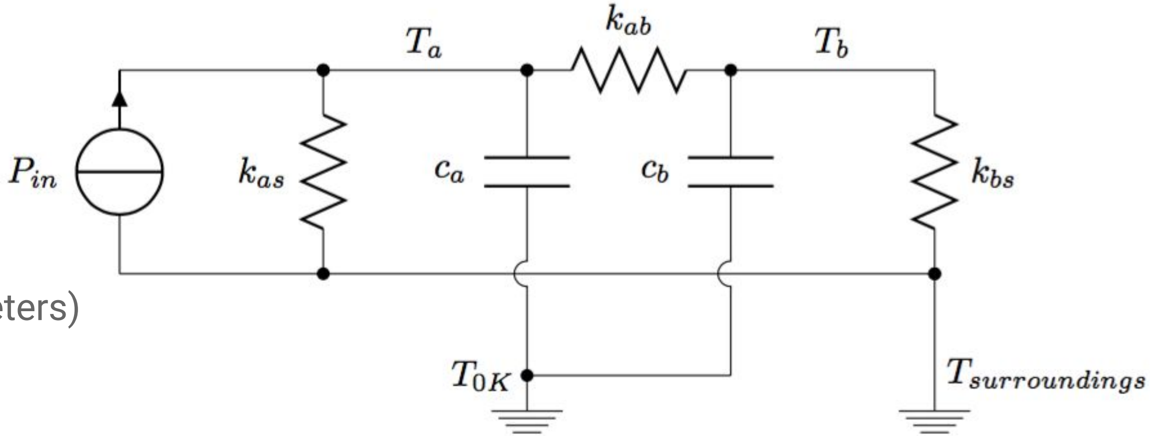
- Input power is the sum of heater power and Q pulse power
- $T_{surroundings}$ is the outer Al block temperature

Two states:

- Ta is the core temperature
- Tb is the inner block

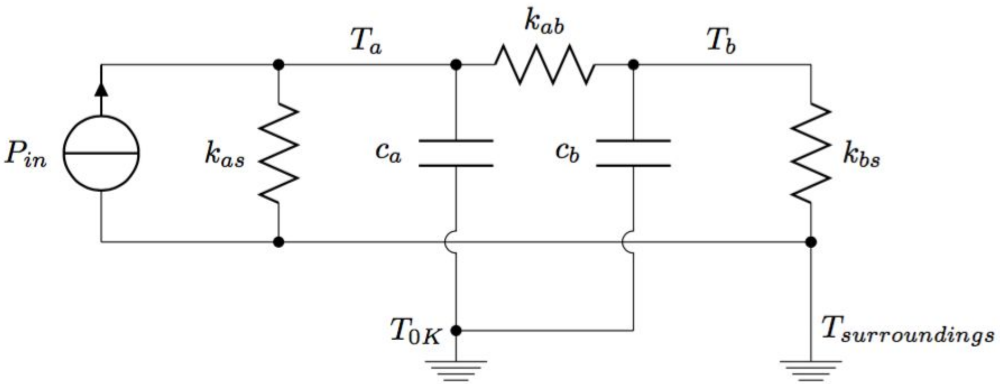
Four elements: (up to twelve fitting parameters)

- Two thermal masses and three conductances
- All elements are capable of fitting non-linearity (in temperature) to second order.



<u>Important reassurance:</u> If the model is not adequate, the calibration will reveal that prior to hypothesis testing

Model differential equation



$$\frac{dT_a}{dt} = \frac{P_{in} - k_{as}(T_a - T_s) - k_{ab}(T_b - T_s)}{c_a}$$

$$\frac{dT_b}{dt} = \frac{k_{ab}(T_a - T_s) - k_{bs}(T_b - T_s)}{c_b}$$

On the method

Grey box

- Structure of the differential equation is known
- Values of model parameters are learned

Nonlinear, time independent:

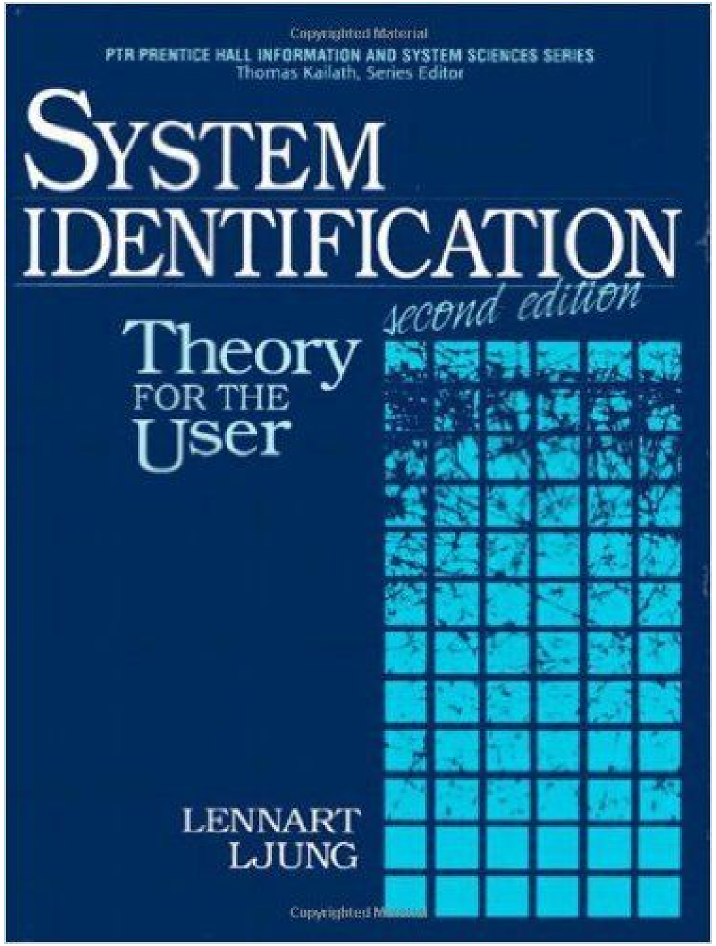
- The model parameters may be temperature dependent, time invariant

System identification

- All time series data are used, the parameters are optimal when the weighted residual error is minimized

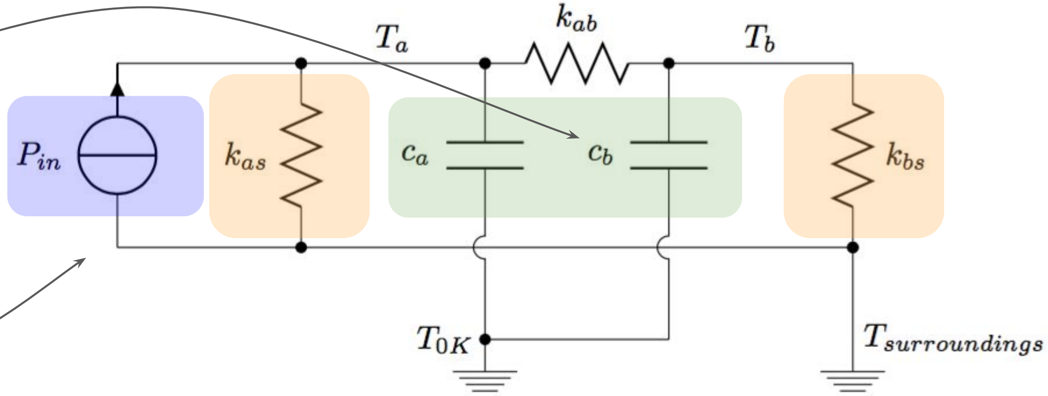
Coefficient of performance

- Modeling of both stored and conducted power
- Instantaneous power and integrated energy COP



Energy COP defined

$$COP_{energy}(t) = \frac{\int_0^t [P_{out}(t) + P_{stored}(t)]\, dt}{\int_0^t P_{in}(t) dt}$$



Example equations for a two state two capacitor model

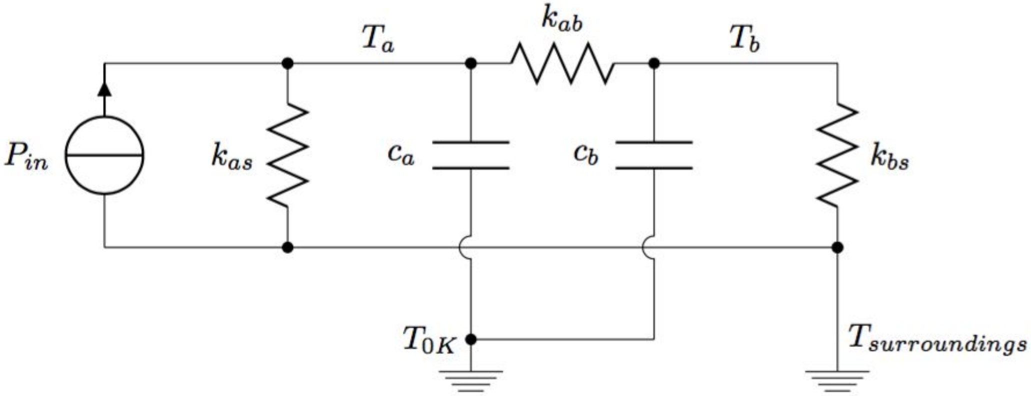
$$P_{out}(t) = k_{as}\,[T_a(t) - T_s(t)] + k_{bs}\,[T_b(t) - T_s(t)]$$

$$P_{stored}(t) = c_a \frac{dT_a(t)}{dt} + c_b \frac{dT_b(t)}{dt}$$

- c's and k's are determined by calibratio
- P_{in} is measured directly and used as an input to solve the model system

Calculation of energy COP

$$COP_{energy}(t) = \frac{\int_0^t [P_{out}(t) + P_{stored}(t)]\, dt}{\int_0^t P_{in}(t) dt}$$



Measured

Calibrated

Calculated

Measured *and* Modelled

$$P_{out}(t) = k_{as}[T_a(t) - T_s(t)] + k_{bs}[T_b(t) - T_s(t)]$$

$$P_{stored}(t) = c_a \frac{dT_a(t)}{dt} + c_b \frac{dT_b(t)}{dt}$$

The measured and modeled temperatures give us what we saw and what we expected to see

What comprises calibration?

Possibilities

- Replace Q pulse with resistive heater
- Replace sample with an inactive material with comparable electrical and thermal properties

Time series data needed

- Heater power
- Q pulse power
- Core temperature
- Inner block temperature
- Outer block temperature

Also nice to have:

- End plate temperature

Next steps