Model Based Optimization in Process Control - Potentials and Challenges

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Outline

1. Status Quo in BASF
2. Success Stories
3. Vision
4. Challenges and Requirements
Status Quo in BASF Ludwigshafen (I)

Quantity Structure Sensors, Actuators, Control Loops

- 67,000 control loops
- approx. 1,000 APC *)
  - (80% Advanced Analysis)
  - trend: + approx. 50 / a
- potential for modelling support
- approx. 100 Model Based Controllers
  - (95% model development specific for control)

460,000 instruments

*) Definition see papers from NAMUR WG 2.2

Status Quo in BASF (II)

Tendencies Supporting Model Based Process Control

- steady state models for most (new) plants
  - process development,
  - conceptual process engineering
- software for “dynamization“ of steady state models
- relatively small but increasing number of dynamic models for complex plant units
  - operability analysis
  - startup sequences
- complex dynamics by energy and material integration
- training simulators for some plants
Status Quo in BASF (III)
Tendencies Supporting Model Based Process Control

• comprehensive toolboxes for controller design
• Plant Information Management Systems (PIMS) for each plant,
  • all measurements available in long-term archives
    ➔ basis for model identification, ...
• powerful DCS (direct realization of APC or interfaces to powerful systems)

➔ perfect infrastructure to
  implement and supervise
  model based controllers

Status Quo in BASF (IV)
Development of Process Control Models

➔ main effort for applying model based controllers is modelling
➔ main challenge is limited number of available specialists for dynamic modelling
➔ need for software based modelling support

Albert Einstein:
„A model should be as simple as possible – but no simpler“

➔ a model should be as perfect as necessary
  - modelling effort
  - (implementation and) maintenance effort
➔ efficient modelling depends on
  - required model scope and model quality
  - already existing models for other purposes
  - automation infrastructure
**Status Quo in BASF (V)**
Development of Process Control Models

- **Real Process**
  - Rigorous dynamic modelling
  - Training simulator
  - Operability analysis
  - Startup investigation

- **Process Control Model**
  - Model identification (open loop, closed loop)
  - Model reduction
  - Empirical modelling
  - Grey box modelling

**Success Stories (I)**
Development of process control models

- **Real Process**
  - Rigorous dynamic modelling
  - Training simulator
  - Operability analysis
  - Startup investigation

- **Process Control Model**
  - Model identification (open loop, closed loop)
  - Model reduction
  - Empirical modelling
  - Grey box modelling

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Success Stories (II)
Control of Semibatch Reactors

Initial situation: best PID control

Modelling for flatness based control:
- Calorimetric reactor model
- Detailed model of cooling system

Success Stories (III)
Flatness Based Control of Semibatch Reactors

- Flatness based control of semibatch reactors enables
  - significant better temperature control
  - higher reproducibility of batches
  - significant batch time reductions

- High control performance requires high state estimation quality
  - Detailed modelling of cooling system necessary
  - Model reduction

- Orthogonal collocation for cooling systems with constant coolant flow rate
- Finite differences for fluctuating coolant flow rate
Success Stories (IV)
Control of Plug-Flow Reactor

Problem: heavy oscillations e.g. after load changes
Cause: strong dynamic coupling between flow and conversion
Solution: model based analysis and robust control

Initial situation

New control

Result: + 8% capacity

Success Stories (V)
Development of process control models

Real process

Rigorous dynamic modelling
- training simulator
- operability analysis
- startup investigation

Reuse steady state flowsheet
(plant structure, physical properties)
Dynamization by supplement of buffers, holdups, controllers

Empirical modelling
Grey box modelling

Model identification
(open loop, closed loop)

Model reduction
-> reduction of apparatus and chemical components

Model identification
(open loop, closed loop)

Process control model
Success Stories (VI)
Dynamic Simulation for Design of Process Control Concepts

- Starting point: steady state flowsheet
- Aim: efficient development of dynamic simulation
- Comparison:
  - reuse of plant structure, physical properties, supplement buffers, holdups, manual reduction of apparatus and chemical components
  - reuse only physical properties, reimplement simplified process model -> faster!
- Dynamic modelling 10x faster as 2000
- Advanced analysis ⇒ 2 PID + 2 injections for approximate decoupling
- Consideration of control concept in early phase of plant engineering

Further need: Configurable model transfer from steady state flowsheet to dynamic simulator -> model reduction
Success Stories (VIII)
Development of process control models

- real process
- rigorous dynamic modelling
  - training simulator
  - operability analysis
  - startup investigation
- reuse steady state flowsheet
  (plant structure, physical properties)
  Dynamization by supplement
  of buffers, holdups, controllers
- empirical modelling
  grey box modelling
- model identification
  (open loop, closed loop)
- model reduction
  -> reduction of apparatus
  and chemical components
- model identification
  (open loop, closed loop)

Success Stories (IX)
Model identification

- 95% educt from
  recovery section
- Educt and water
  From recovery section
- fresh educt
- control valves
- controlled variables
- level measurement
- density measurement
- column reflux
- to synthesis section
- activation of
  new control concept

- Controlled variables: density, level
- Manipulated variables: valve positions for educt and water supply
- Linear 2x2 model derived from historical PIMS data
  - closed loop identification
  - without step tests
- New controller delivers significantly reduced variance
  ⇒ No need for more detailed model or more effort
**Model Based Control in Life Cycle of a Process**

Product Development → Process Development → Engineering → Operation

- **Challenge:** time pressure in projects
- **Challenge:** uncertainties
- **Available:** measurement data

**Contributions to Operational Excellence in all phases**

**Vision:**
Efficient Re-Use of all Model Information by Consistent Model Database

Models Used During Life Cycle
[Bausa, Dünnebier: Life Cycle Modelling in the chemical industries: Is there any reuse of models in automation and control? ESCAPE 2006]

- **Operator training:** Dynamic
- **Control concept:** Dynamic
- **Dynamic optimization:** Dynamic
- **Data reconciliation:** Steady-state
- **Observer:** Dynamic
- **Diagnosis:** Dynamic
- **Soft sensor:** Steady-state
- **Online-optimization:** Steady-state

**Process development:** Steady-state
**Unit design:** Steady-state
**Loop-Pairing:** Steady-state

**Design** → **Operation**
## Challenges and Requirements (I)

**Aim in industry:** Maximization of added value  
**Modelling requires trade-off between**

<table>
<thead>
<tr>
<th>Modelling effort</th>
<th>Model transparency for different target groups</th>
</tr>
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<tbody>
<tr>
<td>-modelling effort</td>
<td>-modelling effort for different target groups</td>
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<tr>
<td>-integrated software platform</td>
<td>-model transparency for different target groups</td>
</tr>
<tr>
<td>-steady state simulation, dynamic simulation, model reduction and identification, controller design</td>
<td>-model transparency for different target groups</td>
</tr>
<tr>
<td>-pragmatic „80/20“ approach</td>
<td>-model transparency for different target groups</td>
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<th>Model accuracy and robustness</th>
<th>Model maintainability in plant life cycle (especially plant changes, …)</th>
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<tr>
<td>-online model check</td>
<td>-complexity</td>
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<td>-event based model updates</td>
<td>-ownership of models (Responsibilities are spread over the organization)</td>
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<td>-fallback concepts</td>
<td>-life cycle of modelling, simulation and control software -&gt; compatibility for years</td>
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## Challenges and Requirements (II)

- **In Process industry,**  
  Process control starts with a capital P and a small c

- Important to understand first the process and then to start with the control part

- Need for  
  - intelligent software  
  - qualified process engineers from universities  
  - modelling know-how
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