Meet the Experts, Lafayette Hill, PA, Sept. 18, 2012

APC and Advanced Services
What’s APC?

- APC – Advanced Process Control
- PID – Proportional, Integral, Derivative
- SISO – Single Input, Single Output
- MPC – Model Predictive Control
- MIMO – Multiple Inputs, Multiple Outputs
- State Space – Linear Algebraic form
- Constraints – Process or Physical Limits
- Linear Programming – Cost Minimization
- IMP – Inferential Modeling Platform
- Scheduling and Batch optimization
Control Performance Issues

Half life of Process Controllers

Given: a 100 PID loops all tuned at once.
Then: it is estimated that within 6 months, 50 of these loops will have a degradation in performance.

PID Controllers are designed to:
- Regulate the process
- Reduce product instability
- Improve operations

However, ABB is finding that PID Automation:
- PID loops are not being maintained
- PID loops have degraded
- PID loops are standing in the way of production and performance.

Simple PID Utilization

- 35% Manual Operation
- 15% Output Out of range
- 30% Increasing Variability
- 25% Improving process
ABB’s APC Project Approach

- **Pre Study + Implementation**
  - Quick Customer Value
  - Project delivery improved

- **APC Project Delivery**
  - Installation and commissioning

- **Process Interaction Matrix Identification - APC Fingerprint**

- **Process Interaction Matrix Identification - APC SCAN**

- **Monitor Performance LoopSCAN**

- **Service**

**Proven Approach**

- Project delivery improved
- No results erosion
- Continuous Improvement
Goal: Continuous Improvement

Process Loops
- Prioritize and Categorize
  - 1
  - 2
  - 3
  - 4

Signal

Actuator

Logic

Tuning

Stand Alone Tools
- Signal Analyzer
- LoopTune
- Loop Analyzer

Continuous Tools
- ServicePort

Action Plan
- Implement
- 1
- 2
- 3
- 4
### Signal Analysis

#### Time Series Selection:
- **Name:**
  - P3.IN
  - P3.MV
  - P3.NS
  - P4.IN
  - P4.MV
  - P4.NS
  - TSIN
  - TSMV
  - TSNS
  - Time

#### Statistics
- **Data Package Name:** LoopTime_TestData.DPF
- **Signal Name:** P5.MV
- **Sample Time:** 0.01 Seconds
- **% Range:** 57.532
- **Inter Quartile Range:** 30.373
- **Third Quartile:** 22.48
- **First Quartile:** -7.895
- **Kurtosis:** 1.13809
- **Skewness:** -0.72766
- **Median:** 18.77
- **COV:** 0.0432
- **Standard Deviation:** 27.06293
- **Variance:** 791.144
- **Root Mean Square:** 19.99606
- **Mean Deviation:** 15.20817
- **Average:** 8.34905
- **Mode, Occurrence:** 22.59, 25

#### Analysis:
- **Statistical Analysis**
  - Descriptive Statistics
  - Raw Data
  - Histogram
  - Correlation
  - Covariance
  - Envelope Trend
- **Frequency Analysis**
  - Descriptive Time Series
  - Amplitude Spectrum
  - Power Spectrum
  - Accumulated Power Spectrum
  - % Accumulated Power
  - COV Spectrum
  - Fast Fourier Transform
  - Inverse Fast Fourier Transform
  - Accumulated Sigma
  - Variance Per Decade

#### Graphs:
- **Accumulated Power Spectrum**
- **Histogram - P5.MV**
- **Amplitude Spectrum**
- **Power Spectrum**

#### ABB Image
LoopTune

- Results stored as a LoopTune channel in ServicePort
- Provides long term process model tracking.

Supports:
- Self Regulating
- Non-Self Regulating
- Auto Model Identification
LoopTune: Tuning/Simulation

Supports:
- 800xA Controllers
- Harmony/Infi90 Controllers
- Mod300 Controllers
- Generic industry standard controllers
- Plug in modules for custom controllers
LoopTune: Loop Tuning Report

Control Loop Tuning Report

1. Overview
   The model identification and tuning results for the control loops that were tuned for ABB Customer on 7/18/2012 are given below.

2. Applications: APC.TC101.P1
   The following are the process model identification and tuning results for control loop "Applications: APC.TC101.P1" during the time period 07/17/2012 15:24:01 to 07/17/2012 15:46:57.
   2.1 Identified Process Model:

   Figure 3: Process Model

   Figure 4: Simulation

ABB
Power and productivity for a better world™
Outline

- Assuring Optimal Control Performance
  - 1) Loop Performance – Dupont
  - 2) Batch Optimization – BASF
  - 3) Boiler Fuel Savings – Arkema
  - 4) QCS Success Story - Paper

- APC – Advanced Process Control
  - 1) Powerhouse Optimization

- Sustaining Results
Abbott Automation & Power World - May 18-20, 2010

CCH-101-1  11:00 Tuesday, room 351C
Doug Reeder, Ted Matsko
Loop Performance Fingerprint for a DuPont Monomers Plant
LoopAnalyzer Tool: Control Loop Diagnoses

<table>
<thead>
<tr>
<th>CONTROL</th>
<th>PROCESS</th>
<th>SIGNAL CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: Manual</td>
<td>P1: FCE Out of Range</td>
<td>S1: Quantized</td>
</tr>
<tr>
<td>C2: Oscillating Setpoint</td>
<td>P2: FCE Size</td>
<td>S2: Excessive Noise</td>
</tr>
<tr>
<td>C3: Deadband</td>
<td>P3: FCE Problem <strong>(stiction)</strong></td>
<td>S3: Spikes</td>
</tr>
<tr>
<td>C4: Offset</td>
<td>P4: FCE Leakage <strong>(flow loops)</strong></td>
<td>S4: Step Out</td>
</tr>
<tr>
<td>C5: Over Control <strong>(aggressive)</strong></td>
<td>P5: Intermittent Disturbance</td>
<td>S5: Compression</td>
</tr>
<tr>
<td>C6: Slow Control <strong>(sluggish)</strong></td>
<td>P6: Persistent Disturbance</td>
<td>S6: Over Filtered</td>
</tr>
<tr>
<td>C7: FCE Travel</td>
<td>P7: Questionable</td>
<td>S7: Sampling Rate</td>
</tr>
</tbody>
</table>

FCE = Final Control Element
Loop Performance Fingerprint
LoopScan Analysis – Performance Calculations

- Navigation options
- Diagnosis results in tree
- Loops Ranked for selected Diagnosis
- Navigate by clicking on bars
- Diagnosis results in frame for selected loop
Process Fingerprint
LoopScan Analysis – More Plots

Quick comparison plots, any plot type, one tag frozen on top half
Process Fingerprint
Oscillating Loops

- When a loop oscillates in automatic mode and there is not evidence of an external disturbance, over tuning is a possible cause.

- Power spectrum shows two frequencies of interest

- This loop is in the TFE Synthesis area
Process Fingerprint
Final Control Element Problem

- This is a flow controller that is the inner loop of a cascade.
- Exhibits classic stiction
- Controller output ramps up and down in triangular pattern
- Process variable moves in square wave
The report highlights some loops, as shown in the previous slides and summarizes the results in tables. This table is for the TFE Synthesis section of the plant.

<table>
<thead>
<tr>
<th>Loop Performance</th>
<th>Oscillating Error</th>
<th>Questionable Control</th>
<th>Manual</th>
<th>Offset</th>
<th>Slow Control</th>
<th>Oscillating Setpoint</th>
<th>Over Control</th>
<th>Output Out Of Range</th>
<th>Error Deadband</th>
</tr>
</thead>
<tbody>
<tr>
<td>0378FC</td>
<td>2344PC</td>
<td>8093TC</td>
<td>2332TC</td>
<td>864PC</td>
<td>8098TC</td>
<td>8175FC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8098TC</td>
<td>8156PC</td>
<td>8098TC</td>
<td>2387PC</td>
<td>0378FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8964PC</td>
<td>8177PC</td>
<td>8116FC</td>
<td>2349TC</td>
<td>8146FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8089FC</td>
<td>8144LC</td>
<td>8173LC</td>
<td>2337FC</td>
<td>8089FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8146FC</td>
<td>0378FC</td>
<td>8085LC</td>
<td>2388FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2344PC</td>
<td>8175FC</td>
<td>8153TC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8177PC</td>
<td>8973PC</td>
<td>2108PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8175FC</td>
<td>8967PC</td>
<td>8146FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8071FC</td>
<td>8165PC</td>
<td>8116FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8093TC</td>
<td>8084FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2377FC</td>
<td>2377FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8085LC</td>
<td>8087PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8087PC</td>
<td>8130PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8116FC</td>
<td>8089FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8156PC</td>
<td>9062PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8173LC</td>
<td>2341FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8153TC</td>
<td>8179FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8064FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2108PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2341FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8973PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8052PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8052PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8067PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8116FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8144LC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Process Fingerprint
PCA Cluster Example

- Find signals with similar patterns, probably due to disturbances
- Not looking for oscillating signals
- Here all signals are in two columns that are adjacent

<table>
<thead>
<tr>
<th>PCACluster13</th>
<th>Tag name</th>
<th>Area</th>
<th>Tag description</th>
<th>Causality</th>
<th>Deadtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>8342FC</td>
<td>BARDE-DRC</td>
<td>DRC REBOILER</td>
<td>STEAM FLOW CTRL</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8322FC</td>
<td>BARDE-DRC</td>
<td>DRC FEED FLOW</td>
<td>CTRL</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8262FC</td>
<td>BARDE-HCL</td>
<td>HCL COL DIST F</td>
<td>FL CTRL</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>8273FC</td>
<td>BARDE-HCL</td>
<td>HCL COL REBOIL</td>
<td>STEAM FL CTRL</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8266FC</td>
<td>BARDE-HCL</td>
<td>DIVER TO HCL</td>
<td>COLFEED CTRL</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>8304FC</td>
<td>BARDE-HCL</td>
<td>HCL COL REFLUX</td>
<td>CTRL</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
Process Fingerprint
Tuning Parameter Cluster Analysis

- Yellow box shows normal area for good tuning for flow loops
- Overall, tuning is a little conservative, but may be satisfactory for process with slower time constants
- Some “outliers” need to be checked.
Workbench: Implementation improvements

Visualization and Setup

Analysis

Identification

Collection

Standard Reporting

Tuning and Simulation

Tool Workbench
Batch Process Optimization
BASF Polymerization Reactor
Introduction
BASF Greenville

- Site History
BASF Batch Reactor Optimization
Polyester – What is it?

- Polyester is produced in our Greenville Ohio site “I” Reactor as an automotive component product.
- Polyester is made by a solvent process in a batch reactor
- Followed by a fractionating column to remove trace amounts of water.
- The processing time can be unacceptably long.
BASF Batch Reactor Optimization
Polyester – Key Equipment in “I” Reactor System

- 5,000 gallon reactor with Therminol-66 heating system
- Fractionator column
- Condenser and Decanter for water collection
BASF Batch Reactor Optimization
Polyester – ABB Study of Process Efficiency

- SymBatch / ProduceIT help ensure consistency on operational steps.

- However, batch cycle time variability came from several factors.

- A multifunctional team of Chemists, Engineers, Operators, and Operations Management continually made improvements, but outside resources were needed.

- ABB offered to help with their Fingerprint service.
BASF Batch Reactor Optimization
Temperature Control Loop Performance

- There are six main control loops, only four are operative
  1. Reactor hot oil temperature (inner loop)
  2. Reactor temperature (outer loop)
  3. Reactor-Coil $\Delta T$ override (outer loop)
  4. Condenser Reflux Rate (not in use)
  5. Fractionator overhead temperature
  6. Reactor Pressure (saturated during vacuum)

- Oscillations observed in reactor temperature and fractionator temperature

- Hot Oil loop override active and saturated output

- Pressure loop saturates
BASF Batch Reactor Optimization
Temperature Control Loop Performance

- Looking at standard data, the oscillations are difficult to see because of the wide range of operation typical in batch processes and different starting times
  - Define steps (events)
  - View by event
Looking at standard data, the oscillations are difficult to see because of the wide range of operation typical in batch processes and different starting times

- Define steps (events)
- View by event
BASF Batch Reactor Optimization
Temperature Control Loop Performance

- Looking at standard data, the oscillations are difficult to see because of the wide range of operation typical in batch processes and different starting times
  - Define steps (events)
  - View by event
Looking at standard data, the oscillations are difficult to see because of the wide range of operation typical in batch processes and different starting times.

- Define steps (events)
- View by event
BASF Batch Reactor Optimization
Temperature Control Loop Performance

- Looking at standard data, the oscillations are difficult to see because of the wide range of operation and different starting times.
  - Define steps (events)
  - View by event
BASF Batch Reactor Optimization

Temperature Control Loop Performance

- Use Loop Analyzer to look at reactor temperature cascade
- Amplitude plot shows oscillation frequency
- Implication is that outer loop is the problem
BASF Batch Reactor Optimization
Process Economics - Quality Control and Production Rate

Process Economics is tied to two things

- **Quality Control**
  - Decrease cost, i.e. lower energy
  - Increase yield at same quality
  - Reduce offspec losses
  - Value increases with quality

- **Production Rate**
  - Hold fixed costs constant
  - Increase production rate, revenue
  - For a batch process, production rate means cycle time

- For this polyester product, Step 4 dominates
BASF Batch Reactor Optimization
Process Economics - Quality Control and Production Rate

- Quality variance is very low for this product
  - Batch held until all specs met ➔ increase time
  - Lab tests repeated, manual adjustments

- This plant is Production Rate limited on this product
  - Long cycle time
  - 5 day x 24 hr work week
  - 120 hrs working time
  - 60 hrs = 2; 40 hrs = 3 batches

- Opportunity
  - Reduce variance of step times
• Quality variance is very low for this product
  • Batch held until all specs met ➔ increase time
  • Lab tests repeated, manual adjustments

• This plant is Production Rate limited on this product
  • Long cycle time
  • 5 day x 24 hr work week
  • 120 hrs working time
  • 60 hrs = 2; 40 hrs = 3 batches

• Opportunity
  • Reduce variance of step times
BASF Batch Reactor Optimization
Reducing Batch Cycle Times

- This plot confirms conclusion about vacuum and batch cycle time
- Real data is not always pretty (scatter)
  - Due to lab measurement, operator manual operations, unknown contaminants

Step4 Elapsed Time(Vacuum)
BASF Batch Reactor Optimization
Reducing Batch Cycle Times

- This plot confirms conclusion about vacuum and batch cycle time
- Real data is not always pretty (scatter)
  - Due to lab measurement, operator manual operations, unknown contaminants

Conclusion:
Investigate cost to improve vacuum
BASF Batch Reactor Optimization
Polyester Batch Reaction - RESULTS

- Difficult analysis: Improvements ongoing

- Reactor:
  - Evaluate more driving force on oil loop.
  - Batch Cascade loop oscillation (1°F) causing heating oil Loop oscillation (10°F) needs tuned.

- Fractionator:
  - Temperature Control could use a feed-forward
  - Identified Fractionator temperature loop failure
  - Identified saturated transmitter

- BASF Advance Process Control (APC) group also analyzed the reactor from a theoretical perspective and arrived at much the same conclusions.

- WE GOT THE CYCLE TIME IMPROVEMENTS!

- Related Harmony Fingerprint Analysis determined BRC100 memory issues needing resolved.
CSE-102-1: Boiler Fingerprint Success Story: How Arkema Saved $300,000 per year on Energy
Boiler Fingerprint : Value

- Energy Savings
- More Responsive to Process Steam Demands
- Extended Operating Range
- More Reliable
- Improved Safety
- Reduced Carbon Footprint
Boiler 2: Simplified Schematic

Steam
165.00 PSIG Header

Gas
1,542 PSIG
LB/HR Nat Gas
15.81 PSIG
39.42 Deg F
2.63 PSIG
40.37 Deg F
36.20 Deg F

Feed Water
238.36 PSIG
KL/HR Water
225.70 Deg F (DA Tank)

Air
36.13 KLB/HR Air
40.37 Deg F
36.20 Deg F

Feedwater Flow
SPC Cascade (unlocked)

Steam Flow
SPC Cascade (unlocked)

Furnace Pressure
SPC Auto (unlocked)

Gas Flow
SPC Auto (unlocked)
FD Fan Control – Combustion Air

Raw Data

Sample Number, Ts = 5, Total Samples = 10801
FD Fan Control – Combustion Air

Raw Data

Sample Number, Ts = 5, Total Samples = 10801

Positioner and Dampers = Suspect
Boiler Hardware Issues

- Positioner drives not operating smoothly.
- Cylinder/Piston assemblies should be rebuilt or replaced.
- Motors are oversized.
Hysteresis – Air and Fuel

Hysteresis in Fuel and Air Controls
14-May-08 PM Data Set
Boiler Fingerprint Recommendations

- **Hardware**
  - Repair FD and ID control drives
  - Resolve O2 transmitter reading issues. Check calibration, find leak, change location.
  - Adequately seal all doors
  - Recalibrate steam flows
  - Add blowdown flow monitoring
  - Adjust, clean, or replace sight glass for drum level

- **Control Logic**
  - Perform full combustion test to fine tune steam to air curves, esp. for oil
  - Update control logic to current implementation standards
  - Adjust logic to know when oil/gas is off
  - Excess Air calculation needs to be updated

- **Tuning**
  - Retune loops to be less aggressive.
  - Reduce output surge and ringing tendencies.
  - Add a small filter to level measurement. This will reduce feed water chatter.
  - Reduce filter on old steam flow measurement.
LoopScan: Cluster Analysis
Loop Parameter Evaluation

<table>
<thead>
<tr>
<th>Tag</th>
<th>Description</th>
<th>Zero</th>
<th>Span</th>
<th>Range</th>
<th>100/range</th>
<th>S5</th>
<th>S6</th>
<th>I</th>
<th>D</th>
<th>S8</th>
<th>S9</th>
<th>S10</th>
<th>Gain</th>
<th>Integral time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-FRD-200</td>
<td>Boiler 2 Steam Flow control</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>2.00</td>
<td>2</td>
<td>0.75</td>
<td>0.5</td>
<td>0</td>
<td>50</td>
<td>10</td>
<td></td>
<td>0.75</td>
<td>90.0</td>
</tr>
<tr>
<td>A-FIC-201</td>
<td>Boiler 2 Air Flow Control</td>
<td>0</td>
<td>60</td>
<td>60</td>
<td>1.67</td>
<td>1.7685</td>
<td>0.5</td>
<td>4.25</td>
<td>0</td>
<td>100</td>
<td>25</td>
<td></td>
<td>0.5</td>
<td>7.1</td>
</tr>
<tr>
<td>A-FIC-230</td>
<td>Boiler 2 Natural</td>
<td>0</td>
<td>3000</td>
<td>3000</td>
<td>0.03</td>
<td>0.0333</td>
<td>0.35</td>
<td>2.5</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td></td>
<td>0.35</td>
<td>8.4</td>
</tr>
<tr>
<td>A-FIC-260</td>
<td>Blr 2 Feedwater Flow Control</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>2.00</td>
<td>2</td>
<td>0.25</td>
<td>1.75</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td></td>
<td>0.25</td>
<td>8.6</td>
</tr>
<tr>
<td>A-FIC-201</td>
<td>Boiler 2 Air Flow Control</td>
<td>0</td>
<td>60</td>
<td>60</td>
<td>1.67</td>
<td>1.7685</td>
<td>0.5</td>
<td>4.25</td>
<td>0</td>
<td>100</td>
<td>25</td>
<td></td>
<td>0.5</td>
<td>7.1</td>
</tr>
<tr>
<td>A-PIC-211</td>
<td>Boiler 2 Furnace Pressure Control</td>
<td>-3</td>
<td>3</td>
<td>6</td>
<td>16.67</td>
<td>16.6</td>
<td>0.2</td>
<td>3.5</td>
<td>0</td>
<td>25</td>
<td></td>
<td></td>
<td>0.2</td>
<td>3.4</td>
</tr>
<tr>
<td>A-FIC-201</td>
<td>Boiler 2 air Flow Control</td>
<td>0</td>
<td>60</td>
<td>60</td>
<td>1.67</td>
<td>1.768</td>
<td>0.5</td>
<td>4.25</td>
<td>0</td>
<td>100</td>
<td>25</td>
<td></td>
<td>0.5</td>
<td>7.1</td>
</tr>
<tr>
<td>A-FIC-260</td>
<td>Blr 2 Feedwater Flow Control</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>2.00</td>
<td>2</td>
<td>0.25</td>
<td>1.75</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td></td>
<td>0.25</td>
<td>8.6</td>
</tr>
<tr>
<td>A-AIC-268</td>
<td>Blr 2 Blowdown Conductivity</td>
<td>0</td>
<td>5000</td>
<td>5000</td>
<td>0.02</td>
<td>0.02</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>-5</td>
<td></td>
<td>1</td>
<td>8.6</td>
</tr>
<tr>
<td>A-PIC-570</td>
<td>Level</td>
<td>-25</td>
<td>25</td>
<td>50</td>
<td>2.00</td>
<td>0.5</td>
<td>10</td>
<td>0.9</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td></td>
<td>10</td>
<td>666.7</td>
</tr>
</tbody>
</table>

Industrial Example: Cluster Analysis **Before vs After** implementation
Updated Air Curves

- **Gas Fuel for Air Curve**
  - Demand for Air vs. Steam Flow (KLB/Hr)
  - Air (Original) vs. Air (New)

- **Oil Fuel for Oil Curve**
  - Demand for Air Flow vs. Steam Flow
  - Air (Original) vs. Air (New)

- **Steam to Trim O2 Curve**
  - O2 Setpoint vs. Steam Flow
  - O2 Trim (Original) vs. O2 Trim (New)
Boiler #2: Customer results

Boiler 1 O2 vs Load
1 Hour Avgs.

Steam Load
% Oxygen

March 2008
February 2009
February All Auto
Boiler #2: Customer results

![Graph showing boiler performance metrics](image)

- % Oxygen vs Steam Load
- Data points for March 2008, February 2009, and February All Auto
- Highlighted areas indicating Fuel Savings

© ABB Inc.
September 25, 2012 | Slide 71
Financial Impact – Boiler #2, Summer 2008

Boiler #2 rated at 40 klb steam/hr

Savings range of 2% to 3% achieved without major capital

Approximate value = $75K to $100K for Boiler No. 2 alone

Savings for all four boilers = $300,000
Optimization Services
Paper machine Fingerprint
Variability – Paper Process

- Machine Direction (MD)
- Cross Direction (CD)
## System Reel Report

### Quality Analysis

#### Basis Wt 1 LBS

<table>
<thead>
<tr>
<th></th>
<th>Target</th>
<th>Actual</th>
<th>Efficiency</th>
<th>RES</th>
<th>MDL</th>
<th>CD</th>
<th>TOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>38.28</td>
<td>38.28</td>
<td>100.00</td>
<td>1.54</td>
<td>0.34</td>
<td>0.81</td>
<td>1.77</td>
</tr>
</tbody>
</table>

#### Moisture 1 PCT

<table>
<thead>
<tr>
<th></th>
<th>Target</th>
<th>Actual</th>
<th>Efficiency</th>
<th>RES</th>
<th>MDL</th>
<th>CD</th>
<th>TOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.70</td>
<td>3.70</td>
<td>100.00</td>
<td>1.08</td>
<td>0.30</td>
<td>0.59</td>
<td>1.26</td>
</tr>
</tbody>
</table>
Optimization Services - Service Areas

**Process Optimization**

Applied to: All Paper Making Systems

- Stock approach
- Machine Chest
- Dilution Valve
- Stuff Box
- Thick Stock Consistency
- CT
- FT
- Stock Valve

**Control Application Utilization**

Applied to: Controls and System usage

- Steam approach

**System Availability**

Applied to: Hardware

- Support

- Maintenance
Fingerprint: Paper Machine

**Provides** information on:
- Controllable Energy
- Mechanical Pulsations of vibrations
- Benchmark of machine stability

**Evaluates**: On control performance of:
- Total Head
- Thick Stock Flow
- Thick Stock Consistency
- Machine Chest Level

**Provides** information on:
- Controllable Energy
- Stock Approach performance
- Tuning Quality
- Oscillation sources

**Evaluates**: Cyclic content of Weight and Moisture in:
- Cross Direction
- Machine Direction
- From High Frequency up 500Hz down to Low Frequency of 5 hours.

**Provides** information on:
- Start up time
- Grade Change recovery
- Disturbance reduction
- Sheet break recovery
- Responsiveness

**Evaluates**: Automatic and Manual mode operation of:
- Weight
- Moisture
- Total Head

**Provides** information on:
- Will CD control improve the profile?
- Is current CD control optimized?

**History (VPA)**

**Profiling Capability**

**Stock Approach Stability**

- Poor regulation
- Offset from setpoint
- Good regulation

**Product Variability**

**Machine Response**

- Cyclic response
- Slow response
- Fast response
Fingerprint: Benchmarking

How does this paper machine compare to others in its class? Where should improvement efforts be focused?

<table>
<thead>
<tr>
<th>Index</th>
<th>Total</th>
<th>Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Variability</td>
<td>24.8</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Fiber Stability</td>
<td>0.63</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>Machine Response</td>
<td>7.3</td>
<td>&lt; 3.0</td>
</tr>
<tr>
<td>Profile Capability</td>
<td>133 to 162</td>
<td>&lt; 30</td>
</tr>
</tbody>
</table>

What is the best control that can be achieved on this machine?
Return on Investment

Every dollar invested in reducing variability, results in a return of 5 to 10 \textit{times}!

<table>
<thead>
<tr>
<th>Mill</th>
<th>Investment</th>
<th>Annual Savings</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>65k</td>
<td>325k</td>
<td>5 to 1</td>
</tr>
<tr>
<td>Fine Writing</td>
<td>95k</td>
<td>610k</td>
<td>6.4 to 1</td>
</tr>
<tr>
<td>Newsprint</td>
<td>20k</td>
<td>250k</td>
<td>12.5 to 1</td>
</tr>
<tr>
<td>Linerboard</td>
<td>70k</td>
<td>650k</td>
<td>9.3 to 1</td>
</tr>
<tr>
<td>Tissue</td>
<td>75k</td>
<td>560k</td>
<td>7.5 to 1</td>
</tr>
<tr>
<td>Pulp</td>
<td>120k</td>
<td>2,270k</td>
<td>18.9 to 1</td>
</tr>
<tr>
<td>\textbf{Average}</td>
<td>\textbf{74k}</td>
<td>\textbf{778k}</td>
<td>\textbf{10.5 to 1}</td>
</tr>
</tbody>
</table>
AGP400: High Speed Data Collection

Portable

Controller

Process or Scanner Interface Cables

Plug or test clips

Any Scanner

Data Collector Hardware

Notebook with Data Collector Software

Disk Logging and Real-Time Displays

Head Position Yo-Yo

Switch/Trigger

Digital Input (DC Voltage)
AGP400: High Speed Data Collection
High Frequency Results

![Amplitude Spectrum Comparison]

**Single Point Frame data** collected at 100 Hz and 1000 Hz for complete high frequency picture.

**Provides insight into pulsation and vibration in both weight and moisture**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Period</th>
<th>BW</th>
<th>MT1</th>
<th>MT2</th>
<th>Diameter</th>
<th>Length</th>
<th>Potential Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.061</td>
<td>16.38</td>
<td>0.27</td>
<td>0.8</td>
<td>0.44</td>
<td>265</td>
<td>832</td>
</tr>
<tr>
<td>B</td>
<td>0.36</td>
<td>2.78</td>
<td>0.048</td>
<td>0.33</td>
<td>0.358</td>
<td>45.1</td>
<td>141.7</td>
</tr>
<tr>
<td>C</td>
<td>0.71</td>
<td>1.39</td>
<td>0.046</td>
<td>0.29</td>
<td>0.25</td>
<td>22.6</td>
<td>70.8</td>
</tr>
<tr>
<td>D</td>
<td>1.84</td>
<td>0.54</td>
<td>0</td>
<td>0.298</td>
<td>0</td>
<td>8.76</td>
<td>27.5</td>
</tr>
<tr>
<td>E</td>
<td>3.15</td>
<td>0.317</td>
<td>0.07</td>
<td>0.38</td>
<td>0</td>
<td>5.13</td>
<td>16.1</td>
</tr>
<tr>
<td>F</td>
<td>6.3</td>
<td>0.159</td>
<td>0.09</td>
<td>0.55</td>
<td>0</td>
<td>2.56</td>
<td>8.06</td>
</tr>
<tr>
<td>G</td>
<td>10.3</td>
<td>0.1</td>
<td>0.07</td>
<td>0.26</td>
<td>0.12</td>
<td>4.9</td>
<td>1.56</td>
</tr>
</tbody>
</table>

(Yankee speed = 3049fpm)
PM Fingerprint: Product Variability

Fingerprint Comparison - % Total COV

Provides a summary of the cyclic energy in the sheet over a corresponding frequency band.

Includes Cross direction, Weight and moisture up to 100 hertz.

QCS  DCS  Mechanical

Weight

Moisture

<table>
<thead>
<tr>
<th>Decade</th>
<th>Weight</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>25.3743210</td>
<td>2.2876263</td>
</tr>
<tr>
<td>Decade 1</td>
<td>50.5483932</td>
<td>84.7719421</td>
</tr>
<tr>
<td>Decade 2</td>
<td>6.1163764</td>
<td>3.6153731</td>
</tr>
<tr>
<td>Decade 3</td>
<td>1.8690249</td>
<td>0.5106572</td>
</tr>
<tr>
<td>Decade 4</td>
<td>6.7068100</td>
<td>0.8314567</td>
</tr>
<tr>
<td>Decade 5</td>
<td>3.6419485</td>
<td>2.8962073</td>
</tr>
<tr>
<td>Decade 6</td>
<td>5.7431180</td>
<td>5.0867424</td>
</tr>
</tbody>
</table>
Data Logger 300: OPC Data Collection

- Conforms to OPC open standards
- Supports OPC DA V1 and later
- Log all OPC supported data types
- Access data from different OPC vendors
  - Log data from OPC servers on the network
  - Log data from multiple servers at the same time
  - Log scalar and array data
- Run multiple logging sessions with different tags in each session
Data Logger 300: OPC Data Collection

- Supports multiple logging start-stop conditions
  - Manual
  - Time
  - Number of samples
  - Multiple OPC tag value condition statements

- Provide data buffering before the logging start event, which is beneficial for root-cause analysis
  - Sheet break
  - Grade change
  - Process value exceeding a limit
  - High variability in a process value
- Loop Analysis

- Statistical Analysis
- Spectral Analysis
- Modeling Analysis
- CD Profile Analysis

- Spectral Analysis

- Statistical Analysis & Model Analysis

- 3D Analysis
Transition, AGC, SB Recovery
PM1 Grade Change Time

ROI $445K - $526K (2260 – 2660 Tons)

AGC Coordination Disabled

Grade Change Time (avg 10)

Each data point is average of 10 grade changes (194 grade changes analyzed)

Optimization Period

Average grade change time before optimization was 35.9 min and is currently down to 21.6 to 19.3 min

Average Grade Change Time reduced by 14.3 to 16.6 min
Oct-Nov 2010 sheet break recovery data showed a 20.9 min reduction in sheet break recovery time (38.5 down to 17.6 min)

ROI $65K - $86K
(1300 – 1725 Tons)
Optimization Summary – Achieved ROI

- Total Optimization Savings 2009: $1.2M – $1.4M

- PM1
  - Grade change time improvement:
    - 14.3 to 16.6 minutes: ROI $445K - $526K (2260 – 2660 Tons)

- PM2
  - Grade change time improvement:
    - 9.5 to 10.0 minutes: $365K - $387K (2080 – 2200 Tons)
  - MD weight and moisture variability reduction improvement

- PM3
  - Recovery Time: ROI $65K - $86K (1300 – 1725 Tons)
ABB’s APC Project Approach

- **Stabilize Process - Loop Performance Fingerprint**
  - Process Interaction Matrix Identification - APC Fingerprint

- **APC Project Delivery**
  - Process Interaction Matrix Identification - APC SCAN

- **Monitor Performance LoopSCAN**

- **Service**
  - Pre Study + Implementation: Quick Customer Value Project delivery improved
  - Installation and commissioning
  - Periodic Service: No results erosion Continuous Improvement

**Proven Approach**
APC Example: Zellstoff Celgar Supervisory Control Architecture

- Multi-Layered Solution

![Diagram of Multi-Layered Solution for APC Example: Zellstoff Celgar Supervisory Control Architecture]
ABB’s APC Solution: Predict and Control

Features

- True Multivariable Control
- State Space, Model Predictive Control (MPC) Structure
- Allows Constraints
- Inferential Model Prediction (IMP) of hard to measure variables
APC - Predict and Control

- Allows safe operation closer to constraints
- Smoothes operation by predicting effects of control moves and compensating
- Works best when base level controls are optimized
Predict and Control: Engineering Tool

- Allows process model development
- Shows interaction effects among variables
- Allows simulation of benefits
Features

- Uses Predict and Control Engineering Tools
- Quantifies critical process interactions
- Determines $ benefits from APC
- Suggests best structure
- Suggests required MV’s, CV’s, DV’s
- Determines additional measurement requirements and value
- Allows customer to get the best APC product for their plant
MPC Simulation Results

- **Shell Heavy Oil Fractionator (HOF) Problem**
  - 3 MVs, product flows
  - 2 DVs (used as unmeasured disturbances)
  - 2 CVs w/SP, product quality
  - 1 CV constraint, temperature
  - 4 PVs available
  - Soft constraint on an MV for process optimization
Optimize IT Predict & Control Performance

- 3 simulation runs of the HOF problem

- Comparing typical DMC treatment of disturbances to state feedback, using the Shell Heavy Oil Fractionator problem with unmeasured disturbances and modeling error
Optimize IT Predict & Control Performance

- 3 simulation runs of the HOF problem

- 1st example DMC like tuning, compositions (blue and red) have large deviations caused by unmeasured cooling duty disturbances, (magenta line, lower grid)
Optimize IT Predict & Control Performance

- 3 simulation runs of the HOF problem

- 2nd example, P&C with Kalman Filter estimate for disturbances.

- Large reduction in PV deviation.

2nd example, P&C with Kalman Filter estimate for disturbances.

Large reduction in PV deviation.
Optimize IT Predict & Control Performance

- 3 simulation runs of the HOF problem

- 3rd example, P&C with Kalman Filter estimate for disturbances.
- Using additional PVs
- Further reduction in PV deviation.

### Table

<table>
<thead>
<tr>
<th>Tagname</th>
<th>Scale Lo</th>
<th>Current Value</th>
<th>Crosshair Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MV1, U1</td>
<td>-1</td>
<td>-0.211</td>
<td>-0.342</td>
</tr>
<tr>
<td>MV2, U2</td>
<td>-1</td>
<td>0.078</td>
<td>0.263</td>
</tr>
<tr>
<td>MV3, U3</td>
<td>-1</td>
<td>0.342</td>
<td>0.339</td>
</tr>
<tr>
<td>PV1, Y1</td>
<td>-1</td>
<td>-0.006</td>
<td>0</td>
</tr>
<tr>
<td>PV2, Y2</td>
<td>-1</td>
<td>-0.016</td>
<td>0</td>
</tr>
<tr>
<td>PV7, Y7</td>
<td>-1</td>
<td>0.669</td>
<td>0.388</td>
</tr>
<tr>
<td>FF1, D1</td>
<td>-1</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>FF2, D2</td>
<td>-1</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>PV1, WSP, Y1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PV2, WSP, Y2</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PV7, Low, Y7</td>
<td>-1</td>
<td>-0.6</td>
<td>-0.3</td>
</tr>
</tbody>
</table>
Loop Optimization helps sustain customer results

**Goal**: Maintain improved performance level

- Adjust maintenance operating procedures
- Adjust standard operating procedures
- Remote process monitoring

- Specifics are a function of the Implement phase
- Periodic monitoring of key process indices utilizing local or remote expertise

Proactive and collaborative
Remote Optimization Services
ABB’s Proactive Architecture

Customer Request

Reactive
- Scheduling
- Collection
- Analysis
- Resolution
- On Site
- Remote
- On Site

Proactive
- Collection
- Analysis
- Resolution
- On Site
- Remote
- On Site

ServicePort
- Data Pool
- Collection
- Analysis
- Resolution
- On Site
- Remote
- On Site

Periodic Fingerprint Modules
- Short Lead time
- Audit
- Long lead time

Scan
- No Lead time

Track
- Event Trigger
- Reactive
- Proactive

On Site Data Pool
- KPI Trending
- Collection
- Analysis
- Resolution
- On Site

Condition Monitoring
- Remote
- On Site

Condition Monitoring
- Remote
- On Site
Service Infrastructure
Remote-enabled services improve access, cut costs

Service Capabilities
- Event Notification
- Control Tuning
- Optimization Services
- Support Services
- Software Support
- System Health Check
- Remote Troubleshooting

Secure Access
- Customer-Defined Access
- HoistScan/Track
- ServicePro
- LoopScan/Track
- DriveScan/Track
- System Scan/Track
- Troubleshooting Services
- APC Scan/Track Services

Secure Tunnel
- Engineering Stations
- Operator Stations
- Drives
- OCS
- Historian
- Instruments/Actuators
ABB ServicePort™
Secure, remote delivery for Scan and Track

- Secure portal residing at customer site through which plant personnel and ABB experts can access:
  - Configuration tools
  - Diagnostic applications
  - Improvement activities
  - Performance-sustaining troubleshooting
  - Scanning software that deploys agreed actions.
- ABB can connect to any system through ServicePort and implement fixes to diagnosed problems.
ABB ServicePort Channels

Main Menu

Value Map

Maintenance Tracking

Loop Performance

Disturbance Analysis

Platform Performance

Alarm/Event Traffic

Application channels
• Platform
• Process
• Control
• Maintenance
Sustain: track KPIs to ensure improvement

- **Q1**: Continuous Improvement
- **Q2**: Production increase!
- **Q3**: Variability decrease!
- **Q4**: Total
- **CD**: RES
- **MDL**: Delivery Schedule
Power and productivity for a better world™