Experimentelle Validierung einer algorithmischen Systemsynthese

TOR Workshop 2015

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Content

- Design of Optimal Technical Systems via MIP
- Modelling Physical Restrictions
- Abstraction of Physical Reality
- Validation with Test Rig
Real Life Application

PRESSURE DECREASES WITH HEIGHT

Upstream 6 bar

2.6 bar
2.9 bar
3.2 bar
3.5 bar
3.8 bar
4.1 bar
4.4 bar
4.7 bar
5.0 bar
5.3 bar
5.6 bar
5.9 bar

12th
11th
10th
9th
8th
7th
6th
5th
4th
3rd
2nd
1st
ground floor

WATER PRESSURE

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Technical System with Optional Components

- TANK (SOURCE)
- TANK (SINK)
- ACCUMULATOR
- PROPORTIONAL VALVE
- PUMPS in size S, M, L

OPTIONAL COMPONENTS
Two Stage Decision

Stage 1: Design

Stage 2: Control

Time-varying load

FLOWRATE

TIME

Anticipation

The design allows and prohibits several control options
Physical Restrictions

- Graph $G = (V,E)$

- Purchase indicator $b_{i,j} \in \{0,1\}$

- Activation indicator $a_{i,j} \in \{0,1\}$ with $a_{i,j} \leq b_{i,j}$

- Volume Flow Conservation:
  \[ \forall v \in V: \sum_{(i,v) \in E} Q_{i,v} = \sum_{(v,j) \in E} Q_{v,j} \]

  \[ \forall (i,j) \in E: Q_{i,j} \leq Q_{\text{max}} \cdot a_{i,j} \]

- Pressure Propagation:
  \[ \forall (i,j) \in E: p_j \leq p_i + \Delta p + M \cdot a_{i,j} \]
  \[ p_j \geq p_i + \Delta p + M \cdot a_{i,j} \]
Technical Restrictions

PIECEWISE LINEARIZED COMPONENT CHARACTERISTICS

Flow Graph

TIME EXPANDED NETWORK

TIME
Accumulator:

\[ \forall (i, t, j, i, t_k) \in E, j < k: \quad p_{i, t_k} = \frac{Q_{i, t, j, i, t_k} \cdot \Delta t}{\pi r^2} \]

Physical Restrictions

\[ t_2 = t_1 + \Delta t \]
Abstraction of Physical Reality

- Linearization
- Quasi-stationary flow

⇒ Modeling error?
Test Rig

Rebuild possible topologies in reality
Measurements

- Volume flow measured by magnetic flow meter with tolerance range of 1 l/min ≈ 0.006 m³/h

- Pressure measured by manometers with tolerance range of 0.01 bar ≈ 0.1 mH₂O

- Data points mean value of 10,000 samples collected within 10s
Experimental Validation

- Three test cases
- Three different time-dependent flowrate demands
- Rebuild computed topology
- Use computed control strategy

⇒ Is the demand met?
⇒ Are the predicted optimal energy costs met?
Test Case 1

Optimal solution:

Pump M fulfills the load

predicted: 478.14 €
measured: (484.23 ± 9.57) €
Test Case 2

Optimal solution:
Pump L, accumulator and valve fulfill the load

predicted: 537.57 €
measured: (584.27 ± 27.91) €
Test Case 3

Optimal solution:
Pumps S and M fulfill the load

predicted: 3436.27 €
measured: (3486.32 ± 59.85) €
Results

- Satisfying agreement of predicted and measured values
- Biggest deviation for solution with accumulator and valve
- Can an optimum be validated?

(Source: KSB AG)