SYSTEMATIC CONTROL PROBLEM ANALYSIS APPLIED TO BATCH PULP DIGESTER CONTROL

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Abstract: The design of control systems must be approached methodically if any success is to be obtained. Systematic control system design is highlighted in the discussion of implementation of a model based control system on a batch pulp digester at Sappi/Saiccor's Umkomaas plant. Steps taken include modelling both system dynamics and controller performance, to ensure that the correct controller structure was implemented and that the controller chosen controller would perform adequately. Once the controller was verified, it was implemented *in-situ* and the performance measured using an impartial performance measure based on the performance of an ideal controller.

Keywords: Batch pulp digester, Control analysis, performance

1. INTRODUCTION

During the process of producing dissolving pulp in the acid sulfite process, wood chips are subjected to high-pressures and temperatures in an acidic sulfite environment. The goal of this treatment is to remove lignin from the wood and to reduce the chain length of the cellulose (Rydholm, 1965). The chain length, expressed as a Degree of Polymerisation (DP), usually has to be controlled between certain limits (Meneghel, 1999).

Base layer control usually has no trouble controlling the variables that are measured at high sampling rates (30 seconds or less) (Watson, 1992). These measurements are temperature, pressure and the flowrate of liquor through the external heat exchanger. However, the control of the final DP is made difficult due to the following (Kilian, 1999; Meneghel, 1999):

- The results of consecutive cooks with the same digester are only loosely correlated.
- The reactions that take place in the digester have a highly nonlinear effect on the final DP.
- There is a general lack of measurements which relate directly to the DP due to the harsh conditions inside the digester as well as the prohibitive cost of on-line measurement of DP directly or indirectly (via pH-measurement).
- Constraints on the manipulated variable (steam flow to an external heat exchanger) and on the required temperature profile reduce the effective handles to the process to only one, namely the maximum temperature in the digester during a cook.

The control problem can therefore be stated as the control of a highly non-linear system with very low sampling rates (6 hours or more for the DP measurements) and very low correlation between consecutive batches, making use of only one effective manipulated variable.

The current controller has not been achieving the desired levels of performance, leading to interest in an improved controller (Meneghel, 1998). The Process Modelling and Control group of the Department of Chemical Engineering at the University of Pretoria has been working on the problem for a number of years and has recently achieved success with an improved controller that addresses the restrictions stated above.

This paper explains how the systematic analysis of this control problem resulted in the implementation of a controller which outperforms the legacy controller installed on the plant. The steps involved in the controller design include

- development of a model of the reactions inside the digester (this work done by Kilian (1999)),
- development of simulations of the current DP controller and the digester and baselayer control system,
- synthesis of a control strategy that is suited to the problem as stated above,
- simulation of the proposed controller along with the current controllers to estimate control performance and
- implementation of the controller on a working digester and monitoring of the results.

2. PROCESS BACKGROUND

2.1 Equipment

The pulping process takes place in a reaction vessel known as a digester, shown diagrammatically in figure 1. The digester is fitted with an external heat exchanger where steam is used to increase the temperature of the cooking liquor circulating through the heat exchanger. Temperatures are measured before and after the heat exchanger. The pressure inside the digester is also measured, along with the flowrate of the external stream flowing through the heat exchanger.

2.2 Process cycle

A batch (known as a cook) begins when the digester is loaded with wood chips and an acidic sulphite containing cooking liquor. The contents of the digester is heated according to a predetermined temperature profile, kept at a constant temperature and then discharged. The temperature that the digester reaches during the final constant temperature phase is the only aspect of the temperature profile that can be changed in order to achieve the correct degree of polymerisation (DP). In general, the higher the temperature during this phase, the lower the DP.

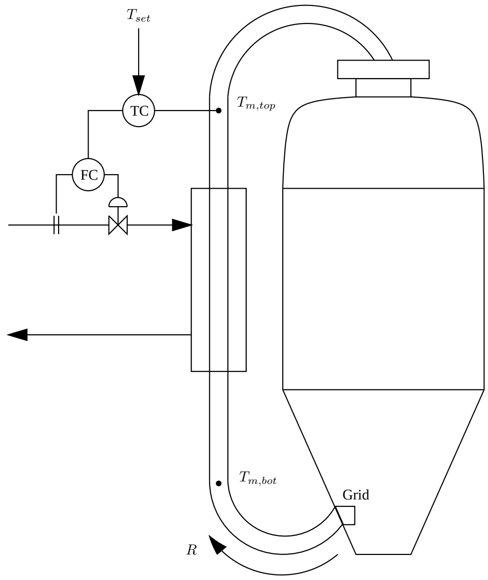


Fig. 1. The digester system, showing the temperature control system

At the end of a batch (referred to as a cook), the pulp is discharged and the DP determined in a laboratory. The result of this procedure is that the resultant DP for a cook is measured only once per cook and the result becomes available only after the cook has been completed.

Once the pulp has been discharged, the digester is loaded with new material and taken through another cycle. The new material often has a different composition to the material used in the preceding cook. This fact, together with many other changing conditions on the plant, means that the DP measured for the previous cook will not be related to the DP resulting from the next cook.

2.3 Control equipment

The digester is controlled by a DCS system which ensures that the digester is taken through all the phases of the process cycle correctly. The temperature control is done by manipulating the steam flowrate to ensure that the temperature of the hot stream exiting the heat exchanger is kept on setpoint in accordance with the temperature profiles discussed in the previous section.

3. STRUCTURED CONTROL ANALYSIS

The control problem seems simple – find a temperature to use as a top temperature that will result

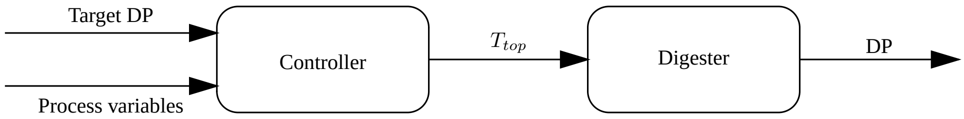


Fig. 2. Control structure showing the digester system and the controller system.

in the correct DP. The problem is, however aggravated by several factors. A structured approach to this problem is imperative.

Gupta & Sinha (1996) highlight the importance of proper controller analysis, even when a controller is already in place, going on to state that ad hoc implementations of control systems are bad engineering practise, will not be reliable and will not be trusted.

It is therefore crucial to proceed according to a well-defined plan. Stephanopoulos (1984) solidifies the initial stages of control analysis in the following three steps:

- Classify the variables. Identify input and output variables.
- Define control objectives.
- Select measurements.

Further steps for implementing a controller are to be found in Skogestad (1996):

- Select performance criteria for adequate control.
- Select a control strategy.
- Evaluate the control strategy theoretically.

Obviously these steps can be broken down even further – the selection of a control strategy can not be seen as just one step. However, this method is generally applicable to most control system designs.

Harris et al. (1996) add two additional steps to ensure that the controller is performing correctly once it has been implemented, namely

- Select an objective measure of performance.
- Monitor the controller performance.

4. IMPLEMENTATION

4.1 Variables

The choice of variables in this study was straightforward. The controlled variable is clearly the DP, while the only variable available for manipulation during the batch is the steam flow rate.

Due to the fact that acceptable temperature control is already in place on the plant, it is possible to design the controller to output a temperature rather than a steam flowrate. The heating of the digester is also constrained in such a way that the only aspect of the temperature profile which is changeable is the temperature reached during the final, constant temperature phase. This is shown graphically in figure 2.

Several process variables are measured before a batch, including the composition of the liquor and the amount of wood and liquor loaded. The temperature and pressure inside the digester and the flowrate of the stream being heated are measured throughout the cook.

4.2 Controller structure and performance

Several factors make this control problem uniquely difficult. The fact that the controlled variable is measured infrequently, only after a cook has been completed, and that this measurement has no direct bearing on the result of the next cook implies that the control action should be feedforward in nature. This in turn implies that a model of the process is required.

The variance of the DP is measured on the plant as a measure of controller performance. It was decided that the controller performance should rather be compared to a theoretical minimum variance benchmark in the interest of obtaining an unbiased and easily interpretable performance measure. To determine the best performance that can be expected, a model of the process was also required.

To ensure that the process model will remain accurate in the face of changing conditions on the plant, the model parameters will have to be adjusted to take into account new information. This model optimisation constitutes a feedback element in the control structure.

4.3 Process model

A model of the reactions inside the digester was developed by Kilian (1999), and was used to create a simulated digester. The model is based on a first principle kinetic analysis combined with empirical modification of the model parameters. The action of the DCS was also simulated, so that a cook could be simulated on the virtual digester.

The benefits of a process model such as the one developed here are that control action can be simulated and evaluated before the controller is implemented on a real digester.

4.4 Monte Carlo simulation

Monte Carlo simulation uses repeated simulations to deduce how a system responds to stochastic inputs (Mooney, 1997). The simulated digester was used together with two simulated versions of the current (S-factor) controller and the proposed (UP) replacement controller to simulate 400 runs of 80 cooks subject to variances in input parameters similar to those measured on the plant. The two versions of the current controller differed in that the one did not allow parameter changes. This controller was included as a low anchor for performance.

5. RESULTS

5.1 Theoretical verification

The proposed controller outperformed both of the simulated S-factor controllers during Monte Carlo testing and provided a convenient lower limit to controller performance.

The results of the Monte Carlo simulation can be seen in figure 3. For these tests, the target DP was kept constant at 50.

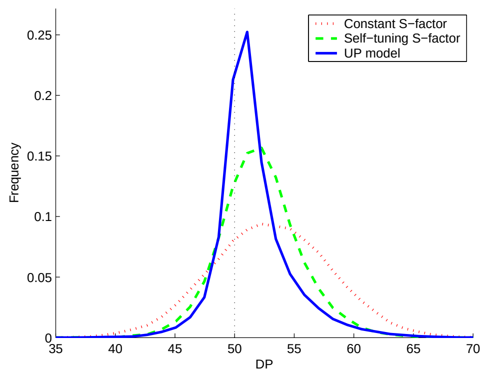


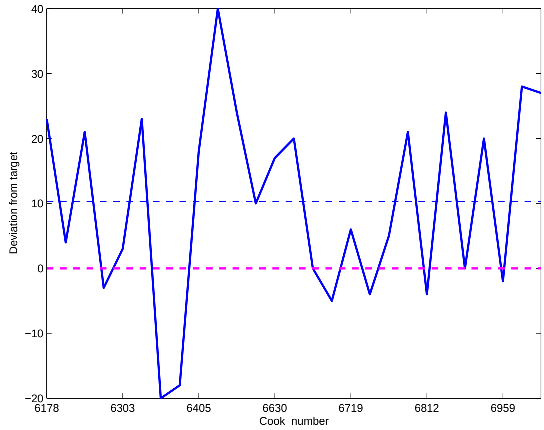
Fig. 3. Variances obtained during simulation of three prospective controllers

Due to the fact that the controller is based on the same model structure as the simulated digester, the performance it exhibited can be taken as the minimum variance given certain variances in the inputs.

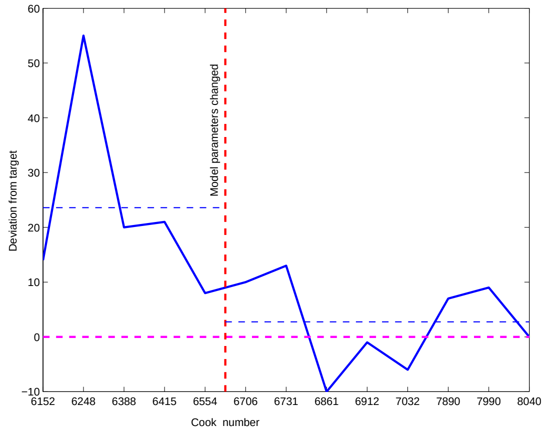
It should be noted that the UP controller shows a tendency to move nearer the target, as is clear from the kurtosis visible in figure 3. Also visible on the graph is the low performance anchor (constant S-factor), which is normally distributed about a point above the target.

5.2 In-situ results

The controller was subsequently implemented on an operational digester.



(a) S-factor controller



(b) UP controller

Fig. 4. In-situ performance of controllers during the same time period

Figure 4(a) shows the performance of the current controller and figure 4(b) shows the performance of the UP controller during the same time period.

It can be seen that the UP controller performs better than the current controller. It exhibited a variance only 4 times the theoretical minimum, while the S-factor obtained 7 times the theoretical minimum variance. Also visible from figure 4(b), is the effect of tuning the parameters. This corresponds well to the simulation results, suggesting that the controller performance will improve with time.

Another significant point is that the current (S-factor) controller does not exhibit the same time-dependant behaviour as observed in the simulations. Indeed, the controller does not improve with time, even though it does incorporate a method of adapting its parameters to fit plant operating conditions.

6. CONCLUSIONS

The method used in this study leads the control engineer from initial analysis of the problem to performance evaluation in a linear and unambiguous fashion. Good results have been obtained in this study by using such a structured approach.

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