IMPROVED WET END STABILITY OF A PAPER MACHINE USING MODEL PREDICTIVE CONTROL

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Keywords: Retention, wet-end stability, model-based predictive control

1. OVERVIEW

This paper describes how the Connoisseur advanced control package has been successfully applied to the broke and retention systems of a high-speed paper machine to provide increased stability and runnability. The paper provides an explanation of the plant testing, identification and modelling techniques used to develop a model-based predictive controller. In addition, details of the controller’s performance are presented.

Increased competition within the paper industry has led to greater emphasis on continuous improvement of product quality and profit maximisation through optimisation of machine runnability. This demand for continuous improvement has led to the development of on-line instrumentation, allowing key wet-end parameters to be continuously observed. In addition, the introduction of highly effective retention chemicals has provided the means to control retention.

The difficulty in the past has been how to “close the loop” to incorporate the new instrumentation and chemicals in a co-ordinated control system. Traditional three term control systems do not have the ability to take account of the interactions between wet end parameters during disturbances such as changes in incoming furnish, broke and recovered fibre flow.

By employing a model-based predictive control scheme, the actual multivariable character of the wet-end of the paper machine can be quantified within the process model and it can then be incorporated into the controller design. The model makes it possible for the effects of disturbances in the broke and retention systems to be predicted, allowing the controller to make an effective, measured response. In an actual implementation reported here, this approach is shown to provide significant improvements in stability and runnability, ensuring that the machine returns quickly to a stable running condition after a paper break. Some extensions to the functionality of the controller, presently being implemented, are also described.

2. INTRODUCTION

The field of wet end control of paper machines has advanced significantly in recent years. Improved instrumentation and the advent of additive chemicals have provided the paper industry with greater opportunities both to measure and to control the wet-end chemistry of high-speed paper machines.

It is now common within the industry to take a three-stage approach to improving wet end stability and machine runnability. Firstly, additional instrumentation is installed to measure key wet end parameters on-line. Secondly, mechanisms are provided to enable appropriate amounts of retention aid chemicals to be added to machine furnish, allowing adjustment of some of the key wet end parameters. Finally, suitable controllers are employed to regulate the rates of addition of retention aid chemicals. To date these controllers have typically been single-input single-output three term controllers.

The project reported in this paper was undertaken at Aylesford Newsprint Limited (ANL), which operates two paper machines producing 400,000 tonnes per annum of top quality 100% recycled newsprint, supplied to leading European publishers. Paper Machine number 14 (PM14) was commissioned in 1995 and has achieved a number of world records for performance, including operating speed, production volume, and efficiency.

PM14’s wet end employs several PID controllers to provide feedback control of key variables. Experience gained by ANL’s staff in using these controllers has demonstrated to them that there are significant multivariable interactions at the wet end.

Arising from this experience, ANL, in partnership with Invensys’ Performance Solutions Group (PSG) EMEA, commissioned a project to evaluate the suitability of applying Advanced Process Control (APC) to the wet-end of PM14. This paper presents results to date, and indicates some directions of further possible controller development.

3. ADVANCED PROCESS CONTROL OF THE WET END

The concept of applying APC to the wet-end of a paper machine is quite a new concept, though not without precedent[1,2]. Therefore the project required a software package that had the flexibility to provide and evaluate various approaches to controller design. One such package is Connoisseur.

Connoisseur has been successfully applied to many processes, providing an integrated capability to develop and support APC systems. The package offers several APC technologies, including Model Based Predictive Control (MBPC), Artificial Neural Networks, Inferential Estimation, Fuzzy Logic and Adaptive Control.

3.1 Model Based Predictive Control (MBPC)

The key technology of Connoisseur is MBPC. In MBPC a mathematical model approximates the dynamic behaviour of the process. Typically, the model is multivariable and has been obtained directly from process response data, by *systems identification.* Once a model has been built, it is employed in the design of a controller to make predictions of the process outputs from the present to the distant future, for given control inputs[3,4], called manipulated variables (MVs). The controller uses these predictions to calculate the best way to move the MVs to achieve the defined control objectives.

With the ability to model and control processes having significant multivariable interactions, MBPC is particularly well suited to control of the wet end of a paper machine.

3.2 APC Project Workflow

Once MBPC had been selected as a suitable technology for wet end control, the initial project was split into two phases. Phase one encompassed an investigation period, process response testing, process modelling and the implementation of a prototype control system. ANL then used the prototype for an evaluation period of four weeks. On completion of the trial period, all results were analysed, evaluated and presented. At this stage, ANL gave approval to progress to phase two. During the second phase, the controller installation was made permanent, by completing the failsafe mechanisms and the operator's interface.

3.3 Towards Integrated Control of Broke, Retention and Wet End Stability

The key to achieving wet end stability is maintaining constant retention, for a given paper grade. (First pass) retention can be defined as the proportion of fibres that, after being forced out of the pressurised head box, remain on the wire to form the sheet. The fibres that are not retained on the wire are collected in the wire pit. The stock in this pit is known as white water and since longer fibres are easier to retain in the sheet, white water contains a higher fraction of short fibres than does the fresh feed. The equation for wire retention is as follows:

$$R = 100x\left(1 - \frac{WWC}{HDBXC}\right) \qquad (1)$$

where: R = wire retention (%)

WWC = white water consistency (g/l)

HDBXC = headbox consistency (g/l).

The investigation period identified the fact that the most significant disturbance to retention stability is the introduction of broke after a paper break. Broke is temporarily stored in the broke tower, fed through the broke system, and re-introduced at the mixing tank. Since the broke tower provides a buffer for the wet end system, should a problem with the machine occur, it is desirable to keep the tower level as low as possible. Reasons why broke flow upsets retention are, firstly, that there is a higher proportion of long fibres in broke than in the fresh stock feed, secondly, that the ash content of broke is usually less than that of fresh furnish and this alters the cationic demand of the headbox furnish, and thirdly, that broke has already been dosed with retention aid.

Compensation for the introduction of broke can be achieved using retention aid two. This chemical is a flocculant that is injected into the thickstock at the machine screens, prior to the headbox. When the flow of retention aid two is decreased, the fibres flock together less readily, decreasing retention. Wire retention is ultimately controlled using a combination of stock flow from the de-inking plant (DIP), broke flow and retention aid two flowrate.

Further to the retention stability issues created by broke introduction, the control of the broke tower presents an operational issue. A time delay of about 20 minutes between the broke tower and the mixing tank makes conventional Proportional, Integral plus Derivative (PID) controllers unsuitable for level control. However, this challenging problem of integrated control of the broke and retention system is one for which MBPC proved to be well suited.

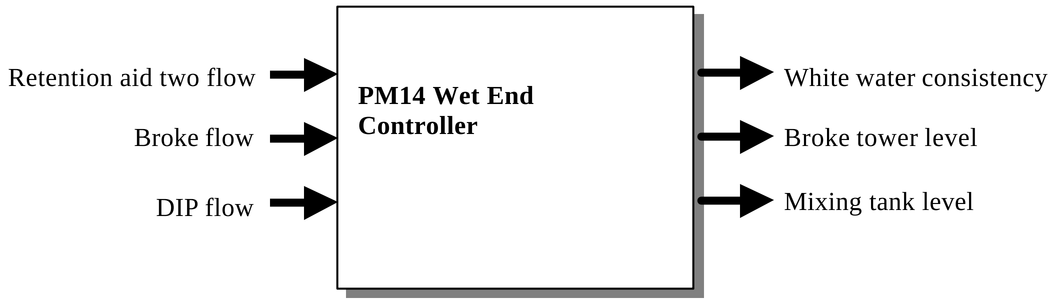

Figure 1 Structure of the First MBPC Wet End Controller for PM14

4. CONTROL SYSTEM DESIGN AND IMPLEMENTATION

For the first project, reported here, the controller's objectives were to stabilise retention by controlling white water consistency to set point, while pushing the broke tower level towards 20%. This was to be achieved by manipulating the flowrates of retention aid two, broke and DIP. See Figure 1.

Traditionally, integrating CVs with pure delay, such as the broke tower, can prove to be difficult to control, particularly when large unmeasured disturbances are present, such as broke in-flow. Our wet end controller design overcomes this problem by employing an Auto-Regressive Moving Average (ARMA) model, which provides superior unmeasured disturbance rejection compared to that of the Finite Impulse Response (FIR) models used by many other MBPC tools. The ARMA model format also allows the integrating nature and pure delay of the level CVs to be easily expressed by a single coefficient.

The controller's unmeasured disturbance rejection properties were further enhanced through the use of Quadratic Programming (QP) in the design. The advantage of using the QP algorithm available in Connoisseur is that it provides a robust solution to all MV and CV constraints in a single calculation. Additionally, Connoisseur's QP allows a CV to be given both set point and constraint objectives simultaneously. This provides two levels of tuning: progressive control within normal constraints to drive to set point and, beyond constraints, aggressive control to keep the process within safe operating limits.

5. CONTROLLER PERFORMANCE EVALUATION

The controller provides significant improvements in stability through tighter control of the broke system and white water consistency (see Figs 2 and 3). This stabilisation has, in turn, improved ash retention, wire retention and headbox consistency: see Table 1 for the results of the evaluation period. There is also a marked improvement in the steadiness of some reel

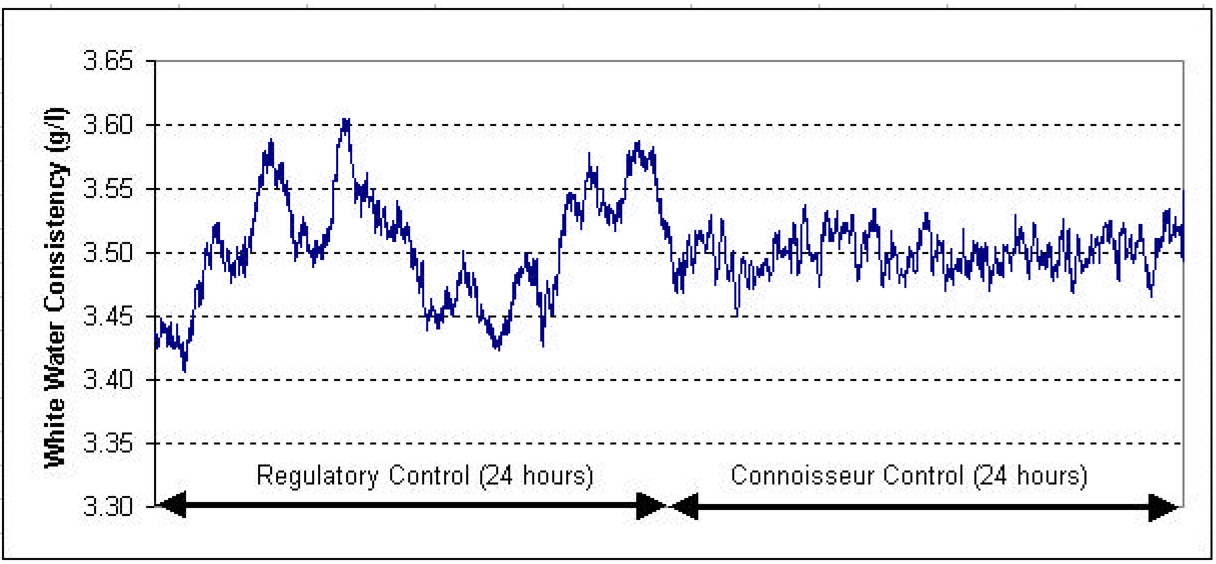

Figure 2: Comparison of White Water Consistency Control Over 24 Hours

Table 1 Comparison of MBPC and Regulatory Control of the Wet End

	Regulatory standard deviation (10 days run time)	Connoisseur standard deviation (20 days run time)	% reduction in standard deviation
White Water Consist'y (g/l)	0.0754	0.0249	67
Headbox Consistency (g/l)	0.0702	0.0418	60
(Wire) Retention (%)	0.487	0.378	22
Ash Retention (%)	0.918	0.797	13

parameters, for example opacity and caliper.

Prior to the installation of MBPC, the regulatory control systems at Aylesford provided quite low variability in the key wet-end variables, by world standards, at least during stable running. Nevertheless, MBPC has provided the ability to reduce the variability considerably, by improved broke system management and disturbance rejection, particularly after a number of paper breaks. Figure 3 compares the performance of MBPC with regulatory control. From this figure the following improvements can be observed:

i) The extended period of white water consistency instability after a number of breaks is eliminated.

ii) The broke flow rate is adjusted in proportion to tower level, eliminating the need to make any large steps.

iii) As the effect of broke on retention is greatly reduced, the maximum broke flow can be greater. This allows the tower to return to set point three hours earlier, maximising its function as a buffer.

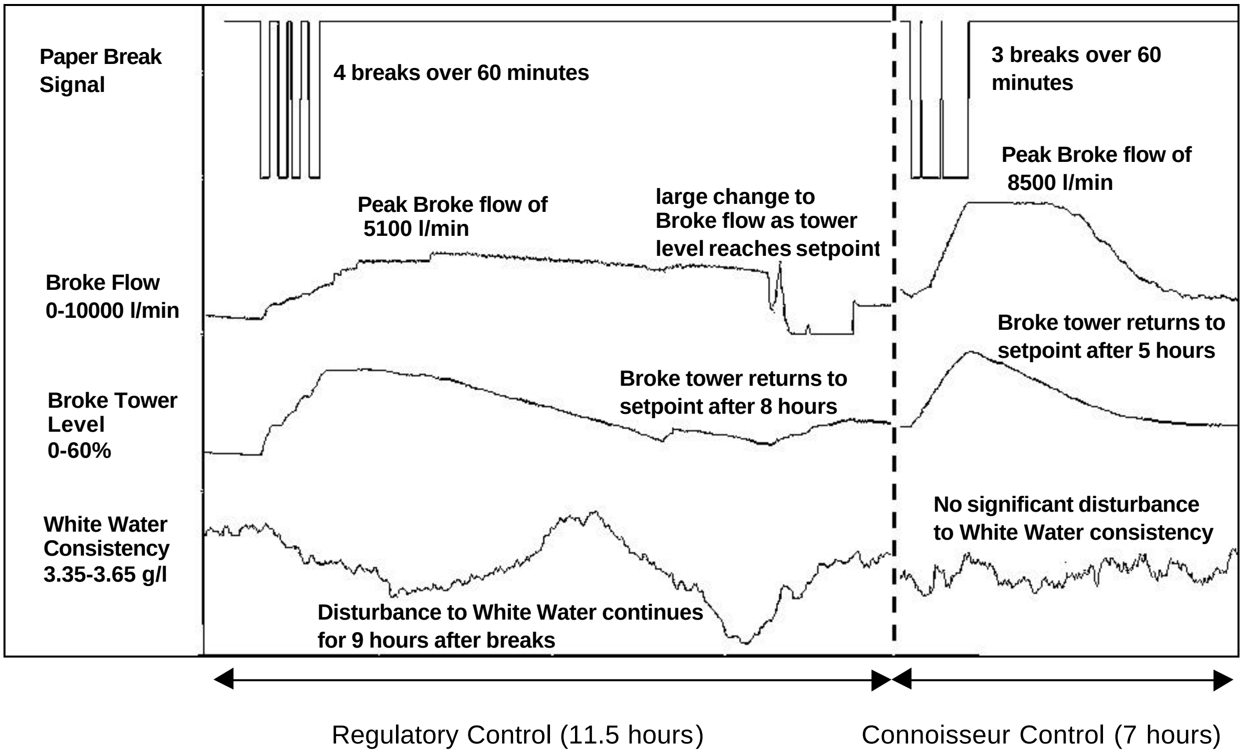

Figure 3: Comparison of Connoisseur and Regulatory Broke Management

6. CONCLUSIONS

MBPC has been successfully applied to the wet end of PM14. The ability to consider the interactions between retention aid, broke and de-inked pulp flow allow the controller to compensate for wet end disturbances. This has provided a significant improvement in wet end stability, to the extent that the effect of the introduction of broke after a paper break is now almost undetectable in its effect upon retention and white water consistency. The controller provides "best in class" white water consistency control, which has resulted in multiple stability benefits. These benefits include significant reductions in the variability of wire retention, ash retention and headbox consistency. In addition, broke system management has been improved, providing effective control of the broke tower, an important feature not available in other retention control systems[1].

The progressive project development approach, combined with the features of the Connoisseur APC package, have provided Aylesford Newsprint with a flexible APC solution. The controller is fully integrated into the existing DCS and can easily be expanded to include additional variables, or process modifications.

Once the project had demonstrated the value of this approach to improving wet end stability, Aylesford and Invensys personnel began to consider further development of the controller. The second stage of the APC controller development project has just been implemented. The APC controller now regulates the flowrates of all three retention aids, with the objective of keeping turbidity and charge within a constraint range and providing control of wire retention using the least possible amount of retention aid two. Furthermore, Connoisseur's optimisers are used in conjunction with the MBPC controller to determine the optimum retention for each grade and then to maintain machine operation at this retention, while keeping white water consistency within prescribed limits. The controller is also now in charge of ensuring that there are no disturbances in stock consistency to the headbox after long periods without a paper break, during which stock in the broke tank can get thin. In addition, there was some evidence that exclusive focus on white water consistency, ignoring the effects of retention aid on formation and other reel parameters, can be unsatisfactory. Taking account of this, the second stage controller has a broader focus.

Future controller extensions are expected to include control of vacuums and drainability, consideration of the effect of retention and drainage rates upon draw, and better control of the dryer.

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