EXPERIENCES OF LARGE-SCALE BOARD MACHINE MODELLING

CHRISTIAN HAAG & DAVID WILSON

Modelling & Simulation Group
Department of Electrical Engineering
Karlstad University, SE - 651 88 Sweden

Abstract

A large-scale dynamic model of a board machine has been developed and implemented in Simons IDEAS. The model extends from the pulp storage towers to the finished sheet including the broke system and the long circulation of white water and predicts the fractions of four kinds of fibers, water, fines, filler, starch and COD. Additionally it can predict key paper quality properties such as density, E-modulus and bending stiffness.

Three simulation examples are presented showing how the model is used to optimise production by focusing on grade changes, and to quantitatively explore the potential of improved, but costly, transducers.

In closing, some reflections on why this technically successful simulation project failed to garner the enthusiasm from industry that we thought it deserved.

Keywords: Modelling, simulation, paper, board machine

1 Introduction

Dynamic simulation of manufacturing processes is now routine, [1–3], even in the pulp and paper industries, [4]. Such a tool, one is lead to believe, can tackle not only problems in design, but also analyse operational problems, assist in retro-fitting and provide test possibilities for model-based control studies. However building, validating and managing models of large-scale systems is still a non-trivial undertaking. We found that despite the continuing improvements in computational power coupled with a serious commitment by the developers to construct an intuitive and user-friendly front-end, the overriding user concern is according to one simulation vendor, [5], computational speed — simulations still take too long to complete.

Stora Enso[1] in collaboration with Karlstad University have developed a dynamic model of a five ply paper board machine located at Skoghall mill, Sweden, producing liquid packing and other board products. Developed using Simons IDEAS[2], the model covers all unit operations from the pulp storage towers to the finished sheet on the jumbo roll, including the broke system and the long circulation of white water. It can predict the fractions of four kinds of fibers, water, fines, filler, starch and COD. Additionally the model predicts paper properties such as density, E-modulus and bending stiffness which are crucial quality parameters of the finished sheet. The model was calibrated using operating data supplemented with in-house regressions collected over many decades.

Clearly such a dynamic model has potential to assist mill engineers in troubleshooting, process optimisation, and re-design. However the complexity of the differential and algebraic equation set rapidly became too unwieldy for some uses (such as operator training), and it was found completely unsuitable for online model-based control purposes. For these purposes, simplified models were developed in a parallel project described in [6, 7]. This paper does not describe the development and validation of the model, but rather reflects the experiences in using it for process optimisation using three concrete examples.

2 The board machine

Board machine #8, (KM8) which was commissioned in 1996, is a five ply machine producing packaging board. A diagram of the board machine including the stock preparation is given in Figure 1 and machine characteristics are listed in Table 1. The troublesome parts of the machine are the long loops recycling the

[1] www.storaenso.com
[2] www.simonstech.com

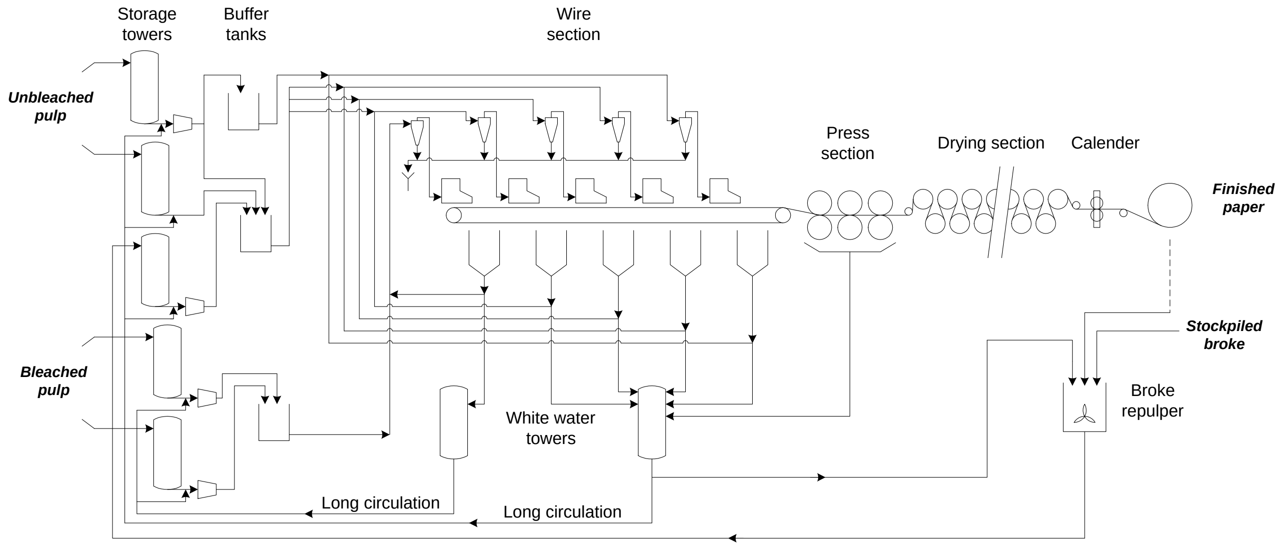

Figure 1: Process flow diagram of board machine KM8.

paper trim, and at times, the off-spec product known as broke, and any material that slipped through the wire screens, known as white water.

Table 1: KM8 machine characteristics.

Length	298 m
Width	8.1 m
Machine speed	800 m/min
Capacity	320,000 ton/year
Basis weights	120 – 300 g/m^2

The board is constructed as an I-beam with the stronger outer plies separated by weaker, but cheaper, bulky middle plies. The top ply consists of bleached long fiber sulfate pulp and some short fiber pulp to improve the surface properties. The three middle plies are formed by a combination of cheap, high-yield chemical thermal mechanical pulp (CTMP) and unbleached sulfate pulp. The bottom ply contains unbleached or bleached sulfate pulp depending on the customer requirements.

3 Simulation environment

Recently the commercial dynamic process simulation software appropriate for modelling of chemical engineering processes seem to be separating along two lines, not dissimilar to the equation-based/sequential modular schism that occurred in process flowsheeting a decade or two ago. The traditional modelling approach, best known perhaps by products such as MATLAB or SPICE is where the user builds the equations in a block like structure, and the executive solves them with minimal rearrangement. An alternative scheme taken by the academic product OMOLA, [8], and commercialised in DYMOLA, [9], is for the executive to undertake extensive symbolic equation rearrangement and massage the differential and algebraic equations in a form for subsequent solution.

Simons IDEAS is a commercial block-oriented dynamic simulation environment, [10], built on the general purpose simulation engine EXTEND from Imagine That[3]. This tool is clearly an engineering tool, as opposed to a research tool, in that it provides little support for model diagnostics in the form of Jacobians and little error checking for model consistency in contrast to, for example, packages such as SPEEDUP, [11] or ASCEND, [12]. Most crucially, it employs a fixed-step integrator solving the accompanying algebraic equations independently rather than solving the differential-algebraic problem. Consequently our simulation model executing four to five times faster than real-time on a 500 MHz PC still required over two days to generate the results presented in Fig. 5. This excessive simulation turnaround had an impact on what type of simulation scenarios were run, and was influential in why we chose not to use it as a training simulator.

The lack of modern numerical support for adaptive integrators, sparse matrices, DAEs etc. is offset by the intellectual property in the library of unit operations

[3]www.imaginethatinc.com

purpose of special interest to the pulp and paper industry. This makes it intuitive for the engineer to construct models by connecting the pre-built generic blocks for pipes, tanks, pressure screens, headboxes, refiners and so forth.

4 Board machine model

The board machine model covers all unit operations from the initial pulp storage towers to the finished sheet on the jumbo roll, including the broke system and the long circulation of white water as shown in Figure 1. The model is based on fundamental mass and momentum balances where possible, although resorts to semi-empirical regressions where little is known. Model inputs include the hundred or so material flows, properties of the different pulps, applied refining energy and tuning constants for the control loops. There are likewise hundreds of parameters: some easily characterised such as tank volumes, pipe lengths, machine speed, and width of the web while other parameters require extensive lab analysis and regression. These latter include parameters that characterise separation performance in filters and screens, or the effect of refining degree on density and E-modulus of each type of fiber.

In any industrial system of this magnitude, not all inputs or parameters have the same impact on the model outputs. However a semi-rigorous model has the advantage that physical components on the machine have a one-to-one correspondence to elements in the model. This makes it easy to rebuild the model following machine retro-fits, and presents a more natural interface to the operators. Most importantly, as the model was not intended for a specific case study, but rather as a 'virtual board machine' to address possible future problems not yet formulated, a certain degree of fundamentalism is essential. The intention is to be able to simulate almost any realistic scenario on the entire machine, without the burden of worrying whether interactions occur on the plant that we fail to notice in simulation due to some neglected components.

5 Simulation examples

The following three examples show how the engineering and operating staff used this dynamic model in the day-to-day operations. The intention of these simulations was to quantify variations in the medium to long term, and to quantify the benefits of either optimising the grade change, or establishing the economic potential of better broke control using a sophisticated but expensive online fiber analyser.

5.1 Chemical additive response

Chemicals are added to the pulp to minimise the absorption of water by the board when used as food or liquid packing. Fig. 2 illustrates that a step change in the chemical, (AKD in this instance), in the middle ply takes around 2 days to reach a steady state concentration — compared to just minutes for the basis weight of the board. The multiple bumps in Fig. 2 are primarily due to the plug flow through the long circulation. Similar, but much faster, bumps have also been observed experimentally due to the short circulation, but the coarse modelling is unable to resolve them. To predict this kind of phenomena, which is interesting for control studies, a much finer time scale is required. However practicalities mean that only part of the machine can then be modelled at this high resolution perhaps requiring a different simulation tool. One example in this direction using SIMULINK is described in a parallel project, [6].

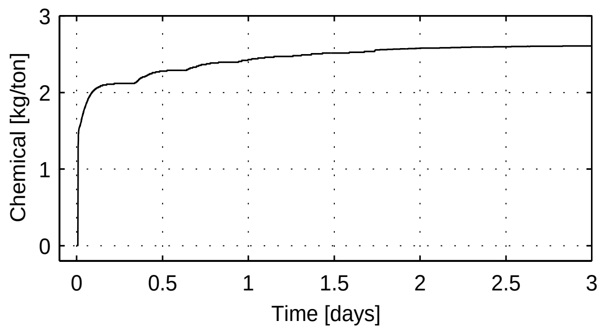

Figure 2: Step response of chemical additive.

Reducing the volume of the storage vessels, (white water and broke towers), in the long circulation loop will improve the response time. Conversely these design changes reduce the robustness and flexibility of the production.

If the response of the chemical addition was the sole object of the study, then one would use a simplified model of the form shown in Fig. 3 whose structure is derived from the process flow sheet, but whose parameters remain unknown, necessitating expensive machine tests. Alternatively by using the full machine model to generate Fig. 2, we can fit suitable parameters to simplified models if desired, and quickly generate similar models for other conditions.

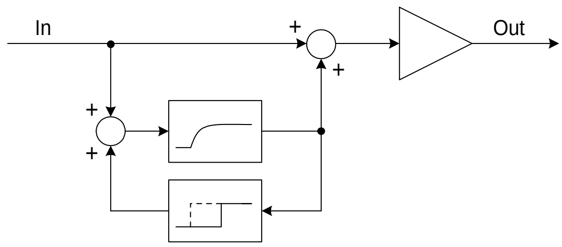

Figure 3: A simplified block structure for the dynamics of chemical additive.

5.2 Grade change

As the board machine makes around 30 different types of board, each with different properties tailored to the customers requirements, it is vital to be able to switch from one grade to another, minimising time spent producing off-specification material. Again grade changes are complicated by the recirculation of pulp, and the usage of broke with its intrinsic variation in quality.

Fig. 4 shows a simulated grade change after an extended period of producing a grade with low CTMP content intended for a product demanding a good printing surface, to production of a product used for packaging that requires a higher bending stiffness and is rich in CTMP. As is evident in Fig. 4, the basis weight rapidly reaches the new setpoint with minimal overshoot in all cases and this is considered acceptable by the industry. However what was not fully appreciated before this simulation study was that a key quality parameter in the finished board, the bending force, takes considerably longer to reach the quality limits of the grade, ('Normal' line in the lower trend of Fig. 4). This is due to the considerable volume of low CTMP pulp used in the previous recipe left lying in the intermediate buffer tanks which takes time to consume.

It is possible however, to schedule the grade change in such a way as to minimise the volume in the recycle storage towers just prior to the change, thereby improving the bending force response time significantly, ('Sink levels' line in Fig. 4). If this operational scheme is combined with a feedback control scheme to stabilise the CTMP component of the broke, then response is further improved ('Sink levels & control' line in Fig. 4).

These results suggest that there is economic benefit to optimise the grade change operations (i.e. to sink

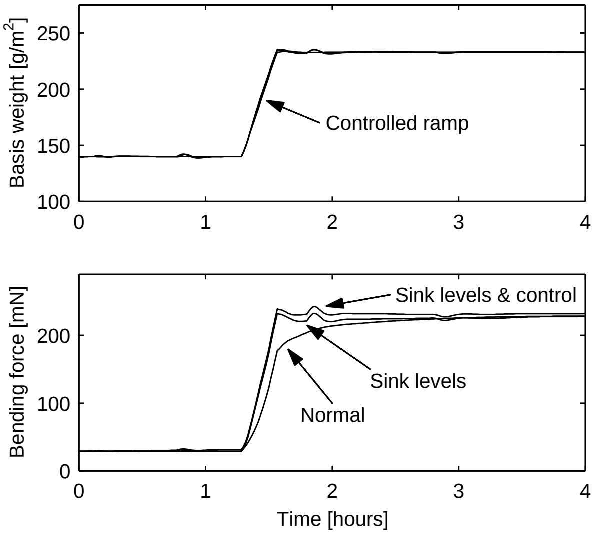

Figure 4: Basis weight, (g/m^2), and bending force, (mN) during a production grade change for 3 different operating cases.

the levels), but arguably not to install the costly feedback control scheme since the further improvement is marginal.

5.3 Variations in broke input

During constant production of a single grade, the quality of the fresh pulp does not vary significantly, but the quality of the previously stockpiled repulped broke does. In Fig. 5, we again simulated the response of the bending force when consuming a significant fraction of recycled broke with a varying CTMP component, (upper trend in Fig. 5 adapted from actual logged data). Under current operation, the varying CTMP component causes unwanted variations in the final board stiffness, ('Normal' line in Fig. 5), however if the amount of feed CTMP fiber in the broke is controlled, the resultant bending force exhibits much less variation, ('Control CTMP' line in Fig. 5). This 75% reduction in standard deviation in a key quality parameter implies considerable economic benefits.

By concentrating on the disturbance rejection, rather than just the transient response of section 5.2, we reverse the previous conclusion since now the simulation indicates that the cost of installing and maintaining the online fiber analyser is more than offset by the improved regulatory response.

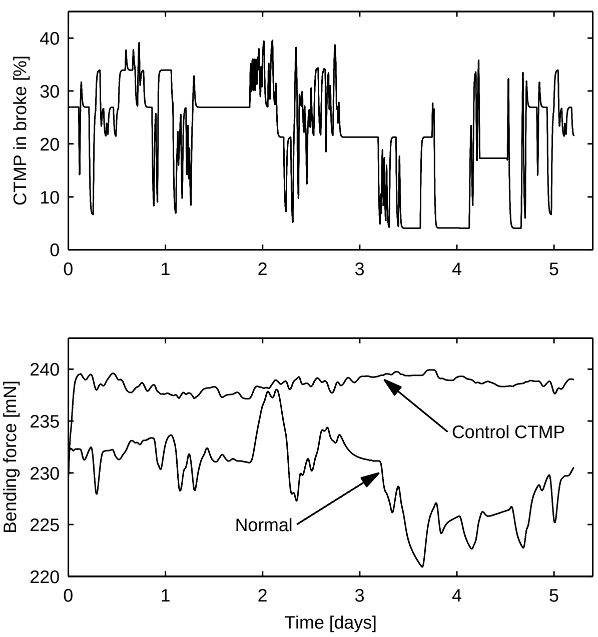

Figure 5: Fraction of CTMP in the incoming recycled broke (upper) and the resultant bending force (lower) for two different operations.

6 Using the model

The simulations presented in the previous section were selected from a larger project. It was found that the simulations frequently needed to be repeated as it is often difficult to pose a suitable scenario until one can study the output results. This dependency of the experimental design phase introduces a level of iteration where for example we may adjust the input stimuli, or log different signals or even chase interesting phenomena uncovered in the previous simulation run. However the excessive simulation turnaround times, sometimes in the order of days, rapidly became very frustrating, hampering the general acceptance of the model by the engineering staff.

When simulating the many different cases, we found that we made many small changes to a master model. Some of these changes were to be used only once, while others were improvements to the master model. The result, perhaps due to poor planning, was a plethora of models, in many stages of development. We eventually realised the value of a version management and tracking tool, and to improve our own internal project management.

Initially in this project, we expected to uncover phenomena that was not known to the operating staff. However they rarely appeared surprised by the simulation findings, perhaps because it just reinforced and quantified what they already deemed reasonable. Consequently one may ponder that as the model is in part the sum of the experience of the model makers, then is it any wonder that the results do not surprise? We feel that these results would be interesting to those outside the model development group, but perhaps less so to those experienced individuals already with a highly developed mental model of the plant.

Associated with this almost disinterest, is the reluctance of the experienced personnel to state their expectations of the simulation outcome prior to the actual running of the simulation. Stating that the model only delivers expected results when one does not offer the necessary prerequisite expectations, we feel, undervalues the true worth of the model.

7 Conclusions

The simulations and conclusions presented above highlight the complex nature of industrial process simulation. Asking the wrong questions, simulating over a too narrow time window, failing to take into account second order effects all can contribute to making poor judgements. Notwithstanding, this project was successful given that it predicted paper properties better than originally expected.

The fundamentally based model illustrated in this paper collected the best available in-house engineering knowledge with second order effects appropriately weighted. As shown, this model can be used to illustrate the tracking of additive chemicals, the advisability for rescheduling grade changes, and the economic potential for better instrumentation and subsequent control.

Such a model will not be the result of just one person's knowledge, but rather an amalgamation of the engineering staff's experience. The idea being that if we cannot hold onto the human experts, we at least retain some intellectual property after they leave or retire.

The process of developing a model of this kind forced the engineers to re-evaluate past, and perhaps forgotten, knowledge, and occasionally running new experiments to generate new knowledge.

Acknowledgements

Financial support from Karlstad University, Skogsindustriellt Centrum, Sweden is gratefully acknowledged. Thanks are due to all the participants at Stora Enso Skoghall and Research, especially Mats Hiertner, and Håkan Johansson without whose support and help this project would not have been possible.

References

[1] C.C. Pantelides and H.I. Britt. Multipurpose process modelling environments. In L.T. Biegler and M.F. Doherty, editors, *Proc. Conf. on Foundations of Computer-Aided Process Design '94*, pages 1–15. CACHE, 1995.

[2] Lorenz T. Biegler, J.D. Seader, and Warren D. Seader. *Process Simulation*. CACHE, 1995.

[3] Arthur W. Westerberg. Process Engineering II — A Systems View. In *90th Anniversary Symposium*. AIChE, Nov 15 – 20 1998.

[4] Ferhan Kayihan. A review of modeling and control in the pulp and paper industries. In *Chemical Process Control – V*, pages 117–132, Tahoe City, USA, 1996.

[5] Raluca Constantinescu. Simons Technologies Inc. Atlanta, GA, USA, 1998. Private communication.

[6] David I. Wilson and Jonas Balderud. Experiences building and validating a large-scale dynamic paper machine model. In D.H. Owens, editor, *Model Validation for Plant Control and Condition Monitoring*, pages 2/1–2/7. IEE, Savoy Place London, WC2R 0BL, UK, 28 March 2000.

[7] David I. Wilson and Jonas Balderud. Model-assisted basis weight control of a board machine. In T. Söderstrom, editor, *Reglermötet 2000*, pages 259–264, MIC, Uppsala, Sweden, 7–8 June 2000.

[8] B. Nilsson. Dynamic Modelling of Chemical Processes Using OMOLA. *Trans IChemE*, 72(A):364–370, May 1994.

[9] F.E. Cellier and H. Elmqvist. Automated Formula Manipulated Supports Object-Oriented Continuous-System Modeling. *IEEE Control Systems*, 13(2):28–38, 1993.

[10] M. McGarry, B. Bickell, and G. Pelkey. A case study of the use of actual controls in simulation trainers. In *83rd Annual meeting technical section — paper, people, progress*, volume 78, pages B357–B360, Montreal, Que, Canada, 1997. Canadian Pulp and Paper Association.

[11] C.C. Pantelides. SPEEDUP: Recent advances in process simulation. In *Annual Conference*, Miami Beach, November 1986. AIChE.

[12] P.C. Piela, T.G. Epperly, K.M. Weterberg, and A.W. Westerberg. ASCEND: An object-oriented computer environment for modelling and analysis: The modelling language. *Computers in Chemical Engineering*, 15(1):53–72, 1991.