Final Scientific Report

Implementation of a TMP Advanced Quality Control System at a Newsprint Manufacturing Plant

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Executive Summary:

This project provided for the implementation of an advanced, model predictive multi-variant controller that works with the mill's existing distributed control system. The method provides real time and online predictive models and modifies control actions to maximize quality and minimize energy costs. Using software sensors, the system can predict difficult-to-measure quality and process variables and make necessary process control decisions to accurately control pulp quality while minimizing electrical usage. This method of control has allowed Augusta Newsprint Company to optimize the operation of its' Thermo Mechanical Pulp mill for lower energy consumption and lower pulp quality variance.

Augusta Newsprint's Thermo Mechanical Pulp(TMP) mill is one of two pulp mills that feed two high speed Newsprint Machines. The TMP mill is comprised of eleven 12,000 horsepower refiners. These refiners, in three stages, take wood chips from approximately 1" x 1" x 1/4" to individual pliable fibers. This process is very energy intensive and can change due to the conditioning of the chips and the operation of the rest of the TMP process, primarily the rate at which fibers are rejected and re-refined.

Figure 1 -Thermo Mechanical Pulp Process Flow Diagram

Results:

The primary goal for this project was the reduction of energy consumption for the mill. Figure 2 shows a savings of ~ 3.5% for the total mill, or \$1.25 million per year at 2001 energy prices. The goal of the project was to save \$1.12 million per year after complete implementation; this is judged on a quarterly basis using a sliding scale of energy usage versus pulp quality (seen in Figure 3). In addition to the energy savings; a goal of 40% pulp quality variance reduction was set (progress can be seen in Figure 4). Other anticipated and recognized benefits were increased pulp quality and reduced usage of supplemental Kraft pulp. These results were achieved while increasing the production rate of the Thermo Mechanical Pulp mill; though many other factors in the mill assisted in these results, i.e. chemical additions, pulp quality targets and various energy reducing projects in the mill.

Figure 2 – Total Mill Energy Consumption

Figure 3 – Burst versus Specific Energy

Figure 4 – Decker Freeness Variability

Project Activities:

Initial Data Analysis

Prior to beginning any mill Advanced Quality Control system, existing historical data was analyzed. The purpose of this analysis is to determine preliminary estimates in the following areas:

- What are the primary areas of control (refiners, screens, blending)?
- What is the present pulp quality and paper quality variance? How does it compare against other mills?
- What are the economic factors affecting this project:
 - Furnish (Kraft, broke, TMP, RNP)
 - Energy (electrical, steam, etc..)
 - Paper Machine Efficiency (speed, breaks, off-spec, etc...)
 - Chemical Costs (bleach, retention aid, filler, pitch control, etc...)
 - Chip Costs...

Control Infrastructure

Advanced Quality Control projects are designed to use a central process control data server. This project task involves the design and implementation of the process control data server. Normally there are two interfaces installed:

- DCS interface – This is for all continuous process data.
- MIS interface – Most off-line testing (pulp and paper quality) is stored in a MIS system. At Augusta Newsprint, PI is the primary system used for data storage.

Initial Simulation

A detailed steady state and dynamic simulation was developed of the mill operation from the chip pile through the pulp mill. The simulation, developed using WinGEMS 5.0, serves a number of purposes:

- Baseline the mill operation
- Identify process bottlenecks
- Further refine the availability of data
- Determine significant time delays in the system for synchronizing process and quality data
- Initial basis for tuning full mill control systems
- Platform for building control systems for the operators

Time Synchronization Simulation

When predicting in real time, the effect of pulp quality at various points in the pulp mill must be time determined, data from throughout the mill must be time synchronized. Time synchronization must deal with the following factors:

- Changing tank levels
- Changing production rates
- Process recycles
- Dead time, mixed tanks as well as non-ideal flow

A specialized WinGEMS simulation called an Event Profiler was developed for determining the process delays. The simulation was first built and tested off-line, then linked to the process control data server for on-line real time synchronization.

Evaluation of Regulatory Control

Advanced Quality Control requires that the regulatory control elements and control loops are designed, implemented, tuned and maintained correctly. A complete evaluation of the applicable regulatory loops was performed. Changes to the regulatory loops and elements were recommended prior to proceeding with Advanced Quality Control.

Detailed Unit Operation Modeling

Whenever possible, historical data or mechanistic models are used to develop the control parameters for the Advanced Quality Control system. However, a portion of the models required for building the controllers does not lie in the historical data analysis or in the first principle mass and energy balances. Mill trials were performed to identify these model coefficients. This was normally in the form of process bump testing.

Detailed Control

Advanced Quality Control has the goal of improving the economics of the process by achieving sustainable and quantifiable economic benefits. Sustainable economic benefits are achievable through coordination of the Advanced Quality Control from throughout the mill. Three process areas were identified for Advanced Quality Control by the initial data analysis: Mainline Refiners, Reject Refiners and the Screen Room.

Post Audit

Once all systems were complete, the system performance was audited to determine the performance level.

Issues during the Process:

- From the beginning of the project it was known that many of the existing regulatory control hardware would have to be upgraded; flow meters, consistency meters, hydraulic controls, etc...
- Separate Energy Reducing Projects; Augusta Newsprint invested an additional \$450,000+ from 2002 to 2004 to reduce energy usage.
- Production Rate of the Thermo Mechanical Pulp mill; this rate which can be driven by outside market forces dramatically impacts the mill's power consumption. The higher the production rate the higher the total mill's energy consumption. 2001, 2002, 2003 and 2004 all had increases in the Thermo Mechanical Pulp mill production rates.
- Major process changes;
 - Mill chose to add a chemical treatment to the pulp that improved strength properties of the pulp,

- Mill reconfigured the Mainline Screens, going from five primary screens to three primary screens and two secondary screens in a feed forward configuration.
- Operational changes in other areas of the mill; during the time period of the project, due to market conditions the paper machines needed a pulp that drained faster.

These issues were dealt with using originally twice weekly strategy meetings to now once weekly meetings. The participants for these meetings are both Pacific Simulation representatives and Augusta Newsprint representatives. Pacific Simulation provided both local and call-in representatives, while Augusta Newsprint representatives included those directly involved with the Thermo Mechanical Pulp mill operations as well as those who could speak for the other areas of the mill.

One of the major shifts in strategy has been a change in pulp freeness (a measure of how quickly water will drain from a pulp solution). This helped the machines run faster, requires less energy to achieve and helps utilize the change in strength due to chemical addition. Figure 5 shows the shift in freeness and the resulting shift in burst (a common measure of pulp strength). Due to this shift, consideration had to be taken when determining the value of energy reduction due to the project versus the energy reduction by merely shifting the freeness target. Much of the rise in the target was made possible by the lower pulp quality variance.

Figure 5 – Final Freeness versus Burst

Computer Modeling:

Operating Environment

The TMP MPC (Model Predictive Controller) application runs on two operating environments, a host distributed control system interfacing directly with the process and a PC/NT server running the MPC/Process control data server application software. Figure 6 shows the basic application architecture. The arrows indicate exchange of data between the operational units (blocks).

Figure 6 – Application Architecture

Multi-Variable Predictive Controller

The MPC package is a Multi-Variable Predictive Controller, written in Visual Basic and Fortran. The optimization engine of MPC is a Fortran program called Minos, which was written and developed at Stanford U. in Connecticut.

MPC has a user-interface for setting tuning parameters and monitoring the control operation. Basic configuration is done in a flat file that specifies manipulated variables, controlled variables, their tag names, and their model-relationships. The configuration information is stored in an MS Access format database.

Data is exchanged with the DCS via MS OLE for Process Control (OPC) and the process control data server interfaces. Every 30 seconds, MPC reads process feedback (i.e. current values of the controlled and manipulated variables), performs the optimisation that calculates the new manipulated variable setpoints and sends them to the DCS.

Process Control Data Server

The process control data server provides a database and an interface to the Data Pipe. The Data Pipe transfers data between the process control data server and the OPC server. The process control data server polls data pipe for data and historizes it in the database. It is the process control data server through which the MPC application reads data from the DCS. Manipulated variable setpoints and other information are sent to the DCS via Data Pipe from IMAS.

Program Server

The program server allows remote dial-in and runs Data Flow Engine applications. The Data Flow Engine applications perform scheduled calculations and interface with the process control data server. A Data Flow Engine application has been developed which calculates "Software Sensor" or model estimates of some of the TMP process variables (see Quality Variable Modeling – Software Sensors Section). These estimates are used by the MPC for controlling the TMP process.

Distributed Control System

A Honeywell TDC 3000 is the distributed control system (DCS) platform for this application. The MPC interface and the low-level PID control loops nearest to the process run on this platform. Setpoints calculated by MPC are sent to these low-level PID control loops (also known as manipulated variables).

Multi-Variable Predictive Control (MPC) Configuration

The MPC configuration includes determining the manipulated and controlled variables, defining the interaction matrix, building the input-output models and defining the optimisation objectives (e.g. maximise production).

Control System Structure and Operation

The control system structure, shown in Figure 7 includes the MPC controller and the Software Sensors. The MPC controller will take controlled variables (process outputs) from the Software Sensors and calculate control moves for the manipulated variables (process inputs).

Figure 7

Manipulated Variables (Process Inputs)

Manipulated variables (process inputs) are the low-level PID controllers used in MPC to move the process to its desired operating state. Based on a regulatory audit, the key low-level loops that influenced pulp quality were evaluated. The manipulated variables used in this application are transfer screw speed, primary motor load, secondary motor load, primary dilution flow and secondary dilution flow for the main line refiners. The manipulated variables used in the reject refiner portion of this application will be motor load, refiner dilution flow, and press feed flow. The manipulated variables for the primary screens will be the five main screen reject flows. The manipulated variables for the reject screens will be the five reject screen reject flows.

Outputs from MPC have to be validated against high and low limits, before being accepted as remote setpoints for the manipulated variables. The MPC application will not allow the manipulated variable setpoints to stay outside these “hard” high and low limits. If a manipulated variable is outside a limit, the MPC application will move the setpoint towards the limit at the maximum allowable rate defined by the controller (see MPC Tuning Section).

The refiner motor load is a key manipulated variable and is controlled by changing the plate position or gap through changing the hydraulic pressure. There is a potential risk here of pinching or plate clashing if the gap gets too narrow. A sure sign of this event happening is when the motor load/plate gap gain inverts (i.e. motor load starts to decrease with increasing plate position). A motor load control strategy has been developed that monitors this gain and automatically backs off the plate position.

Controlled Variables (Process Outputs)

Controlled variables (process outputs) are the measured process and pulp quality variables, which cannot be changed directly by MPC, but are correlated to the manipulated variables (process inputs). They are selected based on available measurements and mill quality criteria. The key controlled

variables are freeness, fiber length, shives, refiner blow line consistency, primary to secondary motor load ratio, average transfer screw speed, total specific energy, and total mill power demand. In addition, the key controlled variables for the reject refiner portion of this application are freeness, fiber length, shives, reject refiner blow line consistency, average reject freeness, average reject fiber length, average long shives, and unrefined rejects chest level. The key controlled variables for the primary screens are accepts freeness, accepts fiber length, accepts shives, and mass reject rate. The key controlled variables for the reject screens are accepts freeness, accepts fiber length, accepts shives, and mass reject rate. Each is available as a Software Sensor value from a data engine located on the NT server. The values are updated every 30 seconds.

“Synthetic” Controlled Variables

Synthetic controlled variables are those derived from the basic process variables. The ones to be used in the MPC application are:

1. TMP average screw speed, i.e. the average of all the individual line transfer screw speeds.
2. Motor load ratio, i.e. the ratio of primary refiner motor load to the total for the line.
3. Main-line long shive, i.e. the production weighted average of the individual line long shive.
4. Main-line freeness, i.e. the production weighted average of the individual line freenesses.
5. Main line fiber length, i.e. the production weighted average of the individual line fiber lengths.
6. Reject average long shive, i.e. the production weighted average of the individual line long shive.
7. Reject average freeness, i.e. the production weighted average of the individual line freenesses.
8. Reject average fiber length, i.e. the production weighted average of the individual line fiber lengths.

Quality Variable Modelling – Software Sensors

MPC requires a stable quality variable measurement that is updated frequently enough to be able to reflect process dynamics, normally found through response testing. While some of the key measurements are available on the PQM, the update interval is only 30 minutes. More frequent measurements are therefore required for continuous control. Other process variables, such as refiner blow line consistency have no on-line measurements and therefore require a continuous estimate for control.

TMP pulp quality models were implemented on the data-flow engine platform located on the NT server. The outputs from the models are called on-line estimators or software sensors. There are software sensors for long shive, fiber length, freeness and blow line for each main line and reject line and for the pulp leaving the main line latency chest and the screens. The basis for modeling long shives, fiber length, and freeness is comminution modeling. The basic inputs for the model relationships are indicated below:

Shives Out = f (Shives In, Specific Energy)

Long Fiber Out = g (Long Fiber In, Shives In, Specific Energy)

Freeness Out = h (Freeness In, Specific Energy)

The above software sensors require inputs such as production rate (transfer screw speed), dilution flows, refiner motor loads, inlet chip moisture, and refiner temperature and pressure. All are available in the DCS, except for chip moisture, temperature and pressure measurements, which can be estimated with some accuracy.

Some of the software sensors are corrected for model error – that is the difference between the PQM measurement and the model output. Every time the PQM outputs a new measurement, the model error is calculated, filtered in time and applied as a correction to the quality estimates for each line.

Samples are taken every 4 hours from the outlet of the secondary refiners and reject refiners. The samples are tested in the lab for freeness and consistency. Daily, the lab conducts a fiber length test on composite samples from the primary, secondary and reject refiners. A hand sheet burst test from 24 hour composite samples from the secondary and reject refiners is performed daily. The results are used to calculate model error for the individual lines and to correct the software sensors for that line.

MPC Execution

The control interval for MPC is 30 seconds. Every 30 seconds MPC polls the control server database for new data from the DCS. The process feedback values for the manipulated and controlled variables are then read in and the internal values in MPC are updated. MPC then defines the control problem and runs the Minos optimization program, which calculates new setpoints for the manipulated variables.

MPC then writes an “.inp” file, which contains the new setpoints for the manipulated and variables and the steady-state estimates for both the manipulated and controlled variables. The data-pipe program reads the “.inp” file and sends the values to the DCS through the OPC interface.

MPC Control Modes

For each line, MPC has, “Predict” and “Control” mode switch, as well as an MPC “on/off” switch. These are known, respectively, as the Mode Switch and the Line Switch. “Predict” mode means MPC is predicting property values on the horizon, but not making any control actions. “Control” mode means MPC is making control actions for any manipulated variables in “MPC” mode. “MPC” mode for a manipulated variable means the low-level controller is taking remote setpoints from MPC (otherwise it's in local/auto or local/manual mode).

MPC Watchdog Timer

A watchdog timer resides in the DCS, which is used for detecting “I'm Alive” status of MPC on the NT station. It counts down from 5 minutes and is reset by MPC every 30 seconds. If MPC fails to reset it after 5 minutes the MPC Master Switch is set to “off” and the operators cannot turn on MPC until it resets the counter. A watchdog timer failure indicates that either the MPC program on the NT server has been turned off or the communication between the NT server and the DCS has failed.

Interaction Matrix

Figures 8-11 are the interaction matrixes that show the relationship between the process inputs (manipulated variables) and the process outputs (controlled variables). A ‘+’/‘-’ entry in the matrix denotes the process output is positively/negatively correlated to the process input. No entry means no correlation. The matrix was developed by process analysis and inspection of the relationships found in the Software Sensor models.

Figure 8 – Main Line Refiner Interaction Matrix

		MAIN LINE REFINER INPUTS				
		Prim. Refiner Motor Load	Prim. Refiner Dilutions	Second. Refiner Motor Load	Second. Refiner Dilutions	Transfer Screw Speed
O U T P U T S	Secondary Freeness	-		-		+
	Secondary Fiber Length	-	-	-	-	+
	Secondary Long Shive	-	+	-	+	+
	Primary Consistency	+	-			+
	Secondary Consistency	+	-	+	-	+
	Motor Load Ratio	+		-		
	Mainline Freeness	-		-		+
	Mainline Fibre Length	-	-	-	-	+
	Mainline Long Shive	-	+	-	+	+
	Specific Energy	+		+		-
	TMP Avg. Screw Speed					+
	Total Mill Power Demand	+		+		

Figure 9 – Reject Refiner Interaction Matrix

		REJECT REFINER INPUTS		
		Refiner Motor Load	Refiner Dilution	Press Feed Flow
O U T P U T S	Freeness	-		+
	Fiber Length	-		+
	Long Shive	-		+
	Consistency	+	-	+
	Unrefined Reject Chest Lvl			-
	Avg Reject Freeness	-		+
	Avg Reject Fiber Length	-		+
	Avg Reject Long Shive	-		+

Figure 10 – Primary Screen Interaction Matrix

		MAINLINE SCREEN INPUTS				
		Reject Flow No. 1	Reject Flow No. 2	Reject Flow No. 3	Reject Flow No. 4	Reject Flow No. 5
O U T P U T S	Accepts Freeness	-	-	-	-	-
	Accepts Fiber Length	-	-	-	-	-
	Accepts Long Shive	-	-	-	-	-
	Mass Reject Rate	+	+	+	+	+

Figure 11 – Reject Screen Interaction Matrix

		REJECT SCREEN INPUTS				
		Reject Flow No. 1	Reject Flow No. 2	Reject Flow No. 3	Reject Flow No. 4	Reject Flow No. 5
O U T P U T S	Accepts Freeness	-	-	-	-	-
	Accepts Fiber Length	-	-	-	-	-
	Accepts Long Shive	-	-	-	-	-
	Mass Reject Rate	+	+	+	+	+

MPC Response Models

For each matrix entry, a dynamic response model is required. This is a model of the response of a controlled variable to a step or impulse change in a given manipulated variable. For the MPC controller used in this application the model is in the form of a step response weights (as opposed to a parametric linear transform function).

As discussed in Quality Variable Modeling – Software Sensor Section, a continuous measurement of some of the controlled variables is not available at a high enough frequency that would allow direct determination of the response models (i.e. through on-line bump tests). Step response models are determined by simulation using the Software Sensor models and the dynamics of the manipulated variable process variables in response to a change in setpoint.

MPC Objectives

The main objectives of the main line MPC are as follows:

1. Maintain freeness for the main line and lines 1, 2, 3, and 4 within a range
2. Maintain fiber length for the main line and lines 1, 2, 3, and 4, above a low limit.
3. Maintain long shives for the main line and lines 1, 2, 3, and 4 below a high limit.
4. Maintain a target average transfer screw speed/production rate.
5. Maintain motor load ratio within a range (between 50 - 60%).
6. Keep total Mill power demand below a maximum limit.

The main objectives of the Reject Line & Screen MPC are as follows:

1. Maintain freeness for the reject system and freeness for lines RJ1, RJ2, and RJ3 within a range
2. Maintain fiber length for the reject system and fiber length for lines RJ1, RJ2, and RJ3 above a low limit.
3. Maintain long shives for the reject system and long shives for lines RJ1, RJ2, and RJ3 below a high limit.
4. Maintain reject refiner blow consistency for lines RJ1, RJ2, and RJ3 within a range.
5. Maintain primary screen accept freeness within a range.
6. Maintain primary screen accept fiber length above a low limit.
7. Maintain primary screen accept long shives below a high limit.
8. Maintain reject screen accept freeness within a range.
9. Maintain reject screen accept fiber length above a low limit.
10. Maintain reject screen accept long shives below a high limit.
11. Maintain unrefined rejects chest level within a range.
12. Maintain Thune press amperage loads within a range.
13. Maintain primary and reject screen Mass Reject Rate within a range.

MPC Tuning

The MPC application moves the setpoints of the process inputs (manipulated variables) to maintain the process outputs (controlled variables) within their limits. The speed or size of change that MPC will make to drive a controlled variable towards its operating limits depends on:

1. How far the controlled variable is away from its configured range.
2. Magnitude of the limit weight.
3. Existing limits on the manipulated variables

Naturally, the farther the controlled variable is from its range, the harder MPC will try to bring it back in. The larger the values of the weights on the limits, the bigger the control actions will be and the fewer steps it will take. The controlled variable limit weights also express the relative importance of getting that variable into its range. The higher the relative value of a limit weight the more attention MPC will pay to getting the variable into the desired operating range.

Limits on manipulated variables are high/low range limits and control action or move size limits. If a controlled variable is outside its range, but all manipulated variables have run up against their limits, then MPC cannot do anything further to rectify the situation. Move suppression parameters are also applied to the manipulated variables. These parameters determine how fast the manipulated variables will change to bring the controlled variables into range.

MPC tuning is a somewhat subjective exercise. A simplified list of the steps required to tune the MPC application is shown as follows:

- Step 1: Prioritise the importance of keeping controlled variables within their desired limits.
 Assign weights to the limits according to the magnitude of the process values.

- Step 2: Simulate how the controller will behave under different scenarios. Adjust the weights until the desired behaviour is observed.
- Step 3: Prioritise the manipulated variables in order of the desired speed of response. The user may want some variables to respond faster than others. Apply move suppressions to the manipulated variables according to their magnitude. The higher the move suppression value the slower the manipulated variable will respond.
- Step 4: Simulate how the controller will behave under different scenarios. Adjust the move suppressions until the desired behaviour is observed.