Wet End Control Applications Using a Multivariable Model Predictive Control Strategy

Stephen Chu, P. Eng.

ABSTRACT

This paper discusses the use of a SpectraFoil MD sensor on a fine paper machine to monitor the pre Dandy Roll consistency and the use of this data in an overall control scheme designed to increase sheet filler content (measured at the pre size press scanner) while maintaining online sheet formation within a desired range. The control scheme is based on a multivariable model predictive control strategy. The paper will discuss the key manipulative variables and controlled variables used and the results obtained.

The wet end of the paper machine is an extremely dynamic and interactive process. With infinite combinations of furnish compositions, chemical additives flows, vacuum box pressure levels and machine speeds, the papermaker refers to papermaking as more art than science. Regulatory control loops (single input / single output - SISO) and new wet end gauges (such as SpectraFoil MD which measures stock consistency on the wire) are useful but possible changes or upset to the paper machine will affect several other variable at the same time. During machine break recoveries and grade changes, the papermaker is constantly looking at multiple monitors to determine if each regulatory loop and gauge measurement is within target.

The Profit Multivariable MPC (Model Predictive Control) controller models the interaction of the key wet end variables and is used in a control scheme discussed in this paper. A significant reduction in variation in the key wet end variables were observed while the Profit Multivariable MPC controller was on. By stabilizing the wet end, the pre size press ash variability was minimized, yielding a more consistent product from grade to grade. Once the wet end variables were stabilized, the pre size press ash setpoint was increased incrementally. The economic goal was to replace fiber with filler while not affecting the paper machine run-ability and paper quality

Identifying the Key Wet End Variables

A large US fine paper manufacturer installed a SpectraFoil MD drainage

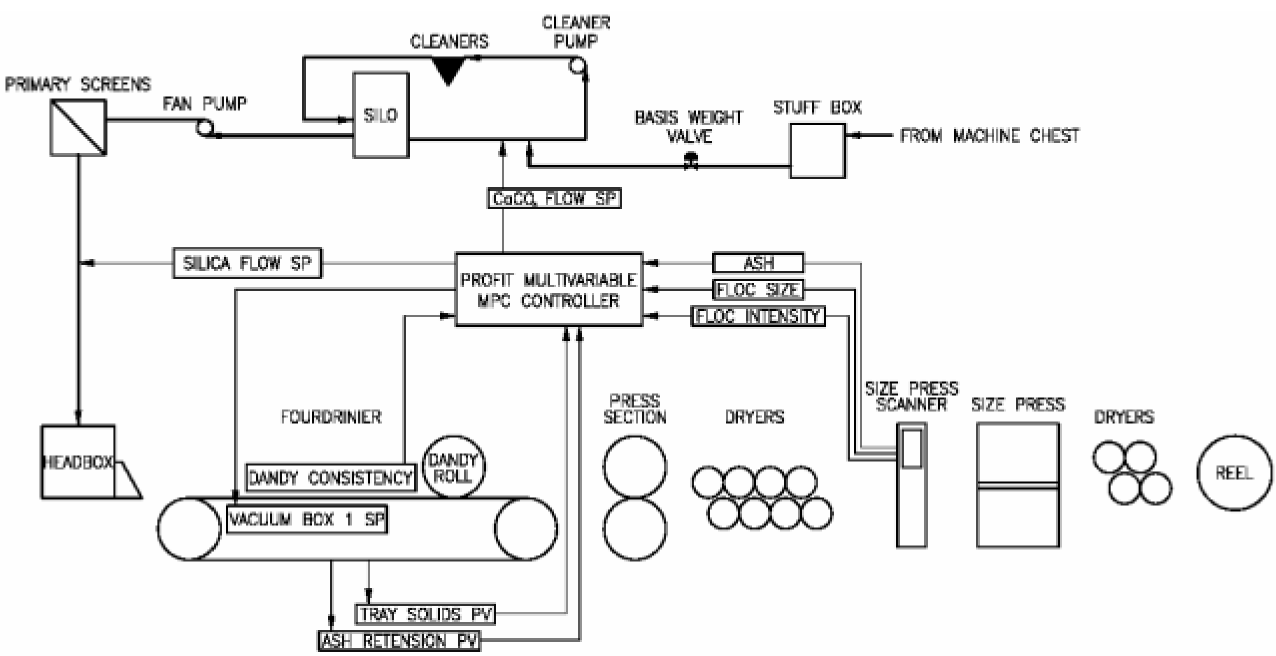

Figure 1

Honeywell 500 Brooksbank Avenue, North Vancouver, B.C. V7J 3S4 Canada

measurement system on their paper machine to monitor the stock consistency on the Fourdrinier prior to the Dandy Roll. The papermaker uses this measurement (Dandy Consistency) as a guideline to monitor the dry line that is located downstream of the Dandy Roll. The dry line is an indication of paper machine run-ability and paper quality if the dry line is too far upstream, the paper machine handles process upsets (i.e. changes in broke ratio, refining and/or base stock fiber) better but the paper quality (formation) gets worse.

The dry line location is manipulated by manually changing the slice lip opening and / or the vacuum box before the Dandy Roll (Vacuum Box 1). Along with this balancing act, the operators must be aware of the wet end retention aid (Silica) and filler ($CaCO_3$) flows that also affect the dry line location and formation. The challenge for the papermaker is to adjust all these variables, which are in manual control or in simple regulatory loop control (SISO) to get the desired machine run-ability and paper quality.

Based on observing the papermaker's manual control moves during grade changes and process upsets, the following variables have been identified for the Profit Multivariable MPC controller: a) The Manipulative Variables (MVs) are $CaCO_3$ flow SP, Silica flow SP and Vacuum Box 1 SP. b) The Controlled Variables (CV) are Ash, Ash Retention PV, Dandy Consistency, Floc Intensity, Floc Size and Tray Solids PV.

The Dandy Consistency is measured by the Honeywell MD SpectraFoil sensor located under the Fourdrinier wire. The Floc Intensity and Floc Size are measured by the Honeywell formation sensor and the Ash is measured by the Honeywell ash sensor. Both formation and ash sensors are located in the size press scanner. The Tray Solids PV and Ash Retention PV are measured using a Chemtronics system.

Figure 1 shows a schematic of the stock approach flow, Fourdrinier and dry end of the paper machine. Also shown are the locations of each Profit variable and how they interact with the Profit Multivariable MPC controller to yield the desired run-ability and paper quality.

Bump Tests

Bump tests were performed on the MVs to determine the relationships among the CVs and to build control models for the Profit Multivariable MPC controller.

The $CaCO_3$ flow SP was bumped as follows: initial setpoint, initial setpoint + 15 kg/ton (bump 1), initial setpoint 10 kg/ton (bump 2) and finally initial setpoint + 25 kg/ton (bump 3)

Figure 2 shows there are

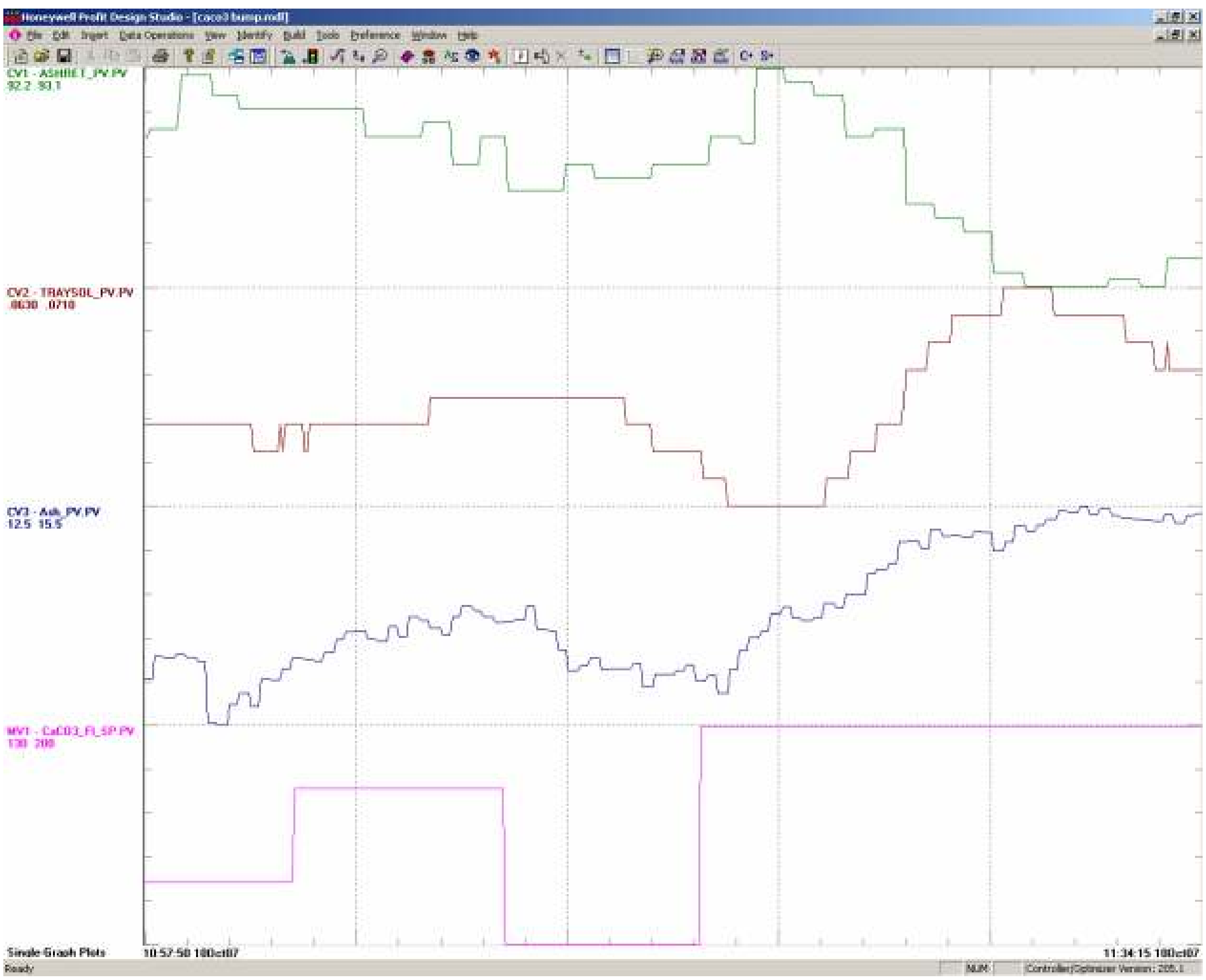

Figure 2

relationships among the $CaCO_3$ flow SP bumps and the following variables: Ash Retention PV (AshRet_PV), Tray Solids PV (TraySol_PV) and Ash (Ash_PV).

The $CaCO_3$ flow SP bumps yields responses that are distinct and well defined for these CVs.

$CaCO_3$ flow SP ↑ , Ash Retention PV ↓ and $CaCO_3$ flow SP ↓ , Ash Retention PV ↑

$CaCO_3$ flow SP ↑ , Tray Solids PV ↑ and $CaCO_3$ flow SP ↓ , Tray Solids PV ↓

More filler ($CaCO_3$) introduced on the wire will increase the Tray Solids PV and decrease the Ash Retention PV.

$CaCO_3$ flow SP ↑ , Ash ↑ and $CaCO_3$ flow SP ↓ , Ash ↓

More filler ($CaCO_3$) introduced on the wire will increase the Ash at the size press scanner.

The Silica flow SP was bumped as follows: initial setpoint, initial setpoint + 0.06 kg/ton (bump 1), initial setpoint - 0.14 kg/ton (bump 2) and finally back to the initial setpoint (bump 3).

Figure 3 shows there are relationships among the Silica flow SP bumps and the following variables: Ash (Ash_PV), Floc Intensity (FlocInt_PV), Floc Size (FlocSize_PV), Tray Solids PV (TraySol_PV), Ash Retention PV (AshRet_PV) and Dandy Consistency (DandyCon_PV).

The Silica flow SP bump yields responses that are distinct and well defined for all these CVs.

Silica flow SP ↑ (more retention aid), Ash ↑ and Silica SP flow ↓ (less retention aid), Ash ↓

Retention aid is working as adding more Silica retains more solids (fibers and fillers) and improves drainage. However with more Silica, formation suffers.

Silica flow SP ↑ , Floc Intensity ↑ and Floc Size ↓ , thus making the paper formation worse.

Silica flow SP ↓ , Floc Intensity ↓ and Floc Size ↑ , thus making the paper formation better.

This relationship is known to the papermakers and they adjust the key variables (in manual) accordingly.

This observation has been observed in many paper mills and has been documented:

"The mechanical retention of the wire is supported by chemical retention aids which form flocs out of the fibers and fillers, thereby improving both retention and drainage at the wire. Since this enables higher machine speeds, retention should be as high as possible. One of the limitations,

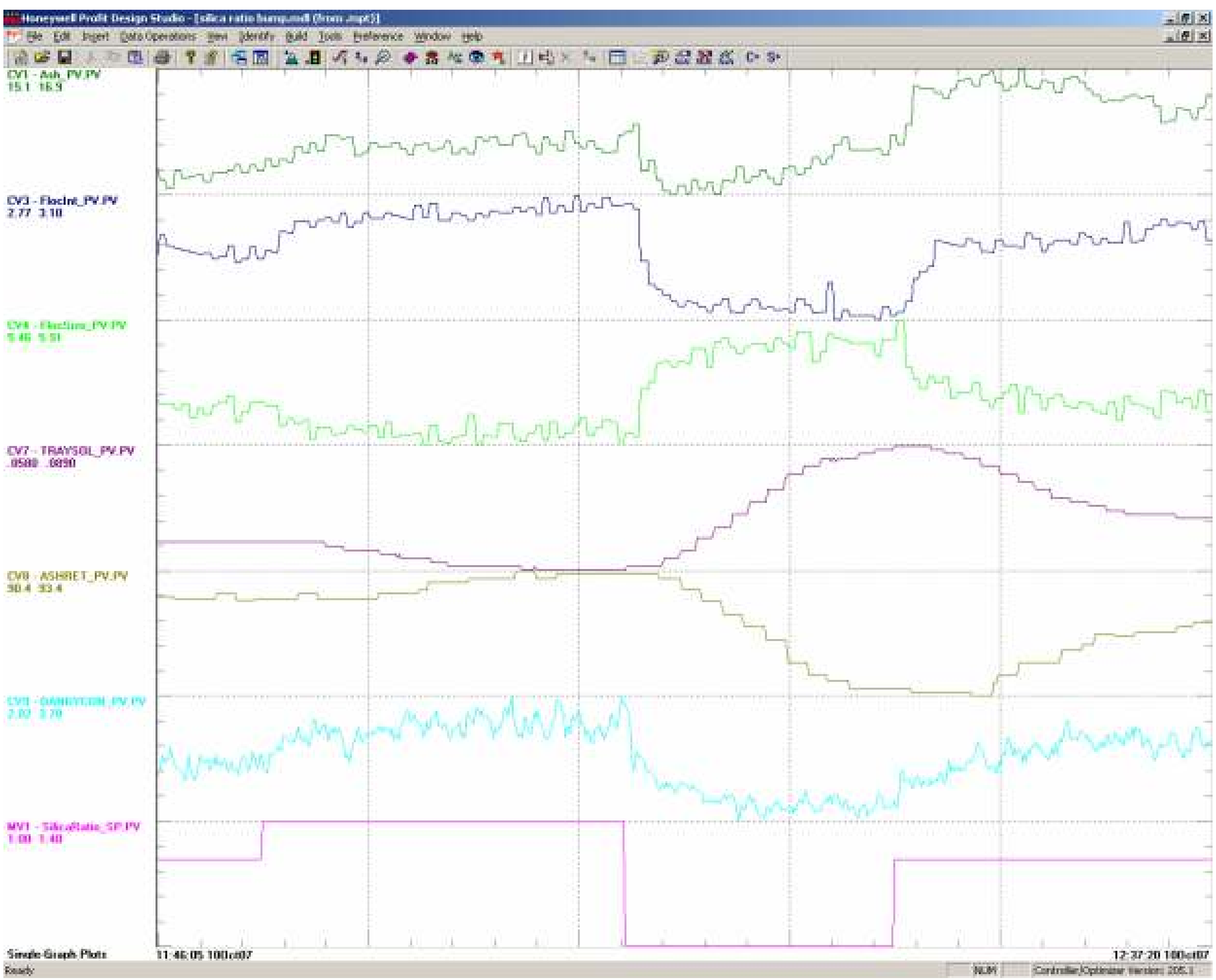

Figure 3

especially in the production of graphical grades, is formation. The best formation is often achieved by lowering retention. This means that the optimum retention has to be determined in each case."[1]

Silica flow SP ↑ , Tray Solids PV ↓ and
Silica flow SP ↓ , Tray Solids PV ↑
Silica flow SP ↑ , Ash Retention PV ↑
and Silica flow SP ↓ , Ash Retention PV ↓

Retention aid is working as adding more Silica retains more solids (fibers and fillers) and improves drainage, thus the Tray Solid decreases and Ash Retention increases.

Silica flow SP ↑ , Dandy Consistency ↑
and Silica flow SP ↓ , Dandy Consistency ↓

Retention aid is working as adding more Silica retains more solids (fibers and fillers) and improves drainage and thus the Dandy Consistency increases and the dry line moves towards the headbox.

The Vacuum Box 1 SP was bumped as follows: initial setpoint, initial setpoint 2.6 cm of H_2O (bump 1), initial setpoint -5.1 cm of H_2O (bump 2), initial setpoint 2.6 cm of H_2O (bump 3) and finally back to the initial setpoint (bump 4).

Figure 4 shows there is a relationship between the Vacuum Box 1 SP bumps and Dandy Consistency.

Vacuum Box 1 SP ↓ (more vacuum), Dandy Consistency ↑ and
Vacuum Box 1 SP ↑ (less vacuum), Dandy Consistency ↓

Profit Multivariable MPC Control Model

Based on these bumps, the following Control Models were implemented in the Profit Multivariable MPC controller (Figure 5).

Profit Multivariable MPC Control - On Control versus Off Control

Figure 4

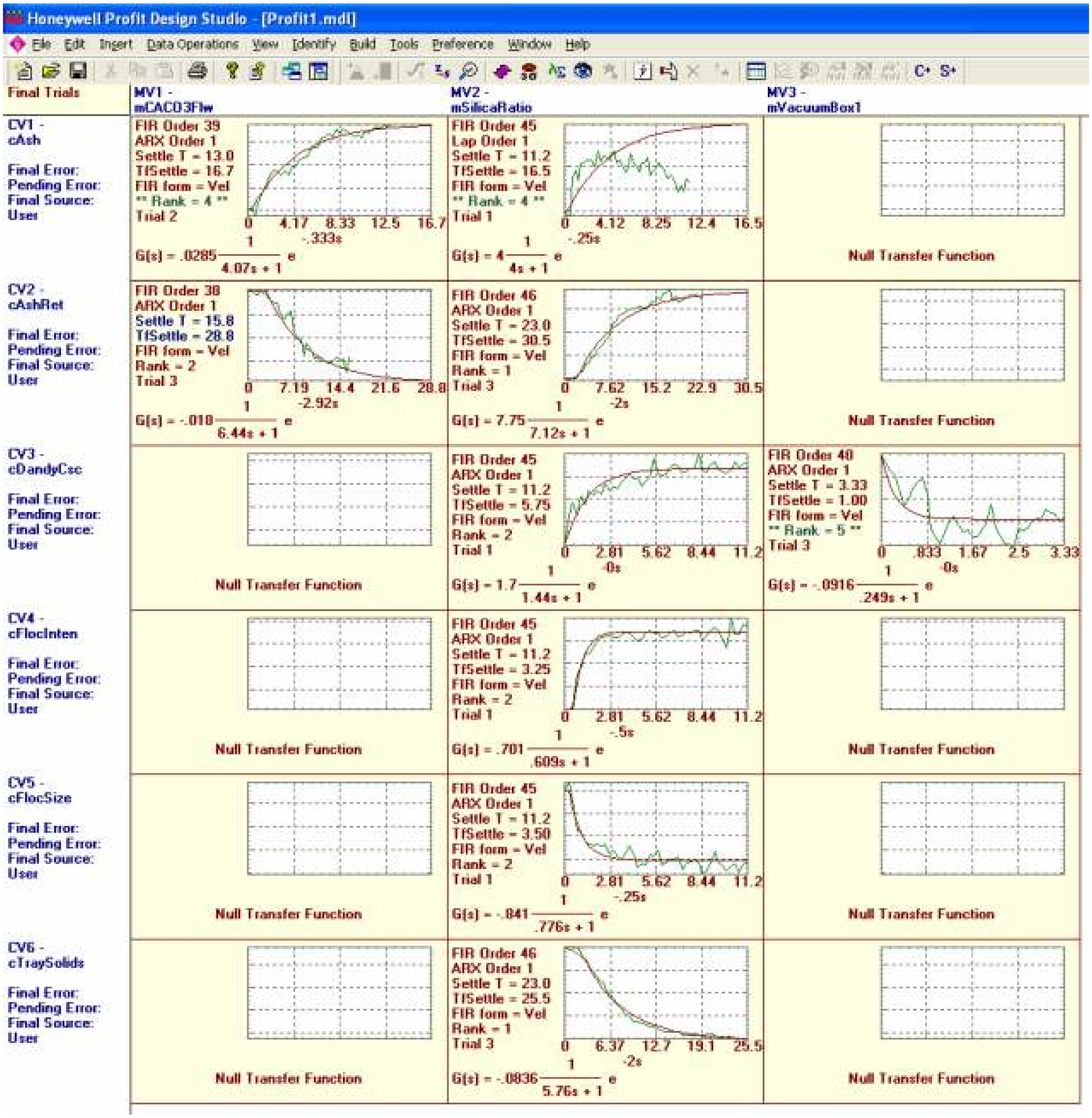

Figure 5

Normal Operation Profit Multivariable MPC Control OFF

During normal operations when the Profit Multivariable MPC controller is off, there is only one regulatory control loop (SISO). The MV is Silica flow SP and the CV is Tray Solids PV.

The remainder of the variables are in manual control:
The papermaker manually adjusts the $CaCO_3$ flow SP to get ash into target range and also manually adjusts the Vacuum Box 1 SP to get the desired dry line location (using the Dandy Consistency as a guideline). Floc Intensity and Floc Size are secondary measurements and are generally overlooked but the papermaker relies on visual tests at the dry end to confirm good formation.

Profit Multivariable MPC Control On Control

All CVs have High Limits (HL) and Low Limits (LL). For example, the Ash HL = 16.0% and the Ash LL = 15 %. This is the target operating range for Ash as determined by the papermaker and past targets. The advantage of controlling to a range is that the Profit Multivariable MPC controller will less likely be constrained and the MVs will have more freedom to go after other CVs that are outside its range.

All MVs have High Limits and Low Limits. The purpose of this was to ensure paper machine run-ability the papermaker does not want the Profit

Multivariable MPC controller to control to a setpoint outside an operating range. The operating ranges are determined by the papermaker and past ranges.

Figure 6 shows the comparison of Ash and $CaCO_3$ flow SP between on and off Profit Multivariable MPC control. During off control, it is clear that the papermaker is adjusting the $CaCO_3$ flow SP manually to get to the target Ash. While on control, the $CaCO_3$ flow SP is smoothly ramped up by the controller to achieve the target ash range. The two-sigma Ash variation was reduced from 2.2 to 0.4 an 81.2% reduction by going on control.

Figure 7 shows the comparison of Ash and Silica flow SP between on and off Profit Multivariable MPC control. During off control, the Silica flow SP is in SISO control controlling the Tray Solids PV. The Silica flow SP has a direct effect on the Ash. At the same time, the papermaker is manually manipulating the $CaCO_3$ flow SP (top of figure 6) to get the Ash within control range. While on control, the Profit controller takes into account all variable interactions thus the Ash variations are reduced by 81.2%.

Figure 8 shows the comparison of Tray Solids PV and Silica flow SP between on and off Profit Multivariable MPC control. Even with Tray Solids PV in SISO control, the Profit Multivariable MPC controller yields a 26.6% lower Tray Solids PV two-sigma variation.

Figure 9 shows the comparison of Dandy Consistency between on and off Profit Multivariable MPC control. During off control, papermaker moves Vacuum Box 1 SP down significantly at 5:17 to get the desired dry line location. While on Profit control, Vacuum Box 1 SP is incrementally moved to get within the target Dandy Consistency range. As a result, the Dandy Consistency two-sigma variations are reduced by

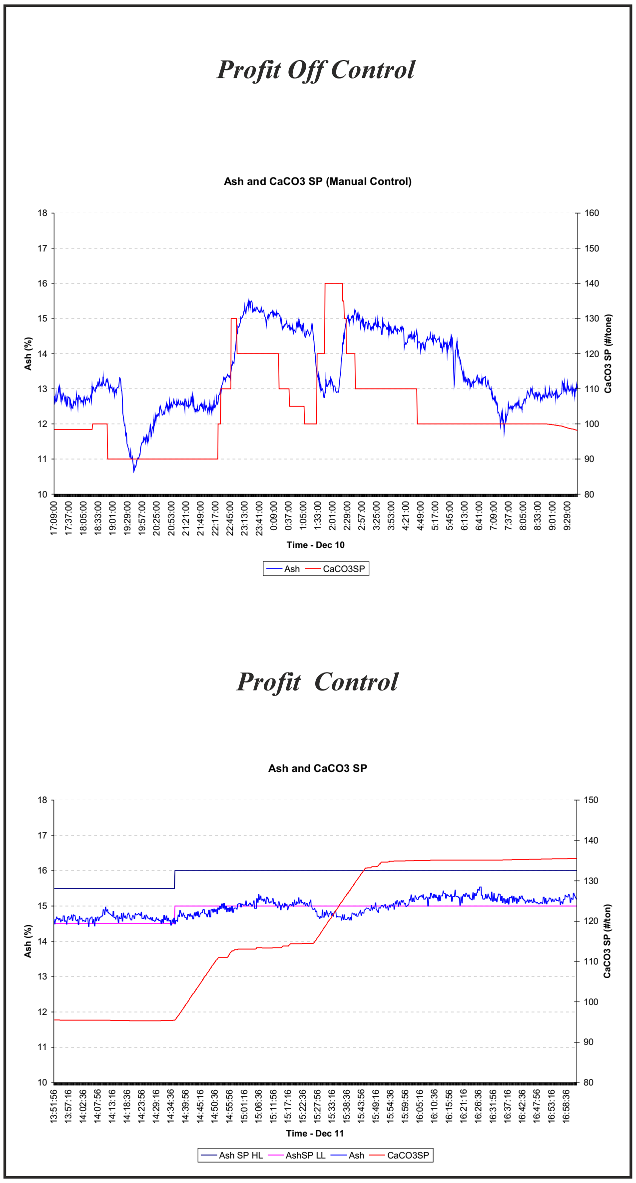

Figure 6

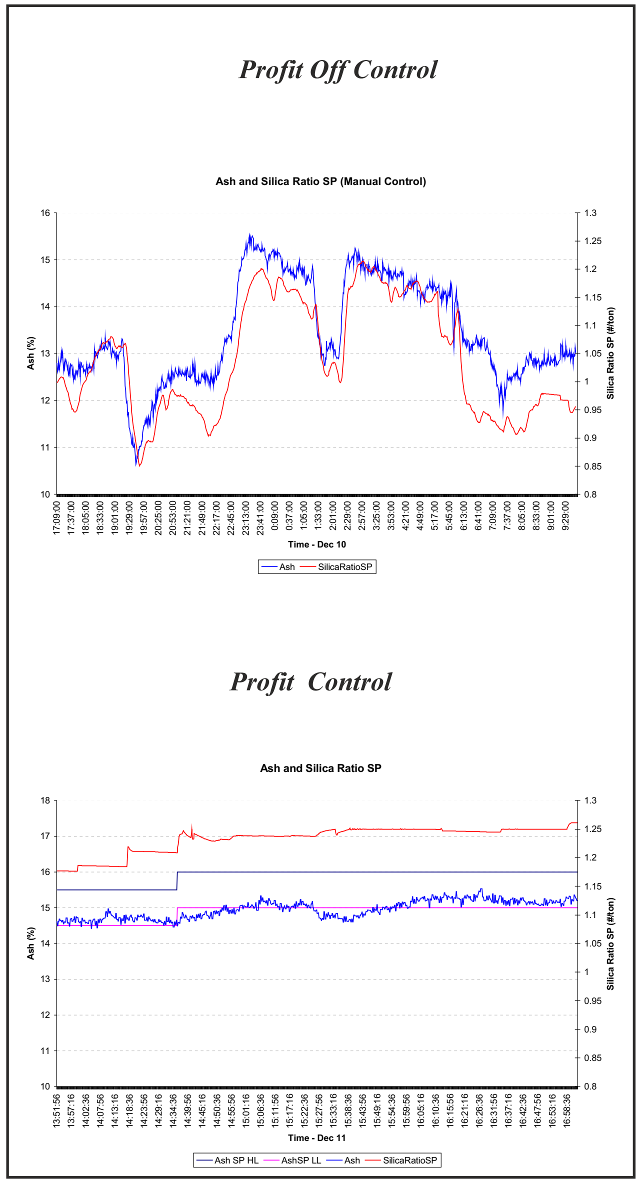

Figure 7

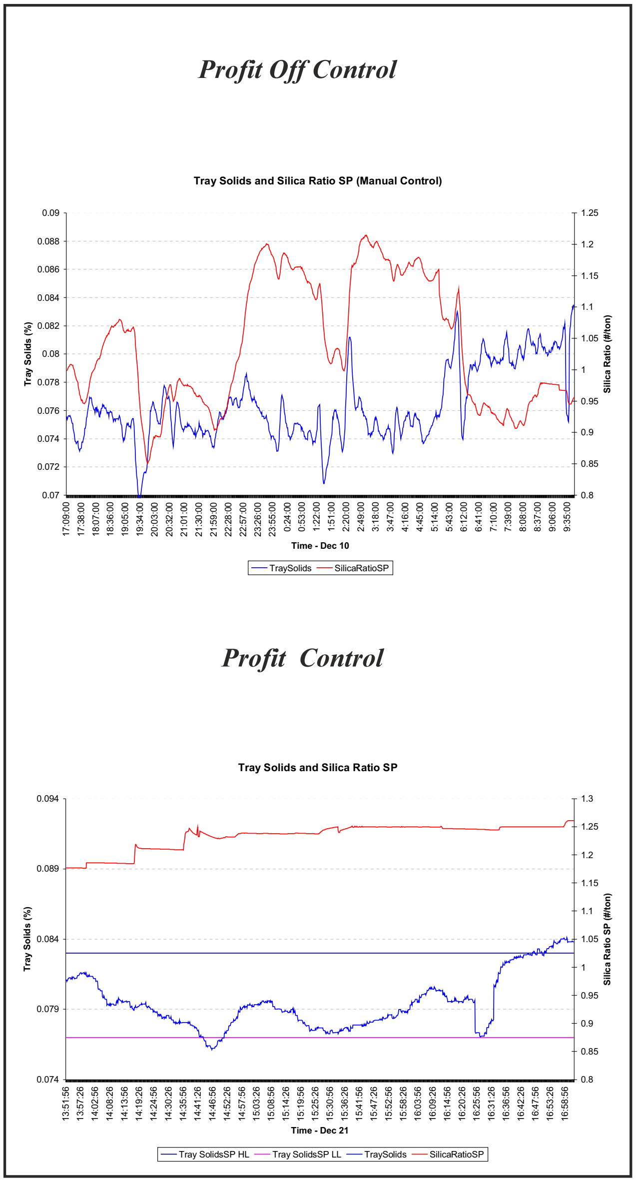

Figure 8

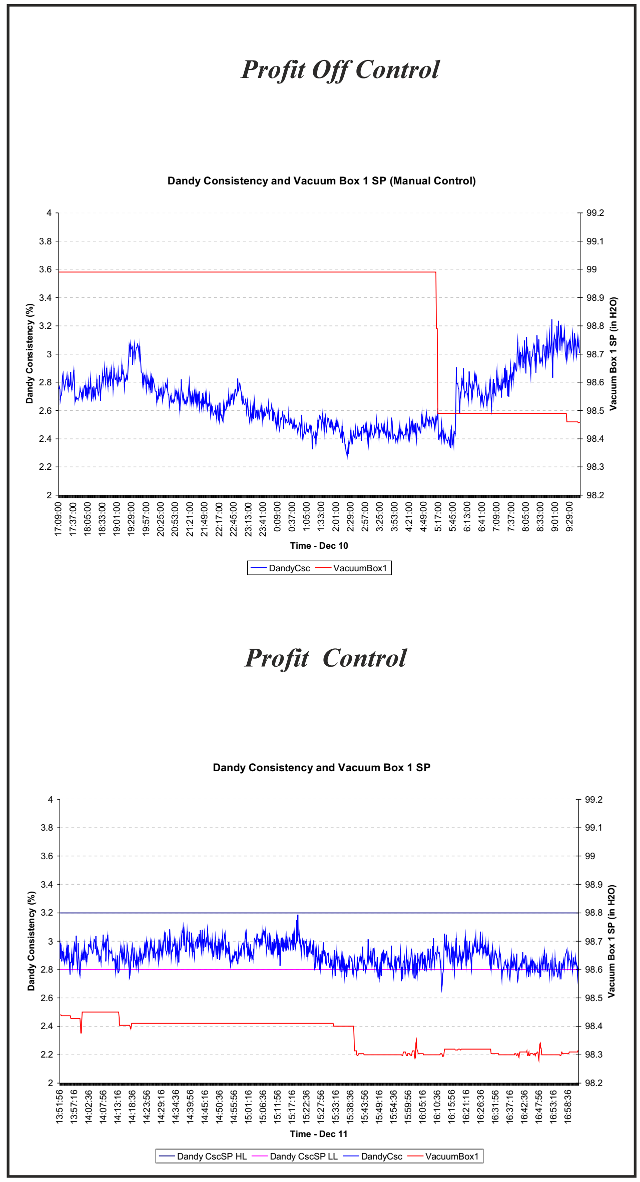

Figure 9

62.7% while in Profit control.

Figure 10 shows the comparison of Floc Intensity and Floc Size between on and off Profit Multivariable MPC control. As a direct result of the Silica flow SP being more stable while on Profit control, the two-sigma variations in Floc are lower by 49.2%.

Table 1 shows the summary of improvements while on Profit Multivariable MPC control. There is a significant reduction in two-sigma variations in these CVs.
With these CVs stabilized, the papermaker can make more consistent product from grade to grade and from shift to shift. Further, there is now a potential to optimize CVs (such as increase ash) in a systematic and scientific manner.

Increasing Ash Content

In Figure 11, the Ash HL and LL were increased by 0.5% and the Profit controller reacted accordingly. After this change, the average Ash increased to 15.05%. In manual control, the Ash was 14.67%. So the difference between Profit control and Ash manual control = 0.38%
While increasing Ash content, all CVs (Dandy Consistency, Floc and Size Intensity, Tray Solids PV and Ash Retention PV) were all within their target ranges. Therefore paper machine run-ability and quality did not suffer while increasing Ash content.

Cost Savings attributed to by the Profit Multivariable MPC Controller

Replacing 1% fiber with 1% Ash saves the paper mill about $0.50 US/Ton and a 0.38% increase in Ash, yields a cost savings of $82,000/year

Conclusion

The desire to save money by reducing raw material costs and not sacrificing paper machine run-ability or paper quality continues. Because of the high interaction of key wet end variables, SISO control loops and new sensors

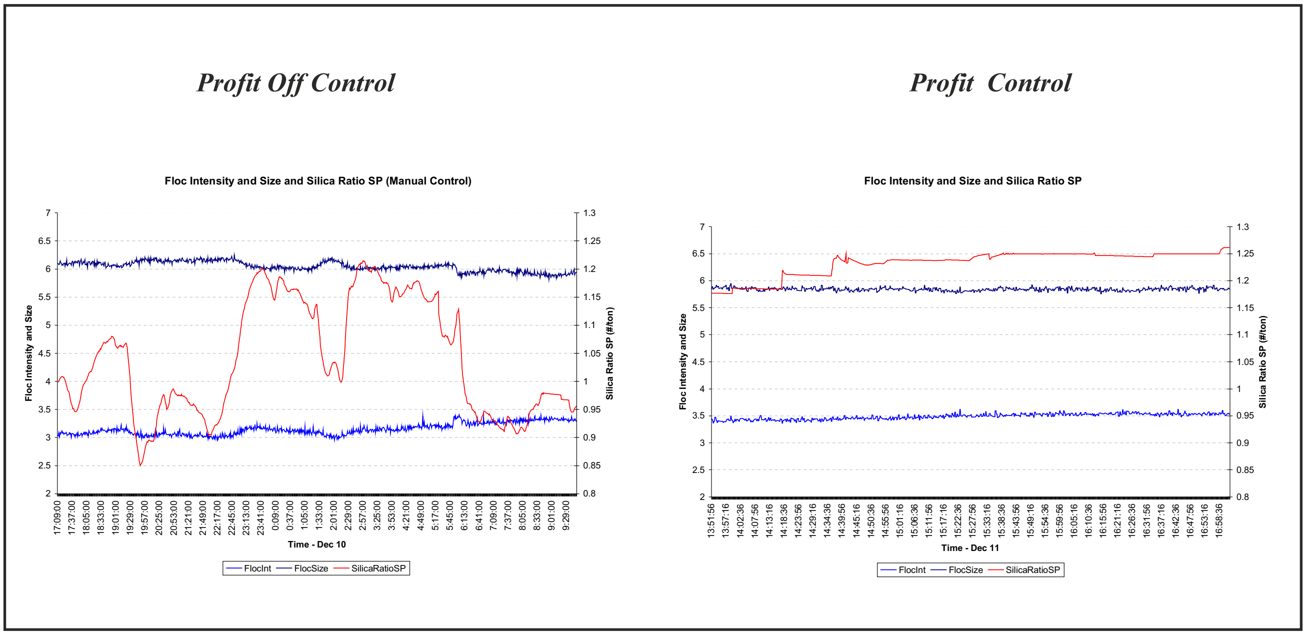

Figure 10

Table 1

Controlled Variable (CV)	(Manual Control) 2-Sigma	(Profit Control) 2-Sigma	Improvement
Ash (%)	2.1913	0.4117	81.2%
Dandy Consistency (%)	0.4046	0.1509	62.7%
Floc Intensity (%)	0.2062	0.1048	49.2%
Tray Solids (%)	0.0052	0.0038	26.6%

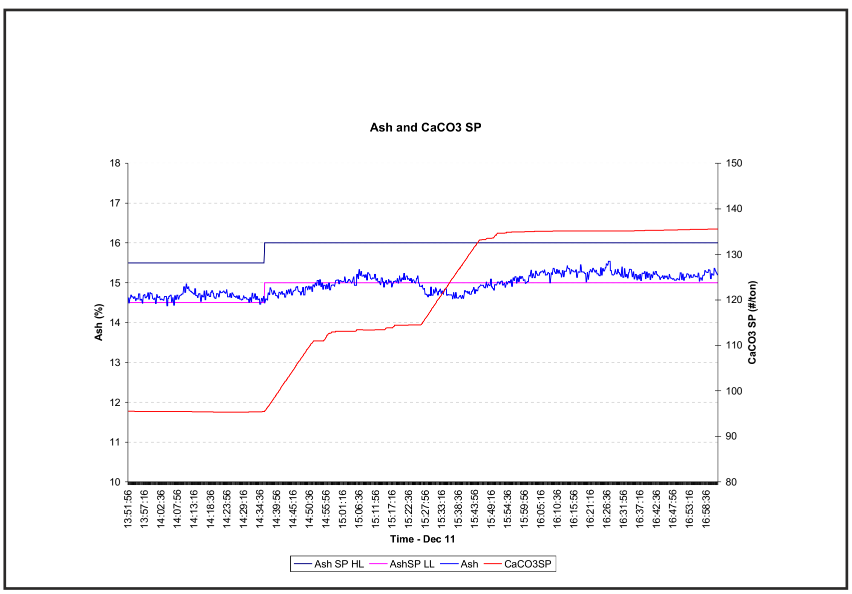

Figure 11

such as the SpectraFoil MD are adequate but not enough to produce consistent product when increasing Ash content for the purposes of reducing raw material costs. The Profit Multivariable MPC controller takes into account all the interactions of the key wet end variables. This allows the papermaker to incrementally increase the ash target setpoint without sacrificing paper machine run-ability and paper quality.

References

[1] R. Rauch, W Falkenberg and D. Watzig, "Optimized retention: the key to process, quality and productivity improvements", Paper Technology, October 2004.

Captions Figures and Tables

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