PERFORMANCE ASSESSMENT, DIAGNOSIS AND PID CONTROL LOOP TUNING AT A CEMENT PLANT

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Topics to be covered in this presentation

Performance Overview at a typical Cement Plant

The benefits of the use of control loop performance assessment and tuning software in cement plants;

Examples of variability reduction and practical results of detailed control loop audit in these plants;

Examples of temperature, pressure, flow and level loops’ tuning and the benefits after the optimization.
Lafarge

Lafarge is a French Group that has plants in Brazil for over 45 years.

Lafarge’s headquarters are located in France;

Lafarge is the biggest cement maker in the world. It is present in France, England, North America, Mediterranean, Asia and Africa.

Lafarge’s products are divided into three groups: Cement, Concrete & Aggregates and Gypsum.

Lafarge in numbers

Lafarge is present in 75 countries;
It has 77,000 employees;
The sales in 2004 reached 14.4 billion Euros;
Lafarge Group has 245,000 stockholders all over the world;

The annual production is:
- 88 million tons of cement;
- 37.6 millions of m³ of concrete;
- 220.4 million tons of aggregates;
- 574 millions of m² of gypsum.

Position in the global ranking:
- 1st in cement;
- 2nd in concrete & aggregates;
- 3rd in gypsum.
Lafarge’s plants in Brazil

Use of PlantTriage at Lafarge

PlantTriage is installed in 4 Lafarge plants in Brazil.

The assessments are integrated in the corporate level.

The headquarter is in Rio de Janeiro.
General statistics of a cement plant

# of assessed loops: 25

20% of the loops were in manual (5 loops)

24% of the loops were saturated (0 or 100%) in the MV (6 loops)

40% of the loops were oscillating (load, valve and tuning) (10 loops)

40% of the loops were inappropriately tuned (10 loops)

Common issues regarding cement plant performance

Throughput
Process waste
Energy costs
Low reliability
Inconsistent operations
Few personnel available
Example of PlantTriage use: Temperature – bag filter

**Goal**: Control the gas temperature at the output of the cooling tower in order to avoid the gas to reach the bag filter at high temperatures.

Temperature – bag filter
Loop Assessor diagnosis

**Diagnosis**
- High variability and absolute error
- Oscillation
Main cause: aggressive tuning
Temperature – bag filter
Tuning

Methodology: double pulse test

(E) Double pulse test performed to find new tuning parameters
(D) 2nd order model found by the tuning tool

Real data X Simulation

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
<td>278</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>4.2</td>
</tr>
<tr>
<td>RRT</td>
<td>200</td>
<td>650</td>
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</tbody>
</table>

Temperature – bag filter
Trend – Before and After

Measured Temperature
Desired Temperature
Valve opening

B E F O R E

A F T E R
Temperature – bag filter
Statistics – Before and After

### Before

- Loop Assessor Diagnoses
- After tuning, oscillation decreased.

#### Loop Assessor Diagnoses

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (μ)</td>
<td>85.00</td>
<td>105.00</td>
</tr>
<tr>
<td>Standard deviation (σ)</td>
<td>15.20</td>
<td>20.30</td>
</tr>
<tr>
<td>Variance</td>
<td>231.84</td>
<td>421.61</td>
</tr>
<tr>
<td>Variability Index</td>
<td>25.7</td>
<td>37.9</td>
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<tr>
<td>IAE</td>
<td>142.25</td>
<td>190.00</td>
</tr>
<tr>
<td>Tuning</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Better</td>
</tr>
</tbody>
</table>

### After

- Loop Assessor Diagnoses
- After tuning, oscillation decreased.
Temperature – bag filter
Loop Assessor Diagnoses

After tuning, the global grade was reduced, i.e., the performance increased.

Kiln headstock pressure
Loop Assessor Diagnoses

Goal: control the kiln pressure near zero, but preventing it from becoming positive.
CL-31-KP – Headstock pressure

This loop was on the top of the Biggest Payback Loops list

<table>
<thead>
<tr>
<th>Loop name</th>
<th>Unit/purpose</th>
<th>Description</th>
<th>Average economic assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL-31-KP</td>
<td>Forno</td>
<td>Pressao na cabeceira</td>
<td>63.5%</td>
</tr>
<tr>
<td>MC-31-MA</td>
<td>Forno</td>
<td>Corriol primario</td>
<td>95.5%</td>
</tr>
<tr>
<td>CL-31-BA</td>
<td>Forno</td>
<td>Uso Alimentacao Fumaca Torre</td>
<td>59.5%</td>
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<td>CL-31-KP</td>
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<td>Pressao Comum</td>
<td>45.6%</td>
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<tr>
<td>MC-31-MA</td>
<td>Forno</td>
<td>Corriol secundario</td>
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<td>Vazao de Ar CL-15-VE</td>
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<td>Forno</td>
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<td>Forno</td>
<td>Vazao de Ar CL-10-VE</td>
<td>29.3%</td>
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<td>Forno</td>
<td>Vazao de Ar CL-5-VE</td>
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<td>Vazao de Ar CL-0-VE</td>
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<tr>
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<td>Forno</td>
<td>Vazao de Ar CL-18-MF</td>
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<td>CL-31-MB</td>
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<td>Vazao de Ar CL-15-MF</td>
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<td>CL-31-MA</td>
<td>Forno</td>
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<td>CL-31-MA</td>
<td>Forno</td>
<td>Vazao de Ar CL-13-MF</td>
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<td>Vazao de Ar CL-11-MF</td>
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<tr>
<td>CL-31-MA</td>
<td>Forno</td>
<td>Vazao de Ar CL-10-MF</td>
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<td>Vazao de Ar CL-09-MF</td>
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<td>Forno</td>
<td>Vazao de Ar CL-06-MF</td>
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<td>Vazao de Ar CL-05-MF</td>
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<td>Forno</td>
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<td>Forno</td>
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<td>Vazao de Ar CL-02-MF</td>
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<td>Forno</td>
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<td>Forno</td>
<td>Vazao de Ar CL-00-MF</td>
<td>27.8%</td>
</tr>
</tbody>
</table>

CL-31-KP – Couplings

The table confirms the correlation between the headstock pressure and the primary corioli, as well as other loops oscillating with the same period.

The secondary corioli does not exhibit the same oscillation period, i.e., is not correlated with the other loops. In fact, the secondary corioli adds fuel far from the burner whereas the primary adds fuel directly to it.
Improvement in the global grade of loop CL-31-KP

The global grade of loop CL-31-KP decreased from 83% to 40.4% just by tuning the coupled flow loops.

CL-31-KP – Variability reduction
Improvement in the grade of loop CL-31-KP

**Drastic variability reduction** of loop CL-31-KP (headstock pressure) due to the tuning of the coupled flow loops.

Significant decrease of the grades (performance improvement!!!)

Improvement in the grade of loop CL-31-KP

- **Tuning of coupled flow loops**
- **Tuning of the loop itself**
Benefits due to variability reduction

Possibility of operating in a more profitable region:

Performance Improvement

Short term

Long Term

Oscillation
% Time in Normal
Noise
Valve Travel
Output at Limit
Process Model
Robustness
Settling Time

Expertune Index
Variability
Efficiency
Reliability
Harris Index

Quality
Availability
Energy costs
Material costs
Operational costs
Maintenance costs

Throughput
Customer Satisfaction
Total cost
Unit cost

Material costs
Maintenance costs

Expertune
TIPS
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LAFARGE
BRASIL
Coal flow to the kiln

Goal: keep the kiln feed constant

Coal flow to the kiln
Active Model Capture

Show data for process model

Figure – Step tests performed by the operator on loop S3FIC162
Coal flow to the kiln
Trend – Before and after tuning

Coal flow to the kiln
Statistics – Before and after
Performance Improvement

Short term → Long Term

- Oscillation
- % Time in Normal
- Expertune Index
- Variability
- Efficiency
- Reliability
- Harris Index

- Quality
- Availability
- Energy costs
- Material costs
- Operational costs
- Maintenance costs

- Throughput
- Customer Satisfaction
- Total cost
- Unit cost

Energy savings – valve travel

Heavy oil Heating System:
- SP=120°C (248 F). Oscillations of 60°C (140 F)

**Loop tuning**

**Oscillations removal**
Energy consumption of the inductive heater decreased from 45KW to 25KW
Energy savings – valve travel

Savings: 20KWh x US$ 0.04 = US$ 0.8 / hour

US$ 0.8 x 24 h x 365 days ≅ US$ 7,008.00 / year (considering this loop only).

Estimate of the energy savings in 25% of the actuators of a typical cement plant with 25 loops:

US$ 7,008 x 6 loops = US$42,048.00 (annual savings due to the reduction of the valve travel).

Cooling Tower temperature
Before and after

Reduction of the temperature and pressure deviations of the gases in this circuit
Increase of the valve lifetime
## Temperature at the gases Cooling Tower

<table>
<thead>
<tr>
<th>Time</th>
<th>% Time in threshold</th>
<th>% T Variability</th>
<th>% T Average error</th>
<th>% T Noise band</th>
<th>% T Oscillating</th>
<th>% T Time in normal</th>
<th>% T Valve reversals</th>
<th>% T Valve travel</th>
<th>% T Output at limit</th>
</tr>
</thead>
<tbody>
<tr>
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<td>18.08</td>
<td>18.4%</td>
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<td>100.0%</td>
<td>0.0%</td>
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<td>5.0%</td>
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<td>66.6%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>0.0%</td>
<td>7.0%</td>
<td>209.0%</td>
<td>70.0%</td>
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<tr>
<td>7:00 AM 9/1/2005</td>
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<td>67.9%</td>
<td>85.4%</td>
<td>88.7%</td>
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<td>8.0%</td>
<td>275.3%</td>
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<td>0.0%</td>
<td>8.0%</td>
<td>283.3%</td>
<td>69.0%</td>
</tr>
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</table>

## Performance Improvement

**Short term** → **Long Term**

- Oscillation
- % Time in Normal
- Noise
- Valve Travel
- Variability
- Efficiency
- Reliability
- Harris Index
- Quality
- Availability
- Energy costs
- Material costs
- Operational costs
- Total cost
- Unit cost
- Throughput
- Customer Satisfaction

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Pool hopper level

Goal: This level control aims to keep the silo always full. This condition reduces the probability of a kiln shutdown due to lack of raw material.

Slave loop tuning - 38JIC800

Before: Great Oscillations

After: Oscillations decreased
Pool hopper level
Time trend – Before and after

Reduction in the energy consumption (flour elevator power)
Uniform and constant feed to the kiln

Kiln feed

PlantTriage assessments indicating undesirable oscillations:

<table>
<thead>
<tr>
<th>Time</th>
<th>Avg % to threshold</th>
<th>%T Variability</th>
<th>%T Avg abs error</th>
<th>%T Noise band</th>
<th>%T Oscillations</th>
<th>%T Time in normal</th>
<th>%T Valve reversals</th>
<th>%T Valve travel</th>
<th>%T Output at limit</th>
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</thead>
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<tr>
<td>4:00 PM 4/27/2005</td>
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<td>0.0%</td>
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<td>44.18</td>
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<td>42.7%</td>
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<td>63.7%</td>
<td>47.8%</td>
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<tr>
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<td>no baseline</td>
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<td>51.2%</td>
<td>100.0%</td>
<td>0.0%</td>
<td>76.6%</td>
<td>52.2%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Kiln feed

Previous strategy:

- Silo > 45 ton
- Close valve
- Silo level decreases quickly
- It disturbs the kiln feed

Kiln feed

Previous strategy (behavior in a 10-minute time window)

- Silo feed is turned off
- Level decreases
- Disturbance in the kiln feed
Kiln feed

Previous strategy (behavior in a 8-hour time window)

- Silo feed is turned off
- Disturbance in the kiln feed (instability and high variability)

Variability of 3.64% (between 92.2 and 103.2)

Every time the silo gets empty, there is a disturbance in the kiln feed

Proposed strategy: cascade control

- Silo level stability
- Kiln feed stability and increased throughput
Kiln feed - Conclusions

Implement new control loops such as a loop to control the silo level, which can improve the process throughput.

A potential *production improvement around 4%* (under the control limits enforced by the current strategy) is estimated. Consequently, the quality can be improved (estimated variability reduction of 75%) and the process can run more stable.

Regulatory x Advanced Control

Great part of the optimization systems available in the market (Expert Systems, Multi-variable Controllers, Artificial Intelligence, etc.), depend on the performance of the PID control loops.

This is because the optimization systems usually define the optimum set-points (intelligent operator) to the control loops based on the operating conditions, while the PID controller is in charge of the control loops’ performance with respect to variations in the process behavior.

Therefore, these two solutions are complementary. One does not exclude the other.
Oscillations in the kiln fuel flow loop

Bad regulatory control

It is not possible to reach the results of the advanced control !!!

Final conclusions

The use of dedicated software for control loops’ performance assessment, diagnosis, and tuning is able to increase the productivity and efficiency of the maintenance teams.

Through practical examples, the benefits of PID loops’ audit was shown, thus yielding:

• Fuel savings;
• Throughput increase;
• Increase in the actuators’ lifetime;
• Improvement in product quality.