Run-to-Run Control: Application to Oxidation Processes

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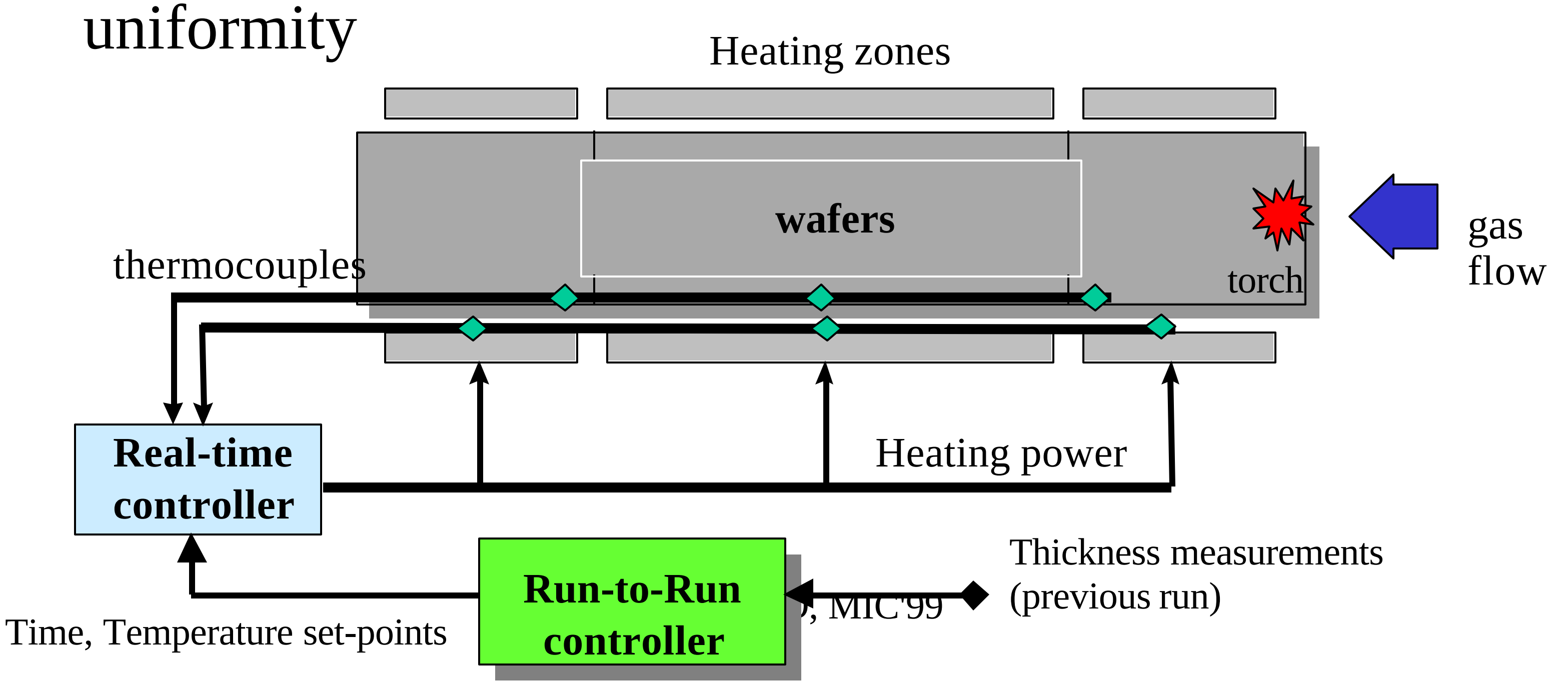
Introduction

- Run-to-Run Control Problem in Diffusion Furnaces
- ARRC Algorithms
  - Control input updates
  - Parameter estimation
- Application to a wet-oxidation test process
- Conclusions

Run-to-Run Control in Diffusion

- Wet oxidation process for silicon oxidation
- Loss of symmetry due to thermal gradients, possible long-term drift
- R2R control inputs: processing time, temperature set-points
- Objectives: minimize deviations from target, across-the-load uniformity



ARRC Algorithms

- SEMY's ARRC (Advanced Run-to-Run Control)
  - Automatic data collection and recipe adjustment

- Modeling: Least squares fit of experimental data

$$q = \arg\min_q \{ \| y_k - f[u_k, q] \| \}$$

  - u_k = inputs/manipulated variables, y_k = measured outputs
  - Issues: Parameterization, Excitation
  - Fitting error: Determines control/adaptation dead-zones

ARRC Algorithms (control)

- Control Updates: Newton-like corrections

$$u_{k+1} = u_k + g_c w_{c,k} e_{c,k} / (1 + g_c w_{c,k}' w_{c,k}), \quad w_{c,k} = \partial f / \partial u$$

  - Standard trade-off between speed of convergence/drift attenuation and steady-state variance
- Nonlinear gain: $g_c = g(e_{c,k}/g_{dz})^2/[1+(e_{c,k}/g_{dz})^2]$
  - Quick correction of large errors, to maintain fast convergence
  - Slow correction of small errors, to keep the steady-state variance small.

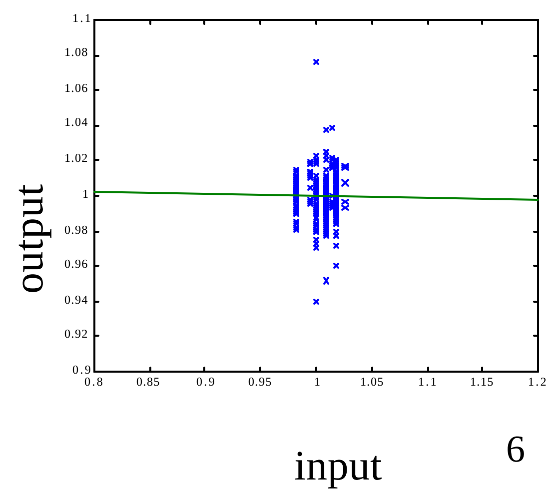
ARRC Algorithms (model adaptation)

- Parameter Updates: Fading-memory least-squares

$$q_{k+1} = \Pi\{q_k + g_p P_k^{-1} w_{p,k} e_{p,k} /(1+g_p w_{p,k}' P_k^{-1} w_{p,k})\}$$
$$P_{k+1} = aP_k + (1-a)Q + g_p a w_{p,k} w_{p,k}'$$

  - $w_p = \partial f / \partial q$, a = fading memory
  - Π: parameter projection on a constraint set
  - Parameter projections and dead-zones are important to provide some immunity to noise-induced parameter drift
  - Ability to perform partial adaptation

• Note: Adaptation constraints are essential since segments of production data may (and do) happen to fit to an opposite slope (insufficient excitation). In such a case, the adaptation may drift to a burst and cause product scrap.

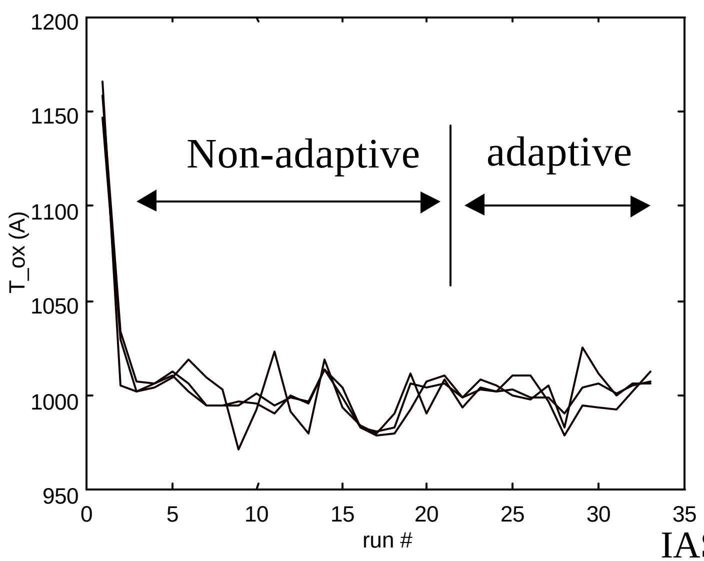


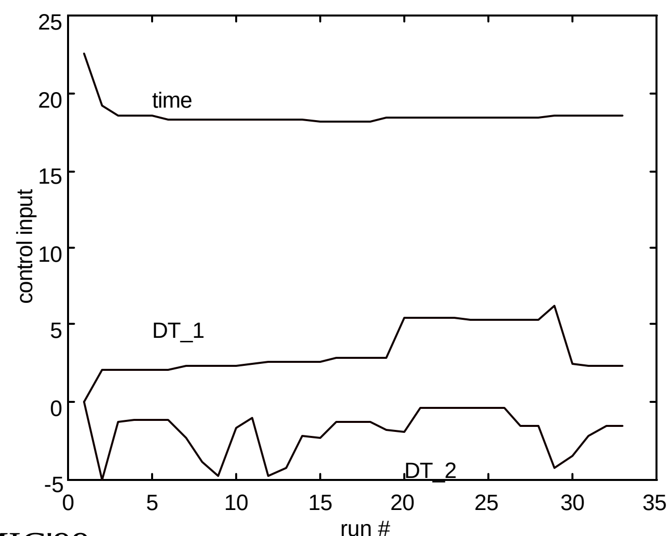
ARRC Implementation

- Wet oxidation test process at AMD
- 22-measurement initial model to establish nominal model parameters and noise variance
- Inputs: Time, Door/Source differential temperature set-points
- Outputs: Center, door, source average thickness
- Diagonal dominance (can use diagonal controller)
- Manual data collection and recipe adjustment (for this test)

ARRC Implementation (results)

- Non-adaptive and adaptive control test
  - Both “center” the process with reasonable steady-state variance (some adjustment of the control gains may be required)
  - Source zone exhibits larger variance (expected)
  - Manual adjustments are error prone! Complete automation in the final ARRC implementation





Conclusions

- Accuracy and uniformity improvement of process results with ARRC
- Integrated, user-friendly tool for modeling, control, model adaptation and any combinations thereof
- Algorithmic and computational reliability
  - Even when supervised, the tool must make correct decisions to be useful
- Complete automation of data transfers and recipe adjustments
- Fully multivariable versions