PREDICTION AND PREVENTION OF SHEET BREAK USING PARTIAL LEAST SQUARES AND AN EXPERT SYSTEM

by

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Abstract

Sheet breaks are of major concern because they diminish the reliability and efficiency of the pulp production process, incur substantial cost, and pose a significant safety risk to plant operators. Consequently, this thesis addresses the problem of predicting and preventing sheet breaks by using Projection to Latent Structures (PLS) to model the sheet break process, and Principle Component Analysis (PCA) to monitor variables and define a region of healthy machine operation. An expert system is then employed to monitor major process variables, trouble shoot problems, and provide remedial action to prevent the occurrence of sheet breaks.

Using data provided by the Weyerhaeuser Canada Pulp Mill in Grand Prairie, PLS modeling is able to reduce 43 measured process variables to three latent vectors that effectively reflect pulp quality and the operation of the headbox, presses and dryer. As such, the PLS model is able to predict 92% of sheet breaks. In addition, the PLS model is used to investigate and pinpoint key variables that are major contributors to sheet breaks, which in this pulp mill include: lumpbreaker loadings, dryer steam pressure, and dryer differential pressure. PCA analysis is then used to define a healthy region of machine operation, and subsequent tests using the model confirmed that when sheet breaks occurred, the scores indeed fell out of the healthy region. From the test set, PCA is able to predict 9 out of 12 sheet breaks. Additional analysis of the stock also reveals that fluctuating consistency of the stock in the headbox...
causes fluctuations in basis weight and consequently diminishes the pulp quality.

The results from PLS analysis regarding variables that cause sheet break, and results obtained from PCA monitoring regarding fault detection are integrated into an expert system. The expert system effectively monitors the pulp production process, trouble shoots the situation when variables trend outside a healthy region of operation, and also suggests an appropriate course of action. Consequently, the expert system developed in this thesis functions to predict and prevent sheet breaks, and ultimately allows improved reliability, efficiency, quality, economics and safety of the pulp production process.
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Chapter 1

Introduction

The production of a pulp sheet begins by cooking wood chips to dissolve the lignin which binds wood fibers. The resulting pulp is bleached, diluted and then placed on a wire where water is removed by the application of suction, pressure, and heat to produce a pulp sheet. A frequent and costly disruption of this process is the occurrence of sheet breaks during pulp production.

Sheet breaks are of major concern because they affect the reliability and efficiency of the pulp production process, and incur substantial cost because each sheet break requires total pulp machine shut down and re-threading of pulp. The Weyerhaeuser Canada pulp mill in Grande Prairie, for example, reported a total of seventeen sheet breaks in one month—at the cost of $25000 per sheet break ([3]). In addition, and most importantly, the safety of pulp
machine operators is a central issue because operators are required to enter a hazardous hot
dryer to pull out broken sheets before the pulp machine can be restarted. In spite of the
frequency of sheet breaks and the cost in terms of efficiency, time, economics and human
safety; there has been a surprising lack of attempts to improve pulp production reliability by
introducing sheet break monitoring and control techniques.

Research has been done, however, in the area of measuring variables related to the quality
of a pulp sheet Ekblad[13], modeling the sheet break process using a continuous Markov
chain Khanbaghi et al.[15], and also managing pulp machine operation after sheet breakage
with a unique break recovery controller Powel et al.[24]. Nevertheless, research to date has
primarily focused on targeting a few process variables and there also remains a paucity of
research regarding the prevention of sheet breaks before they occur. If the majority of sheet
breaks could be predicted and prevented it would greatly increase machine reliability and
also improve the control of paper quality. This has cultivated interest into researching more
complete methods of looking at the sheet break process in which many process variables are
considered simultaneously in an attempt to prevent sheet breaks.
1.1 Scope and Objectives of Study

Because sheet breaks are associated with a host of problems including decreased reliability and efficiency of pulp production, large financial cost, impaired paper quality control, and safety concerns for operators, this thesis will address the problem of predicting and preventing sheet breaks in a pulp plant. Two factor-based statistical modeling techniques will be used to integrate the enormous amount of highly correlated process variables associated with the successful formation of a paper sheet. Firstly, Projection to Latent Structures (PLS) will be used to model the sheet break process; and secondly, Principal Component Analysis (PCA) will be used to monitor the operation of all variables and map out a region of healthy machine operation. Significantly, PLS and PCA possess the advantage of being able to compress tremendous amounts of data and to subsequently analyze a process in a compact space.

This thesis will also use an expert system to continuously monitor major operating variables, detect abnormal pulp properties, and provide expert advice for remedial action in response to problems. Specifically, “an expert system allows operators access to a pre-programmed knowledge base in order to minimize unscheduled shutdowns due to process failure, while at the same time improving the process itself.” [5]

In summary, the important contribution of this thesis will be the establishment of a method for predicting and preventing sheet breaks; this will result in increased reliability of the pulp
production process, reduced financial costs, improved paper quality control, increased safety for plant operators, and provide a significant contribution to pulp and paper research. The scope of this thesis, then, is threefold:

1. To research, consolidate and analyze all process variables using PLS to determine the most important variables that affect sheet susceptibility to breakage.

2. To predict sheet breaks as operating conditions trend away from a statistically controlled region using PCA.

3. To organize the wealth of practical experience on solving sheet break problems and to distill this knowledge into an expert system which will monitor major process variables, trouble shoot problems, and provide remedial action to prevent the occurrence of sheet breaks.

1.2 Thesis Organization

Chapter two contains a literature review which discusses important research done in regards to addressing sheet break problems, and also explains how expert systems have been used successfully in heuristic dependent processes. In chapter three, a detailed description of the pulp production process and associated operating issues are presented. Chapter four details the
use of Partial Least Squares and Principal Component Analysis to model the pulp production process and monitor multivariate variables which are correlated to the occurrence of sheet breaks. Chapter five integrates the important findings from previous chapters into an expert system that is able to monitor and trouble shoot pulp machine function, and most importantly, prevent sheet break occurrence.
Chapter 2

Literature Review

2.1 Introduction

The occurrence of sheet breaks in the pulp production process is very costly in terms of time, economics, process reliability, efficiency, and human safety. Currently, when operating personnel suspect that a sheet break may occur, they provide remedial actions and trouble shoot possible causes. At the root of these skills required to predict, prevent and remedy sheet breaks is an understanding of factors that give rise to sheet breakage.

This chapter addresses the potential causes of sheet breaks by reviewing research that identifies variables highly correlated to sheet breaks, and by documenting practical experience from machine operators regarding factors associated with sheet breaks. Because this thesis
proposes the use of an expert system that consolidates this knowledge into a tool for detecting and preventing sheet breaks, the second portion of this chapter will highlight examples of successful expert system applications in the pulp and paper industry.

2.2 Causes of Sheet Breaks

Newsprint mills attempt to re-circulate the maximum amount of white water, but this often proves to be a disadvantage because the amount of re-circulation is a major disturbance that impacts the production and the quality of the paper. To highlight this principle, Khanbaghi et al. (1996) developed a statistical model of paper breaks for an integrated TMP newsprint mill that shows how the broke re-circulation ratio and operation speed are associated with the paper break rate [15]. The paper break process was modeled as a continuous Markov chain with three states: the first represents the operational state; the second models wet breaks which occur in the press and dryers; and the third represents dry breaks which occur in the calendar and reel. Khanbaghi et al. (1996) found that the machine speed and broke re-circulation ratio were strongly correlated to the sheet break rate and loss of paper quality [15]. The results obtained were explained as follows:

1. As the speed of paper production increases, the tensile force to which the sheet of paper is subjected increases, resulting in increased probability of sheet breakage.
2. As the broke re-circulation increases, the quality of paper decreases secondary to increased fines, ultimately resulting in a higher incidence of sheet breaks.

Critically speaking, however, Khanbaghi et al. only considered machine operation speed and broke re-circulation as the major variables to be monitored and modeled; there are many other variables which were not analyzed but are also measurable on the paper machine. The Markov model is also limited in representing the “causality issue”: when paper breaks occur repeatedly, increased fines are re-circulated, which in turn results in decreased paper quality; decreased paper quality increases the probability of more paper breaks—thus resulting in a vicious cycle. In summary, future research should address other variables that are related to sheet breaks, and attempt to provide models that adequately consider the “causality issue”.

Another paper by Fisher (1996) discusses why paper machine stock systems must be stable to prevent web breaks [11]. His work discusses how unmonitored instability and oscillations in flows can lead to upsets, and that simply monitoring the two criteria frequently used for machine stability is not sufficient for prevention. The two criteria that are generally used, and which often provide a superficial appearance of a stable operation, include:

1. Constant flow and consistency when virgin stocks and broke are combined.

2. Constant flow and pressure within the thin stock system.
Fisher (1996) provides an explanation for the observation that sheet breaks often occur in clusters [11]. Following a break, the broke system strips fines using white water and re-circulates them in greater quantity, thus resulting in increased broke flow. This causes oscillations in the drainage characteristics of the stock, which increases the probability of paper breaks. With repeated sheet breaks, these oscillations are amplified, consequently leading to increased probability of breaks following initial breaks. In conclusion, Fisher (1996) states that the paper machine must be isolated from sudden surges in fines in order to reduce wet and dry breaks [11].

Other causes of sheet break have also been documented by operating personnel from the Weyerhaeuser Canada pulp mill in Grande Prairie. These causes include the following:

1. High moisture profile of the sheet. This is can be due to problems with equipment that are responsible for water removal and drying of the sheet: the vacuum system, steam hood and dryer.

2. Problems with sheet formation. This is usually attributed to improper functioning of equipment primarily responsible for sheet formation: the headbox, and presses.

3. Pulp quality of the stock. There exists a delicate balance between the amount of short and long fibers in a paper sheet: long fibers bond well, but more energy is required to remove water; on the other hand, short fibers do not bond well, but their presence
improves water drainage.

4. Wrinkles in the paper sheet. The cause of wrinkles is currently unknown and under investigation; their presence, however, is associated with increased sheet breakage. Consequently, wrinkles should be eliminated before entering the dryer.

2.3 Applications of Expert Systems in the Pulp and Paper Industry

"An expert system is a computer program that thinks and reasons as an expert would in a particular domain" [23]. Parker (1993) describes four areas in which expert systems can be incorporated into pulp and paper mills: customer service and scheduling; equipment monitoring for preventive maintenance; problem diagnostics; and modeling of processes in the mill [23]. Parker also provides examples of expert systems that are available or currently in use. The following is a list of expert systems with applications related to paper quality, partial modeling of a mill, and scheduling:

1. EPAQ Matrix Quality Advisor, developed by ABB (Finland), is an expert system that advises an operator on paper quality. Using on-line and off-line measurements, and a mathematical quality model concurrently with a rule base, this system was able to
reduce quality variations and production cost.

2. AESOP is an expert system developed by Temple-Inland in conjunction with Texas A & M. AESOP contains diagnostic knowledge about the papermaking process, and has a domain area that identifies visual paper defects.

3. At RUST, a system was developed to manage and schedule the use of steam and power. This expert system was also able to solve the problem of load-shedding.

G. Nault et al. (1996) describes an on-line Dryer Expert System (DES) which uses a multi-variable approach to follow and optimize complex processes in the dryer and press section of a pulp mill [21]. The DES was responsible for monitoring five separate data sets (the steam and condensate system, the press section, the hood, the wet end and the vacuum system) and generating alarms to allow optimal operation of the presses and dryers. Interestingly, after using the DES, mill personnel were able to identify five problems in the process that they were previously unaware of:

1. Very heavy fluctuations in temperatures of the air supplied to the air pockets.

2. Spills of condensate to sewers.

3. False press dryness readings due to instrument errors.

4. Problems with thermocompressor operation.
5. Changing of the press moisture on a continuous basis

Thus, the DES demonstrates that an expert system not only allows for optimal process operation, but in this case, also improved the process by providing new information that allowed changes to take place.

Xia et al. (1995) discuss the successful use of an expert system in performing fault diagnosis and decision making for the Daishowa Peace River Division, and Slave Lake Pulp Corporation mills in Alberta [29]. The main functions for the system are:

1. Fulfilling production scheduling according to market variations and customer requirements.

2. Monitoring process variables to detect undesirable situations.

3. Advising corrective actions to operators in order to prevent undesirable situations.

4. Optimizing process operating conditions.

This particular expert system was also a powerful tool because it allowed mill operators to implement new applications (quality control, graded transitions, and trouble shooting) without needing to have full knowledge of the process mechanism.

Allen et al. (1992) describe a very successful expert system called the Kraft Pitch Expert that is used for pitch control [1]. Mills that have used the Kraft Pitch Expert System have
reported economic benefits that have already exceeded the costs of development. The Kraft Pitch Expert System has also provided a new medium for technology transfer; mill personnel using the system simultaneously learn more about pitch control. As a result, the Kraft Pitch Expert system is an example of how successful expert systems ultimately provide an economic advantage as well as a significant avenue for educational purposes. It should be noted that the Kraft Pitch Expert System is only available to Member Companies of Pulp and Paper Research Institute of Canada (PAPRICAN) in order to provide these companies with a competitive advantage.

2.4 Conclusions

From the literature review it has been documented that the frequency of sheet breaks is correlated with factors that include speed of paper production, the broke re-circulation rate, and the re-circulation and sudden surges of fines. In addition, discussions with plant operators have also revealed an even wider range of factors that have been found to be associated with sheet breaks: high moisture profile of the pulp sheet, problems with sheet formation secondary to impaired equipment function, wrinkles, unfavorable sheet properties, and incorrect measurements. This thesis will use multivariate statistical techniques to also investigate a host of other potential causes of sheet breaks, and will ultimately assess the extent to which
a specific variable is associated with sheet breaks.

This chapter also reviewed the successful application of expert systems that are currently used to perform tasks such as scheduling, monitoring, problem solving, modeling and advising. Examples of expert systems that improve the efficiency of a process, serve as a medium for educational transfer, and most importantly, provide economic benefits, were also reviewed.

Though causes of sheet breaks are documented in the literature, there is no published method that prevents sheet breaks by using an expert system that models the breaks process while simultaneously trouble shooting potential dangers such as equipment failure. Consequently, this thesis will propose an expert system that prevents sheet breaks by modeling, monitoring and trouble shooting the sheet break process. Before addressing the breaks process, a more detailed understanding of pulp machine operation is required. The next chapter will discuss important operating issues concerning pulp machines.
Chapter 3

Operating Issues of Pulp Machines

3.1 Introduction

Pulp production is a complex process in which many things can go wrong. With the purpose of understanding the intricacies of this process, this chapter describes the pulp production process and provides a detailed description of the pulp machine and its key components. This is followed by a discussion of those aspects of pulp machine operation that affect sheet susceptibility to breakage. The specific data on which the following chapter is based originate from the Weyerhaeuser Canada Ltd. pulp mill in Grande Prairie; more importantly, the principles and details in the following discussion are relevant in application to all Kraft mills.
3.1.1 The Pulp Production Process

Figure 3.1 provides an overview of the pulp production process and depicts the key pulp production units involved. Pulp sheet production begins by placing wood chips in a digester that cooks the wood and dissolves the lignin that binds the wood fibers. The resulting pulp is then cleaned and bleached in the bleach plant and subsequently treated in the stock preparation unit, where chemicals are added and the pulp is blended to a desired consistency. The processed pulp is then stored momentarily in the machine chest. Pulp from the machine chest is combined with pulp from the machine white water chest and is then pumped into the headbox, where high turbulence is used to prevent fiber flocculation. The stock is placed on the wire where the pulp sheet is first formed and excess water is sucked out of the sheet. The water and fibers that are sucked out are collected in the machine white water chest and re-circulated for later use. The resulting pulp sheet is then pressed and dried to the desired moisture and basis weight. For the purpose of monitoring the sheet break process, and because the process variables affecting pulp quality occur after the machine chest unit in the production process, this thesis will focus on the process variables that occur after the machine chest. The following section describes the pulp machine in greater detail, as this is the essential component involved in making the pulp sheet and in understanding the sheet break process.
3.2 The pulp machine

The following sections describe a general pulp machine and its specific components: the headbox, press and dryer. It also discusses major operating variables directly correlated to the consistent and successful formation of a pulp sheet. Figure 3.2 shows the schematic of a typical Fourdrinier pulp machine.

3.2.1 The Headbox of the Pulp Machine

The headbox has the greatest influence on both the properties and quality of the pulp sheet produced, and as a result, ultimately affects the production efficiency of the pulp machine[14]. The headbox determines the nature of the pulp sheet because it is responsible for the uniform dispersion of fibers: pulp fibers have a natural tendency to flocculate together, so in order
to achieve uniform dispersion, the headbox uses turbulence to de-flocculate the fibers. As one might expect, there is a delicate balance in using the correct amount of turbulence. The key to successful headbox operation is to produce turbulence high enough to achieve some de-flocculation but low enough to avoid large flow disturbances in the discharge jet [14]. Consequently, it is important to have a well controlled headbox.

A well controlled headbox has many advantageous results that include the following:

1. The variability in the basis weight and moisture at the reel will be reduced. This results in higher sheet production and a saving in fibers.

2. The wet web strength will be higher (i.e. a higher strength sheet will be produced), and
since a stronger sheet is less susceptible to break, the reduction of sheet breaks will be realized.

3. Drainage of water at the wire, the couch and the presses will be better, thereby saving energy in the dryer section.

4. The first pass and overall retention will be increased and this in turn results in a reduced usage of expensive fillers, reduced effluent total solids and an improvement in the cleanliness and the stability of the system.

Since a well controlled headbox is essential for stable operation and obtaining a well formed sheet, the next section will deal with how a well controlled headbox can be achieved. Specifically, the following section discusses the effect of certain key controllable variables on headbox operation.

### 3.2.2 The Effect of Headbox Total Head

The total head, which represents the pressure in the headbox, is the process variable which controls the \( jet/wire \) ratio. The \( jet/wire \) ratio is also known as the \( rush/drag \) ratio. The relationship between total head and jet speed is governed by the well known equation:

\[
V = C_v \sqrt{2gh}
\] (3.1)
where:

\[ V = \text{jet velocity} \]

\[ g = \text{gravitational acceleration} \]

\[ h = \text{total head} \]

\[ C_v = \text{velocity coefficient} \]

The value of \( C_v \) depends on the viscosity and mass density of the stock [14]. This means that \( C_v \) is different for any given set of conditions such as, headbox consistency, filler content, stock temperature etc. From equation 3.1 one can see that as the total head within the headbox increases, the jet velocity also increases. Hence, the presence of total head fluctuations in the headbox can produce significant variations in the basis weight of the pulp sheet. This is easily demonstrated if one considers the following equation:

\[ q = C_d b V = C_d b C_v \sqrt{2gh} \quad (3.2) \]

where:

\[ q = \text{the volume of stock delivered} \]

\[ b = \text{slice opening} \]

\[ C_d = \text{discharge coefficient} \quad (C_d \text{ depends on the headbox slice opening}) \]

In summary, equation 3.2 shows that pressure fluctuations in the headbox will produce significant variations in the flow rate of fibers from the slice opening, and hence cause variations in the basis weight of the sheet. As a result, a well controlled headbox must
strictly monitor the total head.

### 3.2.3 The Effect of Headbox Consistency

In addition to total head, another important variable that affects sheet formation is headbox consistency. Headbox consistency, which is a measure of the consistency of stock flowing to the wire, is dependant upon the amount of fiber flowing from the fan pump to the headbox. The headbox consistency and slice opening are inversely proportional: when the headbox consistency is low, the slice opening is high in order to allow the correct amount of flow to the wire—thus providing the proper basis weight. The headbox consistency is usually run as low as possible because this decreases the chance of flocculation; however, allowing the headbox consistency to run too low causes jet instability and hence affects basis weight uniformity. Therefore, it is very important to have a well controlled and correct headbox consistency in order to obtain a well formed sheet. The reader is referred to Locke (1966), Blomberg et al. (1975), Dahl et al. (1975), and Rempel (1977) for further information on the principles behind selecting the correct headbox consistency for different types of headboxes [18, 4, 9, 25].
3.2.4 The Effect of the Rectifier Roll

After attaining the correct headbox total head and headbox consistency, the pulp is evened out by the rectifier roll before it is distributed to the wire. The rectifier roll within the headbox has two functions: it evens out any disturbances coming in with the stock flow, and it induces turbulence in the stock as it passes out through the slice in order to prevent flocculation [14]. The two major operating variables for the rectifier roll are the speed and direction of rotation.

Theoretically, the roll speed should match the velocity of the fiber suspension in the headbox [18]. If the speed is too high it causes unnecessary disturbances on the wire; if the speed is too low, poor fibre dispersion occurs. Rocheleau (1965) showed how varying the roll speed independently caused variations in the machine direction and cross machine direction of the pulp sheet [26]. Thus, it is important to control machine roll speed to ensure uniform quality throughout the pulp sheet.

The direction of rotation of the rectifier roll is normally in the direction of the flow of fiber. Rocheleau found, however, that if there are great disturbances coming through the fiber distribution system, changing the direction of rotation (so that it would be opposite that of the flow) could produce a force dampening the disturbances in the fiber distribution system [18]. Consequently, the direction of rectifier roll rotation could prove to be another important factor in preventing disturbances in pulp sheet quality.
3.2.5 The Slice Setting

The function of the slice is to take stock delivered by the headbox at high static head and low velocity, and subsequently accelerate and deliver it to the wire at high velocity [18]. Mardon \textit{et al.\,(1969)}, Bubick \textit{et al.\,(1979)}, Muller \textit{et al.\,(1957)}, Nelson (1960), Attwood (1967), and Cole (1958) have proven that final sheet properties are highly dependent upon the headbox slice setting [19, 7, 20, 22, 2, 8]. It is therefore important that headbox slice variables such as the jet and impingement angles are set correctly and well controlled to allow optimal sheet formation and uniform basis weight.

3.2.6 The Press and Dryer Section of the Pulp Machine

After the pulp sheet is formed on the wire, it passes through a series of presses in order to reduce the moisture content of the sheet. The major operating variables that are controlled are rotational speed and loading of the presses. If the rotational speed is too high, the sheet will tear; but if it is too low, the sheet will crush. The loading of the presses occur in multiple stages of gradually increased loading, thus allowing the pulp sheet to be incrementally dried and simultaneously strengthened. Consequently, rotational speed and loading of the presses are operating variables that need to be controlled to maintain the integrity and strength of the pulp sheet.
With respect to the mechanics of the loading process, applying the appropriate loading to the different presses squeezes water out of the sheet. Pressing occurs in stages because as water is squeezed out by the first press the sheet becomes less porous, and as a result, more pressure needs to be applied to the subsequent presses for further water removal [10]. Thus, water is first squeezed out of large structure pores in the pulp sheet, and then extracted from within the actual fibers. After sufficient water has been squeezed out, the pulp sheet then goes into the dryer.

Drying is done using steam and also occurs in stages. In the initial stages, water is evaporated out of the sheet, and the moisture content consequently decreases linearly as a function of time [10]. This phase is followed by a second period where the drying rate is a decreasing function of moisture. The first phase of drying corresponds to the evaporation of water from the fiber interpores, whereas the second phase corresponds to the evaporation of water from fiber lumens and capillaries.

In summary, section 3.2 has looked at the roles of the headbox, presses, and dryer in sheet formation. It has also discussed major operating variables highly correlated with the consistent and successful formation of a pulp sheet. Now that sheet formation and the drying process has been discussed, it is necessary to look at those stages of operation where sheet breaks most commonly occur.
3.3 Distribution of Sheet Breaks

Figure 3.3 is an example of how sheet break occurrence is recorded, and represents the incidence of sheet breaks from October 1, 1994 to December 31, 1994. A sheet break indicator of "1" shows that the pulp machine is operating without a sheet break, whereas a "0" indicates that machine operation has ceased because of a sheet break or a scheduled shutdown. Figure 3.4 shows a distribution of 139 sheet breaks according to location of the
break, which was recorded by Weyerhaeuser operating personnel from January 2, 1992 to Dec 1, 1995. It should be noted that, this record does not reflect all the sheet breaks for those years, but only those recorded by operating personnel with the location of break specified.

According to Weyerhaeuser pulp mill personnel in Grande Prairie, a common place for sheet breaks is in the top three decks of the dryer. This is supported by figure 3.4, which demonstrates that sheet breaks in the dryer occurred 81 times in the given time period, thus
corresponding to 61% of all sheet breaks. Even though the strength of a sheet is dependent on the way it is processed before entering the dryer, a break often occurs because the sheet remains free-wheeling in the dryer. In this unsupported state, the pulp sheet is often too weak to withstand the tension exerted when the sheet is pulled within the dryer. In addition to this lack of strength, other causes of sheet breaks in the dryer include:

1. Retained pulp piece in the dryer. After each sheet break, the dryer is cleaned. Sometimes, however, a piece of broken sheet may be overlooked and left in the dryer, which in turn, can cause another sheet break as a new sheet passes through.

2. Widened pulp sheet. During the formation process, the sheet may become too wide, and as a result, get stuck in the dryer, causing the sheet to crush and eventually break.

3. Incorrect dryer inlet and outlet tension. Due to wrong input values for tension, the sheet can potentially crush or tear.

4. Incorrect speed. When an operator increases the speed of the pulp machine, he will adjust the dryer so that it also speeds up accordingly. Sometimes, however, the correct dryer speed is not attained quickly enough.

5. Oscillations in sheet profile. When the operators are making frequent profile adjustments (for example, basis weight valve adjustments), the dryer may not be able to adjust
quickly enough.

6. Equipment failure. Blow boxes that are responsible for blowing hot air on the sheet may fail at times. In addition, sometimes the drives that push the sheet forward fail and get stuck.

Figure 3.4 also illustrates that sheet breaks occurred 38 times in the couch, which corresponds to 13% of all sheet breaks. The couch is responsible for both pulling and lifting the pulp sheet from the Fourdrinier table. When the pulp sheet is pulled too hard, the sheet will tear; furthermore, if the sheet is not pulled and lifted high enough, it will sag and break. Other reported causes for the breaks at the couch include:

1. Power loss to the breaker which drives the couch.

2. Production rate change.

3. Sheet snap during start up due to a weak sheet.

In addition to sheet breaks occurring in the dryer and the couch, the press section had a record of 18 breaks, which accounts for 8% of total sheet breaks. Sheet breaks at the press section are primarily due to inappropriate loading on the presses. Moreover, excessive wear or damage to the felt on the presses can also cause sheet breaks. Two sheet breaks were also
reported on the wire. These were secondary to malfunction of equipment that was responsible for guiding the pulp on to the wire.

3.4 Analysis of Variables Associated with Sheet Breaks

As previous sections have alluded to, sheet breaks can be caused by many variables, and may also result from the contribution of several factors simultaneously. Consequently, in order to avoid sheet breaks during the complex process of sheet formation, more than 140 potential variables can be measured. Examples of some significant variables being measured and monitored in relation to sheet breaks are listed in table 3.1. For further information, appendix A includes a more detailed list of all the measurement variables used in monitoring the pulp machine.

Following is an example using real data that illustrates how headbox consistency (table 3.4) affects the quality of the pulp sheet, and ultimately, its propensity to break. Figure 3.5 is an example of real process data taken on January 1, 1995, between 8:00 A.M. and 10:00 P.M., from the Weyerhaeuser Grande Prairie pulp mill. Figure 3.5 shows a decline in headbox consistency 3 hours prior to sheet break. In order to correct this, the consistency was increased 1 hour before the sheet break. As discussed in section 3.2.1, the headbox has a great influence on the quality of the pulp, and this is evident as one takes a look at figure
Table 3.1: Summary of some variables measured

<table>
<thead>
<tr>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headbox level</td>
</tr>
<tr>
<td>Headbox pressure</td>
</tr>
<tr>
<td>Headbox consistency</td>
</tr>
<tr>
<td>rush/drag ratio</td>
</tr>
<tr>
<td>Vacuum under the Fourdrinier Table</td>
</tr>
<tr>
<td>Press loadings</td>
</tr>
<tr>
<td>Couch Amps</td>
</tr>
<tr>
<td>Dryer inlet and outlet tensions</td>
</tr>
<tr>
<td>Dryer steam pressure</td>
</tr>
<tr>
<td>Steam use/dryer temperature ratio</td>
</tr>
<tr>
<td>Steam use/pulp ratio</td>
</tr>
<tr>
<td>Sheet width</td>
</tr>
<tr>
<td>Moisture profile of the sheet</td>
</tr>
</tbody>
</table>
3.6, which shows that fluctuations in consistency result in variations of the basis weight. Thus, fluctuations in headbox consistency, with consequent variations in basis weight and pulp quality, may well have been one of the contributing causes of sheet break on the tenth hour of operation. Chapter 5 will discuss any remedial actions that should be taken.

There are several vacuum boxes under the Fourdrinier table that are responsible for sucking water out of a pulp sheet. Figure 3.7 shows measurements from one of the vacuum boxes during a 12 hour period from October 26 to October 27, 1994. Figure 3.8 details the
Figure 3.6: Basis Weight Profile Before and After a Sheet Break
Figure 3.7: Vacuum Level Before and After a Sheet Break
moisture levels of the pulp sheet at different positions in time. Combining Figure 3.7 and figure 3.8, it can be seen that at time $t=7$ to time $t=9$ the level of vacuum declines, resulting in insufficient water removal from the sheet, and this ultimately causes the sheet to break. The recommendations to this problem are stated in chapter 5.
3.5 Conclusions

This chapter discussed the pulp production process and the key components of the pulp machine. It also explained the importance of a well controlled headbox and discussed how major operating variables affect the formation of a pulp sheet. Distribution of sheet break location, and the associated factors that influence sheet break formation, were also detailed. Lastly, this chapter also provided a summary of the many variables that can potentially cause sheet breaks.

The pulp production process is complex because the consistent and successful formation of a pulp sheet depends on many variables. Consequently, operators face a huge challenge in monitoring the many variables that are required for proper process function. Thus, the next chapter will focus on multivariate statistical modeling of sheet breaks and will discuss how the large amount of process data can be compressed into manageable and useful information.
Chapter 4

Pulp Machine Monitoring Using Multivariate Statistical Techniques

4.1 Introduction

In attempting to prevent sheet breaks, operating personnel are only able to monitor a few variables which include, for example, vacuum swing, headbox control variation, pulp quality, basis weight and steam quality. In spite of this, there are more than 100 other variables recorded on-line that may also play important roles in causing sheet breaks. Furthermore, the complexity of monitoring is compounded by the fact that variables may not be singularly
associated with sheet breaks, but rather, when taken in combination with other variables, only then be highly correlated with the occurrence of sheet breaks.

Because multivariate statistical techniques like PCA and PLS are capable of compressing tremendous amounts of data into low dimensional spaces while retaining most of the information [16], PCA and PLS can be used to investigate, monitor and model the complexity of variables which should be given more attention in preventing sheet breaks. This chapter presents the mathematical and algorithmic details of Principal Component Analysis (PCA) and Partial Least Squares (PLS), and specifically discusses how PCA can be used for monitoring pulp machine operation, and how PLS can be used for modeling the sheet break process. In addition, PLS is used to identify the extent to which each variable is associated with sheet breaks, while PCA analysis is used to define a region of "healthy" machine operation.

### 4.2 Principal Component Analysis

Principal Component Analysis (PCA) deals with the analysis of one data matrix $X$, with the goal of forming orthogonal variables which are linear composites of the original variables. If the original variables are correlated, it is possible to summarize the variability present in the parameters in terms of a lower subspace. The variability in the lower subspace is then represented by a few new variables, or principal components.
Consider a mean centered and scaled data matrix $X$ consisting of $n$ variables. The number of observation in each one of them is $m$.

$$X_{m \times n} \rightarrow [x_1 \mid x_2 \mid ... \mid x_n]$$

PCA relies upon eigenvector decomposition of the covariance matrix, which is defined as:

$$\text{cov} x = \frac{X^T X}{m - 1}$$

(4.1)

The objective of PCA is to find a linear combination of the $X$ variables that has the maximum variance compared to all other possible linear combinations. PCA decomposes $X$ as the sum of the outer product of vectors $t_i$ and $p_i$ plus a residual matrix $E$:

$$X = t_1 p_1^T + t_2 p_2^T + ... + t_k p_k^T + E$$

(4.2)

where $k$ is less than or equal to the smallest dimension of $X$, i.e. $k \leq \min(m, n)$. The $t_i$ vectors are known as scores and contain information of how the samples relate to each other. The $p_i$ vectors are known as loadings and contain information of how the variables relate to each other. The individual $p_i$ are the eigenvectors of the covariance matrix $X^T X$.

Following is the NIPALS algorithm for decomposing $X$ [6].

1. take a vector $x_j$ from $X$ and call it $t_i$

$$t_i = x_j$$

(4.3)

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2. calculate $p'_i$

$$p'_i = \frac{t_i X}{t'_i t_i}$$

(4.4)

3. normalize $p'_i$ to length 1

$$p'_{i_{new}} = \frac{p'_{old}}{\|p'_{old}\|}$$

(4.5)

4. calculate $t_i$

$$t_i = \frac{X p_h}{p'_h p_h}$$

(4.6)

5. compare the $t_i$ used in step 2 with that obtained in step 4. If they are the same stop the iteration; if they differ, go to step 2.

It is useful to plot projections of data onto eigenvectors, a process referred to as score plotting, for the purpose of showing relationships between data points. Consequently, PCA score plotting can be used for pattern recognition and as a sample classification technique [28]. Figure 4.1 shows an example of a score plot: during “healthy” machine operating conditions, the samples cluster in one region, while during a fault, the samples fall outside the region.

Loadings plots are plots of the eigenvectors themselves and show the relationship between the original variables in the data set. Figure 4.2 shows a loadings plot, and is an example of how correlation among variables can be readily observed in these plots. Specifically,
Figure 4.1: A Sample Score Plot
figure 4.2 depicts how measurements from the couch, vacuum boxes under the fourdrinier, and blade unfoil vacuum cluster together. On the loadings plot, one can observe that all variables sharing the same information content tend to cluster together; such clusters of variables usually dominate different PCA dimensions.

It is common to use loadings plots as a method for fault isolation [17]. Though loadings plots do not provide an answer regarding the source of the fault, they definitely provide an initial starting point for detecting possible causes. An expert system can be used at this stage to pinpoint the exact cause of the fault and suggest corrective action.

### 4.3 Partial Least Squares

PLS connects a data matrix $X$ to a quality matrix $Y$ via a set of latent vectors that are of lower dimension than $X$ and $Y$. The PLS model can be considered as consisting of an outer relation ($X$ and $Y$ block individually) and an inner relation that links both blocks [6]. The outer one is a decomposition of the $X$ and $Y$ data as a sum of a series of rank 1 matrices. The outer relation for the $X$ block (see former PCA section) is:

$$X = T P' + E = \sum t_h p'_h + E \quad (4.7)$$
Figure 4.2: A Sample Loadings Plot
Similarly, one can build the outer relation for the $Y$ block:

$$Y = U Q' + F = \sum u_h q'_h + F$$ (4.8)

where $T$ and $U$ represent score matrices while $P$ and $Q$ represent loading matrices. The summation is over the number of latent variables desired. The goal of PLS is to describe $Y$ as accurately as possible by making $\|F\|$ as small as possible, and at the same time obtain a useful relationship between $X$ and $Y$. The inner relation links the $X$ and $Y$ matrices through their scores by a linear regression of $t_h$ on $u_h$ such that

$$\hat{u}_h = b_h t_h$$ (4.9)

and

$$b_h = \frac{\hat{u}_h t_h}{t'_h t_h}$$ (4.10)

This leads to the mixed relation:

$$Y = T B Q' + F$$ (4.11)

After the required number of dimensions are extracted, $F$ and $E$ contain irrelevant information such as noise and redundancies.

In summary, the PLS algorithm is as follows [6]:

1. For each component take $v_{start} = \text{some } y_j$
2. In the $X$ block:

$$w' = \frac{u' X}{u' u} \quad (4.12)$$

$$w'_{new} = \frac{w'_{old}}{||w'_{old}||} \text{(normalization)} \quad (4.13)$$

$$t = \frac{X w}{w' w} \quad (4.14)$$

3. In the $Y$ block:

$$q' = \frac{t' X}{t' t} \quad (4.15)$$

$$q'_{new} = \frac{q'_{old}}{||q'_{old}||} \text{(normalization)} \quad (4.16)$$

$$u = \frac{X q}{q' q} \quad (4.17)$$

4. Compare $t$ in step 4 with the one from the preceding iteration. If they are equal (within a predefined tolerance) go to step 9, else go to step 2. If $Y$ consists of only one variable, steps 5 to 8 can be omitted by putting $q = 1$, and no more iteration is necessary.

5. Calculate the $X$ loadings and rescale the scores and weights accordingly:

$$p' = \frac{t' X}{t' t} \quad (4.18)$$

$$p'_{new} = \frac{p'_{old}}{||p'_{old}||} \text{(normalization)} \quad (4.19)$$

$$t_{new} = t_{old} ||p'_{old}|| \quad (4.20)$$
\[ w'_{new} = w'_{old} \| p'_{old} \| \]  

\[ p', q' \] and \( w' \) are saved for prediction

6. Find the regression coefficient \( b \) for the inner relation:

\[ b = \frac{u' t}{t' t} \]  

(4.22)

7. Calculate the residuals of \( X \) and \( Y \) (for component \( h \) for example)

\[ E_h = E_{h-1} - t_h p'_h \]  

(4.23)

\[ F_h = F_{h-1} - b t_h q'_h \]  

(4.24)

8. Replace \( X \) and \( Y \) by \( E_h \) and \( F_h \) respectively, and proceed to step 1 for calculating the next component.

### 4.3.1 An Example of Sheet Break Modeling using PLS

In the data used in analysis for this project, \( Y \) contains an on-line recorded variable called sheet break indicator which is defined by whether or not a sheet enters into the dryer. An entry of "0" in \( Y \) indicates no sheet break, while an entry of "1" indicates a broken sheet.

PLS compresses data into a lower dimension subspace, and in the subsequent example, \( X \) is \( 100 \times 4 \) large and consists of the following variables:
<table>
<thead>
<tr>
<th>LV#</th>
<th>X-Block This LV (%)</th>
<th>Total (%)</th>
<th>Y-Block This LV (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.70</td>
<td>23.70</td>
<td>18.13</td>
<td>18.13</td>
</tr>
<tr>
<td>2</td>
<td>13.24</td>
<td>36.95</td>
<td>15.29</td>
<td>33.42</td>
</tr>
<tr>
<td>3</td>
<td>57.74</td>
<td>94.69</td>
<td>2.35</td>
<td>35.76</td>
</tr>
</tbody>
</table>

1. Dryer differential pressure
2. Dryer steam pressure
3. Dryer air temperature
4. Steam to flakt dryer temperature

In addition, the Y quality matrix is $100 \times 1$ large and represents sheet break. Figure 4.3 shows 100 samples of each of the process variables in X. PLS regression results are summarized in table 4.1.

As the three variables in table 4.1 are highly correlated, they can be easily compressed into one single variable. The results indeed demonstrate that, in this particular example, two components or latent variables are adequate for modeling. The third variable only shows

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Figure 4.3: Measurement Data From the Dryer
a slight improvement in the variance captured while predicting \( Y \); since variance captured in \( X \) is not the focus of PLS, only the two latent variables that capture the most variance in predicting \( Y \) are used for modeling. It should be noted that since this example was only limited to four input variables, the variance captured in predicting \( Y \) is low. The variance captured would be increased if more input variables were used. Figure 4.4 shows the regression vector that was calculated and used for predicting \( Y \). By looking at the regression vector one can see which variables are important in the prediction. Of note, figure 4.4 shows that the dryer steam pressure contributed the most to sheet break prediction. The actual prediction of sheet break using the two latent variables instead of the four process variables is shown in figure 4.5. Most importantly, it demonstrates that the PLS model was able to predict the sheet break that occurred after 67 hours of operation.

4.4 Data Treatment

Although the pulping process potentially involves a lot of processing parameters, most of the pulp quality variables are controlled at a prescribed setpoint and measured at the machine chest. Therefore, \( X \) contains most of the variables measured at and after the machine chest. In selecting the variables for the PLS model, 38 basis weight pin measurements and 38 moisture pin measurements were omitted from the input data matrix. The reason for this is
Figure 4.4: Regression Vector For Sheet Break Prediction Using only 4 process variables
Figure 4.5: Example of Sheet Break Prediction
that these variables are measured after the sheet has gone through the dryer, while the sheet break indicator is a measurement of whether or not the sheet enters the dryer. After a sheet break occurs, the basis weight and moisture measurement is zero because the scanner scans a non-existent sheet. Therefore, these variables are indicators that sheet break has occurred but cannot be used as predictors. In order to prove that the 76 basis weight and moisture measurements are not true inputs to the model, PLS analysis has been done using these 76 variables to try and predict sheet break. Figure 4.6 shows the regression vector for this model of which the first 38 inputs are basis weight measurements and the last 38 inputs are moisture pin measurements. As expected, it shows falsely that all the variables are equally important in predicting sheet break and that moisture content has a positive relationship to sheet break, whereas basis weight has a negative relationship.

After the removal of the 76 variables, a total of 43 variables were used to model sheet breaks. Data were collected every hour. Consequently, the $X$ matrix was 3180 by 43 large and consisted of scaled process variables collected from the last quarter of 1996. Appendix B shows the arrangement of the variables in $X$.

Each time a break occurs, the pulp machine is shut down, and hence a lot of process variables vary greatly as an effect of sheet break. These variables are simply affected by sheet break and are not indicators of imminent sheet break. PLS analysis was done at first by ignoring this fact and it was found that PLS would try to fit the variance in $X$ with that
Figure 4.6: PLS Regression Using Basis Weight and Moisture Measurements
Table 4.2: Percent Variance Captured by PLS Model Without Pre-treatment of Data

<table>
<thead>
<tr>
<th>LV#</th>
<th>X-Block</th>
<th>—</th>
<th>Y-Block</th>
<th>—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This LV</td>
<td>Total</td>
<td>This LV</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>65.40</td>
<td>65.40</td>
<td>82.71</td>
<td>82.71</td>
</tr>
<tr>
<td>2</td>
<td>4.71</td>
<td>70.12</td>
<td>7.23</td>
<td>89.94</td>
</tr>
<tr>
<td>3</td>
<td>4.09</td>
<td>74.20</td>
<td>2.73</td>
<td>92.67</td>
</tr>
<tr>
<td>4</td>
<td>2.96</td>
<td>77.16</td>
<td>0.42</td>
<td>93.08</td>
</tr>
<tr>
<td>5</td>
<td>1.65</td>
<td>78.81</td>
<td>0.26</td>
<td>93.35</td>
</tr>
</tbody>
</table>

of $Y$ and would pick out variables that contain large variances. This would give a false impression of which variables actually predict sheet break. This issue is also known as the causality issue. The results of this first PLS analysis without pre-treatment of the data are summarized in table 4.2 below.

Since there was no significant improvement (table 4.2) in predictive power with more than three latent variables, the final PLS model was built using three latent variables. The resulting regression vector is shown in figure 4.7. It is evident from this figure that the variables concerning the press loadings seemed to be most indicative of sheet break. The reason for this is that during the break, the machine is shut down, and the press loadings and speed
Figure 4.7: Regression Vector Resulting From No Pre-treatment of Data
decreased. Therefore, this analysis showed falsely that the operation of the presses are most predictive of sheet breaks. As shown in figure 4.8, when this PLS model was used to predict sheet breaks in another data set, all occurrences of sheet breaks were correctly calculated. Realistically, however, it is impossible to predict all sheet breaks—especially those caused by sudden mechanical failure of equipment. Thus, in order to find out which variables are actual predictors of sheet break, data were pre-treated in a very unique way, which is described in the following.

All the data at and during sheet break were changed and given values of their setpoint. Since the primary interest is in data leading up to the sheet break—and not at or during sheet break—this treatment of the data takes care of the causality issue. If the data were not pre-treated in this way, PLS would pick up all the variables that co-vary simultaneously with the sheet break indicator and mistakenly report that those variables are reliable predictors. The reason for this is that PLS finds latent variables that are descriptive of predictor variable variance and also correlated with the predicted variable [27].

4.5 PLS Modeling

After pre-treating the data as outlined previously, PLS analysis was repeated for the new data set. The results of the PLS analysis are detailed in table 4.3: it can be seen that three
Figure 4.8: Prediction Resulting From No Pre-treatment of Data
latent vectors are sufficient to explain 60.13% of the output matrix; four latent vectors, on the other hand, only resulted in a slight improvement of 63.74% in modeling. Thus, because this improvement is not significant, only three latent vectors are used for predicting $Y$.

By plotting the regression vector, as in figure 4.9, one can see which variables are important in predicting sheet breaks. The variables that are most predictive of sheet breaks have been consequently elucidated using PLS and are summarized in table 4.4. Because these particular variables—lumpbreaker loadings, dryer steam pressure, and the dryer differential pressure—have not been intuitively obvious to operating personnel, PLS modeling has significantly shed light on understanding the breaks process.

In an attempt to understand why lumpbreaker loading is such an important variable in sheet breaks, as determined from regression vector analysis, figure 4.10 shows the dynamics of the back side and tension side loading of the press and its association with sheet break occurrence. In addition the figure also shows the occurrence of sheet break during the same period. It can be hypothesized that when there is a significant difference in back side and tension side loadings, water removal from a wet sheet is not optimal, ultimately affecting the rest of the pulp production process and increasing the probability of sheet breaks.

As noted in table 4.4, two other major variables associated with increased incidence of sheet breaks include the dryer differential pressure and the dryer steam pressure. Figure 4.11 shows the heavy fluctuations that occurred in the dryer differential pressure and dryer steam
Table 4.3: Percent Variance Captured by PLS Model With Pre-treatment of Data

<table>
<thead>
<tr>
<th>LV# (%)</th>
<th>X-Block</th>
<th>—</th>
<th>Y-Block</th>
<th>—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This LV (%)</td>
<td>Total (%)</td>
<td>This LV (%)</td>
<td>Total (%)</td>
</tr>
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<td>3.88</td>
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<td>60.13</td>
</tr>
<tr>
<td>4</td>
<td>7.82</td>
<td>24.94</td>
<td>3.62</td>
<td>63.74</td>
</tr>
<tr>
<td>5</td>
<td>4.50</td>
<td>29.52</td>
<td>3.54</td>
<td>67.28</td>
</tr>
<tr>
<td>6</td>
<td>4.85</td>
<td>34.38</td>
<td>1.89</td>
<td>69.17</td>
</tr>
</tbody>
</table>

Table 4.4: Summary of variables contributing to sheet break

<table>
<thead>
<tr>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>The lumpbreaker loadings</td>
</tr>
<tr>
<td>The dryer steam pressure</td>
</tr>
<tr>
<td>The dryer differential pressure</td>
</tr>
</tbody>
</table>
Figure 4.9: Regression Coefficients in Final Model with 3 LV
Figure 4.10: Dynamics of B.S. and T.S. Lumpbreaker Loading
pressure along with the occurrence of sheet break during the same period. By comparing the two figures, it can be observed that prior to a sheet break, there are heavy fluctuations in the dryer steam pressure and differential pressure. Fluctuations in these pressures in turn cause the temperature within the dryer to fluctuate. The consequent unstable operation of the dryer may be one explanation of why most sheet breaks occur in the dryer section (cross reference section 3.3).

4.5.1 Testing of the PLS model

After the PLS model was developed, it was tested on a different set of data which is plotted in figure 4.12. Figure 4.13 shows the prediction of sheet breaks in this test set using the PLS model. It should be noted that the predicted values for sheet break have been scaled to fall between one and zero. Most importantly, out of the 12 sheet breaks that actually occurred, the PLS model only failed to predict the one sheet break that occurred at t=37 hours. The reason for this may be that the dryer steam pressure start dropping after the 30th hour, but the dryer differential pressure and lumpbreaker loadings remain the same. Figure 4.14 illustrates how the decline in steam pressure may be the cause of the sheet break on the 37th hour of operation.

The model also predicted five potential sheet breaks at t=385, 398, 498, 1074, and 1381
Figure 4.11: Dynamics of pressures within the dryer
Figure 4.12: Raw Data Used in Testing the PLS Model
Figure 4.13: Estimated and Predicted Break using PLS model
Figure 4.14: Decline in Steam Pressure Causing Sheet Break
hours; although figure 4.13 does not show any actual breaks occurring at these times, the PLS model may still be performing acceptably. A possible explanation for apparent false positives could be that operators may have noticed a problem and implemented corrective actions in order to prevent sheet break occurrence.

In summary, the PLS modeling of the sheet break process accurately predicted 11 out of 12 sheet breaks in the test data set, which is different from the data set used to construct the model. In addition, the PLS model had five apparent false positive predictions of sheet breaks, which may be secondary to operator correction of problems. Thus, from this test data set, PLS accurately predicted 92% of sheet breaks and had 42% false-alarming.

4.5.2 PLS Modeling Using Lagged Data

The data used for calibration and building of the first model was modified, in order to confirm that the “causality issue” was dealt with and that the previously mentioned variables are indeed the major contributors to sheet break. The first modification was as follows: the calibration data set was first lagged by one hour (i.e. the first row of $X$ and the last row of $Y$ were deleted) and a new PLS model was built in order to see if the variables that contributed most to sheet break were the same. Table 4.5 shows the results of using this new calibration set. As expected, the first 3 latent vectors described 53.47% of the output matrix, which is less than
using the original calibration set. However, by analyzing the regression vector, figure 4.15, one can observe that the dryer steam pressure, differential pressure and lumpbreaker loadings were, again, the variables that contributed most to sheet break. In addition, the vector also shows that couch roll vacuum is a significant contributor to sheet break. Figure 4.16 shows the dynamics of the couch roll vacuum in the original data set. This variable fluctuates a lot as well, and may well be another major contributor to sheet break. The newly developed model was tested on the same test data set as the normal PLS model was (see previous section), and figure 4.17 shows that the model developed using the lag model predicts sheet break quite accurately. Once again, the predicted values for sheet break have been scaled to fall between one and zero.

The second modification was similar to the previous one, but this time the calibration data set was lagged by two hours and a new PLS model was built in order to see if the variables that contributed most to sheet break were the same. Table 4.6 shows the results of using this new 2 hour lagged calibration set. Because the data is lagged significantly and is therefore less precise, the first 3 latent vectors describe even less of the output matrix, namely 46.19%. However, by plotting the regression vector, figure 4.18, one can observe that the dryer steam pressure, differential pressure, lumpbreaker loadings and couch roll vacuum were again the variables that contributed most to sheet break. The newly developed model was tested again on the same test data set as the normal PLS model was (see previous section), and figure 4.19
Table 4.5: Percent Variance Captured by PLS Model With Pre-treatment of Data

<table>
<thead>
<tr>
<th>LV#</th>
<th>X-Block</th>
<th>Y-Block</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This LV (%)</td>
<td>Total (%)</td>
</tr>
<tr>
<td>1</td>
<td>8.26</td>
<td>8.26</td>
</tr>
<tr>
<td>2</td>
<td>5.00</td>
<td>13.26</td>
</tr>
<tr>
<td>3</td>
<td>4.07</td>
<td>17.33</td>
</tr>
<tr>
<td>4</td>
<td>7.62</td>
<td>24.96</td>
</tr>
<tr>
<td>5</td>
<td>5.17</td>
<td>30.12</td>
</tr>
<tr>
<td>6</td>
<td>4.97</td>
<td>35.09</td>
</tr>
</tbody>
</table>
Figure 4.15: Regression Vector for PLS Model Using 1 Hour Lagged Data
Figure 4.16: Dynamics of the Couch Roll Vacuum
Figure 4.17: Prediction of Sheet break Using Model Developed for 1 Hour Lagged Data
Table 4.6: Percent Variance Captured by PLS Model With Pre-treatment of Data

<table>
<thead>
<tr>
<th>LV#</th>
<th>X-Block This LV (%)</th>
<th>Total (%)</th>
<th>Y-Block This LV (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.72</td>
<td>8.72</td>
<td>24.64</td>
<td>24.64</td>
</tr>
<tr>
<td>2</td>
<td>4.59</td>
<td>13.31</td>
<td>14.59</td>
<td>39.23</td>
</tr>
<tr>
<td>3</td>
<td>4.39</td>
<td>17.71</td>
<td>6.96</td>
<td>46.19</td>
</tr>
</tbody>
</table>

shows that the model developed using the lag model also predicts sheet break quite accurately.

The whole procedure was repeated again with time lag of 3 hours in the calibration data set. As expected, the variance explained became less and the variables that were considered as significant predictors of sheet break were consistently the same. Therefore, these tests show that the “causality issue” was indeed adequately dealt with, as the results remained consistent. It should be noted that there could be some hidden dynamics that are not accounted for in the PLS model, since the data used in developing the model was collected hourly. Because data at her higher frequency is lacking, a thorough study of the behavior of the system could be studied at this time.
Figure 4.18: Regression Vector for PLS Model Using 2 Hour Lagged Data
Figure 4.19: Prediction of Sheet break Using Model Developed for 2 Hour Lagged Data
4.6 PCA Monitoring

PCA is similar to PLS because both rely on a decomposition of the predictor variables. Since PCA only deals with the analysis of one data matrix \( X \) (refer to section 4.2), this decomposition is based on variance–rather than covariance–criteria [27]. In other words, PCA uses parameters that are descriptive of variance only in the predictor variables.

The purpose of using PCA for monitoring pulp production is to detect abnormalities in process variables and to subsequently use an expert system to correct abnormalities before a sheet break occurs. Of note, the primary objective is to monitor process variables and not the sheet break indicator because, after all, when a sheet break occurs, nothing can be done in terms of prevention. Currently, there are no systems in place that adequately monitor abnormalities that the pulp production process may trend toward, and as a result, PCA may be appropriately employed to perform process monitoring.

The PCA model uses 10 principal components and is consequently able to capture 59.10% of the variance within the input matrix; as expected, PCA does not explain as much of the variance when compared to PLS, since PLS also incorporates information from the \( Y \) matrix into the \( X \) matrix. Table 4.7 summarizes the results from PCA monitoring, and illustrates that the variance captured does not increase significantly after the tenth component. In fact, by solely plotting the scores of the first two principal components, a well defined region of
“machine health” is already obtained (figure 4.20).

Figure 4.20 is a score plot with two clusters of data: the first cluster represents normal operating conditions that were obtained using an ideal data set, depicted by “o”, to calibrate and map out a region of normal operation. PCA was then used to monitor a second set of test data, depicted by a “+”, and subsequently was able to pick up nine out of twelve sheet breaks. Figure 4.20 shows “+” outside the “healthy” region during the down-times that were caused by sheet break. The three sheet breaks which the model was unable to pick up occurred at t=93, 218 and 1321 hours, and the explanation for this is that the process variables at those particular times still fell into the healthy region of operation. However, equipment failure may have caused a sudden sheet break.
Table 4.7: Percent Variance Captured by PCA Model

<table>
<thead>
<tr>
<th>Principal component</th>
<th>% variance captured</th>
<th>% variance captured total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.98</td>
<td>12.98</td>
</tr>
<tr>
<td>2</td>
<td>10.29</td>
<td>23.27</td>
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<tr>
<td>3</td>
<td>7.30</td>
<td>30.57</td>
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<td>4</td>
<td>6.40</td>
<td>36.97</td>
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<td>5</td>
<td>4.61</td>
<td>41.58</td>
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<td>6</td>
<td>3.92</td>
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<td>7</td>
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<td>9</td>
<td>3.41</td>
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<tr>
<td>10</td>
<td>3.11</td>
<td>59.10</td>
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<td>11</td>
<td>2.87</td>
<td>61.97</td>
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<tr>
<td>12</td>
<td>2.66</td>
<td>64.63</td>
</tr>
<tr>
<td>13</td>
<td>2.58</td>
<td>67.21</td>
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<tr>
<td>14</td>
<td>2.29</td>
<td>69.50</td>
</tr>
<tr>
<td>15</td>
<td>2.20</td>
<td>71.70</td>
</tr>
</tbody>
</table>
Figure 4.20: Scores on First two PCs for Old (o) and New (+) Data
4.7 Conclusions

This chapter presented the mathematical and algorithmic details of Partial Least Squares and Principal Component Analysis (PCA). It also specifically discussed how PLS can be used for modeling the sheet break process, and how PCA can be used for monitoring pulp machine operation. In addition, PLS was used to identify those variables which contributed most to sheet breaks in this particular mill-lumpbreaker loadings, dryer steam pressure and dryer differential pressure—and subsequently accurately predicted 92% of sheet breaks with a 42% false-alarming rate. PCA analysis was also used to define a healthy machine operating region and subsequent tests using the model confirmed that when sheet breaks occurred, the scores indeed fell out of the healthy region.

The knowledge revealed by PLS analysis regarding key variables that cause sheet break, and the results obtained from PCA monitoring regarding the definition of healthy machine operation can be incorporated and integrated into an expert system. The next chapter, therefore, will focus on the details of such an expert system.
Chapter 5

Expert System for Pulp Machine Monitoring

5.1 Introduction

After developing a model of the pulp production process using PCA, and by showing how PCA can be used for monitoring pulp machine operation, it is possible to develop an expert system that monitors, trouble shoots, and ultimately prevents the sheet break process. Figure 5.1 shows how PCA and an expert system would work together in order to solve the problem of sheet breaks. PCA is used to monitor all variables that are measured, whereas the expert
system uses the PCA results in addition to information entered by the operator regarding observable properties to monitor the process and trouble shoot problems. Any suggestions for improvement of the process are made by the expert system and implemented by an operator. This chapter discusses knowledge regarding the breaks process and how this can be organized and incorporated into rules for specific sections of the pulp machine. Subsequently, these rules are incorporated into an expert system shell that is designed to trouble shoot the pulp production process when it trends away from a region of healthy operation. An explanation is provided of how the expert system diagnoses problems and then suggests appropriate interventions. This chapter concludes with specific examples of expert system diagnostics.
5.2 Knowledge Base Development

Plant operating personnel were interviewed in order to collect knowledge regarding the prevention of sheet breaks. Specifically, each person interviewed was asked two sets of questions: the first set pertained to how the process could go wrong with a certain piece of equipment, and how this would make a sheet more susceptible to a break; the second set reviewed the practical interventions that could be done to prevent a certain fault from occurring. As discussed in previous chapters, the area of the pulp production process focused upon involved equipment that included the headbox, wire, presses, felts, dryer, and the steam hood (see figure 5.2).
5.2.1 Collection of Knowledge on the Headbox

As mentioned in Chapter 3, the headbox has the greatest influence on the properties and the quality of the sheet that is being produced. Problems specific to the headbox, described in the paragraphs below, include incorrect headbox pressure, incorrect headbox level, fluctuating headbox consistency, air leaks, improper rush/drag ratio, plugged slice lip, faulty actuaor setting, and incorrect rectifier roll setting.

1. Incorrect headbox pressure. In this particular mill, reductions in headbox pressure during normal operation are infrequent. The primary cause for drops in headbox pressure, which occurs only on rare occasions, is when operators would open the headbox lid and forget to close it, thus resulting in pressure drop. For the most part, however, the headbox pressure was well controlled.

2. Incorrect headbox level. The headbox level is also another well-controlled variable and did not cause major upsets. In the instances that the headbox level would fluctuate, it was found that the sensor had failed or was improperly calibrated. Specifically, when the de-foaming showers responsible for determining the correct headbox level failed to work, the reading would be incorrect and also cause fluctuations in headbox levels.
3. Fluctuating headbox consistency. In this pulp mill, the headbox consistency was not well controlled. (See figure 5.3) When the stock from the stuff box is not well mixed because of inadequate agitation, the headbox receives stock with fluctuating consistencies, consequently causing fluctuations in headbox consistency that are strongly associated with sheet breaks. A remedy for this problem is to provide sufficient agitation of stock in the stuff box.
4. Air Leaks. Air leaks out of the headbox cause pressure pulsations that in turn affect the nature and quality of fiber mat formation. When air leaks happen, operators must find the source of leakage and repair it.

5. Improper Rush/Drag Ratio. The rush/drag ratio is currently set at a specific rate (1.02), and therefore, as discussed in Section 3.2.2, does not take into consideration changes in the viscosity and mass density of the stock. In addition, because the impact of short fibers on machine operation is not well understood, it is difficult to set an optimum rush/drag ratio that takes into account fiber length [3]. It is recommended that the control strategy be improved.

6. Plugged slice lip. A dirty and plugged slice lip will cause an uneven suspension of fiber on the wire, which in turn can cause a pulp sheet to be weak in certain spots. This problem can be remedied by proper maintenance and periodic cleaning of the slice lip.

7. Faulty actuator setting. A wet streak results when a faulty actuator setting causes an insufficient amount of fiber to be pushed out at a certain position, thus leaving a thin and weak streak of fiber in the pulp sheet. The streak is visible to operators because it has a lighter color than the rest of the pulp sheet.
8. Incorrect rectifier roll setting. The rectifier roll as described in Section 3.2.4 is responsible for smoothing out the pulp before it is distributed to the wire. If the rectifier roll is damaged or not well positioned, fiber leaks out of the headbox, and causes poor sheet formation. Problems with sheet breaks have occurred when the rectifier roll has been changed or the rotation (which in this mill is counter clock-wise to stock flow) is set incorrectly.

5.2.2 Collection of Knowledge on the Wire and its Vacuum System

The wire contains tiny pores through which water can be drained out of a pulp sheet. The vacuum system under the wire is positioned such that as the sheet moves towards the presses, increasing vacuum is applied. Problems that can arise at this point to cause improper sheet formation include dirty water, pitch buildup, damaged wire, and sticking valves.

1. Dirty water. The pores in the wire can become plugged if the water used to dilute the pulp is dirty. A solution to this problem is to analyze the water used for dilution and have a system that shuts off the supply of recycled water if it is too dirty.

2. Pitch build up. Pitch can build up on the pulp sheet (causing the sheet to crush), in the pores of the wire, and in the internal valves of the vacuum system. In order to inhibit pitch formation, it is necessary to use talcum powder which inhibits pitch formation,
and also to clean the wire regularly.

3. Damaged wire. A damaged wire can cause the pulp sheet to have holes or weaknesses at certain spots. Wire damage can be caused if the pH of the showers is too acidic; consequently, operators must ensure that the shower pH is acceptable before and during operation.

4. Sticking valves. The valves that regulate the level of vacuum can adhere to each other and thus also have to be properly maintained.

5. Drop in vacuum level. Vacuum pumps can become flooded with water and cause the level of vacuum to drop. A remedy is to monitor vacuum levels, and as the levels trend away from the norm, backup pumps can be started while flooded pumps are taken off-line for repair.

5.2.3 Collection of Knowledge on the Presses and Felts

By squeezing water out of a pulp sheet, the presses play an important role in the formation and strengthening of the sheet. Each press roll has a grooved surface that allows for water drainage, and also has a shower at its nip to wash away residual pulp. The surface of each press roll is covered by porous felt that optimizes water drainage. In addition, a vacuum box
dries the press roll felt before it goes through another rotation. Mill personnel have identified that pitch build up, old or damaged felt, incorrect press loading or alignment, old press rolls, incorrect press alignments, plugged grooves and vacuum box failure are factors that can result in weak sheet formation:

1. Pitch buildup. Felt pores can become plugged due to pitch build up, and as a result, insufficient amounts of water will drain out of one spot and can ultimately cause a hole in the pulp sheet.

2. Old felt. As felt ages, the pores become smaller and its function in water drainage is compromised. An accurate maintenance record of the felt will ensure that the felt is replaced before it causes problems.

3. Damaged felt. Felts are washed every two months with a chemical solvent. If care is not taken, the solution may be too acidic and thus damage the felt and impair its drainage properties.

4. Incorrect press loadings. As discussed in section 3.2.6, incorrect press loadings will not properly reduce moisture content, and this can increase the likelihood of the sheet to tear. To remedy this problem, press loadings must be strictly monitored.
5. Incorrect press alignments. Improper press alignments will also exert unequal loadings on the sheet and will produce a sheet that is not uniform.

6. Incorrect press speed. As discussed in section 3.2.6, if the rotational speed is too high, the sheet will tear; but if it is too low, the sheet will crush.

7. Plugged grooves. The showers at the nip can fail to operate and predispose the press roll grooves to become plugged.

8. Old press roll. When a press roll has been in use for a long time, the diameter decreases and the grooves become smaller. Consequently, water that is squeezed out has difficulty draining from the press, and is actually returned to the pulp sheet when the roll completes its rotation. Thus, as the diameter of the rolls get smaller in time, the roll needs to be replaced because its drainage function becomes impaired.

9. Vacuum box failure. If the vacuum box fails due to mechanical problems, the wet felt will weaken the pulp sheet as it returns water back onto the sheet.

5.2.4 Collection of Knowledge on the Dryer

A common place for the occurrence of sheet breaks, as previously discussed in section 3.3, is in the dryer. Variables that increase the probability of sheet breaks in the dryer include:
1. Fluctuating steam pressures. Drying is done using steam to evaporate water out of the sheet, and the evaporation rate is greatly influenced by the steam pressure used inside the drying cylinders. As the pressure of steam increases, the condensing temperature also increases to provide a higher rate of heat transfer. Needless to say, the steam pressure has to be strictly monitored and controlled to allow incremental drying and strengthening of the sheet.

2. Clutch sticking up. Whenever the dryer is shut down for repairs or after a sheet break occurs, the clutches are disengaged. Sometimes at startup, when the clutches are re-engaged, one clutch will stick out and subsequently catch or jerk a pulp sheet.

3. Reversal of flow. The motor of circulating fans in the dryer occasionally burns out. After they are replaced one needs to be careful to have the new motor rotating in the correct direction. If the direction is reversed, the sudden reversal of flow will cause a sheet to break.

4. Blow-box failure. The blow boxes are responsible for suspending a sheet as it goes through the dryer. If one blow-box fails to blow air, the sheet will fall, catch in one spot, and break.
5. Incorrect volume of air. The dryer needs a specific amount of airflow to provide enough heat exchange for drying. If the air supply is set incorrectly, the sheet will not be sufficiently dried. Therefore, the volume of air supplied to the dryer should be closely monitored.

6. Incorrect inlet and outlet tensions. The inlet and outlet tensions of the dryer are determined by the rate of pulp sheet production. In turn, tension is generated by the roll speed at the inlet and outlet of the dryer. If the roll speed is incorrect, the pulp sheet may be too weak to withstand the tension exerted when the sheet is pulled within the dryer. A solution to this problem would be to establish a set of operating conditions for inlet and outlet tension that is determined by required rate of production.

5.2.5 Collection of Knowledge on the Steamhood

The steamhood provides the source of steam for drying pulp sheets. Unless a pulp sheet is dried properly, it has an increased probability of breaking. Consequently, the following factors with respect to the steamhood must be monitored to prevent sheet breaks:

1. Condensate leakage. If the steamhood has cracks, condensate will leak out and make the pulp sheet wet. The steamhood should therefore be periodically maintained and replaced.
2. Pressure and flow sensor failures. The steam flow, as monitored by pressure and flow transmitters, needs to be accurate in order to supply the correct amount of steam to the various parts of the drying process.

3. Condensate flooding. When a shut down has occurred and insufficient time has been given to startup, the steamhood can be flooded with condensate. If the steamhood is flooded, no steam will flow out of the steamhood. It would therefore be beneficial to incorporate a standard procedure like a visual check of the steamhood before startup.

4. Inaccurate steam flow. The average sheet moisture is used for the calculation of how much steam needs to be supplied. The moisture profile, however, is obtained after the dryer and often adjustments are made too late. It would, therefore, be useful to measure the moisture content of the sheet before it enters the dryer, but currently in this mill, this value is unavailable.

5. Inappropriate steam pressures for heating. The temperature of the sheet depends on the pressure of the steam used to dry the sheet. Currently the temperature of the sheet is not being measured. Ideally the temperature of the sheet should be kept constant at an optimal temperature.

Figure 5.4 shows that the temperature of the stock that is pumped to the headbox fluctuates quite significantly, and hence the temperature of the pulp sheet is not constant.
Ideally, the steam pressure should compensate for this disturbance in order to keep the pulp sheet temperature in an optimum range for efficient drying. According to mill personnel, however, the pressure of the steam supply is currently not being adjusted, and consequently insufficient heating for drying occurs during the times when the stock temperature is low. In order to remedy this, the temperature of the pulp sheet should be measured and the steam pressure should be adjusted accordingly so that optimal drying can take place.

5.2.6 Collection of Sheet Properties and Formation

High quality material is required to produce a high quality pulp sheet. Furthermore, the rate of production of a pulp sheet is determined in part by the quality of the stock: higher quality stock/sheets are stronger, and consequently can be subjected to the greater stress that results from a faster pulp production rate. Two factors, the K number of the pulp, and the freeness of the pulp are important indicators of stock quality:

1. The K number of the pulp.

The K number provides information about the quality of a pulp sheet and the manner in which it will drain. For example, if fibers are overcooked, resulting in shorter fibers, the K number will be low. As a result, water will drain well from the pulp sheet, but
Figure 5.4: The Temperature of the Stock Pumped to the Headbox
the sheet will be weaker because of the increased amount of short fibers. Conversely, if the fibers are undercooked, resulting in longer fibers, the K number will be high, but the sheet may still be weak because water will not drain well. Consequently, there is an optimum K number that represents stock that balances an ideal mixture of long and short fibers with a superior draining quality. Currently, when this K number is not in the optimum range, operators run the pulp machine at lower rates to prevent sheet breaks that could occur from overcooked or undercooked pulp.

2. Freeness of the pulp. The freeness is dependent on the mixture of spruce and pine used in making the pulp. If the freeness of the pulp is low, the rush/drag ratio has to be reduced because the shorter fibers produce a weaker sheet.

5.3 Organization of Knowledge

The knowledge that was gathered from experienced operating personnel regarding the causes and prevention of sheet breaks, as summarized in section 5.2, can be organized into a fishbone chart that contains a hierarchy of knowledge from areas of concern down to root causes. Figure 5.5 shows the general structure of such a fishbone chart. Specifically, with reference to figure 5.5, the “equipment” branch contains detailed information about the key equipment of the pulp machine: the headbox, presses, wire, felts, dryer, vacuum system, and steamhood.
The "sheet properties" branch synthesizes all the information on stock quality. Under the "measurement" category, all information with respect to acceptable limits of process variables is stored. The "method" branch organizes information regarding standard operating procedures like, for example, "things to check before startup". Lastly, the "people" and "environment" sections are tutorials within the expert system where past experience and general knowledge about environmental issues are documented. Issues such as bad operator habits and wrong conclusions that were previously made are all documented and are used to see if any past mistakes are repeated.

5.3.1 Example of Using the Fishbone Chart

Figure 5.6 illustrates how the expert system utilizes the fishbone organization of knowledge to trace the cause of a sheet break and provide remedial solutions. When a sheet break occurs, the expert system looks for a cause by analyzing process data and then subsequently searching through the fishbone organization of knowledge. For example, if a sheet break occurs, and the operator notes that there is a "spotty" sheet, the expert system can infer from the "sheet properties" section that there is poor sheet formation. Subsequently, the expert system will analyze process data and may find that the freeness variable in this category has declined due to short fiber length. As a result, the system finally recommends an adjustment of the
Figure 5.5: A Fishbone Chart
Pulp mill has a sheetbreak in the dryer

why?

Poor sheet formation (spotty, blotchy sheet) on the machine

why?

Freeness declined 2.8%

why?

Fibre length dropped from 2.48 mm to 2.38 mm

why?

Operating parameters not effective for shorter fibres

why?

Reduce rush/drag by 10.5% to optimize for shorter fibres

Figure 5.6: Funnel of information to detect cause

rush/drag ratio to accommodate shorter fiber lengths.

5.4 Rules

The expert system has rules for monitoring equipment, scheduling for regular maintenance, process problems, and most significantly, also suggests a course of action to remedy a problem. The rules govern the monitoring process by comparing main sensor values to an acceptable pre-programmed tolerance (the details of the rules can be found in Appendix C). When an alarm
is triggered, a message is displayed in the workspace of the equipment with the problem, and further details regarding the problem can be accessed by clicking on "ALARMS" menu (see figure 5.10). In addition, since proper maintenance is necessary to operate successfully, the expert system has rules that manage the schedules of when equipment changes have been last made, and when they are due again. The expert system has a flexible option whereby all logs containing information about equipment changes can be exported to files outside the expert system. Most importantly, when a problem arises in the pulp production process, the expert system uses rules to suggest the cause and the appropriate corrective action. Interestingly, when the cause is unknown, plant operators can interact with the expert system and provide further information to aid the expert system in trouble shooting.

5.4.1 Headbox Rules

The expert system has rules governing the headbox that monitors key variables (headbox consistency, level, and pressure), manages maintenance schedules, and also organizes a startup routine. When the headbox consistency, for example, goes outside of its control boundaries, the expert system alarms operators to check the dilution process, and advises operators to ensure that pulp is diluted to a certain consistency. With respect to managing maintenance schedules, maintenance records of factors like checking for air leaks can be accessed from
Figure 5.7: The Workspace with the Process Schematic
the “MAINTENANCE” menu option (see figure 5.10). In the case of headbox pressure fluctuations, the expert system suggests that operators check the air leak maintenance log to determine if an air leak may potentially be the problem. In addition, there also is a maintenance log for the slice lip. Rules regarding a routine check at startup are also incorporated in the expert system to avoid certain problems. For example, to ensure that the slice lip openings are correct, operators are asked to look at the wire and see if there are any wet streaks present. All the actuators are adjusted accordingly, and the rush/drag ratio valid for the specific consistency of the stock is checked and confirmed. The positioning and directional rotation of the rectifier roll is also verified at startup to ensure that the pulp is evened out before pulp production begins.

5.4.2 Wire and Vacuum System Rules

The expert system contains rules that monitor the vacuum levels under the wire, the pH of the stock, and the cause of plugged pores. If the vacuum levels suddenly drop, the expert system advises the operators to check if there is a build up of pitch and also to see if any of the valves are sticking. In order to prevent the wire from getting damaged, showers that rinse the wire are equipped with pH sensors, and consequently, the expert system is able to ensure that the pH is not too acidic. To prevent plugged pores on the wire, a log of when
the next washing of the wire is due is also recorded in the expert system. In addition, results from manual tests (also known as bear traps) can be performed to determine whether or not the vacuum system is draining enough water out of a pulp sheet, and thus provide a good indication of whether or not wire pores are plugged. The results of bear traps may be entered into the expert system when available, and can certainly be helpful in trouble shooting.

5.4.3 Rules for Presses and Felts

The expert system monitors key variables related to the presses and also has a log for the maintenance of press felts and rolls. All the vacuum levels of the presses are monitored by the expert system and an alarm is displayed if a vacuum box fails. Press loading is also strictly monitored to ensure uniform pulp sheet formation. Furthermore, the speed and power consumption of the presses is watched because this provides operators with a measure of how well the press is functioning.

The expert system has a log for the maintenance of press felts and suggests when they need to be replaced because of aging. The log also contains information of when the felt was last washed, as increased sheet break incidence may be related to the possibility of damage to felt secondary to excessive acidity of recent wash material. Lastly, in order to prevent the usage of an old roll with worn grooves, the expert system keeps track of when a roll needs
replacement.

5.4.4 **Dryer Rules**

With respect to dryer operation, the expert system uses rules to tightly regulate key variables such as the steam pressure and temperature, and the differential pressure and air temperature. (Similar rules also exist for the pre-dryer.) If the steam pressure and temperature fall out of their acceptable levels, the rules suggest actions for checking the steamhood and steam supply. If the air temperature drops out of acceptable levels, it indicates that there is not enough heat exchange taking place in the dryer; subsequently, a rule will suggest that operators check the volume of air supplied to ensure that the temperature returns to acceptable levels. When a sheet break in the dryer occurs on startup, the expert system will suggest courses of action like checking to see if there is a clutch sticking out in the dryer or if there is a piece of pulp stuck in the dryer. In addition, there is a maintenance log available to check when a circulating fan has last been installed, and if the installation is recent, operators have a clue that the fan may be causing flow in the opposite direction.
5.4.5 Steamhood Rules

In order to prevent starting up with a steamhood flooded with condensate, the expert system reminds operators to check the steamhood. It also reminds operators to ensure that all the steam valves are open, so that steam may be distributed to the appropriate locations. A maintenance log exists to check when the last examination for condensate leakage was performed. If repairs are made to the steamhood due to leakage, operators will update the log. As discussed in section 5.2.5 a lot of measurements for better operation of the steamhood are not available and consequently, only the steam pressure and flow are being monitored by the expert system.

5.5 System architecture

Both the PCA model and the expert system work together in predicting and preventing possible sheet breaks. Figure 5.8 shows how these two systems work together. PCA is used for process monitoring and is able to indicate when the process is not within statistical control limits. It will trigger a series of data analysis by the expert system which will search for the possible cause and provide recommendations from the rule base. The expert system is also designed to interact with operators so that additional information such as non-measurable variables
can be entered. With such a scheme, early detection of problems is possible and ultimately machine reliability can be improved.

5.6 Expert System Development

5.6.1 Expert System Shell

G2 is a development environment for creating intelligent real-time applications. It is developed by Gensym Corporation located in Massachusetts, Cambridge [12]. G2 provides a graphical environment for modeling and design of applications. An application developed in G2 is called
a knowledge base, or KB. Objects that are created within G2 are placed upon workspaces. Naturally, a KB will have many workspaces, which the user creates and customizes.

Class Hierarchy

Since G2 applications are based on object-oriented designs, the knowledge is stored within objects called classes. G2 is supplied with a large set of system-defined classes, but the user can also define their own classes. Each class has its own attributes that define the properties of that class. Figure 5.9 shows an example of an attribute, level, that is associated with the stuff-box-class. The classes in G2 are arranged in a hierarchy. Item is the highest class that exists in the hierarchy. In figure 5.9 the stuff-box-class hierarchy is tank, equipment, object and item. The classes item and its subclass object are G2 defined classes, whereas equipment and tank are user defined classes. An advantage of having a class hierarchy is that attributes of user-defined classes can inherit attributes from any number of superior classes.

Modules

G2 allows development of a large KB from smaller, more manageable pieces called modules. As development progresses, one can easily add-on more capabilities to the existing KB. When developing another application that uses information similar to the module that already exists, one can simply merge the existing module into the KB. When one wants to upgrade the
<table>
<thead>
<tr>
<th><strong>STUFF-BOX-CLASS, an object-definition</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Notes</strong></td>
</tr>
<tr>
<td><strong>Authors</strong></td>
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<td><strong>Menu option</strong></td>
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<tr>
<td><strong>Inherited attributes</strong></td>
</tr>
<tr>
<td><strong>Attribute initializations</strong></td>
</tr>
</tbody>
</table>

**Figure 5.9: Attribute Definition Within Each Class**
knowledge in a particular KB, one just works on that particular module without interrupting the whole application. As the upgrade is completed, one can merge in the new upgraded module and delete the old module. As a module is deleted, all the workspaces associated with that module are deleted.

G2 Configurations

G2 can be configured for specific users. The administrator mode is a G2 defined mode and has access to all items. All other user modes are defined by the programmer. Each mode of operation can be configured differently, for example, when an operator uses the KB he is not allowed to delete items. The “delete” option does not exist in this mode and therefore, equipment cannot accidentally be deleted. G2 can also be made secure by assigning pass words to each user mode, so that only authorized personnel may use the expert system.

5.6.2 Organization of Workspaces Within the Knowledge Base

At the startup of the knowledge base, a workspace is shown where information is given about correspondence to the author. At the same time the compiler compiles the G2 menu system that allows the user to have pull-down menu options. The pull down menu options and the initial workspace are shown in figure 5.10.
Figure 5.10: Compilation of the Menu System at the Start.

When the user presses on the “BEGIN” button (figure 5.10) a schematic of the process is shown. Figure 5.7 shows the workspace with the key equipment. When in user-mode clicking on each equipment opens a subworkspace associated with the equipment. On the subworkspace, graphs are available to plot the key variables that are monitored. There are also tables that display the numerical values of key variables.

Choices available under the pull down menu are shown in figure 5.11. Under the “Utility” option one can navigate to workspaces that are useful when developing the expert system, or changing its behavior. The “GMS Menu” option brings the user to the workspace that stores the code for generating the menu bar. If for example, the developer wants to eliminate
the category "maintenance" it can be done on this workspace. When clicking on the "Object Definition" choice, the user gets to a workspace where all objects are defined. If the developer wants to add more equipment or change attributes of certain classes, it would be done on this workspace. The "Sensor Storage" option brings the user to a workspace where all the sensors for monitoring are located. The sensors receive values from a spreadsheet, and if the developer wants to add more sensors as more measurement data is available, it would be done on this workspace.
The “Alarms” menu choice gives access to the workspaces where all the alarms are displayed. The “Maintenance” menu choice allows the user to access the workspaces where all the logs are kept regarding equipment replacements and repairs. The logs can be edited when needed and saved. The final menu choice allows the operator to switch modes of usage. Usually, the “User” mode will be selected unless a programmer who is familiar with G2 programming switches to administrator mode in order to edit the code.

5.7 Monitoring and Expert System Diagnostic

Sheet breaks can be caused by one variable going out of control, or may also result from the contribution of several factors simultaneously. It is therefore important to monitor key variables in order to have an idea of which variables trend away from normal operating conditions. The following sections describe two examples of scenarios that may occur. Real plant data were used in all of these examples. The examples include a description of how the expert system was used to detect and troubleshoot the cause of sheet break. The first example is that of a variable going out of control and causing a sheet break.
5.7.1 Detection of a Variable That is Not Within Its Limits

The purpose of this example is to show how the expert system's alarms trigger before a break occurs. Figure 5.12 shows a trend chart within the expert system depicting that the variable “steam pressure within the flakt dryer” is out of its allowable limits. The alarms that were triggered before the break occurred and the message that accompanied it are shown in figure 5.12. The alarms started to trigger at the moment the steam pressure was below 110 PSIG. This alarm occurred on January 8, 1996, at 3:00 A.M. The steam pressure was then corrected, but over-shot to 140 PSIG on January 10, at 5:00 A.M. No break occurred the first time the steam pressure went out of control but eventually a break occurred during the second time this variable went out of bounds. The expert system was able to pick up both instances of the steam pressure fluctuation and forewarn the operators. The sheet break could have been avoided, if the steam pressure had been properly managed right after the first alarm was triggered.

5.7.2 Detection of Multiple Causes to Sheet Break

The second example is that of two variables that went out of their allowable limits causing a sheet break. Figure 5.13 shows that PCA has plotted a score out of the healthy region. As trouble shooting occurred in the expert system, a few alarms were triggered. One alarm that
#1086 3:04:47 a.m. The steam pressure in the flakt dryer is not within control CAUSE: There could be a problem with the steam supply. SUGGESTED ACTION: Bring the steam pressure back down to 120.

Figure 5.12: Alarm Triggered by the Expert System Before a Sheet break
was triggered is that of the machine chest. Figure 5.14 shows that prior to the machine chest level, the blend chest level alarm was also triggered. This means that machine chest level fluctuated as a result of the blend chest level fluctuations. The trend chart in figure 5.14 indeed shows that the level of the machine chest was fluctuating significantly. Another alarm that was triggered was that of the #2 back side press loading. This variable was gradually increasing until the loading went out of its HI limit. The alarm message and the trend chart for this variable is shown in figure 5.15. One can observe that a sheet break resulted as both machine chest level and press loadings went out of their limits. Hence, as PCA showed a score that was out of the normal operating region, the expert system trouble shoots and pinpoints the cause of this "unhealthy" behavior. In summary, both examples have demonstrated the effectiveness of using an expert system to monitor process variables and provide advance warning of impending problems.

5.8 Conclusions

This chapter reviewed knowledge regarding the sheet break process collected from mill personnel and demonstrated how this can be incorporated as rules into a knowledge base. Subsequently, these rules were integrated into an expert system that was able to monitor process variables, trouble shoot the pulp production process when it drifted from a region of healthy
Figure 5.13: PCA Plot of One Abnormal Score
Figure 5.14: Machine Chest Alarm Triggered by the Expert System
The B.S. loading of #2 press is incorrect. CAUSE: An incorrect setting may have been placed, or the felt is not installed properly. SUGGESTED ACTION: Ensure that the press loading is set to 42.

Figure 5.15: Press Loading Alarm Triggered by the Expert System
operation, and most importantly, suggest a remedial course of action when necessary. Examples of two different scenarios were provided that reinforced the ability of this expert system to alert personnel of potential problems that could lead to sheet break. Consequently, it is evident that this expert system can be employed as a powerful tool in the prediction and prevention of sheet breaks.
Chapter 6

Conclusions

Though causes of sheet breaks are documented in the literature, there apparently is no published method that prevents sheet breaks by using an expert system that models the breaks process while simultaneously trouble shooting causes of impending sheet break. As a result, this thesis presents a model for the prediction and prevention of sheet breaks using PLS, PCA and an expert system. In summary, this paper provides the following contributions to pulp and paper research:

1. A current literature review of research regarding causes of sheet breaks and the use of expert systems in heuristic dependent processes.
2. A documentation of factors associated with sheet breaks according to the practical knowledge and experience of pulp machine operators. The analysis of factors associated to sheet break revealed that fluctuations in headbox consistency, with consequent variations in basis weight and pulp quality, contributed to the cause of sheet break.

3. The use of PLS to model the complexity of variables involved in the pulp production process and to determine the extent to which a variable is associated with sheet break. The PLS model predicted 92% of sheet breaks in a test data set and also revealed the most important variables that contributed to sheet break: lumpbreaker loadings, dryer steam pressure, and dryer differential pressure.

4. The use of PCA analysis to define a healthy region of machine operation in order to provide fault detection when conditions begin to trend outside a region of healthy operation.

5. The design and development of an expert system that effectively monitors the pulp production process, trouble shoots the situation when variables occur outside a normal region of operation, and also suggests an appropriate course of action in response to problems.
6. Consequently, the expert system developed in this thesis functions to predict and prevent sheet breaks, and ultimately allows improved reliability, efficiency, quality, economics and safety of the pulp production process.

After studying the pulp production process at the Weyerhaeuser Pulp mill in Grande Prairie, the following recommendations for better operation of the mill can be made:

1. Install an agitator in the stuff box to ensure that the pulp is well mixed.

2. Use a consistency control strategy to ensure that the consistency of the stock going to the headbox is constant.

3. Improve on the control strategy currently available for lumpbreaker loading, so that back side and tension side loadings are equal.

4. Install sensors that measure the temperature of the sheet, so that the correct pressure of steam can be used to dry the sheet.

5. Install a continuous freeness tester of the pulp and calculate the correct rush/drag ratio based on the freeness measurement.

6. Improve the control strategy of the couch vacuum.

7. Measure the moisture content of the sheet before it goes into the dryer and calculate the amount of the steam necessary in the dryer.
8. Use a temperature control strategy to ensure that the stock that is being pumped to the headbox is at constant temperature.

9. Implement a strategy that ensures that dirty water is not used in the system. Have filters to clean the water, and testers to see if the water is acceptable.

It is recommended that for future research:

1. The impact of short fibres on rush/drag ratio should be studied in order to optimize pulp production.

2. An accurate calculation of the rush/drag ratio should be developed that takes into account the consistency, temperature, viscosity and mass density of the stock.
Bibliography


Appendix A

Summary of variables measured

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#1 comp 9 blade unfoil
#2 comp 9 blade unfoil
B.S. lumpbreaker loading
T.S. lumpbreaker loading
couch roll vacuum
couch amps
#1 press vacuum
#1 press amps
T.S. #1 press loading
B.S. #1 press loading
#2 press vacuum
#2 press amps
T.S. #2 press loading
B.S. #2 press loading
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131
low pressure condensate receiver

mill water flow

mill air pressure

$SO_2$ flow

pulp freeness

basis weight 1...38

moisture 1...38
## Appendix B

### Summary of variables used for modeling

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41 stuff box level
42 wire pit level
43 mill air pressure
Appendix C

Rules Used in The Expert System
**Command:**

write to the file rule.txt every rule assigned to module breakrules

**Results follow this line:**

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<thead>
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<th>Options</th>
<th>Notes</th>
<th>Authors</th>
<th>Item configuration</th>
<th>Names</th>
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**Timeout for rule completion**

use default

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<td>ilse (2 Sep 1997 2:01 a.m.)</td>
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<td>if the Differential_pressure of FLAKT-DRYER &lt; 6 then inform the operator on dryer-ws that</td>
<td></td>
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"The Differential_pressure of the dryer is too low CAUSE: There could be a problem with the steam supply or incorrect controller setting for differential pressure
SUGGESTED ACTION: Ensure that the Differential_pressure is set to 7 and eliminate fluctuations in steam supply"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 2:02 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the air_temp of FLAKT-DRYER < 215 then inform the operator on dryer-ws that "The air temp of the dryer is too low CAUSE: There could be a problem with the steam supply or a blowbox may have failed. SUGGESTED ACTION: Bring the air temp back up to 225 by supplying more steam. Check steam supply"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 2:01 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the air_temp of FLAKT-DRYER > 235 then inform the operator on dryer-ws that "The air temp of the dryer is too hot for normal operation CAUSE: There could be a problem with the steam supply. SUGGESTED ACTION: Bring the air temp back down to 225 by supplying less steam. Check steam supply"
if the steam_pressure of FLAKT-DRYER > 130 or the steam_pressure of FLAKT-DRYER <= 110
then inform the operator on dryer-ws that "The steam pressure in the flakt dryer is not
within control CAUSE: There could be a problem with the steam supply. SUGGESTED ACTION:
Bring the steam pressure back down to 120."

if the steam_pressure of pre-DRYER > 132 then inform the operator on dryer-ws that "The
steam pressure of the pre-dryer is too high CAUSE: There could be a problem with the
steam supply or the sheet might be too wet SUGGESTED ACTION: Ensure that the Steam
pressure is set to 130 and eliminate fluctuations in steam supply"
if the steam_pressure of pre-DRYER < 128 then inform the operator on dryer-ws that "The steam pressure of the pre-dryer is too low CAUSE: There could be a problem with the steam supply SUGGESTED ACTION: Ensure that the Steam pressure is set to 130 and eliminate fluctuations in steam supply"

if the steam_temp of FLAKT-DRYER > 130 or the steam_pressure of FLAKT-DRYER <= 110 then inform the operator on dryer-ws that "The steam pressure in the flakt dryer is not within control CAUSE: There could be a problem with the steam supply. SUGGESTED ACTION: Bring the steam pressure back down to 120. "

140
if the differential_pressure of pre-dryer > 7.3 then inform the operator on dryer-ws that
"The differential pressure of the pre-dryer is too high. CAUSE: The sheet might be too wet or the supply steam pressure is fluctuating SUGGESTED ACTION: Check that the steam supply is on target. Bring it back to 7.0"

if the differential_pressure of pre-dryer < 6.2 then inform the operator on dryer-ws that
"The differential pressure of the pre-dryer is too low. CAUSE: The supply steam pressure is fluctuating SUGGESTED ACTION: Check that the steam supply is on target. Bring it back to 7.0"
If the pH of fourdrinier > 5.1 or the pH of fourdrinier < 4.8 then inform the operator that "The wire stock pH is running out of control. CAUSE: There may be some problem with the acid supply line. SUGGESTED ACTION: Make sure the stock pH gets to 5".

Scan interval: 1 second
Focal classes: none
Focal objects: none
Categories: none
Rule priority: 6
Depth first backward chaining precedence: 1
Timeout for rule completion: use default

Options: invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

If the flow of stock > 5200 then inform the operator that "The stock to machine flow is too high. CAUSE: A wrong entry in the basis weight valve or the fan pump is pumping too much stock. SUGGESTED ACTION: Check the fan pump".

Scan interval: 1 second
Focal classes: none
Focal objects: none
Categories: none
Rule priority: 6
Depth first backward chaining precedence: 1
Timeout for rule completion: use default

Options: invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

If the flow of stock < 4500 then inform the operator that "The stock to machine flow is
too low. CAUSE: A wrong entry in the basis weight valve or the fan pump is pumping too little stock. SUGGESTED ACTION: Check the fan pump and the stuff box level.

if the stock_temp of stock > 155 or the stock_temp of stock < 145 then inform the operator that "The stock temp is running out of control. CAUSE: There may be some problem upstream with temp control. SUGGESTED ACTION: Check the hot water supply."

if the stock_to_machine_consistency of stock > 3.25 then inform the operator that "The stock to machine consistency is too high and might cause fluctuation of basis weight. CAUSE: The stuff box is not well-stirred. SUGGESTED ACTIONS: Use more white water to dilute to 3.23 consistency."
if the stock_to_machine_consistency of stock < 3.21 then inform the operator that "The stock to machine consistency is too low and might cause fluctuation of basis weight. CAUSE: The stuff box is not well-stirred. SUGGESTED ACTIONS: Use less white water to dilute to 3.23 consistency"

if the ts_loading of #2 press > 42.5 then inform the operator on press-ws that "The T.S. loading of #2 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 42"

if the ts_loading of #2 press > 42.5 then inform the operator on press-ws that "The T.S. loading of #2 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 42"
if the ts_loading of 2-press < 41.5 then inform the operator on press-ws that "The T.S. loading of #2 press is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 42 in order to prevent a sheet with too much moisture"

if the bs_loading of 3-press > 53.5 then inform the operator on press-ws that "The B.S. loading of #3 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 53"

if the ts_loading of 2-press < 41.5 then inform the operator on press-ws that "The T.S. loading of #2 press is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 42 in order to prevent a sheet with too much moisture"

if the bs_loading of 3-press > 53.5 then inform the operator on press-ws that "The B.S. loading of #3 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 53"
if the bs_loading of 3-press < 52.5 then inform the operator on press-ws that "The B.S. loading of #3 press is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 53 in order to prevent a sheet with too much moisture"

if the ts_loading of 3-press > 53.5 then inform the operator on press-ws that "The T.S. loading of #3 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 53 "

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
if the ts_loading of #3 press < 52.5 then inform the operator on press-ws that "The T.S. loading of #3 press is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 53 in order to prevent a sheet with too much moisture"

if the bs_loading of lumpbreaker > 56.2 then inform the operator on press-ws that "The B.S. lumpbreaker loading is too high CAUSE: Incorrect setting SUGGESTED ACTION: Ensure that the B.S. loading is set to 56.0"

if the bs_loading of lumpbreaker < 55.8 then inform the operator on press-ws that "The B.S. lumpbreaker loading is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the B.S. loading is
if the ts_loading of lumpbreaker < 55.8 then inform the operator on press-ws that "The T.S. lumpbreaker loading is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the T.S. loading is set to 56 in order to prevent a sheet with too much moisture"

if the ts_loading of lumpbreaker > 56.2 then inform the operator on press-ws that "The T.S. lumpbreaker loading is too high high CAUSE: Incorrect setting. SUGGESTED ACTION: Ensure that the T.S. loading is set to 56.0 "

set to 56 in order to prevent a sheet with too much moisture"
if the bs_load of 1-press > 18.1 then inform the operator on press-ws that "The B.S. loading of #1 press is high
CAUSE: An incorrect setting may have been placed, or the felt is not installed properly
SUGGESTED ACTION: Ensure that the press loading is set to 18"

Scan interval     1 second
Focal classes     none
Focal objects     none
Categories        none
Rule priority     6

if the bs_load of 1-press < 17.9 then inform the operator on press-ws that "The B.S. loading of #1 press is low
CAUSE: An incorrect setting may have been placed, or the felt is not installed properly
SUGGESTED ACTION: Ensure that the press loading is set to 18 in order to prevent a sheet with too much moisture"
a rule

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

Notes OK
Authors ilse (2 Sep 1997 1:59 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the ts_loading of 1-press > 18.1 then inform the operator on press-ws that "The T.S. loading of #1 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 18."

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

Notes OK
Authors ilse (2 Sep 1997 1:59 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the ts_loading of 1-press < 17.9 then inform the operator on press-ws that "The T.S. loading of #1 press is low CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 18 in order to prevent a sheet with too much moisture."

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining

Notes OK
Authors ilse (2 Sep 1997 1:59 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the ts_loading of 1-press > 18.1 then inform the operator on press-ws that "The T.S. loading of #1 press is high CAUSE: An incorrect setting may have been placed, or the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is set to 18."

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default
if the bs_loading of 2-press/= 42 then inform the operator on press-ws that "The B.S.
loading of #2 press is incorrect CAUSE: An incorrect setting may have been placed, or
the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is
set to 42 "
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Notes OK
Authors ilse (2 Sep 1997 2:00 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 2_comp9-blade_unfoil > 5.3 then inform the operator on vacuum-ws that
"The vacuum level of #2 comp 9 blade unfoil vacuum is high CAUSE: The sheet may
contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox
consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal.
Check if the felt is plugged"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Notes OK
Authors ilse (2 Sep 1997 1:43 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the bsLoading of 2-press/= 42 then inform the operator on press-ws that "The B.S.
loading of #2 press is incorrect CAUSE: An incorrect setting may have been placed, or
the felt is not installed properly SUGGESTED ACTION: Ensure that the press loading is
set to 42 "
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Notes OK
Authors ilse (2 Sep 1997 1:43 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 2_comp9-blade_unfoil > 5.3 then inform the operator on vacuum-ws that
"The vacuum level of #2 comp 9 blade unfoil vacuum is high CAUSE: The sheet may
contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox
consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal.
Check if the felt is plugged"
if the vacuum of 2_comp9-blade_unfoil < 4.7 then inform the operator on vacuum-ws that
"The vacuum level of #2 comp 9 blade unfoil is low CAUSE: The sheet may have been
broken before or there are too many short fibres which allow good moisture drainage.
SUGGESTED ACTION: raise the vacuum level to 5.0 because the sheet will be too wet and
susceptible to break"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:44 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 1_comp9-blade_unfoil > 4.3 then inform the operator on vacuum-ws that
"The vacuum level of #1 comp 9 blade unfoil vacuum is high CAUSE: The sheet may
contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox
consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal.
Check if the felt is plugged"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:44 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the vacuum of l_comp9-blade_unfoil < 3.7 then inform the operator on vacuum-ws that
"The vacuum level of #1 comp 9 blade unfoil is low CAUSE: The sheet may have been
broken before or there are too many short fibres which allow good moisture drainage.
SUGGESTED ACTION: raise the vacuum level to 4.0 because the sheet will be too wet and
susceptible to break"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:43 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the vacuum of l_5-blade_unfoil > 1.1 then inform the operator on vacuum-ws that "The
vacuum level of #1 5 blade unfoil vacuum is high CAUSE: The sheet may contain too
much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency
is too low. Use Bear traps to confirm vacuum levels and moisture removal. Check if
the felt is plugged"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:43 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the vacuum of l_5-blade_unfoil < 0.9 then inform the operator on vacuum-ws that "The
vacuum level of #1 5 blade unfoil is low CAUSE: The sheet may have been broken before
or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 1.0 because the sheet will be too wet and susceptible to break.

if the vacuum of 2_5-blade_unfoil > 2.1 then inform the operator on vacuum-ws that "The vacuum level of #2 5 blade unfoil vacuum is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal. Check if the felt is plugged".

if the vacuum of 2_5-blade_unfoil < 1.9 then inform the operator on vacuum-ws that "The vacuum level of #2 5 blade unfoil is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 2.0 because the sheet will be too wet and susceptible
if the vacuum of 7-blade_unfoil > 3.3 then inform the operator on vacuum-ws that "The vacuum level of 7 blade unfoil vacuum is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal. Check if the felt is plugged"

if the vacuum of 7-blade_unfoil < 2.7 then inform the operator on vacuum-ws that "The vacuum level of 7 blade unfoil vacuum is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 3.0 because the sheet will be too wet and susceptible to break"
if the vacuum of couch-vac > 20 then inform the operator on vacuum-ws that "The vacuum level of couch-vac is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal. Check if the felt is plugged"

if the vacuum of couch-vac < 19 then inform the operator on vacuum-ws that "The vacuum level of couch-vac is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 18.0 because the sheet will be too wet and susceptible to break"
if the vacuum of orthoflo > 1.65 then inform the operator on vacuum-ws that "The vacuum level of orthoflo is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"

if the vacuum of orthoflo < 1.4 then inform the operator on vacuum-ws that "The vacuum level of orthoflo is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 1.5 because the sheet will be too wet and suscetible to break"
if the vacuum of 1-flatbox > 2.1 then inform the operator on vacuum-ws that "The vacuum level of 1-flatbox is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"

if the vacuum of 1-flatbox < 1.9 then inform the operator on vacuum-ws that "The vacuum level of 1-flatbox is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 2.0 because the sheet will be too wet and susceptible to break"
if the vacuum of 2-flatbox > 3.1 then inform the operator on vacuum-ws that "The vacuum level of 2-flatbox is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"

if the vacuum of 2-flatbox < 2.9 then inform the operator on vacuum-ws that "The vacuum level of 2-flatbox is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 3.0 because the sheet will be too wet and susceptible to break"
if the vacuum of 3-flatbox > 4.1 then inform the operator on vacuum-ws that "The vacuum level of 3-flatbox is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:41 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 7-multivac > 7.4 then inform the operator on vacuum-ws that "The vacuum level of 7-multivac is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:41 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 3-flatbox < 3.9 then inform the operator on vacuum-ws that "The vacuum level of 3-flatbox is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 4.0 because the sheet will be too wet and susceptible to break"

Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (2 Sep 1997 1:41 a.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the vacuum of 7-multivac < 7.4 then inform the operator on vacuum-ws that "The vacuum level of 7-multivac is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 4.0 because the sheet will be too wet and susceptible to break"
if the vacuum of 7-multivac < 6.0 then inform the operator on vacuum-ws that "The vacuum level of 7-multivac is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 7.0 because the sheet will be too wet and susceptible to break"

if the vacuum of 15-multivac > 16.0 then inform the operator on vacuum-ws that "The vacuum level of 15-multivac is high CAUSE: The sheet may contain too much moisture and will be too weak SUGGESTED ACTION: Check if the headbox consistency is too low. Use Bear traps to confirm vacuum levels and moisture removal"
if the vacuum of 15-multivac < 14.0 then inform the operator on vacuum-ws that "The vacuum level of 15-multivac is low CAUSE: The sheet may have been broken before or there are too many short fibres which allow good moisture drainage. SUGGESTED ACTION: raise the vacuum level to 15.0 because the sheet will be too wet and susceptible to break"

if the level of machine-chest > 15.5 or the level of machine-chest <= 14.5 then inform the operator on tank-ws that "The level of the Machine Chest is running out of control. CAUSE: pump failure or level control not working properly SUGGESTED ACTION: Check the pump which pumps stock from Stock prep or Check with Stock Prep to see what is going on"
a rule
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (1 Sep 1997 11:30 p.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the level of blend-chest > 13.0 or the level of machine-chest <= 11.5 then inform the
operator on tank-ws that "The level of the Blend Chest is running out of control.
CAUSE: pump failure or level control not working properly SUGGESTED ACTION: Check the
pump which pumps stock to the blend chest"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (1 Sep 1997 11:31 p.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the consistency of headbox > 1.4 or the consistency of headbox <= 1.3 then inform the
operator on headbox-ws that "The consistency of the Headbox is running out of control.
CAUSE: Too much or too little white water being recirculated SUGGESTED ACTION: Check
that the dilution of the pulp is done appropriately and ensure that the level of pulp
in the machine chest is acceptable"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via
if the hot_h20_heater_temp of hot_water_heater > 190 or the hot_h20_heater_temp of hot_water_heater < 170 then inform the operator that "The hot H2O heater temp is running out of control. CAUSE: There could be loss of heat/power to the heater.
SUGGESTED ACTION: Bring up the temp to 180 before the pulp temp gets out of hand"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes OK
Authors ilse (1 Sep 1997 11:32 p.m.)
Item configuration none
Names none
Tracing and breakpoints default

if the pressure of CONDENSATE-RECEIVER > 32 or the pressure of CONDENSATE-RECEIVER <= 28 then inform the operator that "the low pressure condensate receiver is receiving condensate at an abnormal pressure. CAUSE: Insufficient drying may be occurring. SUGGESTED ACTION: Check all the equipment that input into the receiver"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

Options invocable via backward chaining, invocable via forward chaining, may cause data seeking, may cause forward chaining
Notes INCOMPLETE
Authors ilse (1 Sep 1997 11:31 p.m.)
if the hot_h20_heater_temp of hot_water_heater > 190 or the hot_h20_heater_temp of hot_water_heater < 170 then inform the operator that "The hot H20 heater temp is running out of control. CAUSE: There could be loss of heat/power to the heater. SUGGESTED ACTION: Bring up the temp to 180 before the pulp temp gets out of hand" ...

if the value of 33fil30.pv > 1000 then inform the operator that "The mill water flow has increased substantially. CAUSE: unknown SUGGESTED ACTION: Make sure the pulp is not being diluted too much."

if the value of 33fil30.pv < 900 then inform the operator that "The mill water flow has decreased substantially. CAUSE: unknown SUGGESTED ACTION: Make sure the pulp is still
at the right consistency"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK
Authors ilse (28 Aug 1997 2:56 a.m.)
Item configuration none
Names none
Tracing and breakpoints default
initially show begin-ws
Scan interval none
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default

a rule
Options invocable via backward chaining, invocable via
forward chaining, may cause data seeking, may
cause forward chaining
Notes OK, but DISABLED.
Authors ilse (1 Sep 1997 11:32 p.m.)
Item configuration none
Names none
Tracing and breakpoints default
if the value of 33fi067.pv > 130 or the value of 33fi067.pv <= 70 then inform the operator
that "The SO2 flow to unit 3 is abnormal. CAUSE: unknown SUGGESTED ACTION: Bring the
flow to 90 by moving the valve of the SO2 line"
Scan interval 1 second
Focal classes none
Focal objects none
Categories none
Rule priority 6
Depth first backward chaining precedence 1
Timeout for rule completion use default
if the value of 33ac103.pv > 6.7 or the value of 33ac103.pv <= 5.8 then inform operator
that "the pH of the machine shower is not correct. CAUSE: Acid supply line has a
chemical imbalance SUGGESTED ACTION: Call the unit responsible for shower pH and bring
the shower pH back to 6"

if the level of stuff-box > 2.42 or the level of stuff-box <= 2.28 then inform the
operator that "The Stuff box level is not within control. CAUSE: The machine chest is
not supplying enough pulp SUGGESTED ACTION: Phone stock prep and ask them to increase
the pulp flow and Check that the Headbox level does not go down."

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