Gain Delay Retune in Multivariable Controls for the Paper Making Process

Stephen Chu
Software Application Manager, Honeywell
500 Brooksbank Ave., N. Vancouver, BC
V7J 3S4, Canada
Tel: (604) 980-3421
E-mail: stephen.chu@honeywell.com

Joyce Choi
Software Application Manager, Honeywell
500 Brooksbank Ave., N. Vancouver, BC
V7J 3S4, Canada
Tel: (604) 980-3421
E-mail: joyce.choi@honeywell.com

ABSTRACT

The paper making process, like many industrial processes, exhibits nonlinear behavior. The nonlinearities can become more severe in situations where large operating condition changes take place. Performing multivariable MD (machine direction) control based on linear process models formulated as first or higher order transfer functions in the Laplace domain becomes insufficient and inaccurate when these large operating condition changes are encountered. The problem is that a multivariable MD control transfer function uses a static gain and time delay, which will vary with operating conditions in a nonlinear process.

This paper examines a solution that involves automatically retuning the gain and time delay based on nonlinear mass balance and process interactions. The studied paper machine was in “slow-back” mode due to production limitations where the machine speed was almost half of its nominal speed.

INTRODUCTION

In today’s economy where paper demand fluctuates, papermakers struggle with operations of their paper machines. To meet these fluctuations, the papermakers stress their paper machines beyond their tuned operational constraints to keep their paper machines running. The papermakers inevitably accept lower quality paper and risk stable runability during a “slow-back” run as it is the better of two evils – keep their paper machine running at a lower machine speed rate or shutdown their paper machine entirely and start back up again when they are guaranteed to sell their production at full speed.

Multivariable model predictive control (MPC) transfer functions are typically determined with bump tests at nominal paper machine speeds (i.e. the typical speeds that are encountered during paper manufacturing). These transfer functions assume the paper process to be linear in the operating range for them to be accurate. When the machines speed is significantly reduced, these transfer functions become inaccurate because the paper machine operating conditions fall outside this linear range and the paper quality and runability suffer. Automatically retuning the gain and time delay based on a nominal machine speed and the current “slow-back” machine speed will address this issue that papermakers are faced with today.

The Gain Delay Retune Function is a software application that runs in conjunction with the MPC MD controls. This paper examines the Gain Delay Retune Function in the MPC MD control package and shows results on the studied paper machine that produces linerboard.

MODEL PREDICTIVE CONTROL

Backström [1] has documented the description and history of the use of MPC in MD controls in the paper industry. The current version of this controller is called Profit™ and is what is used today for multivariable MD controls. The problem is that the MPC MD control transfer functions use a static gain and time delay and these will vary with large machine speed changes. The Gain Delay Retune Function automatically retunes the gain and time delay based on a nominal speed and the current speed.

THE LINERBOARD PROCESS

The studied paper machine produces linerboard and the manipulated variables (MVs) and controlled variables (CVs) are typical of any paper machine MD controls. It is a Fourdrinier machine with a press section, five dryer sections and a reel scanner that measures dry weight and moisture.

The control elements in the machine direction are:

1) Stock Flow – (MV)
2) 1st Dryer Section Steam – Biased to 5th Dryer Section Steam
3) 2ndDryer Section Steam – Biased to 5th Dryer Section Steam
4) 3rd Dryer Section Steam – Biased to 5th Dryer Section Steam
5) 4th Dryer Section Steam – Biased to 5th Dryer Section Steam
6) 5th Dryer Section Steam – (MV)
7) Machine Speed – (MV)
8) Reel Dry Weight – (CV)
9) Reel Moisture - Controlled Variable (CV)

Figure 1 shows the paper machine overview with multivariable MPC with gain delay retune and Figure 2 shows the MPC matrix.

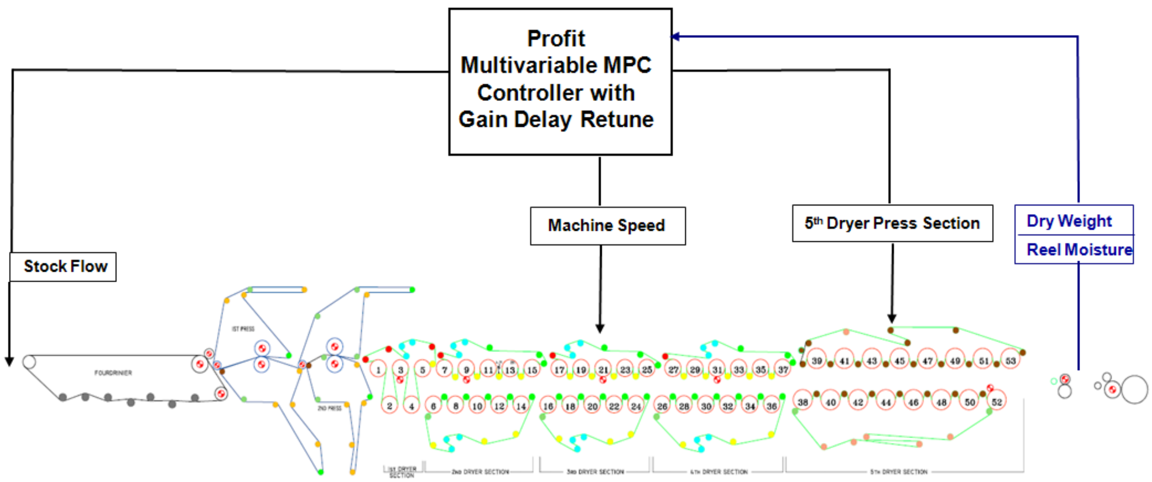

Figure 1. *Paper Machine Overview with Multivariable MPC with Gain Delay Retune*

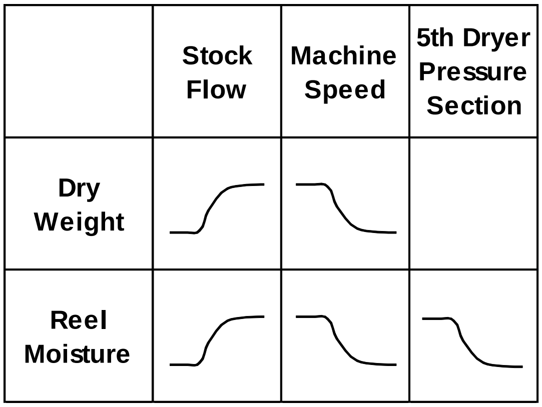

Figure 2. *Multivariable MPC Control Matrix*

MULTIVARIABLE MPC LINEAR TRANSFER FUNCTION – NOMINAL BASELINE

The Gain Delay Retune Function requires a baseline to be established beforehand so the function can use this baseline to determine how the gain and time delay of a linear process model vary due to operating conditions changes. The baseline is defined by the nominal process values of the CVs and MVs in the system, and nominal gains and time delays of the linear process model relating the CVs and MVs.

The nominal process values are collected before the bump tests to ensure they represent steady state values. The nominal gains and time delays are obtained from the linear process models identified based on the results of the bump tests performed in the same steady state.

Figure 3 shows the transfer function of the of the CV-MV pair Moisture-5th Dryer Pressure at the nominal machine speed of 2100 fpm.

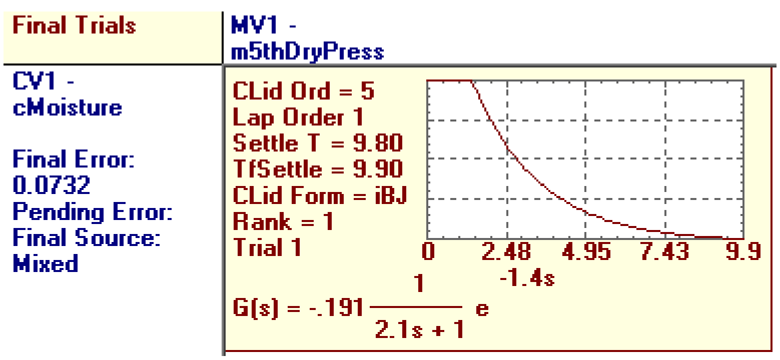

Figure 3. *MPC Transfer Function for Moisture-5th Dryer Pressure*

In this paper, only the CV-MV pair Moisture-5th Dryer Pressure was enabled for the Gain Delay Retune Function. Other CV-MV pairs were not enabled because the Dry Weight CV was unaffected by the "slow-back" run of the paper machine.

GAIN DELAY RETUNE ON MACHINE SPEED

For the part of the gain retune, the Gain Delay Retune Function calculates an Effective Gain (Equation [2]), which is calculated from a Speed Gain Retune Factor (Equation [1]) that is based on the current machine speed and the nominal machine speed. The Effective Gain is the gain used in the MPC MD controller.

$$\text{Speed Gain Retune Factor} = 1 - \frac{(\text{Current Machine Speed} - \text{Nominal Machine Speed}) \times \text{Speed Gain Retune Factor Weight}}{\text{Current Machine Speed}} \qquad (1)$$

Where the Speed Gain Retune Factor Weight = 1

A Speed Gain Retune Factor Weight more than 1 gives more emphasis on a speed change. A Speed Gain Retune Factor Weight less than 1 gives less emphasis on a speed change. A Speed Gain Retune Factor Weight of 0 turns off the Gain Delay Retune Function.

$$\text{Effective Gain} = \text{Speed Gain Retune Factor} \times \text{Nominal Gain} \qquad (2)$$

For the part of the delay retune, the Gain Delay Retune Function calculates a delay offset, which is the difference between the delay calculated by the Gain Delay Retune Function and the nominal delay for the linear process model CV-MV pair Moisture-5th Dryer Pressure. The delay offset is the result of the change in variable (transport) time delay due to the change in machine speed.

GAIN DELAY RETUNE ON A LINERBOARD MACHINE

Figure 4 shows the trended values of the CV-MV pair Moisture-5th Dryer Pressure along with the Machine Speed while the Gain Delay Retune Function was off and then turned on. The linerboard machine was in "slow-back" mode because of production limitations. The nominal machine speed is 2100 fpm and the machine speed was continually being reduced to a minimum of 1225 fpm. With the Gain Delay Retune Function turned off, a model mismatch of the CV-MV pair Moisture-5th Dryer Pressure was observed – the 5th Dryer Pressure MV exhibits oscillations at approximately the same frequency of the Moisture CV. Paper quality and stable runability were at risk.

At approximately 8:30, the Gain Delay Retune Function was turned on and the Moisture CV immediately flattened (along with the 5th Dryer Pressure MV). The Moisture 2σ was reduced from 0.49 to 0.34, or a 30% reduction. Paper quality and runability immediately improved with the Gain Delay Retune Function enabled.

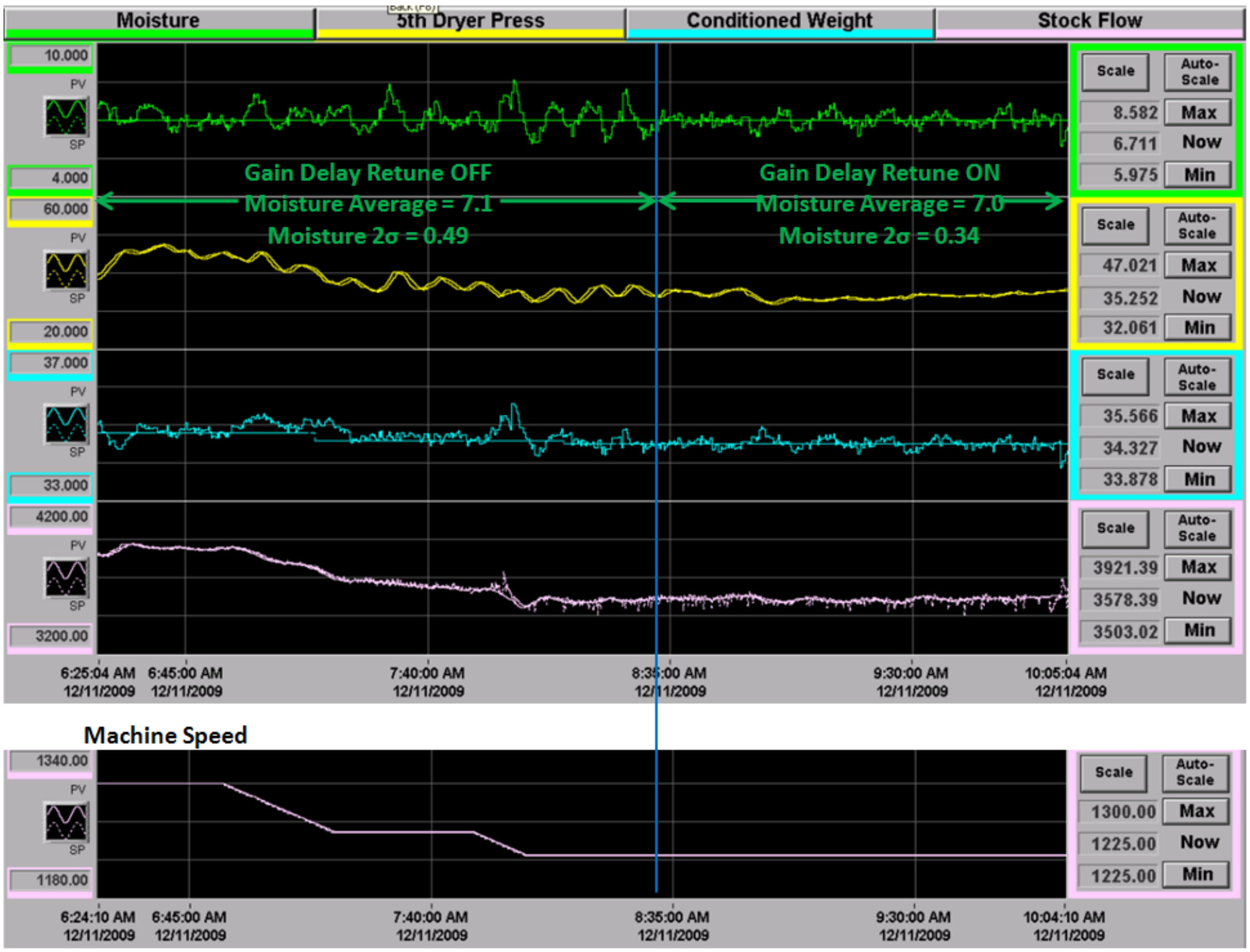

Figure 4. *Gain Delay Retune on a Linerboard Machine*

<u>CONCLUSION</u>

There are great benefits of using MPC for MD control in the paper industry. It has been well documented that MPC can significantly reduce energy costs [2], raw material costs [3], and can maximize production consistently in a dryer limited operation [4]. However, the limitation in using MPC is that the transfer functions assume the paper process to be linear in the operating range. This is more than adequate during normal operations, but in today's economy where paper demand fluctuates, the papermakers are asked to reduce production in a "slow-back" mode. These operating conditions are beyond the linear range and the papermakers are forced to produce lower paper quality and risk stable runability.

The Gain Delay Retune Function in the MPC MD controls addresses this issue by automatically retuning the gain and time delay based on a nominal machine speed and the current "slow-back" machine speed. The studied linerboard machine showed a significant reduction (30%) in 2σ spread in moisture when the Gain Retune Function was enabled thereby increasing the paper quality and runability.

REFERENCES

[1] J. U. Backström, P. Baker, "*A Benefit Analysis of Model Predictive Machine Directional Control of Paper Machines*", Proceedings from 2008 Control Systems/Pan Pacific Conference, June 16-18, Vancouver, BC, Canada, pp. 197-202.

[2] S. Chu, R. MacHattie, J. U. Backström, "*Multivariable Control and Energy Optimization of Tissue Machines*", Proceedings from PACWEST 2009, June 10-13, Delta Sun Peaks, BC, Canada.

[3] S. Chu, "*Wet End Control Applications using a Multivariable Model Predictive Control Strategy*", Proceedings from PACWEST 2008, June 18-21, Jasper, AB, Canada.

[4] S. Chu, J. U. Backström, "*Multivariable Control and Production Optimization of Paper Machines*", Proceedings from PACWEST 2010, June 9-12, Delta Sun Peaks, BC, Canada.