Turning Data to Models:
A Vision on Intelligent Information Systems

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Contents

1 Introduction/Motivation

- IT plays a leading role in productivity improvement in oil, gas and chemical industries
- Real time databases (e.g. PI) form the base of IT technology in manufacturing industries
- (Dynamic) Models are valuable entities for process simulation, monitoring, control and optimization
- Models can be obtained from real-time data — *system identification*
- Basis of an intelligent (adaptive) information system:

Real-time database + Modeling/identification modules

2 The MPC Problem

- A large size MPC controller can make $1.5 million benefit per year
- However, to commission and to maintain MPC system are costly
- The most difficult and time consuming part of MPC projects are modeling and identification
  - To test a crude unit or an FCCU will need 20 days = 60 man days!!!
  - Data analysis and model identification cost another 20 man days!!
  - Open loop and manual tests are difficult!
  - Open loop tests disturb unit operation!!!
  - Conflict between control group and operation personnel!

3 A Solution: Adaptive Identification Module

- Four Components:
  1) A real-time database (e.g. PI)
  2) A controller performance monitor
  3) A testing/excitation program (need to write to MV tags)
  4) A recursive model identification algorithm

- Three important tasks:
  1) Automatic and closed-loop tests (instead of manual and open loop)
  2) Automatic model identification (instead of manual …)
  3) Automatic model validation/selection (instead of manual …)

3 A Solution: Adaptive Identification Module (Cont.)

- Why Close-Loop Identification?
  1) Reduce disturbance to process operation
  2) Shorter test, easy to carry out
  3) Better model for control

- Misunderstandings about closed-loop identification
  1) The process is not identifiable using closed-loop test data
  2) MV signals should be independent

4 ASYM Method of Identification (Tai-Ji ID)

1) ASYM Identification Test

- Signals: **GBN (PRBS)**, filtered white noise, Schroeder, …
- Operator intervention allowed
- Automatic closed-loop test (open loop is a special case)
- Optimal signal spectrum

$$\Phi_r^{opt}(\omega) \approx \mu\sqrt{\Phi_r(\omega)\Phi_v(\omega)}$$

- Test design examples

Processes	GBN switch time	Test time
Crude Unit (15 ~25 MV's)	50 ~ 60 min.	90~120 hours
FCCU (15 ~25 MV's)	50 ~ 60 min.	90~120 hours

2) ASYM parameter estimation

A) Estimate a high order ARX model

$$\hat{A}^n(z^{-1})y(t) = \hat{B}^n(z^{-1})u(t) + \hat{e}(t)$$

B) Frequency weighted model reduction by minimizing

$$\sum_{i=1}^{p}\sum_{j=1}^{m}\int_{\omega_1}^{\omega_2} |\{|\hat{G}_{ij}^n(\omega) - \hat{G}_{ij}(\omega)|^2 \, [\Phi^{-1}(\omega)]_{jj}^{-1}\Phi_{v_i}^{-1}(\omega)\}| \, \mathrm{d}\omega$$

3) ASYM order selection using ASYC

$$\sum_{i=1}^{p}\sum_{j=1}^{m}\int_{\omega_1}^{\omega_2} |\{|\hat{G}_{ij}^n(\omega) - \hat{G}_{ij}(\omega)|^2 - \frac{n}{N}[\Phi^{-1}]_{jj}(\omega)\Phi_{v_i}(\omega)\}| \, \mathrm{d}\omega$$

4) ASYM model validation

Upper error bound

$$\left|G_{ij}^{o}(e^{i\omega})-\hat{G}_{ij}^{n}(e^{i\omega})\right|\le 3\sqrt{\frac{n}{N}[\Phi^{-1}(\omega)]_{jj}\Phi_{v_i}(\omega)} \quad \text{w.p. } 99.9\%$$

Grading the models

A, very good

B, good

C, marginal

D, poor or no model

Test redesign

- Doubling amplitude will half the error
- Doubling test time will make the error 1.414 times smaller
- Doubling PRBS switch time will half the error at the low frequencies and double it in high frequencies

5. Industrial Applications

ASYM has been applied successfully to over 80 processed in MPC projects. At least, the following 4 are closed-loop tests:

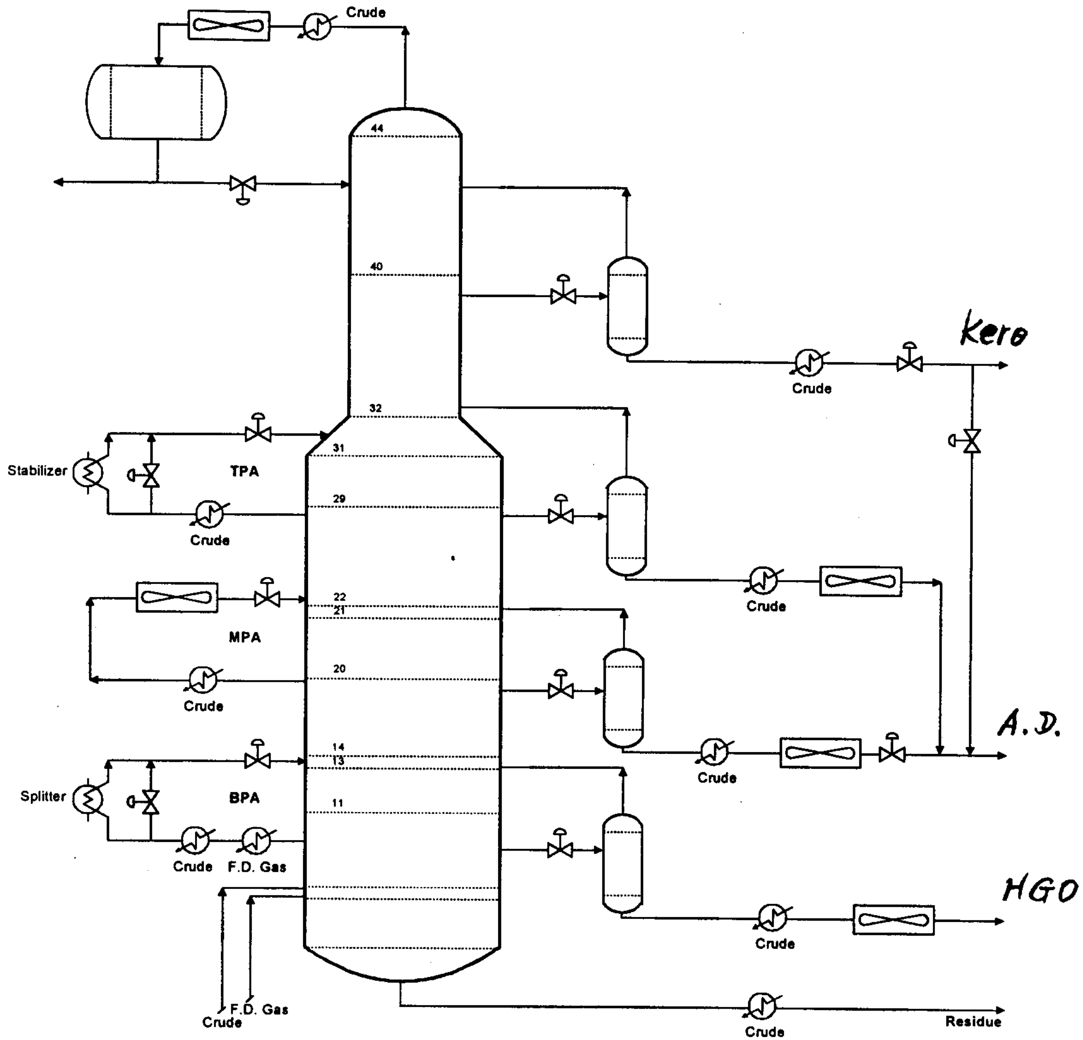
1) Partial closed-loop identification of a chemical plant for DMC, Germany, 1998

2) Partial closed-loop identification of a debutanizer for MPC, Statoil, Norway, 1998

3) Partial closed-loop identification of a deethanizer for DMC, Dow Chemical, The Netherlands, 1999 (This presentation)

4) Partial closed-loop identification of two distillation columns of a chemical plant for DMC, ExxoMobil, USA, 1999

Case 1: Open Loop Identification of a Crude Tower for DMC



Problem Description

DMC controller

- 19 MV's,
- 3 DV's
- 36 CV's

Conventional single variable step test

- 14 days test time (normally 20 days)
- model quality poor

Solution

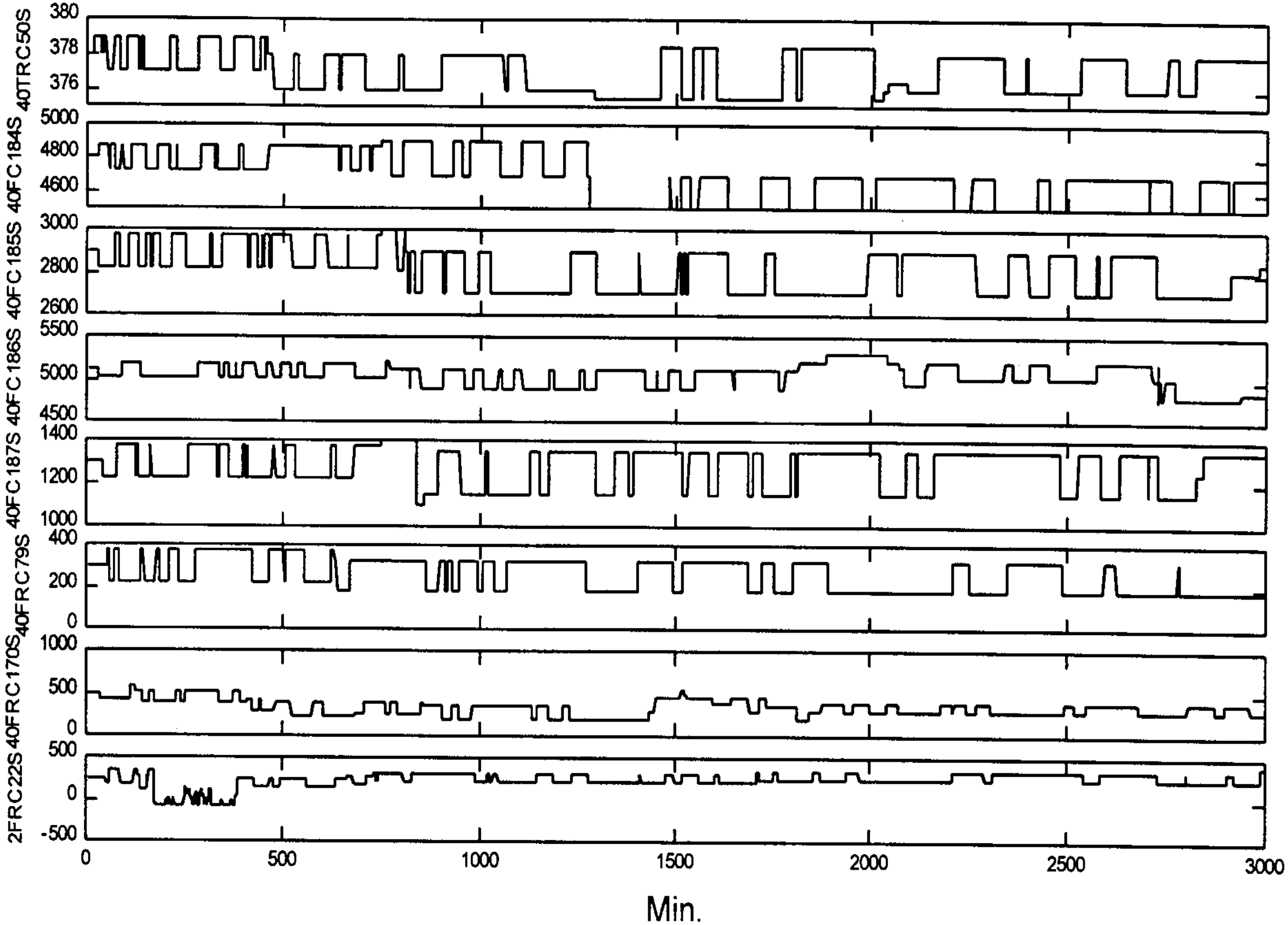
MIMO open loop tests

- test 1, two days, 9 MV's
- test 2, two days, 7 MV's
- ASYM method used for identification

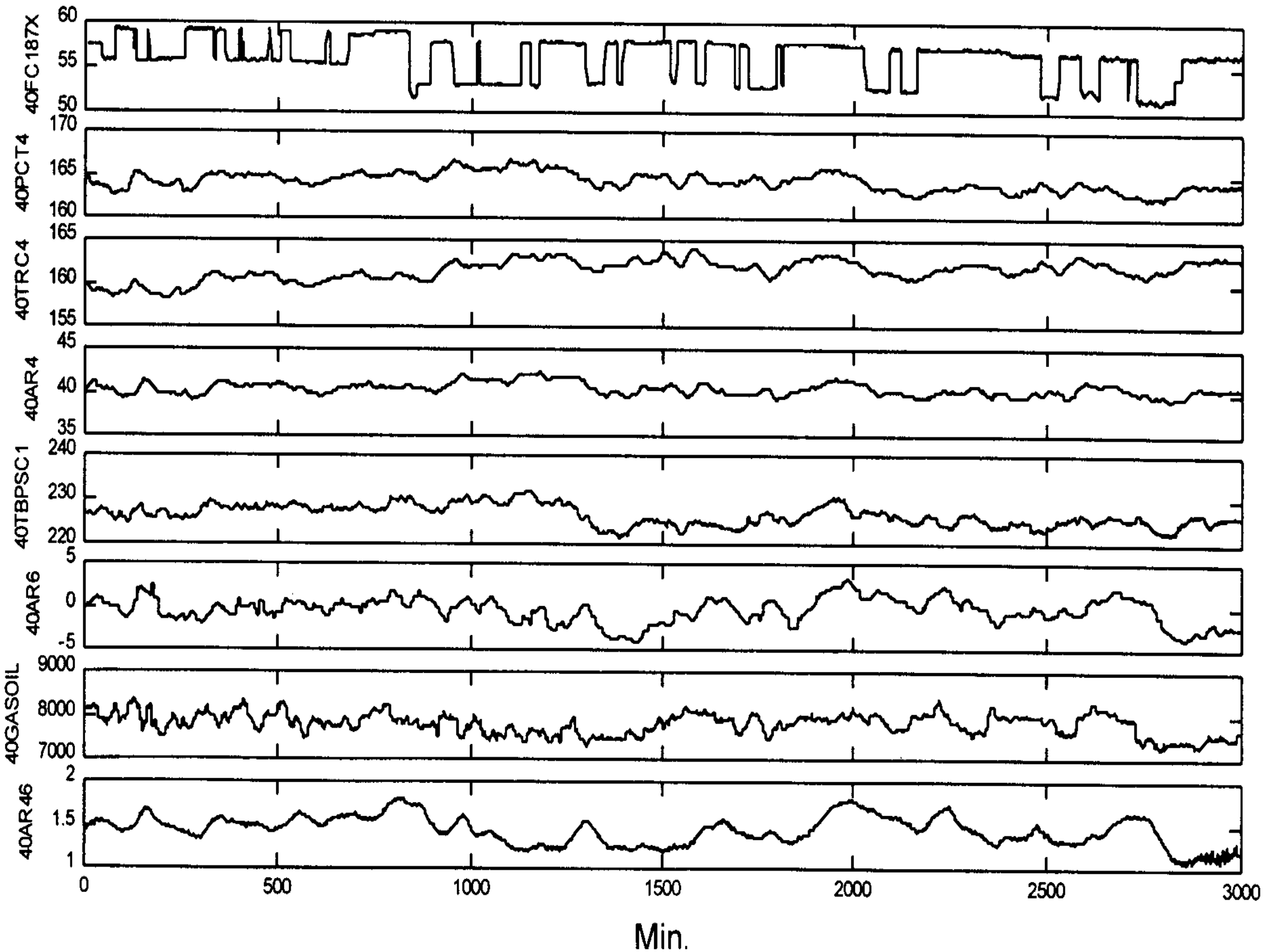
Result

Successful DMC commissioning in two weeks

Part of MV’s, test 1

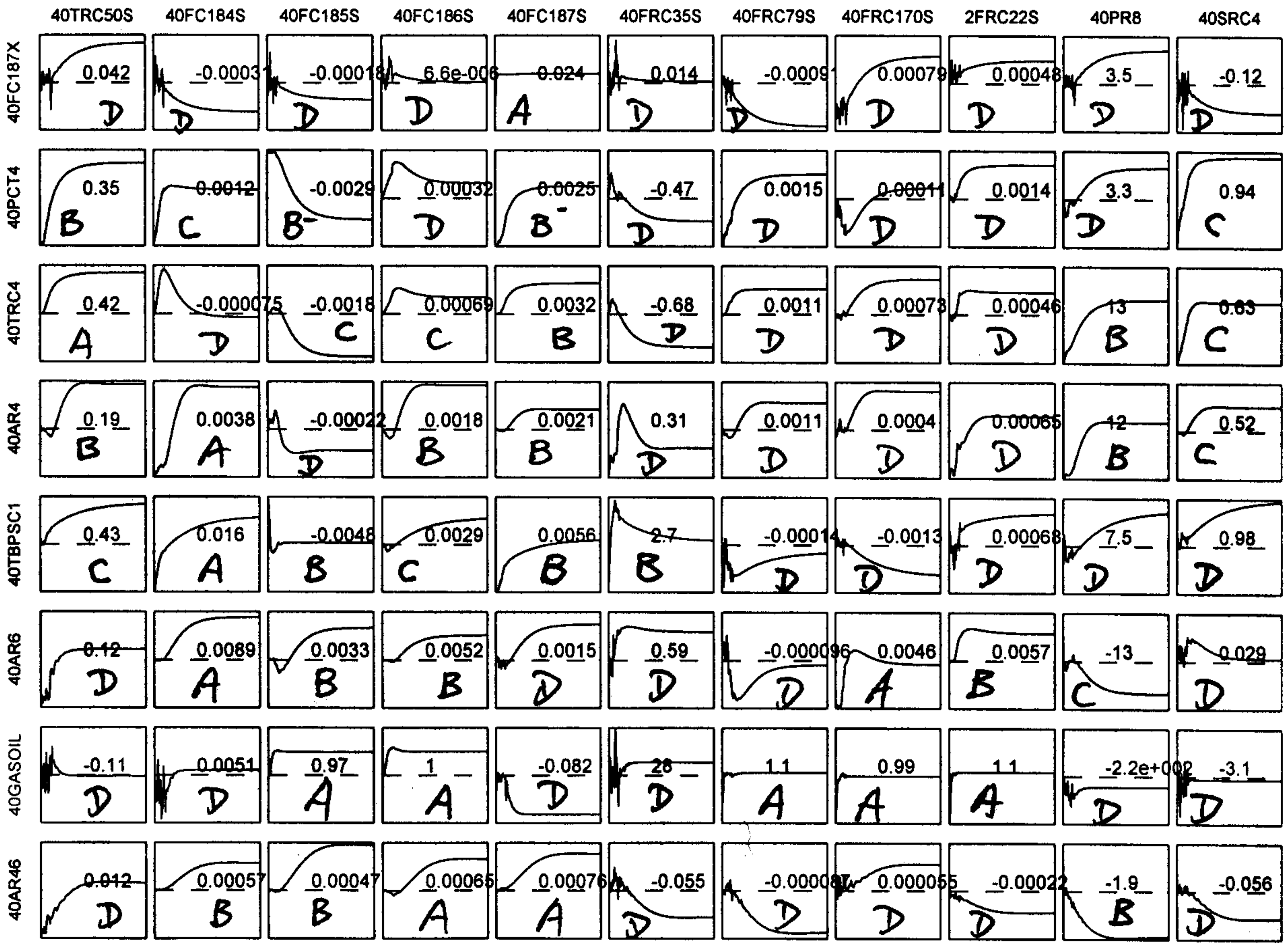


Part of CV's, test 1



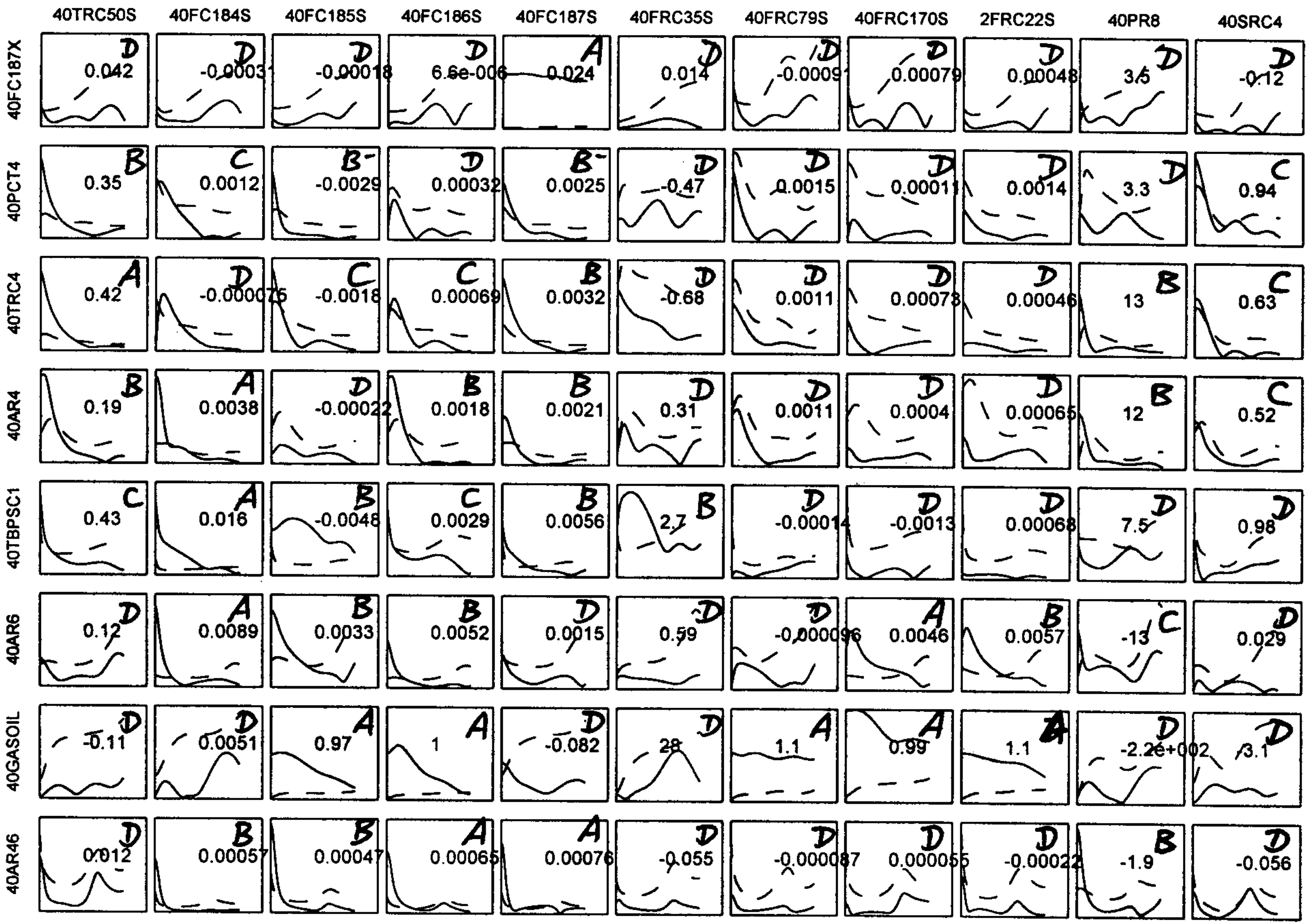
Tai-Ji Control

Step responses



Time [min], total 200.

Frequency resp.



Norm. freq [rad/min], total 0.785398.

Case 2: Partial closed-loop identification of a Deethanizer for DMC

MVs of the controller:

Reflux:	Reflux flow setpoint
Steam:	Reboiler steam flow setpoint
Preheater:	Feed preheater flow setpoint

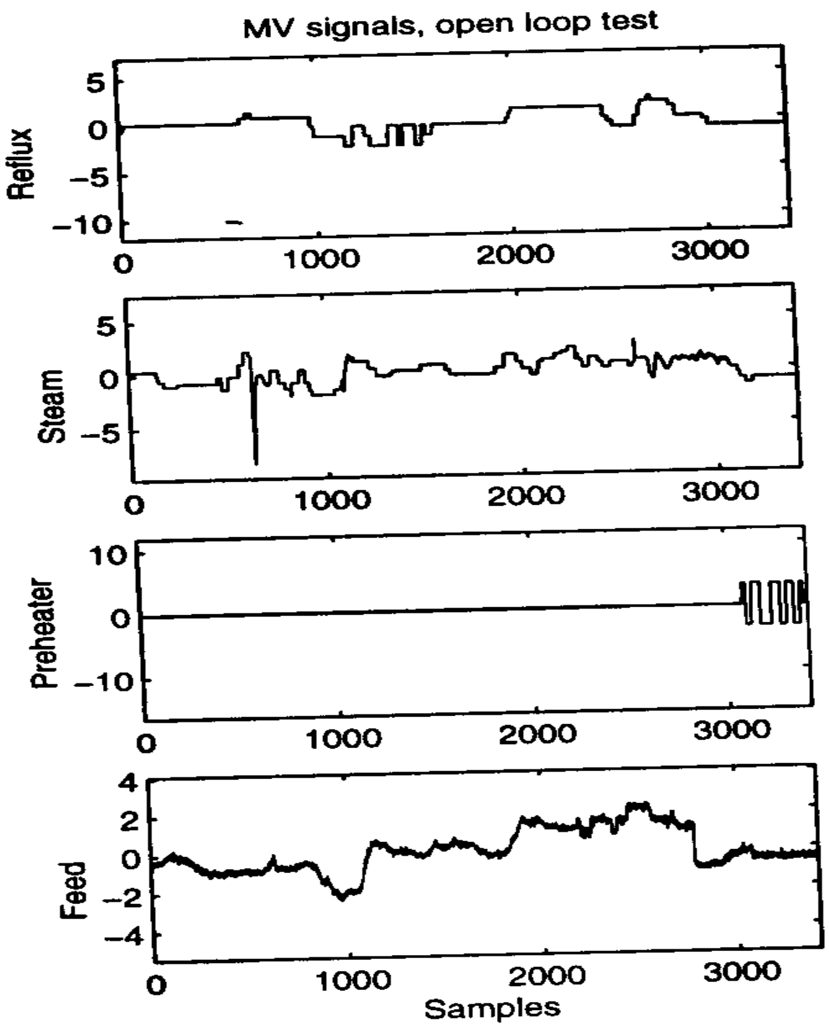
DV:

Feed:	Column feed flow

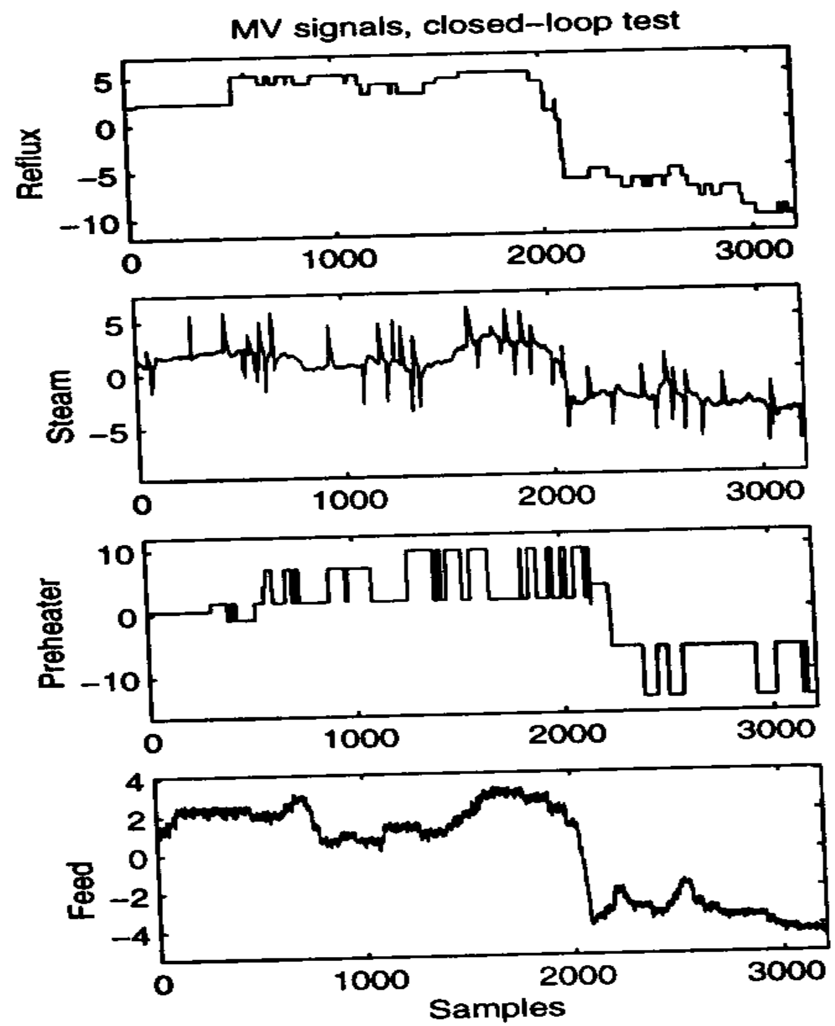
Main CVs of the controller:

OverhdC3:	Overhead C3 composition
DeltaPress:	Column pressure difference
BotTemp:	Bottom temperature
TopTemp:	Top temperature
TrayTemp*:	A tray temperature

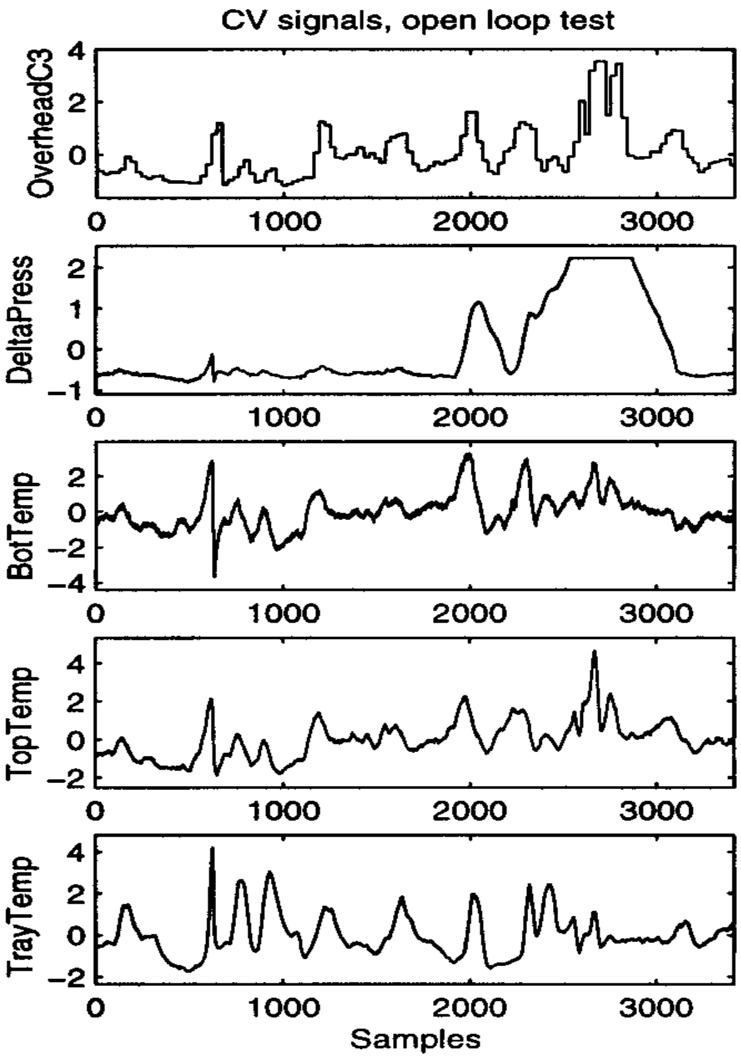
Open loop test



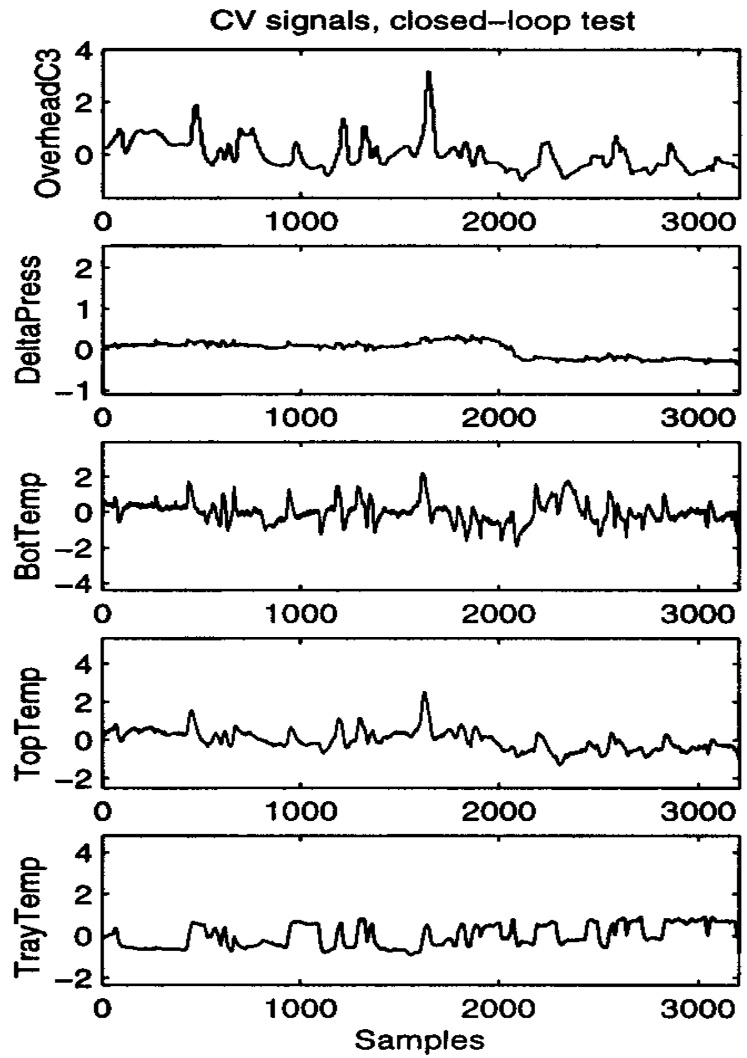
Closed-loop test

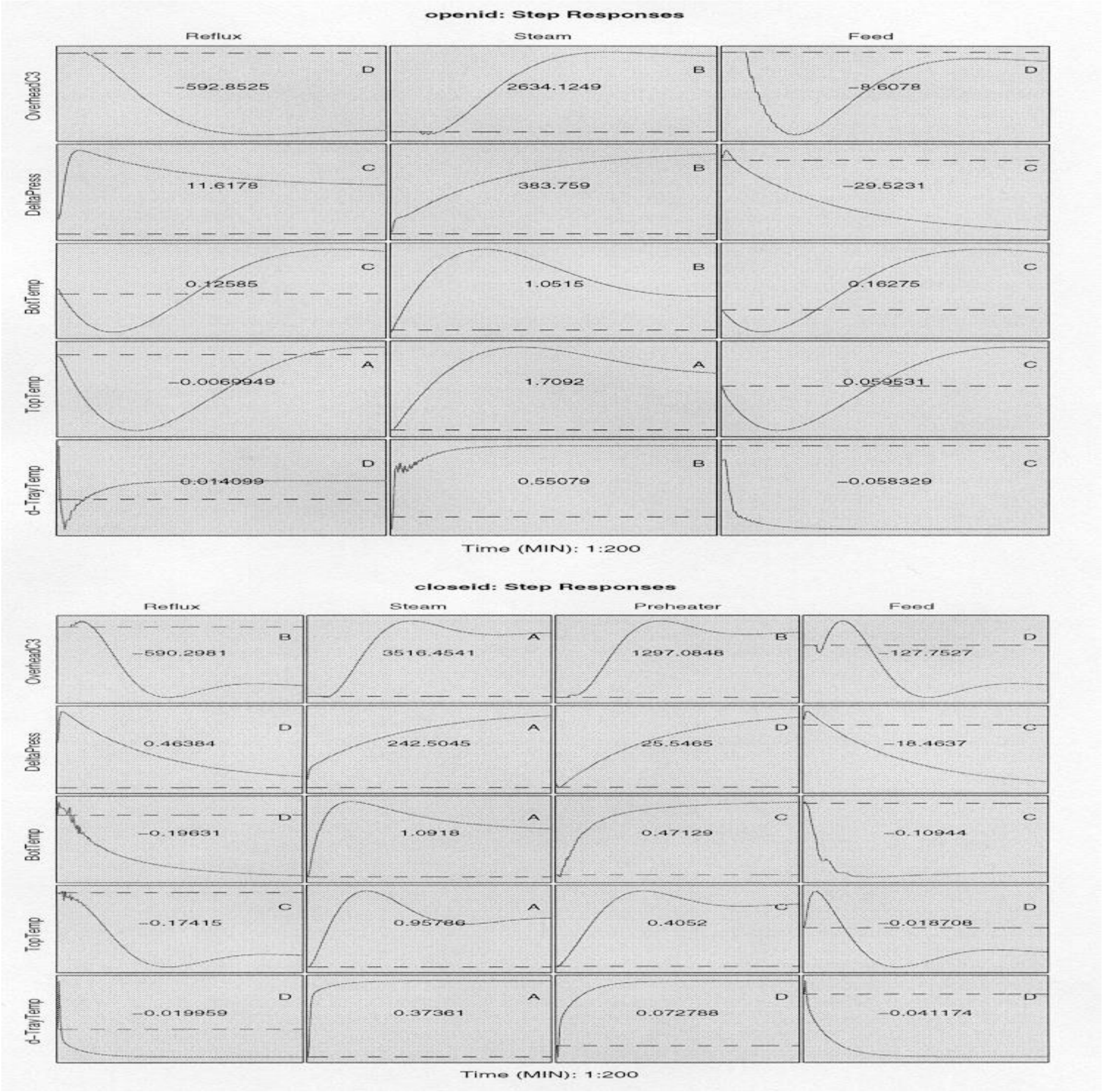


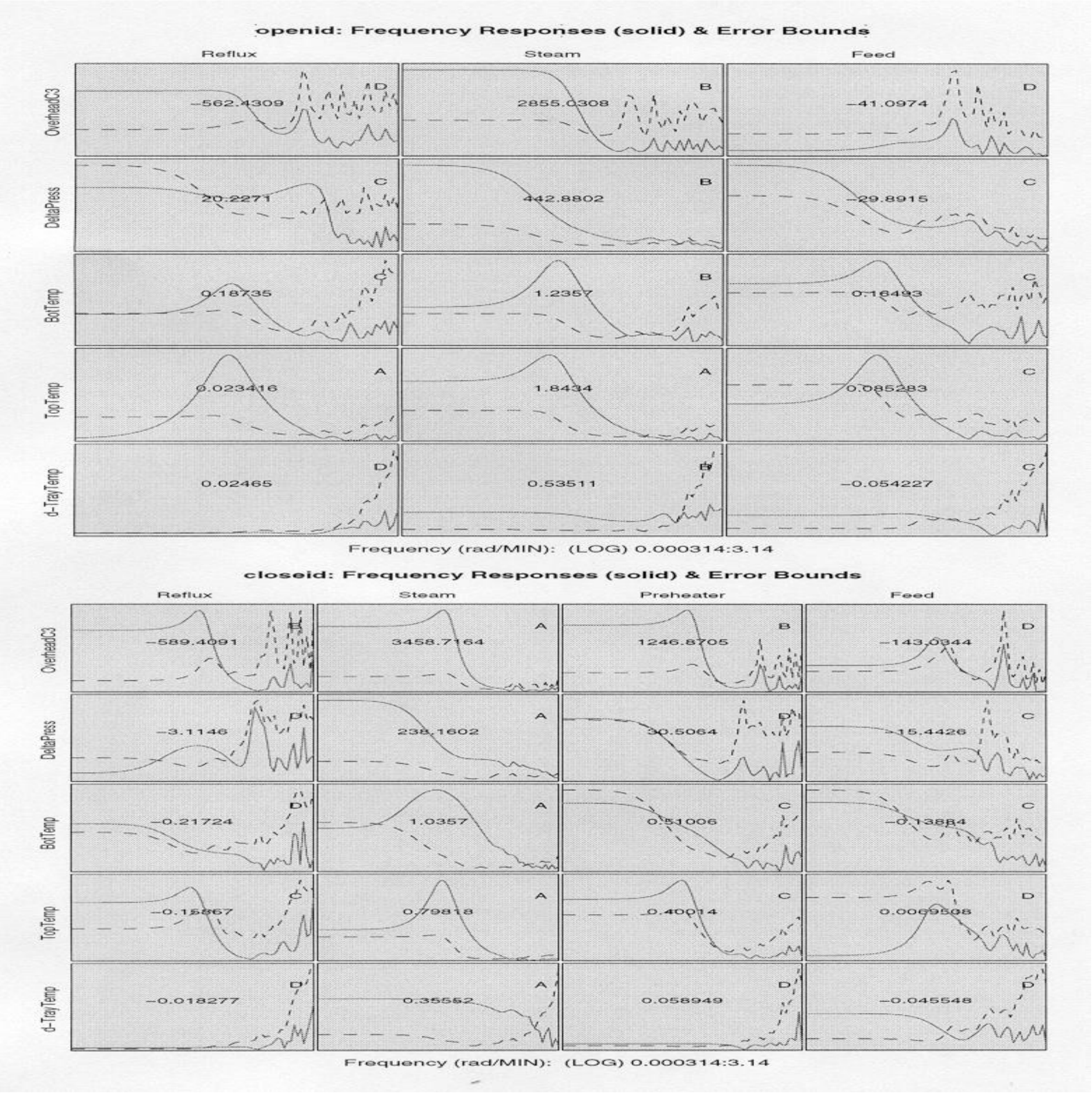
Open loop test

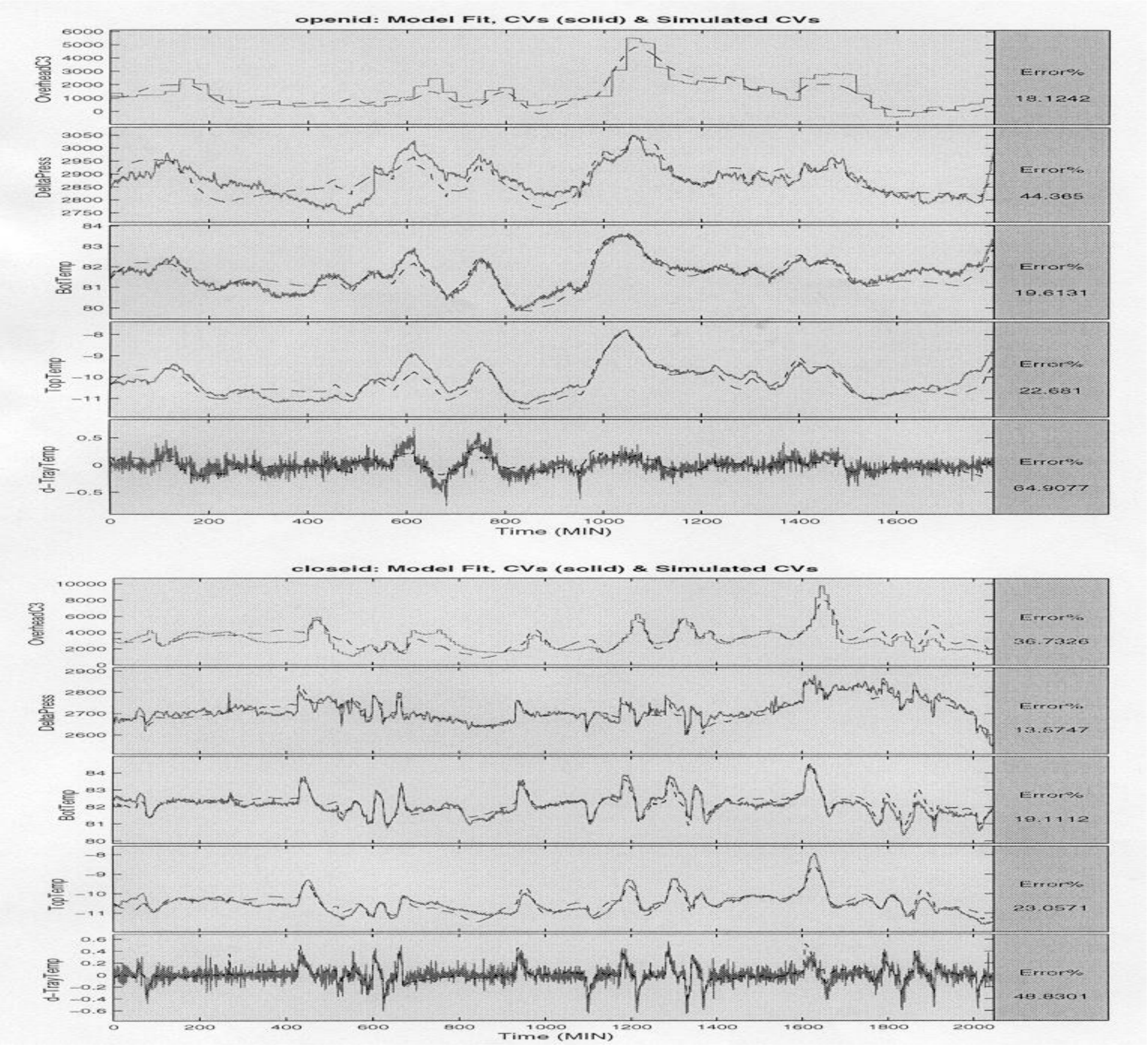


Closed-loop test




openid: Step Responses
Reflux
Steam
Feed
OverheadC3
DeltaPress
BotTemp
TopTemp
d-TrayTemp
-592.8525
2634.1249
-8.6078
11.6178
383.759
-29.5231
0.12585
1.0515
0.16275
-0.0069949
1.7092
0.059531
0.014099
0.55079
-0.058329
Time (MIN): 1:200
closeid: Step Responses
Reflux
Steam
Preheater
Feed
-590.2981
3516.4541
1297.0848
-127.7527
0.46384
242.5045
25.5465
-18.4637
-0.19631
1.0918
0.47129
-0.10944
-0.17415
0.95786
0.4052
-0.018708
-0.019959
0.37361
0.072788
-0.041174
Time (MIN): 1:200


openid: Frequency Responses (solid) & Error Bounds
Reflux
Steam
Feed
OverheadC3
DeltaPress
BotTemp
TopTemp
d-TrayTemp
-562.4309
2855.0308
-41.0974
20.2271
442.8802
-29.8915
0.18735
1.2357
0.16493
0.023416
1.8434
0.085283
0.02465
0.53511
-0.054227
Frequency (rad/MIN): (LOG) 0.000314:3.14
closeid: Frequency Responses (solid) & Error Bounds
Reflux
Steam
Preheater
Feed
OverheadC3
DeltaPress
BotTemp
TopTemp
d-TrayTemp
-589.4091
3458.7164
1246.8705
-143.0344
-3.1146
238.1602
30.5064
-15.4426
-0.21724
1.0357
0.51006
-0.13884
-0.15867
0.79818
0.40014
0.0069508
-0.018277
0.35552
0.058949
-0.045548
Frequency (rad/MIN): (LOG) 0.000314:3.14


openid: Model Fit, CVs (solid) & Simulated CVs
OverheadC3
DeltaPress
BotTemp
TopTemp
d-TrayTemp
Error%
18.1242
44.365
19.6131
22.681
64.9077
Time (MIN)
closeid: Model Fit, CVs (solid) & Simulated CVs
Error%
36.7326
13.5747
19.1112
23.0571
48.8301

6 Conclusions and Perspectives

1) Process ID has become a bottleneck for MPC in the HP industry
2) ASYM method provides systematic solutions for MPC identification
3) The advantages of ASYM
    - More accurate model for control
    - Reduce unit disturbance
    - Save 70% test time
    - Automatic ID, very user friendly, save 80% analysis time
4) Future work for the adaptive identification module
    - Implement recursive ASYM method
    - Develop controller monitor algorithm
    - Connect them to a real-time database (e.g. PI)