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Model-assisted basis weight control of a board machine

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Abstract

The incentive to increase production whilst minimising variance was the motivation for a joint project between Karlstad University and Stora Enso to develop a dynamic model of a 5-ply board machine using the pulp and paper dynamic simulation package Simons IDEAS. This rigorous model while suitable to quantify the possible benefits of suggested process improvements offline, quickly became too unwieldy for model-based control studies so a slightly simplified model was re-engineered in Simulink. Finally transfer function models, suitable for online control and optimisation tasks were identified from production data with a structure given by semi-rigorous reasoning. All three models were adjusted and subsequently validated against almost one year of plant operating data.

This paper highlights the difficulties in validating a large industrial system with widely varying time constants, dubious transducers and the ubiquitous noise. We also demonstrate the use of simplified models to improve the performance of an adaptive IMC controller for the basis weight in the finished board and the improvement of MPC over the commonly employed IMC for grade changes.

1 Unique aspects of pulp and paper simulators

The renewed interest in modelling in the pulp and paper industry can be explained by the now ubiquitous PC with adequate computing power in the control room and on the engineers desk coupled with the often underestimated attractive user-interface. Such a tool can tackle not only problems in design, but also analyse operational problems, assist in retrofitting and provide test possibilities for model-based control studies. The result is that users, with automated modelling tools and little training, are encouraged to construction complex models and experiment with "what-if" scenarios in a wide variety of industries and applications. An industry-wide overview of modelling with particular attention to control is given in [18, 10]. When considering just paper and board machines, studies such as [6, 11] are typical of steady-state investigations while data driven models (or blackbox models) such as [1, 19, 13, 8], are typical of dynamic models. Models based on first principles such as mass, energy and momentum balances, [15, 14, 4, 22], while potentially more useful are less common due to difficulties in development, validation and maintenance.

Despite the readily available computing power and a wide variety of simulation tools, the tackling of realistic industrial problems by the non-specialist is still an open problem. This is particularly true for the pulp and paper industry which is still poorly served by the standard chemical process simulators, [9, p1141] as evidenced by the only cursory attention paid to dynamic simulation tools in [21, p2-5]. General purpose simulators (such as SpeedUp, [16]; gProms, [17]; Omola, [3]; Dymola/Modelica [7]) tend towards strong underlying numerical routines and often innovative thinking fall short on industry specific requirements such as physical property data on components such as pulp fiber types, fines, clay additives, non-Newtonian flow models, and correlations of paper properties such as bending stiffness, tear strength and brightness. These latter issues are addressed by simulation products with a specific pulp and

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paper industry focus (FlowMac[1], IDEAS, Entech[2]) but tend to implement crude integration routines in a sequential modular approach with little scope for algebraic optimisation.

To the author's knowledge, no single modelling tool is yet optimal, and in building medium to large scale models, we found problems in simulating noise and (the associated problems in integrating stochastic differential equations), and without a disciplined modelling approach we faced a rapid explosion in complexity. We also regularly observe excessive stiffness in the differential equations due to an ill advised choice in state variables, under-utilisation of results from modern numerical analysis (such as sparse matrix routines, adaptive integrators, DAE solvers etc) and often poor implementation of unusual events such as deadtimes, hystersis and other discontinuities.

However our overriding concern, (and according to one simulation vendor,[5], we are not alone), is computational speed — simulations still take too long to complete. While there are many factors influencing the execution speed, our tests on a 5-layer board machine located at Skoghall Sweden, [22], indicate that it is the computation of the pressure/flow balance of the network that limits the integration speed. An ongoing investigation using an analytical solution to the implicit Colebrook-White friction factor model shows substantial simulation turn-around time improvement and will the subject of a future report.

1.1 Hierarchical simulation tools

During the course of this investigation, it was found necessary to use three levels of simulation (using two different simulators) since no single product satisfied all the demands. At highest level we used IDEAS (Integrated Design Engineering with Advanced Simulation)[3] from Agra-Simons which is a dynamic simulator built on top of Extend from ImagineThat![4] targeted originally at the pulp and paper industry, [12]. Our original intention was to use this product exclusively for the modelling task, but in practice it proved too slow, (only 2 to 3 times faster than real time) in part due to a constant step-size numerical integration routine, and it also took some experience to both scale the problem and find reasonable initial conditions so the solver could get started.

These problems necessitated that we re-engineer a slightly simplified model in SIMULINK. This model retained the nonlinearities and most of the physically meaningful components such as vessel sizes, pipe lengths, pump characteristics etc. and the dynamics associated with the transducers, particularly the scanning frame for moisture and basis weight.

From this still complex nonlinear dynamic SIMULINK model of the stock preparation and wet-end of the machine we developed still simpler models suitable for model based control studies. These models are best considered as grossly simplified fundamentally based models rather than totally blackbox models.

2 Process description

Skoghall mill, located in central Sweden, produces 230,000 t/yr of board products on a 5.4 m wide, 5 layer board machine which has a top speed of 540 m/min. The three grades given in Table 1 were chosen as representative of the 30 different grades of board products manufactured. These are used as nominal operating points.

Table 1: Nominal grades chosen as representative operating conditions.

Basis Weight, g/m^2	*Machine Speed*, m/min
350	295
262	412
230	489

3 Validation

A complete validation of the IDEAS model is a challenging task, so we separated the requirements to: (1) validating the steady-state conditions of flows and concentrations (consisten-

[1] http://www.papermac.se
[2] http://www.entechcontrol.com/index.htm
[3] http://www.simonstech.com/
[4] http://www.imaginethatinc.com

cies) where measured of the DCS with those predicted by the full-scale IDEAS model, then (2) using these flow values as constants in the SIMULINK we fine-tuned the dynamics. Finally we built simple transfer function models suitable for model based control tasks using the now validated SIMULINK model as our truth model. Fitting black-box transfer function models to production data without any physical based reasoning failed to capture the nonlinearities and varying deadtime of the true plant. Consequently these models could not be extrapolated to grades not used for the identification.

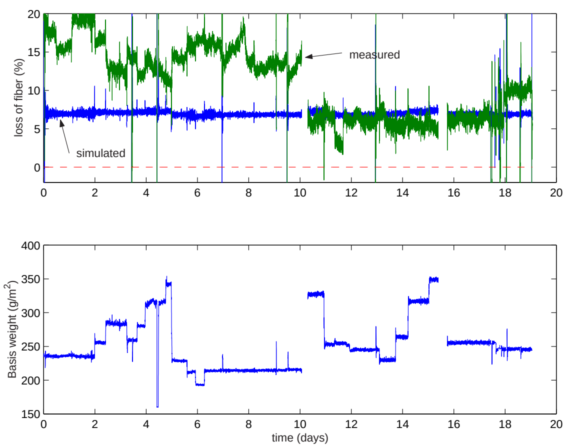

Figure 1: Production over 3 weeks showing (a) Fiber loss (measured and simulated) and (b) Basis weight.

3.1 Steady-state validation

Even though IDEAS is a dynamic simulator, its principle use was to fine tune the steady-state values of the flows and concentrations of fiber around the approach system which is a complex interconnected system with hydrocyclone cleaners and recycle. Since the model is physically based, ideally there should be few parameters to be regressed, but in practice we needed to adjust vessel mixing and pipe friction parameters, cleaner efficiencies, and wire retention values to match the experimental steady-state values of concentrations and flows, and the sporadic laboratory sampling at points not measured online.

Fig. 1 shows the total fiber balance over almost 3 weeks spanning a shutdown and cleaning stop around day 10. Due to trimming of the sheet and cleaning losses, we expect the fiber loss to be about 9% which is the case after the cleaning stop. This figure gives an indication of the quality of the overall model, at least when using reliable transducers.

3.2 Dynamic validation

The main dynamics of the board machine are due to the deadtime through the press and dryer sections, unusual filtering due to the scanning frame for moisture and basis weight measurements and the recirculation of fibers from the wire through the short circulation and dilution water.

Typical operating conditions are appropriate for establishing system gains while grade changes can give some dynamic information. However during a grade change, where the machine speed is ramped under manual operation, only the gain is substantially changed, which makes it difficult to resolve between the deadtime and time constants. Dynamic studies are better done by adjusting the thickstock flow, preferably staggered in different layers during the period just prior to a shut down, when we have the opportunity to change inputs without concerns with off-specification production.

Fig. 2 shows the results of the model prediction and measured basis weight for a series of bump tests in thickstock flow in the top, middle three, and bottom layers of the board. During these tests, the machine was disturbed by other factors (such as water added to tanks running low) which were accounted for in the model. Two scanning frames were used: one in a fixed position on the sheet and one scanning across the sheet. The fixed position scanner, due to its position, is sensitive to the excessive moisture, and due to an erroneous internal filter was sensitive even to the cross-profile, so consequently delivered unreliable readings and is only included for comparison in Fig. 2.

It is known from past tests that the lip opening, the moisture readings in the scanning frame and the flow rates are relatively accurate, but the consistency readings suffer from a bias, especially at low concentrations, and since they are located before the machine chest, do not give an accurate reading of the consistency in the thickstock just prior to the input to the wet end of

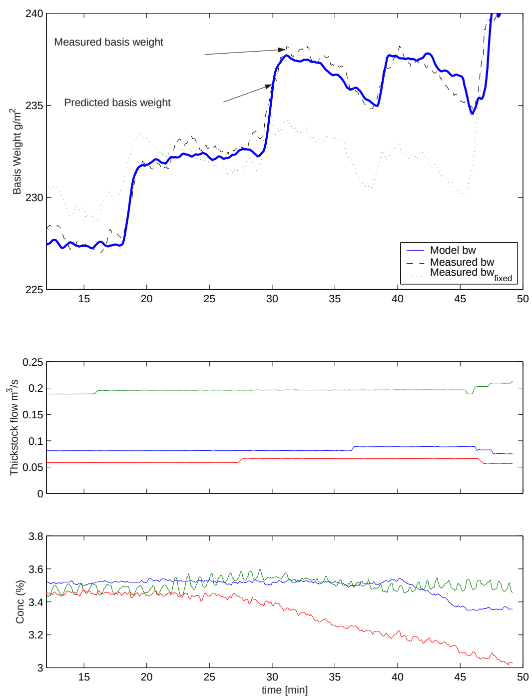

Figure 2: Model predictions compared to measured basis weight (upper plot) due to changes in thickstock flow and concentrations in the three plys (lower plots).

the machine. Therefore the main adjustments to the model are parameters in the consistency transducers (particularly a bias term) and minor adjustments to the time constants of the flow between the mixing and machine chests. The fitted model is validated by comparing model predictions against the logged basis weight during a grade change in normal operation in Fig. 3.

4 Improving the model based control scheme

The internal model-based control (IMC) scheme using an optimised adaptive model (described in [2]) can be compared to the current model-based control scheme implemented by the ABB engineers in the DCS. The IMC controller is commonly used in the industry for basis weight control and has been previously shown to outperform the Smith predictor, [20]. Fig. 4 illustrates the (simulated) benefit in using the improved model-based controller with an appropriate gain scheduler to correctly handle the nonlinearities in the plant for small grade changes at the low, medium and high basis weights chosen as nominal operating points in Table 1.

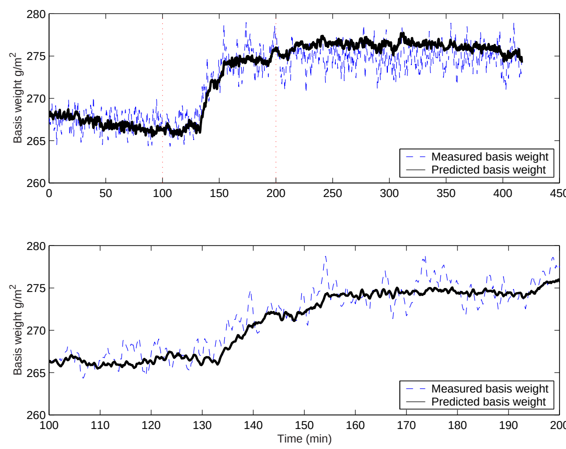

Figure 3: Model validation using the model from Fig. 2 against data from normal production. The lower plot shows a zoomed version of the grade change in the upper plot.

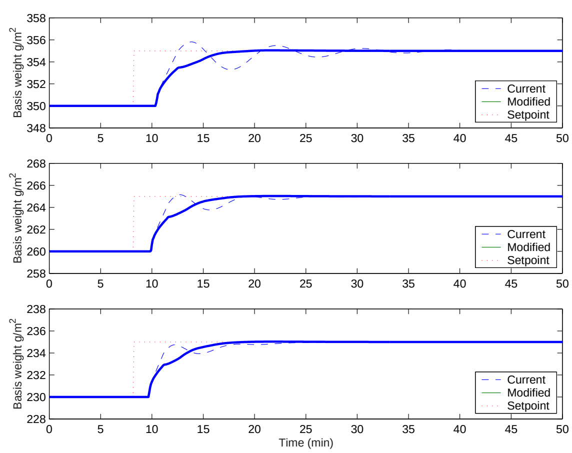

Figure 4: Improved controller model comparisons. 5 gram step changes at high (top), medium (middle) and low (bottom) basis weights.

The grade changes in Fig. 4 are sufficiently small that the machine speed was unchanged. For larger grade changes, when the machine speed is varied, it is known that the IMC gives a less than satisfactory performance. This is supported by the logged data presented in Fig. 5 which shows a number of different grade changes (offset for clarity) taken, in part, from the operating data presented in Fig. 1.

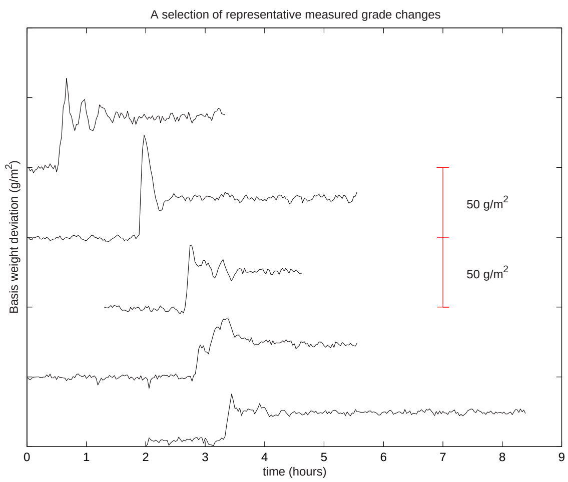

Figure 5: A representative collection of logged grade changes (with shifted and offset scales for clarity) using the standard IMC controller.

In fact, grade changes are routinely run in manual by the operator rather than automatic for this reason. Fig. 6 compares a (simulated) IMC controller similar to what is routinely used on board machines to a MPC controller. This latter controller is essentially a DMC controller applied to the nonlinear model from §3.2 with constraints. Further details are given in [2]. The MPC controller, with the added advantage of using both the machine speed and thickstock flow exhibits less overshoot than the IMC so we anticipate that this type of controller is suitable to address the grade change problems illustrated in Fig. 5.

5 Conclusions

A detailed dynamic model of the short circulation of a 5 layer board machine was developed using a three layer simulation approach and validated from both bump tests and typical operating data. The model is intended to be used for improving the grade change sequencing, enabling "what-if" scenarios to help solve various operational problems posed by the staff at the mill. Due the complexity, the model was built and validated in 3 parts. The resulting simplified models indicated substantial improvements when used as part of an internal model controller for basis weight during grade changes.

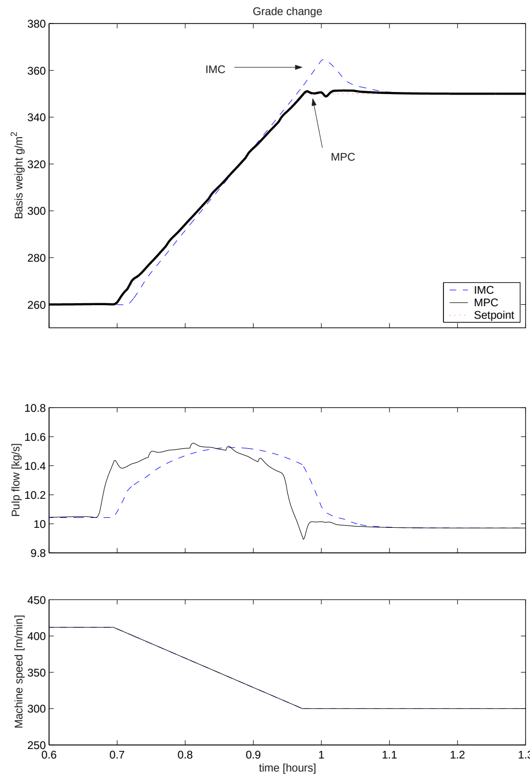

Figure 6: Comparing IMC (dashed) with MPC (solid) for the control of basis weight during a grade change (upper plot) with manipulated variables thickstock pulp flow and machine speed (lower plots).

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