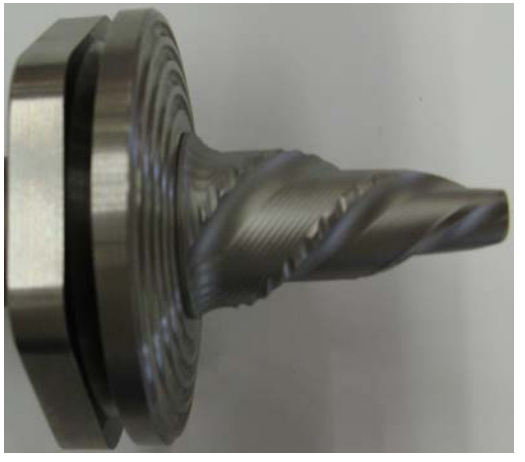
FASTER TEMPERATURE RESPONSE AND REPEATABLE POWER INPUT TO AID AUTOMATIC CONTROL OF FRICTION STIR WELDED COPPER CANISTERS

L. Cederqvist[1,2], R. Johansson[3], A. Robertsson[3], and G. Bolmsjö[2]

[1]Swedish Nuclear Fuel and Waste Management Company (SKB)
[2]Lund University, Division of Design Sciences
[3]Lund University, Department of Automatic Control

Objective & roadmap

- Automatic welding procedure to reliably produce ≥6,000 canisters, starting 2018

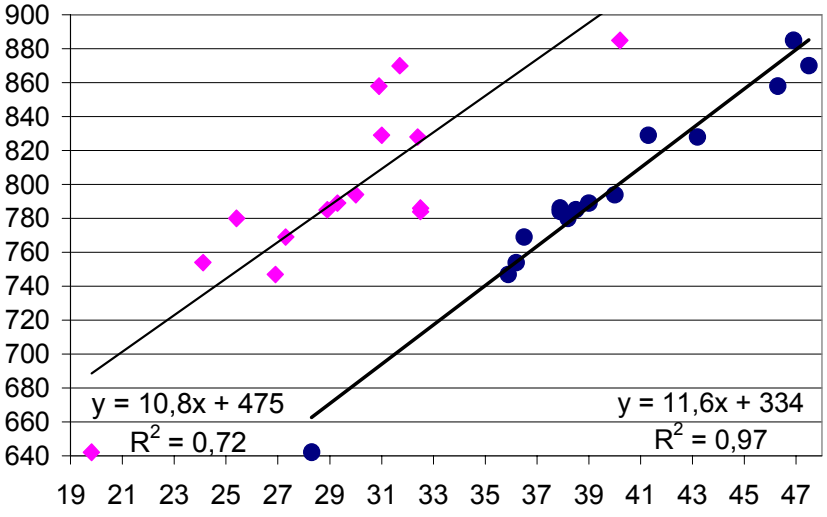


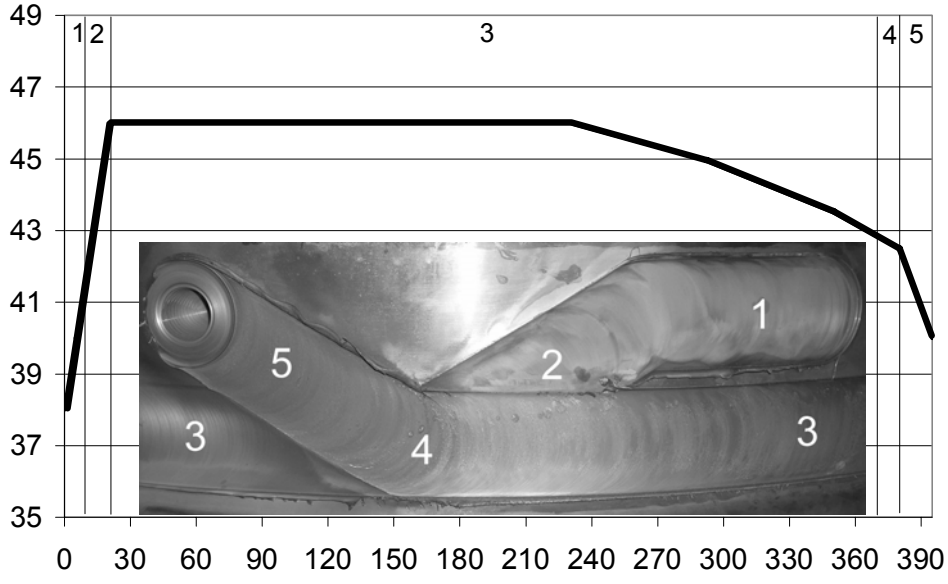
Chosen road:

1. Find most stable tool geometry
2. Find optimal parameters
3. Develop and test software for automatic control

$$\Delta\omega = \Delta\omega_{feedforward} + k_1 \cdot \left(T_{probe} - T_{desired}\right) + k_2 \cdot \frac{dT_{shoulderID}}{dt} + k_3 \cdot \left(Power_{current} - Power_{desired}\right)$$

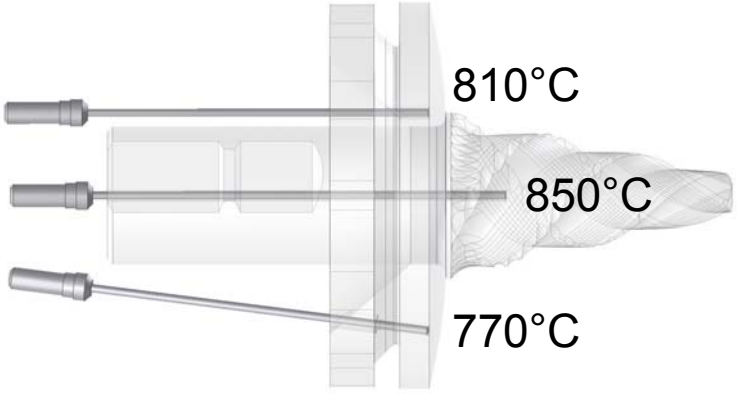
The weld cycle and power input

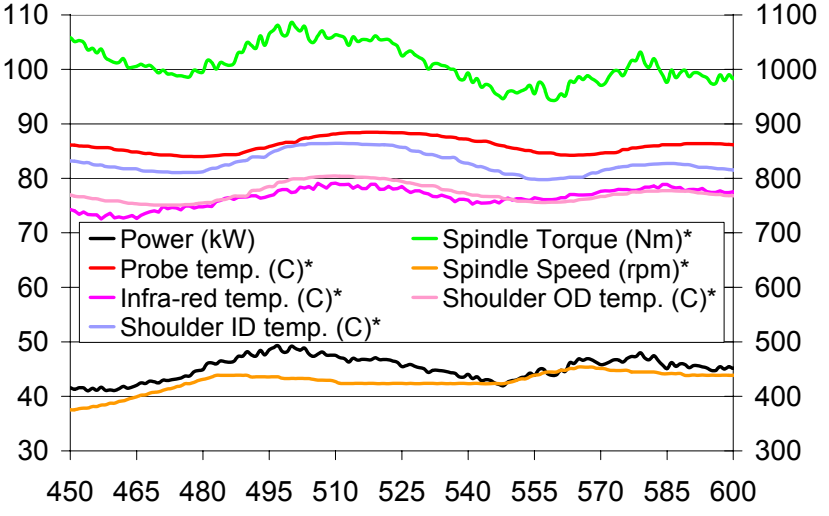




- Sequences in a full-circumferential weld cycle:
  1. acceleration, 2. downward, 3. jointline, 4. overlap, 5. parking
- Required power input, a function of position around lid

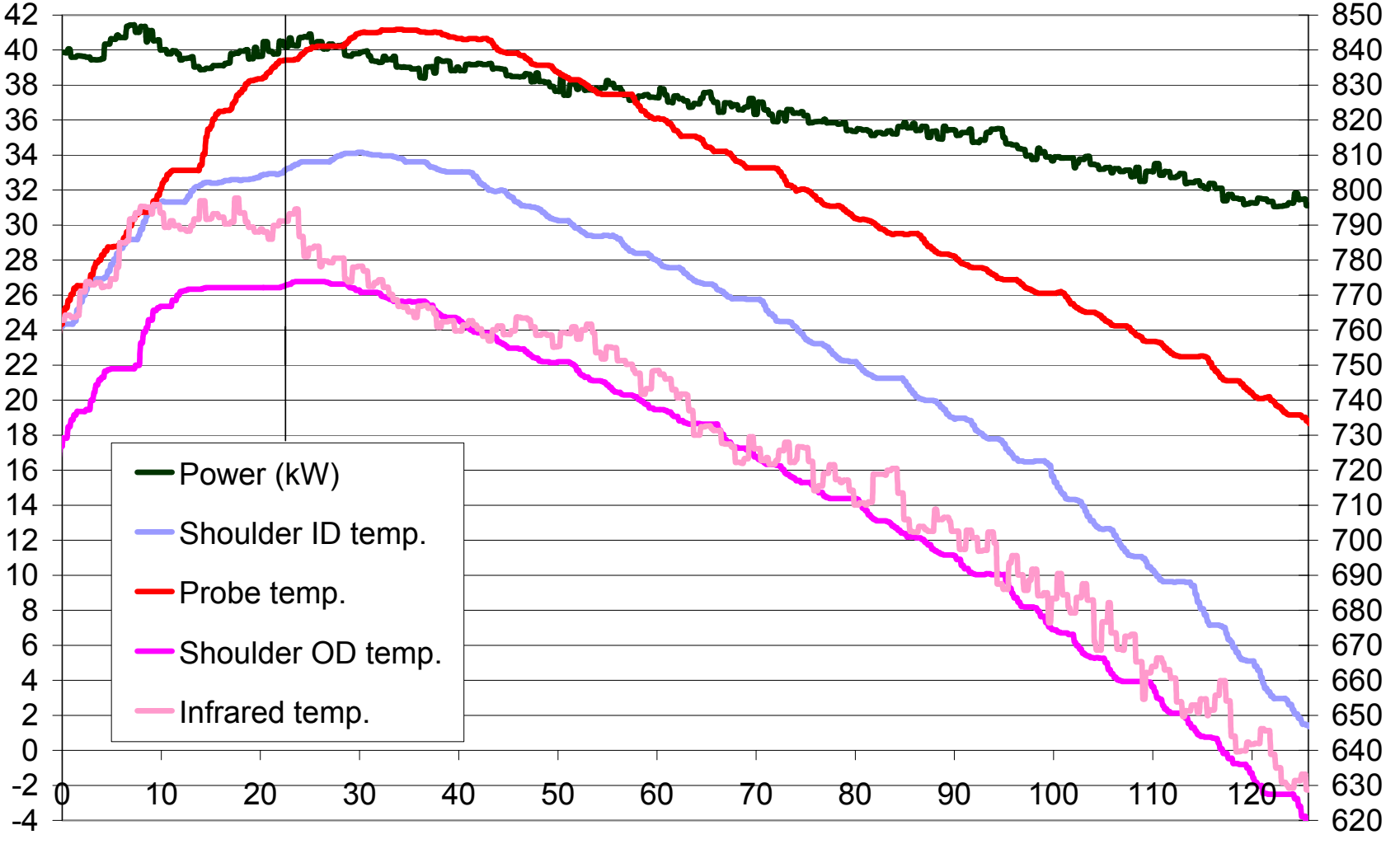
Temperature measurements





- 0, 10, 14 & 21 sec response for IR, ID, OD & Probe
- Process window for Probe temp.: 790-910°C, which results in a desired temp. of 850°C (1562°F)

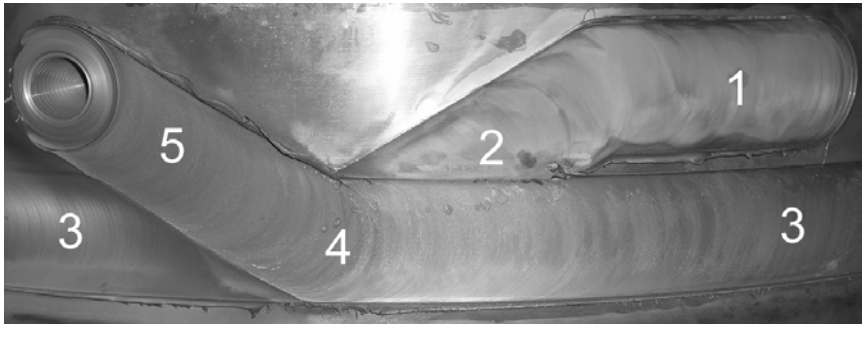
What if no adaptive control?

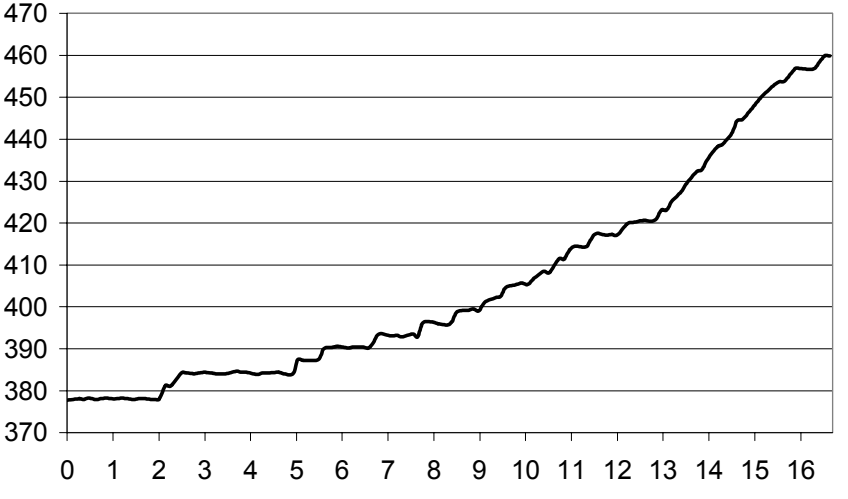


First generation automatic software

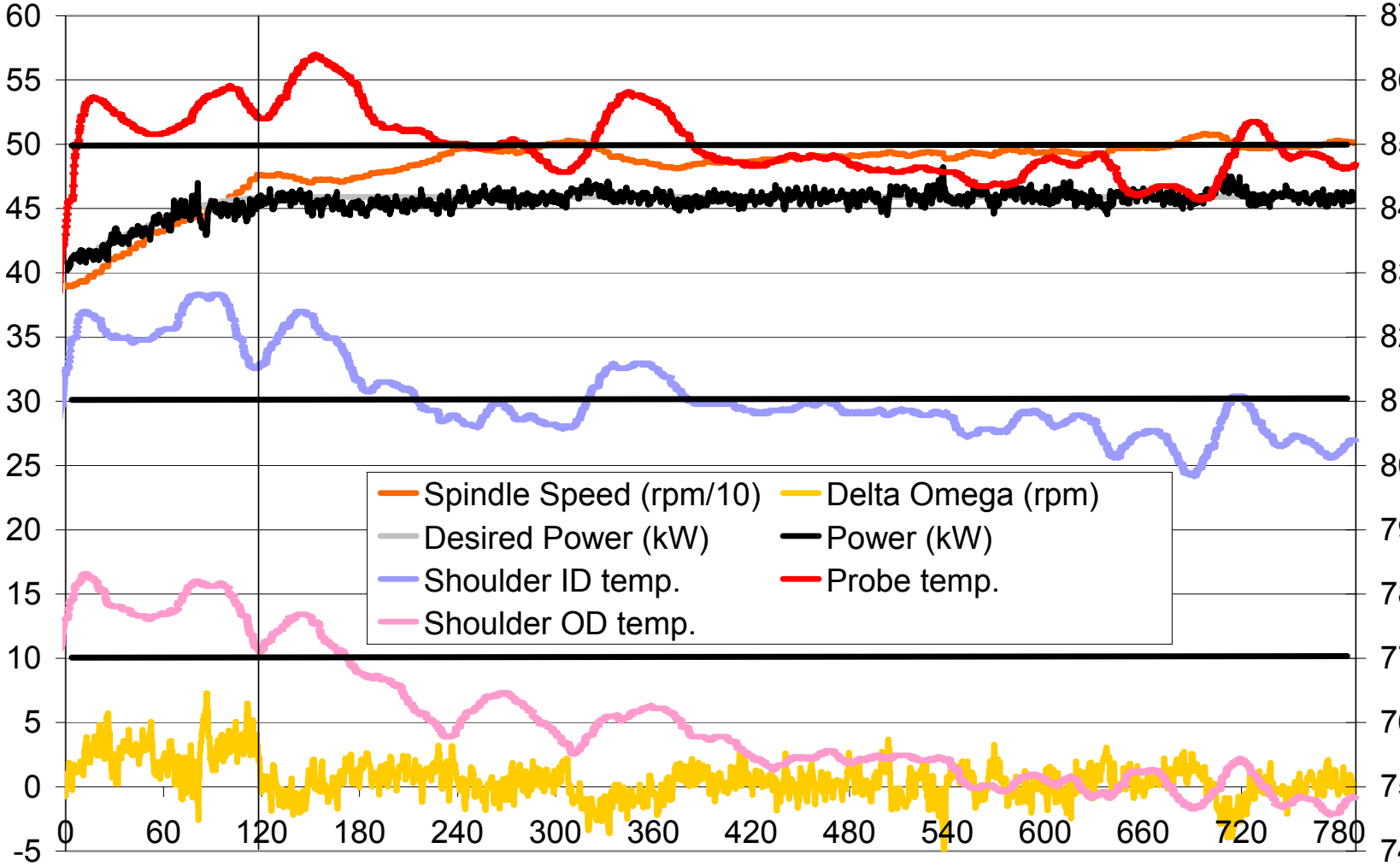
$$\Delta\omega = \Delta\omega_{feedforward} + k_1 \cdot \left(T_{probe} - T_{desired}\right) + k_2 \cdot \frac{dT_{shoulderID}}{dt} + k_3 \cdot \left(Power_{current} - Power_{desired}\right)$$

- Three parts: Feedforward, PID (PD), and Cascade
- Only Power-part used during acceleration sequence
- $\Delta\omega_{feedforward}$ only used during downward sequence
- $T_{desired}$ = 850°C or 810°C





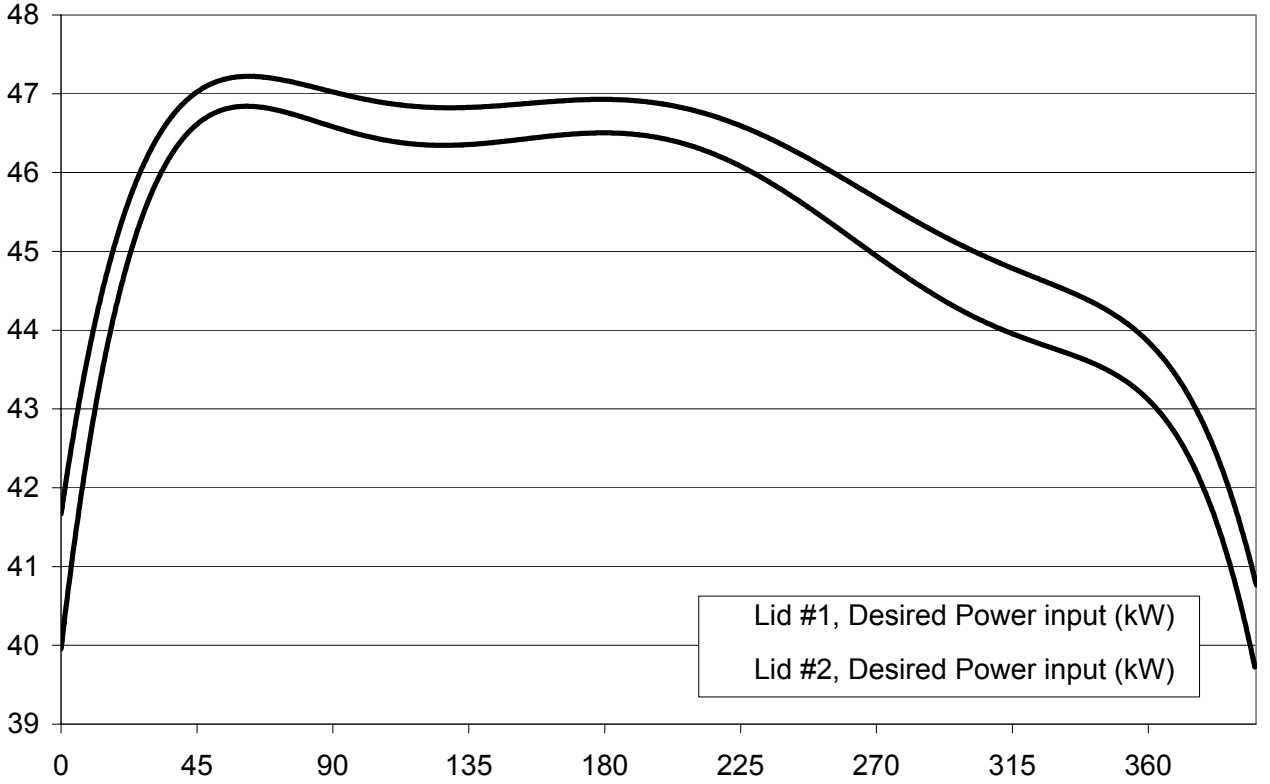
Initial results



$$\Delta\omega = \Delta\omega_{feedforward} - 0.1 \cdot \left(T_{probe} - T_{desired}\right) - 0.25 \cdot \frac{dT_{ID}}{dt} - 2.5 \cdot \left(Power_{current} - Power_{desired}\right)$$

Current issue

- What if unrepeatable required power inputs?
  - Smaller k_3-values and/or use $\frac{dPower_{current}}{dt} - \frac{dPower_{desired}}{dt}$ instead of $Power_{current} - Power_{desired}$?
  - Use IR-temperature reading, value or derivative?



Summary

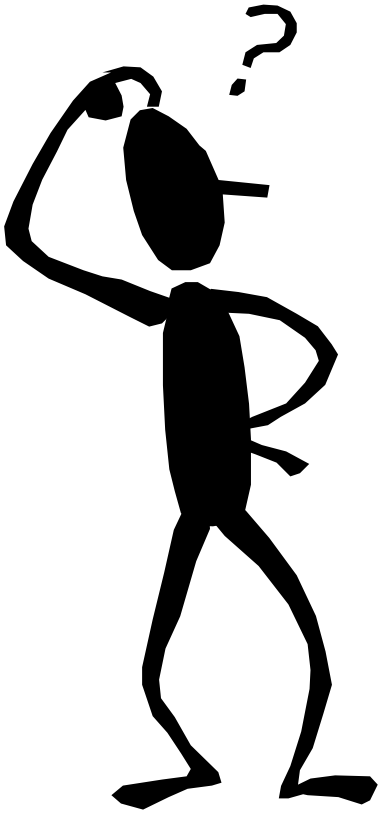
- Less lag/dead time by using $T_{shoulderID}$ instead of T_{probe}
- Most probably, better correlation $T_{shoulderID}$ and voids

Future tests:

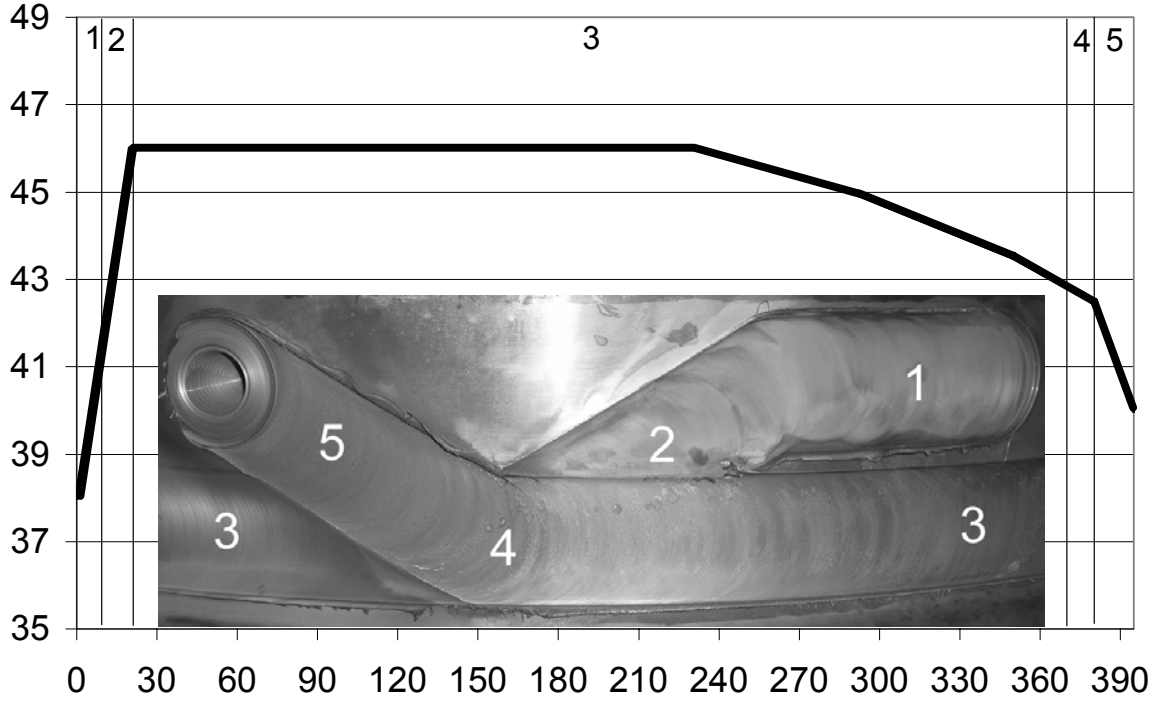
- Need to determine and verify how to use Power in the regulator in the best way possible
- Check repeatability b/w multiple weld cycles and determine k-values, $\Delta\omega_{feedfwd}$ and $Power_{desired}$

$$\Delta\omega = \Delta\omega_{feedforward} + k_1 \cdot \left(T_{shoulderID} - T_{desired}\right) + k_2 \cdot \frac{dT_{shoulderID}}{dt} + k_3 \cdot \left(Power_{current} - Power_{desired}\right)$$

Questions???



The weld cycle and power input



- Sequences in a full-circumferential weld cycle:
  1. acceleration, 2. downward, 3. jointline, 4. overlap, 5. parking
- Required power input, a function of position around lid