Decoupling control loops using ExperTune software

Theory, diagnosis, and practical considerations

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Topics to be covered in this presentation

- Brief ATAN’s presentation
- PlantTriage tools to find coupled loops
- How to decouple control loops:
  - Detuning / tuning tighter
  - Static and dynamic decouplers
  - Control strategy
- How to define variables’ pairing in a multiloop system using the RGA technique;
- Examples
Customers
Geographical Distribution

Customers
Market Segments
**Automation Technology**

**Industrial Automation**

- **INSTRUMENTATION, CONTROL E SUPERVISION IN ON SHORE E OFF SHORE Environments**
  (focus in turn-key project)

  - Systems specification and configuration (SCADA/PLC, UTR, DCS, radio frequency, data communication, etc.)
  - Communication drivers development
  - **Start up and commissioning**
  - Training
  - Technical assistance
Automation Technology
PIMS – Plant Information Management System

Production Information and Management Systems (Historian Systems – PI, Infoplus.21, iHistorian, others):

- Interface with control / Supervision systems (PLCs, DCS and SCADA)
- Temporal Databank / Real-time process data
- Interface with Corporate Systems / Relational databank (ERP, Oracle, MS-SQL Server, etc...)
- Tools for data manipulation and analysis
- Development of customized applets
- Training
- Continuous Help Desk

Automation Technology
Consulting

- Master Business Plan
- Technical and economic feasibility study
- Business plan
- Conception, ROI assessment
- Variability reduction studies
- Basic Engineering
  - Field information collection,
  - Functional Specification
  - Solution definition System configuration
  - Execution Planning
Information Technology
Production Management - MES

- **Features:**
  - Process Tracking
  - Downtime Management
  - Production Planning
  - Product Tracking
  - Production Metrics (KPIs)
  - Asset Management
  - Activity Based Costing
  - TPM
  - Quality Management
  - Shop floor integration
  - Labor accounting
  - Production accounting

Special Solutions
SCORE

- **SCORE** is a Supervisory and Control solution for the primary aluminum production industry:
  - SCORE 7 – Control and supervision semi distributed system
  - SCORE 8 – Control and supervision semi distributed system
  - SCORE 9 - Control and supervision distributed system
  - SCORE Ultra Vision – supervision system (HMI- SCORE)
  - Top-SCORE – Web based information system
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Which loops are coupled?
Treemap Oscillation Detection – Coupled Loops generally cycle together

Many loops oscillate at the same frequency ≈ 280 sec
Finding possible couplings with PlantTriage

Process Interaction Mapping diagnosis:
No coupled loops (Metallurgical Furnace)
Simple strategy to decouple control loops: detune the controller

Making the tuning of a loop more conservative by changing the PID parameters – robustness change.

Example 1 – Decoupling level and temperature loops

Detuning a level loop reduces oscillation in a temperature loop

\[ K_p \downarrow \quad T_i \uparrow \]
Example 2 - PIC-321 – Control of the combustion air pressure in a furnace

<table>
<thead>
<tr>
<th>Loop name</th>
<th>Description</th>
<th>Unit operation</th>
<th>Oscillation periods</th>
<th>Oscillation periods</th>
<th>On delay</th>
<th>Dec. Tuning</th>
<th>Rec. Tuning</th>
<th>Rec. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC 321</td>
<td>Control of the voltage of Air Combustion Reg 1</td>
<td>FORNO</td>
<td>20.97</td>
<td>0.236</td>
<td>50</td>
<td>30</td>
<td>0</td>
<td>80</td>
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<td>FORNO</td>
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<td>30</td>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>

What is the best tuning?

The implementation of the best tuning for all loops can decrease the performance of the entire system!

RRTs of the loops PIC321 and FIC 307.1 became closer after optimal tuning of these loops:
- RRT of PIC 321 changed from 20 sec to 63 sec after tuning
- RRT of FIC 307.1 was 6 times bigger and became 2 times bigger only

Coupling between loops!!
PIC-321
Tuning synchronism - RRT

The loops were tuned again to adjust the RRTs and reduce the coupling.

RRT of the loop PIC321 became 3 times smaller than that of FIC 307.1

Decoupled Loops

Spectral Analysis
PIC-321 x FIC 307.1

Before
FIC-307.1

After
Spectra of PIC-321 and FIC-307.1 became different

Coupling removed !!!!!!!
PIC-321 and FIC 307.1 after decoupling

Example 3 – Metallurgical Plant – Initial General Statistics
Initial Assessment
Couplings among loops

Fan control loops: PIC104, PIC204, PIC305 and PIC405

<table>
<thead>
<tr>
<th>Loop name</th>
<th>Description</th>
<th>Deviation from set point</th>
<th>Deviation from bump</th>
<th>Deviation from load</th>
<th>Deviation from set point</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC104 (L)</td>
<td>Pressures at Eductor 3</td>
<td>985.3</td>
<td>14.31</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC204 (L)</td>
<td>Pressures at Eductor 4</td>
<td>982.4</td>
<td>16.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC305 (L)</td>
<td>Pressures at Eductor 2</td>
<td>206</td>
<td>12.22</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC405 (L)</td>
<td>Pressures at Eductor 1</td>
<td>203.1</td>
<td>10.39</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC104 (L)</td>
<td>Pressures at Eductor 4</td>
<td>303.1</td>
<td>15.77</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>PIC204 (L)</td>
<td>Pressures at Eductor 3</td>
<td>192.9</td>
<td>27.49</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC305 (L)</td>
<td>Pressures at Eductor 2</td>
<td>12.9</td>
<td>12.47</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC405 (L)</td>
<td>Pressures at Eductor 1</td>
<td>12.7</td>
<td>12.52</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC104 (L)</td>
<td>Pressures at Eductor 4</td>
<td>180.4</td>
<td>21.12</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>PIC204 (L)</td>
<td>Pressures at Eductor 3</td>
<td>150</td>
<td>29.7</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>PIC305 (L)</td>
<td>Pressures at Eductor 2</td>
<td>76.87</td>
<td>17.95</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>PIC405 (L)</td>
<td>Pressures at Eductor 1</td>
<td>76.06</td>
<td>11.64</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Coke (carbon fuel) production
Process Chart
Is making the tuning more aggressive a good way to decouple loops?

Strategy for tuning: **RRT is the key !!!**

**Goals:**

- PIC104 Relative Response
  - Time at least 3 times bigger

**Steps of the job:**

- Tests for process identification
- Adjustment of the Relative Response Time (RRT)
Decoupling: smaller oscillation strength

<table>
<thead>
<tr>
<th>Loop name</th>
<th>Description</th>
<th>Oscillation periods (list only)</th>
<th>Oscillation strengths (list only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 (1)</td>
<td>Pressure before</td>
<td>460.2</td>
<td>41.90</td>
</tr>
<tr>
<td>120 (2)</td>
<td>Pressure after</td>
<td>457.3</td>
<td>36.47</td>
</tr>
<tr>
<td>120 (3)</td>
<td>Pressure after</td>
<td>233.6</td>
<td>14.64</td>
</tr>
<tr>
<td>120 (4)</td>
<td>Pressure before</td>
<td>232.0</td>
<td>9.195</td>
</tr>
<tr>
<td>120 (5)</td>
<td>Pressure before</td>
<td>130.8</td>
<td>15.52</td>
</tr>
<tr>
<td>120 (6)</td>
<td>Pressure before</td>
<td>88.89</td>
<td>9.17</td>
</tr>
</tbody>
</table>

Results – Response to disturbances

- Loop name
- Description
- Oscillation periods (list only)
- Oscillation strengths (list only)

- 120 (1) Pressure before 1: 175.5, 23.4
- 120 (2) Pressure before 1: 170.5, 25.96
- 120 (3) Pressure after 1: 175.8, 18.95
- 120 (4) Pressure after 1: 93.53, 9.976
- 120 (5) Pressure before 1: 93.28, 13.06
- 120 (6) Pressure before 1: 53.99, 18.85

4 minutes 25 sec
PlantTriage Assessments

Final Assessment
General Statistics

### Plant Summary List - snapshot at 1:00 PM Wednesday, November 23, 2005

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>Oscillating Loops</th>
<th>Loops in Manual</th>
<th>Saturated Loops</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coquiera 1</td>
<td>50%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Coquiera 2</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Plant Summary List - snapshot at 7:50 PM Tuesday, November 29, 2005

<table>
<thead>
<tr>
<th>Unit operation</th>
<th>Oscillating Loops</th>
<th>Loops in Manual</th>
<th>Saturated Loops</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>After</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coquiera 1</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Coquiera 2</td>
<td>50%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Decoupling loops based on tuning

Change tuning (robustness) of the coupled loops in order to have RRT (Relative Response time) as far as possible from each other (at least 3 times).

Decoupling

However, in some cases, detuning can really harm the performance of the detuned loop to unacceptable levels.

Alternative solution

Decouplers design and implementation
Decouplers Design

Types of decouplers

1. Dynamic
   \[ D_{21}(s) = -\frac{Gp_{21}(s)}{Gp_{22}(s)} \]

2. Static (simpler)
   \[ D_{21} = -\frac{Kp_{21}}{Kp_{22}} \]
Finding the models in PID Tuner

Option Advanced of the Loop Setup:
- Configuration of extra pens – allows for monitoring other variables simultaneously (Multiloop Analysis)

Finding the models in PID Tuner

Option Advanced of the Loop Setup:
- Configuration of extra loops – After configuring the extra trends, create a new loop for multiloop analysis. E.g.: Modeling couplings
Finding the models in PID Tuner

Configuration of extra loops:

- The data acquisition of all variables is done simultaneously.
- Through the off-line analysis option, it is possible to choose another PV-CO pairing and then model the interaction between these variables (couplings).

Example: Finding the models in PID Tuner

Coupling between flow and temperature in DemoMMI
Example: Finding the models in PID Tuner

Step in the flow loop CO while the temperature loop is in manual control.

Model between the flow loop CO and the temperature.
Example: 5x5 multiloop system

Decoupling - example
Matrix of the system’s transfer functions with the relevant interactions

\[
\begin{bmatrix}
1.210e^{-6s} & 0 & 0 & 0 & 0 \\
-0.180 & 0.110 & -0.016 & 0.025 & 0 \\
0 & 0 & 0.192 & -0.030 & 0 \\
0 & 0.124e^{-31s} & 0 & 0.175e^{-29s} & 0.185e^{-28s} \\
0 & 0 & 0.407e^{-5s} & 0 & 0.590e^{-49s}
\end{bmatrix}
\]
Decoupling - example

Simulation - Implementation of the TFs in MATLAB

Decouplers Design

<table>
<thead>
<tr>
<th>Loop causing the disturbance</th>
<th>Loop affected by the disturbance</th>
<th>Decoupler designed to compensate the disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>TP Level</td>
<td>$D_{\text{Flow-MTP}} = 1.636$</td>
</tr>
<tr>
<td>TP Level</td>
<td>TP Temperature</td>
<td>$D_{\text{TP-MTP}}(s) = \frac{0.709 \cdot 1.75 s + 1}{85 s + 1} e^{-3t}$</td>
</tr>
<tr>
<td>TA Level</td>
<td>TA Temperature</td>
<td>$D_{\text{TA-TP}} = 0.690$</td>
</tr>
<tr>
<td>TA Level</td>
<td>TP Level</td>
<td>$D_{\text{TA-MTP}} = 0.145$</td>
</tr>
<tr>
<td>TP Temperature</td>
<td>TP Level</td>
<td>$D_{\text{TP-MTP}} = -0.227$</td>
</tr>
<tr>
<td>TP Temperature</td>
<td>TA Level</td>
<td>$D_{\text{TP-TP}} = 0.156$</td>
</tr>
<tr>
<td>TA Temperature</td>
<td>TP Temperature</td>
<td>$D_{\text{TA-TP}}(s) = \frac{1.05 \cdot 1.75 s + 1}{692 s + 1} e^{-3T_D}$</td>
</tr>
</tbody>
</table>
Decoupling - example

The only decoupler for this system that is not feasible was:

\[
D_{NTA \rightarrow TTA}(s) = \frac{0.407 e^{-5s}}{15s + 1} = \frac{0.590}{489s + 1} \frac{489s + 1}{15s + 1} e^{44s}
\]

\[
D_{NTA \rightarrow TTA}(s) = 0.690
\]

Hence, the following was adopted instead:

\[
D_{NTA \rightarrow TTA}(s) = 0.690
\]

Decoupling - example

Implementation of the decouplers in MATLAB
Decoupling - example

Some results achieved by decoupling the system:

Influence of a change in the TTP flow

Without decoupler

With static decoupler

With dynamic decoupler

Decoupling example - furnace

Global diagram of the PID control loops of a 4x4 system and the couplings among them
Example of the use of FBD

Conventional PID with decouplers and feedforward structure

Implementation of dynamic decouplers

\[ D(s) = \frac{Ke^{-Ts}}{Ts + 1} \]
Example of static decoupling

Decoupling between the differential pressure loop and the temperature in a LPG combustion chamber

Without decoupler

With decoupler

Other strategies

Description of the process: Pulp sump at an iron ore processing plant

Control loops:
- Level – actuates in a pump regulating the pulp outflow to flotation columns in order to keep the level constant
- Density – actuates in a valve that adds water into the sump to reduce the density

Disturbance: pulp feed to the sump (it depends on the upstream stages of the process)
Old control strategy

Disturbance in the foam level of the flotation column downstream

Process behavior

Disturbance in the foam level of the flotation column downstream

Level of the pulp sump

Foam level of the flotation column
New control strategy

Results of the change in the control strategy

Level of the pulp sump

Foam level of flotation columns
Results of the change in the control strategy

Reduction in the variability of the foam level of the flotation column

Control System Design

What should we do if the disturbances are so strong that our decoupling strategies cannot handle them?

Study the control system design and variable’s pairing (CO x PV)
RGA

RGA: Relative Gain Array

Goal: Through the steady-state gains of the system, determine the degrees of interaction among the process variables

Result:
- Definition of the best variables’ pairing

RGA – First Step

Find the Steady State gains based on the matrix of the system’s transfer functions already obtained with PID tuner

\[
\begin{bmatrix}
1.210e^{-6s} & 0 & 0 & 0 & 0 \\
\frac{-0.180}{s} & 0.110 & \frac{-0.016}{s} & \frac{0.025}{s} & 0 \\
0 & 0 & \frac{-0.192}{s} & \frac{-0.030}{s} & 0 \\
\frac{0}{85s + 1} & \frac{0.124e^{-31s}}{85s + 1} & 0 & \frac{0.175e^{-23s}}{175s + 1} & \frac{0.185e^{-208s}}{692s + 1} \\
0 & 0 & \frac{-0.407e^{-5s}}{15s + 1} & 0 & \frac{0.590e^{-49s}}{489s + 1}
\end{bmatrix}
\]
RGA

The elements of the RGA can be calculated by the following expression:

$$\lambda_{ij} = K_{ij} \ast H_{ij}$$

$K_{ij} =$ steady-state gain between $C_i$ and $M_j$,
$H_{ij} =$ $(i,j)$$^{th}$ element of $H$

Steps to determine the RGA:
- Computation of $K$ (gains’ matrix)
- Calculation of $H = (K^{-1})'$
- Calculation of $\lambda_{ij}$

$$\Lambda = \begin{bmatrix} MV_1 & MV_2 & \ldots & MV_j \\ CV_1 & \lambda_{11} & \lambda_{12} & \ldots & \lambda_{1n} \\ CV_2 & \lambda_{21} & \lambda_{22} & \ldots & \lambda_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\
CV_n & \lambda_{n1} & \lambda_{n2} & \ldots & \lambda_{nn} \end{bmatrix}$$

RGA analysis

The elements in a row of column always sums to 1
$\lambda > 1 : CV_i$ and $MV_j$ interact and the degree of interaction grows as $\lambda$ increases.
$\lambda < 0 :$ The sign of the open-loop gain and of the closed-loop gain are different; thus, $CV_i$ and $MV_j$ should not be paired.
$\lambda = 1 :$ ideal pair – there is no interaction with other loops.
$\lambda = 0 :$ $MV_j$ does not affect $CV_i$; therefore they should not be paired.
$0 < \lambda < 1 :$ There is interaction between the loops.
**Example of RGA application**

**K (Gains’ matrix)**

<table>
<thead>
<tr>
<th></th>
<th>FCV1</th>
<th>LCV2</th>
<th>LCV1</th>
<th>TCV1</th>
<th>ÂNG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VZ</td>
<td>1.210</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NTP</td>
<td>−0.180</td>
<td>0.110</td>
<td>−0.016</td>
<td>0.018</td>
<td>0</td>
</tr>
<tr>
<td>NTAQ</td>
<td>0</td>
<td>0.014</td>
<td>0.192</td>
<td>−0.025</td>
<td>0</td>
</tr>
<tr>
<td>TTP</td>
<td>0</td>
<td>−0.124</td>
<td>−0.021</td>
<td>0.122</td>
<td>−0.180</td>
</tr>
<tr>
<td>TTAQ</td>
<td>0</td>
<td>0</td>
<td>−0.407</td>
<td>0</td>
<td>−0.560</td>
</tr>
</tbody>
</table>

**Example of RGA application**

**Matrix Λ (RGA)**

<table>
<thead>
<tr>
<th></th>
<th>FCV1</th>
<th>LCV2</th>
<th>LCV1</th>
<th>TCV1</th>
<th>ÂNG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VZ</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NTP</td>
<td>0</td>
<td>0.8989</td>
<td>−0.0240</td>
<td>0.1252</td>
<td>0</td>
</tr>
<tr>
<td>NTAQ</td>
<td>0</td>
<td>−0.0172</td>
<td>0.9384</td>
<td>0.0788</td>
<td>0</td>
</tr>
<tr>
<td>TTP</td>
<td>0</td>
<td>0.1183</td>
<td>−0.0164</td>
<td>0.7960</td>
<td>0.1020</td>
</tr>
<tr>
<td>TTAQ</td>
<td>0</td>
<td>0</td>
<td>0.1020</td>
<td>0</td>
<td>0.8980</td>
</tr>
</tbody>
</table>
Conclusions

- Couplings among loops are harmful to process performance. This is quite common in industry;
- PlantTriage has some tools to help you find the coupled loops;
- Once detected, the loops need to be decoupled. Possible approaches:
  - Change Tuning
  - Design decouplers
  - Change control strategy
- In order for the control system to reach a great performance level, the variables’ pairing needs to be carefully chosen. The RGA technique can help you to define the best variables’ pairing in a multiloop system and PID Tuner can be used to find the models.