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New technologies for performance evaluation and control loops audit at pulp and paper plants

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ABSTRACT

The purpose of this paper is to present, through practical examples in the pulp and paper industry, new tools for performance evaluation and audit of control loops. The control of the various process variables available is fundamental for the good performance of the plant and final product quality, resulting in a higher profitability. As pulp and paper plants have in general a great number of loops, in many cases over 1000 units, it is practically impossible to evaluate and diagnose each of them without tools designed for this task. For this reason the performance evaluation software can list the loops according to performance and economic return, making it possible to prioritize the loops presenting the worst performance, which may yield the best results if optimized. Using these loop monitoring technologies allows a continuous production process improvement because it is possible to act in a pro-active way when the evaluation indices are already pointing to a tendency towards performance decrease, thus avoiding higher losses. Besides indicating the optimization priorities, the software makes already available dozens of automatic diagnostic indexes of control loops. It also has several tools for carrying out detailed loop audit and tuning. This work will present several examples of utilization of these tools at industrial pulp and paper plants.

INTRODUCTION

Pulp and paper plants have a great number of control loops due to the complexity of the productive process. At this type of plant, the control of several variables, such as Kappa values (at the digester outlet in the pulp production) and the stock consistency in the headbox of a paper machine, is fundamental for the final quality of the product. The pulp consistency measure and control are absolutely critical for the product quality at the pulp and paper industry. Variations in this key parameter affect the whole process, from the web formation to the basis weight and the moisture, strength, opacity and any other important aspect of the product. Thus, the consistent consistency control is one of the fundamental factors to guarantee the quality of the product (Buckbee and Swartz, 2001). In addition, it is necessary to control temperatures, pressures, levels, among other variables, in an approximate total amount of 1000 control loops per plant. From these loops, about 20% typically operate in manual mode, increasing the variability of the process. Besides, there is the presence of strong couplings between the loops, which must be reduced to enhance the performance of the process.

Considering that the average instrumentation cost of a control loop amounts to approximately 15000

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dollars, a pulp and paper mill has invested about 15 million dollars only in control loops. Having this in view, it can be clearly perceived that it is necessary to optimize the investment already made, continuously monitoring and evaluating the control loops of the plant and making the adjustments required for them to act in an optimized way.

The loop checking procedure traditionally applied was the inspection of tendency graphs in supervisory softwares and reports supplied by the operators of the system. It was attempted to act on the control loops only when relevant consequences of the low performance of these loops impaired the process. However, new tendencies towards continuous monitoring of the control loops, automatic diagnoses of problems and tools for loop audit can guarantee not only the operation of the system within the desirable quality levels, but also the reduction in the input consumption.

By using these tools it is possible to continuously monitor the control loops by means of individual notes for each loop, as well as global notes for the process areas. Thus, the maintenance team can act at the very moment the loop begins to present a decrease in performance i.e. before this will cause serious problems in process operation.

In addition to the PID controller tuning, several further problems may significantly impair the performance of the process, such as nonlinearities, noises, oscillations, couplings, hysteresis and valve jamming. Thus, it is also important that the monitoring tool is able to detect them.

A control loop monitoring and evaluating tool will be presented in this work, which has all previously mentioned characteristics, such as continuous evaluation, tuning and automatic loop problem detection. Using this tool may significantly increase the efficiency of the loop auditing works, which may considerably reduce maintenance and input consumption expenses. It is possible to obtain significant reductions in variability, in actuator wear, in the number of loops operating in manual mode, among other problems. This work will present several real examples and results already obtained at the pulp and paper mills.

CONTROL LOOP PERFORMANCE EVALUATOR

The communication of the performance evaluation software with the control systems (SDCDs, CLPs, instruments etc...) is done through the OPC protocol, which is already considered to be an industrial standard for system connectivity. Data may be collected through OPC DA (in real-time) or OPC HDA (historical data). The collected data are used by the software to evaluate and measure the performance of the plant, process or control loops. The performance is standardized in accordance with the period of time during which the plant works at its optimum performance desired. A period of evaluation is defined as the period of time after which the KPIs (Key Performance Indicators) are calculated, an amount of over 45 KPIs being calculated during each period of evaluation. These KPIs inform groups of users (managers, engineers, operation and maintenance) about performance of the processes and control loops, equipment availability, presence and sources of oscillation and operating conditions of the equipment.

As the KPIs supply performance measures of their production assets, specifically control loops in this article, the users can focus their efforts on the points at which the impact on the production quality yields the highest return on investment (ROI). Figure 1 illustrates an example of a Canadian paper mill (Emond *et. al*, 2004) that lists the ten loops presenting the worst performance, but which may yield the highest financial benefits if optimized.

Besides presenting a global note for the control loops, areas and plants, the

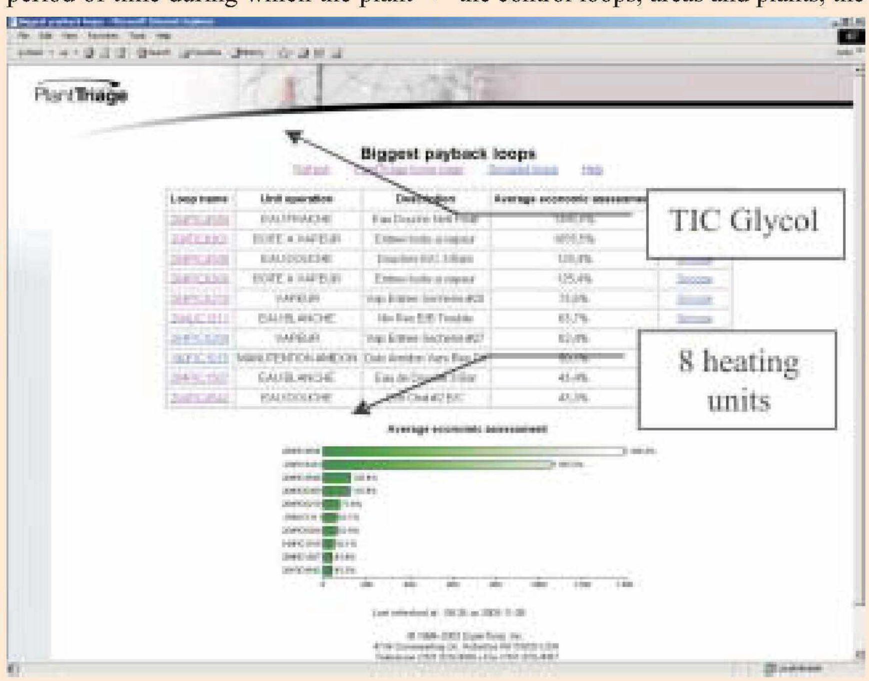

Figure 1. Performance evaluation software lists through reports in the WEB the loops with the worst performance and which may yield the best economical return (Emond *et. al*, 2004). The higher the note in percentage, the higher the potential for gain with the optimization.

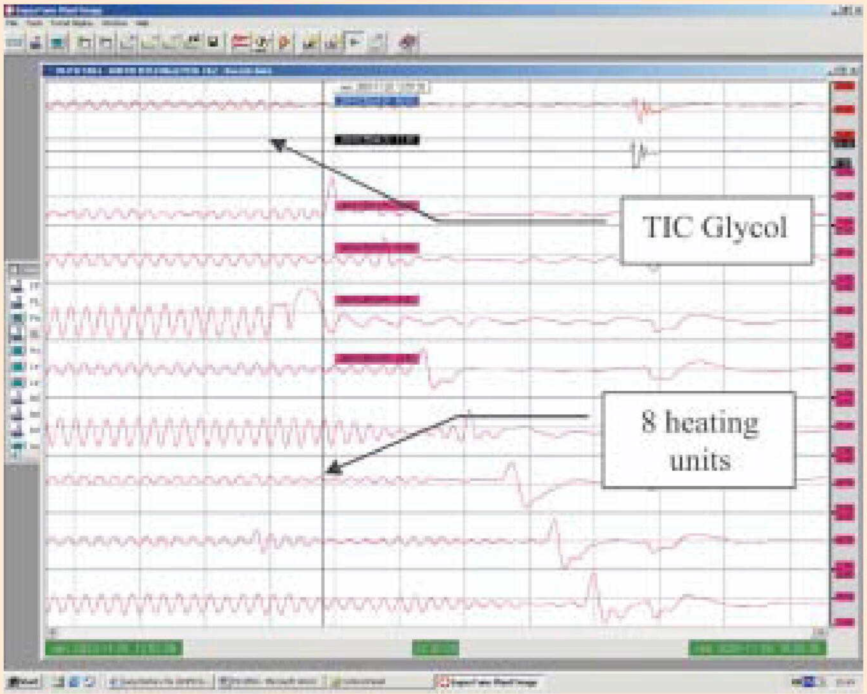

Figure 2. Aggressive tuning in a temperature loop caused oscillations in several other loops. By means of the suitable loop tuning it was possible to eliminate the oscillations (Emond *et. al*, 2004).

software continuously calculates several diagnosis indexes, such as variability, absolute average error, Harris index, plant models, noise level, percentage of time in which the loop remains in manual mode or with its output saturated, actuator wear, among other (Fonseca et al, 2004; Torres *et. al*, 2004a; Torres *et. al*, 2004b).

For a detailed analysis, the evaluation software presents various diagnosis and analysis tools, such as cross correlation, autocorrelation, robustness graph, verification of hysteresis and restrained valve, identification of oscillations, their causes and their periods (determined through spectral power density), histograms and statistical analyses, among other. All evaluations and history of the collected data are stored in an own data bank, with present storage capacity of up to 100 data-years.

3. EXAMPLES OF APPLICATIONS

3.1 – Oscillations and Tuning

Figure 2 illustrates the oscillation analysis on a paper machine. The aggressive tuning of a temperature loop (TIC Glycol) caused oscillations that affected the paper machine steam distribution, causing 8 further loops to oscillate. By using the performance evaluation software, it was observed that the loop's oscillation indices of this unit were at 100%, i.e. even before observing the time graph shown in Figure 2 it was already possible to identify the loops that were oscillating, as well as the periods of oscillation. These periods are identified through spectral power density analysis, which uses Fourier transform to identify the oscillation peaks and their spectral power in a reliable and efficient way (Ruel and Gerry, 1998). Ordering by the periods of oscillation, coincident periods for all loops have been identified, with the same glycol loop period. Through the tuning of the glycol loop and of the remaining loops, using the performance monitoring and analysis software, more conservative parameters have been adopted, eliminating the oscillations and guaranteeing the more stable operation of the system. Checking the robustness of the tuning parameters can be also made through the software, as it can be observed in Figure 3. On the robustness graph, the cross represents the identified loop model and the light blue area a region of instability. In other words, if the process changes and the closed loop simulation of the tuning is

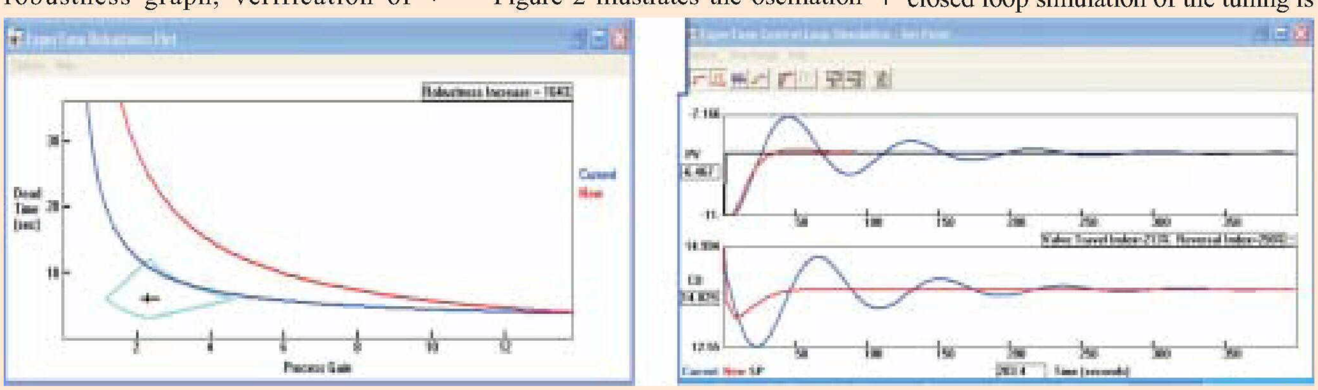

Figure 3. Robustness graph and simulations indicate that the new tuning parameters will be more conservative i.e. more robust and less likely to bring the system to oscillations. The blue curve presents the present tuning and the red curve the new tuning.

Year	Utilization time
1997	83.3%
1998	84.3%
1999	83.2%
Average	**83.6%**

Table 1: Utilization time of the paper machine in the years prior to its optimization (Ruel, 2000).

Month	Utilization time
Nov./99	90.1%
Dec./99	83.3% (Christmas shutdown)
Jan./00	88.4%
Febr./00	88.6%
Mar./00	89.4%
April/00	90.2%
Average	**88.3%**

Table 2: Utilization time of the paper machine in the months that followed its optimization (Ruel, 2000).

within this area (blue and red curves on the graph), the system may be brought to instability. The farther from the light blue area, the greater will be the tuning parameter robustness. In this figure, for instance, the red curve, situated farther from the light blue area, presents a more robust behaviour.

3.2 – Efficiency increase on a paper machine

A paper mill had efficiency problems on one of its paper machines, compared to the remaining machines (Ruel, 2000). The utilization time of this machine was 83%. At the same time, its variability was high, amounting to 1.4% for the basis weight and 6.1% for the moisture. Table 1 shows the utilization time values of the machine prior to its optimization.

After optimization the utilization time of the machine increased by 5%, resulting in a profitability increase of 1.8 million dollars per year. In addition, the product became more uniform and presented a better quality, with less variability (0.71% for the basis weight and 2.91% for the moisture). Table 2 presents the utilization times of the machine in the six months that followed its optimization.

3.2.1 – Benefits from the paper machine audit

A very important step in the paper machine audit was to calculate the gains obtained by it. For this purpose, data from all important paper machine loops have been collected and each variable was analyzed so as to detect the hidden oscillations (by using correlation and spectral power density analysis).

The analyzed data were as follows:
- variability
- spectral power density
- valve performance (hysteresis, restrain and process gain).

Once the main problems had been solved and the loops correctly adjusted, the data have been collected again for the same loops and the same variables analyzed, in order to be possible to calculate the economic gain from the audit.

Figure 4 presents the time graphs prior to and after the paper machine optimization, obtained by the quality monitoring system for basis weight, moisture and dry weight. Since the graphs are based on the same scales, the reduction in the process variability after the audit can be clearly observed.

Figure 5 presents the spectral power density analysis prior to and after the audit for the basis weight. As it can be seen on the spectral power

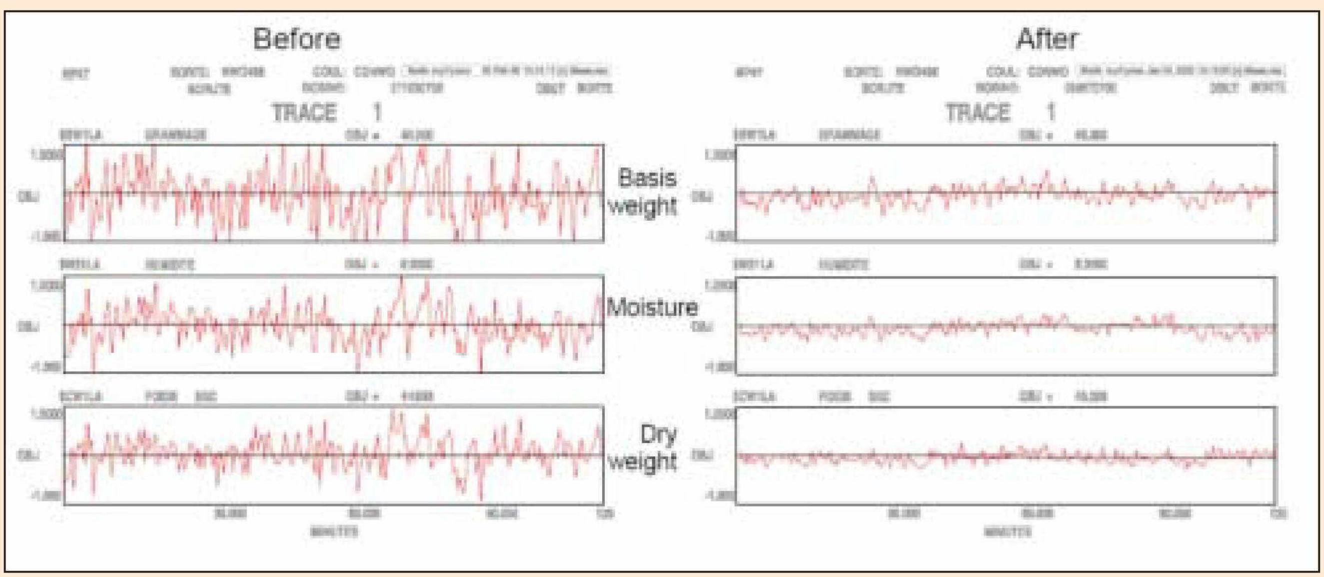

Figure 4. Comparison between the time graphs prior to and after the paper machine optimization. These graphs have been generated by the quality monitoring system. As both graphs are based on the same scale, a considerable decrease in variability can be observed (Ruel, 2000).

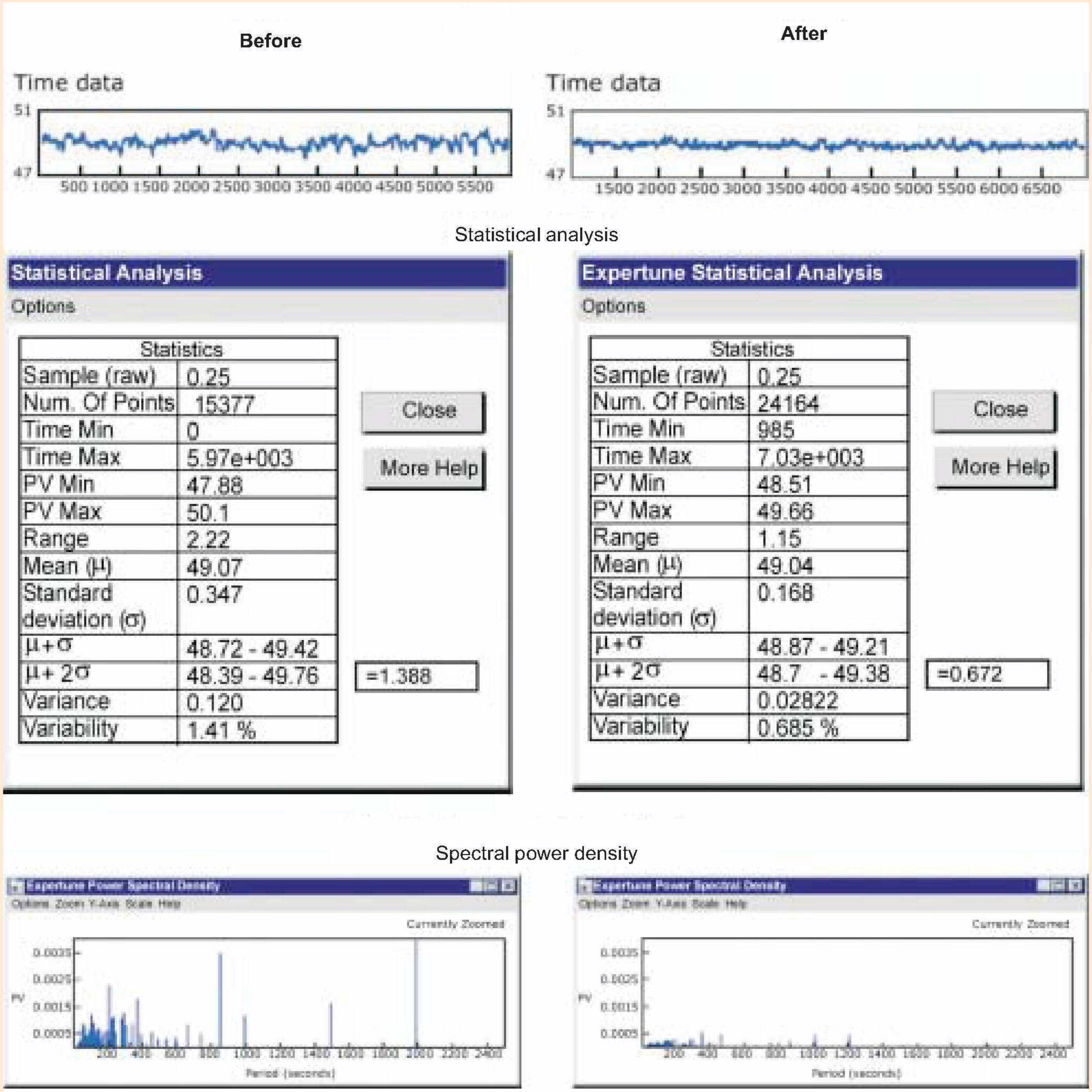

Figure 5. Basis weight analysis by the monitoring software. Variability was reduced from 1.41% to 0.685%. Besides, by the spectral power density graphs, it can be seen that the oscillations also decreased in a significant way (Ruel, 2000).

density graphs, the oscillations decreased significantly, the same results having been observed for the remaining loops.

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Based on the data obtained prior to and after the audit, it was possible to calculate the following benefits:
- better paper machine performance: start is easier to carry out after less frequent basis weight variation and breaks;
- higher efficiency;
- increase in productivity;
- estimated economic gain of 1.8 million dollars.

In addition, the audit resulted in other gains, which in spite of being nonmeasurable are as important as the measurable gains, such as:
- better paper machine knowledge;
- better runnability;
- personnel better trained to solve problems on the machine;
- better quality of the final product;
- knowledge reapplicable to other paper machines;

- smooth operation;
- less equipment wear;
- tools and data available for predictive maintenance;
- reduction in maintenance requirements.

As the estimated audit costs amounted to approximately 68 thousand dollars, it follows that the return on investment takes place in less than one month. This result shows that the process optimization yields us one of the highest returns on investment in plants, as its purpose is to optimize the use of already available equipment.

3.3 – Identification of oscillations by means of spectral analysis

A very important issue in the paper industry is the interaction between the various control loops (Ruel and Gerry, 1998). The result of it is that problems such as variability tend to spread across the paper machine in an oscillatory way. The oscillations remain as one of the greatest variability sources in the paper production process, from the pulp preparation up to the final drying. The reduction or elimination of this cyclic environment can result in an expressive reduction in variability. In general, about 50% of the machine variability comes from oscillations.

A paper machine was producing out-of-specification paper due to a 16 minute cycle in basis weight, moisture and dry weight, which was causing an unacceptable increase in product variability (Ruel and Gerry, 1998).

The paper machine receives pulp in three ways: kraft pulp, thermomechanical pulp (TMP) and recycled pulp. This latter pulp is obtained from the rejected product, which was sent to a beater, where it was mixed with water and diluted. All paper machines are fed with the same

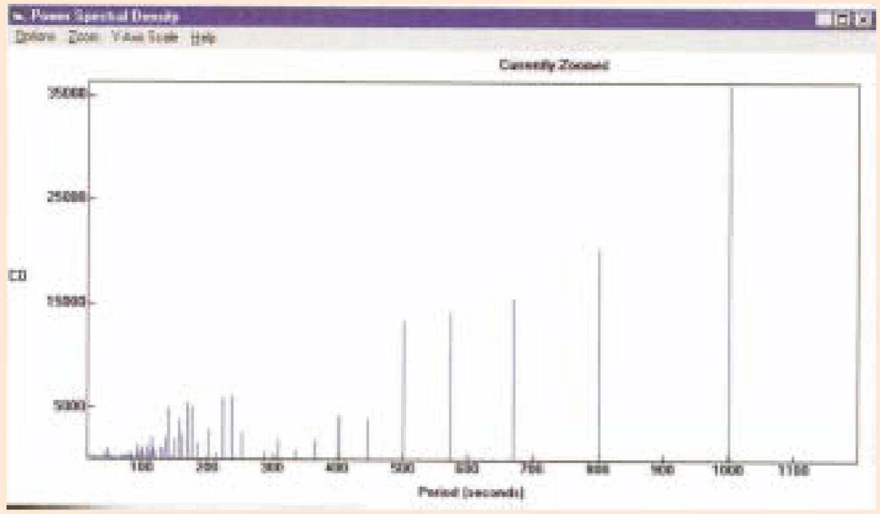

Figure 6. Spectral power density analysis from data obtained at a localized point before the paper machine (Ruel and Gerry, 1998).

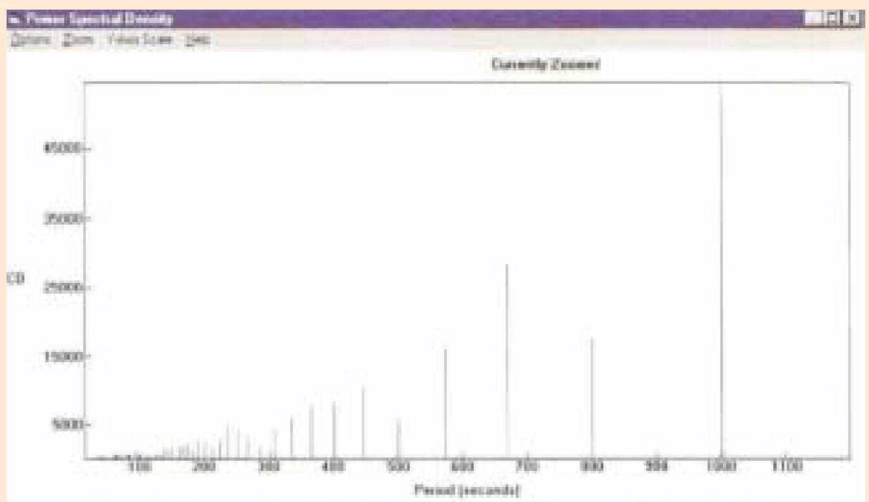

Figure 7. Spectral power density analysis from data obtained at a localized point after the paper machine (Ruel and Gerry, 1998).

kraft and TMP pulps. The recycled pulp is different on each machine, as this one is derived from its own out-of-specification paper.

The software was used to calculate the spectral power density by using data obtained at a localized point before the paper machine. The spectrum is shown in Figure 6, where it is possible to clearly note that the power density of the 1000 second frequency (16.5 minutes) distinguishes itself from the remaining ones, which corresponds exactly to the cycle seen in the rest of the process.

In order to check it, data were collected at the paper machine outlet and the spectral power density presented in Figure 7 was obtained, where it can be seen again that the 1000 second frequency distinguishes itself from the remaining ones.

These two spectral power density graphs clearly show an oscillation problem at the 16 minute frequency and in addition one came to the conclusion that the problem was situated before the paper machine. Based on this knowledge, it was decided to check whether the cause

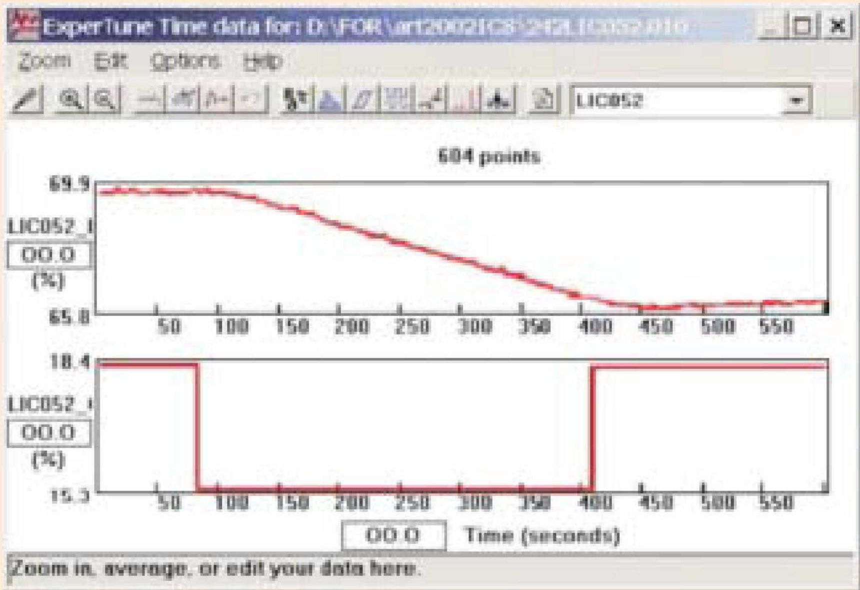

Figure 8. Data collected by the software to obtain the dynamic model of the process. The upper curve represents the variation of the process variable and the lower one the alteration at the controller output.

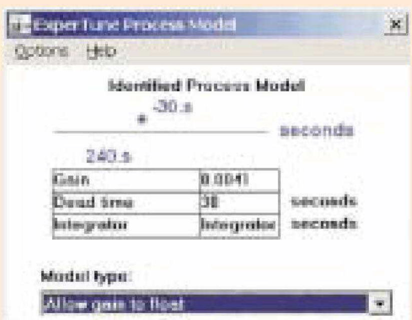

Figure 9. Model obtained from the data obtained by the software.

of the problem would be the pulp recycling, by switching it temporarily off. After two hours, the process oscillation disappeared i.e. the source of the problem was found. The product was again within acceptable values.

As this was accomplished, the problem was now to discover what caused the oscillation in the pulp recycling process. After a short time it was discovered that the problem was caused by a circulating pump that was designed to pump low consistency fluid. However, as it circulated the pulp, consistency became thicker at the pump suction and the flow decreased almost to zero. At the same time, at the machine outlet, the pulp diluted. As the coarse pulp mixed with the fine one, the pump gradually began to pump again. This cycle lasted about 16 minutes, some time pumping and some time without pumping. To confirm this result, the circulating pump was switched off and the recycled pulp was introduced anew into the paper machine. In this situation there was no presence of oscillation, but when the pump was switched on again the oscillation reappeared.

This example shows how the control loops have a significant impact on the variability of the final product and how the spectral power density analysis can quickly identify the source of the oscillation problems. Knowing the periods of oscillation, problems related to vibration, loop adjustment, interaction between loops and mechanics are readily solved.

3.4 – Modelling and Tuning

An important tool of the loop monitoring and tuning software is the capacity to model the process (Gerry and Ruel, 2002). To model the loop, the software needs the data of the manipulated and process variables after a variation carried out in the loop. In the example presented by Figure 8, in a pulp mixing tank, the data were collected by the software and the model was calculated (see Figure 9).

Using this model it is possible to adjust the controller parameters resulting in the best process performance. Besides, it is possible to simulate the process response to load or set point disturbances, as it can be seen in Figure 10. In this figure, the blue curve represents the process response when the old tuning parameter values are used, while the green curve presents the response when the new parameters are used. It is possible to find out that the old adjustment is very aggressive, causing oscillation at the process variable and consequently all over the paper machine. The new parameters, on the other hand, result in a more damped response, without causing oscillation at the process variable.

The above results demonstrate that the simulation of a good model can help choose the best adjustments of the PID parameters.

CONCLUSIONS

The process optimization is one of the plant areas with higher return on investment, as its purpose is to make sure that the present equipment works on its best level i.e. there is no need of new installations, involving engineering, installation and maintenance costs.

Another point of high return is the predictive maintenance, as the maintenance personnel have the tools and the abilities required to maintain the gains. They are able to detect and to solve the problems before they have an impact on production. The same techniques may be used on other paper machines and other sections.

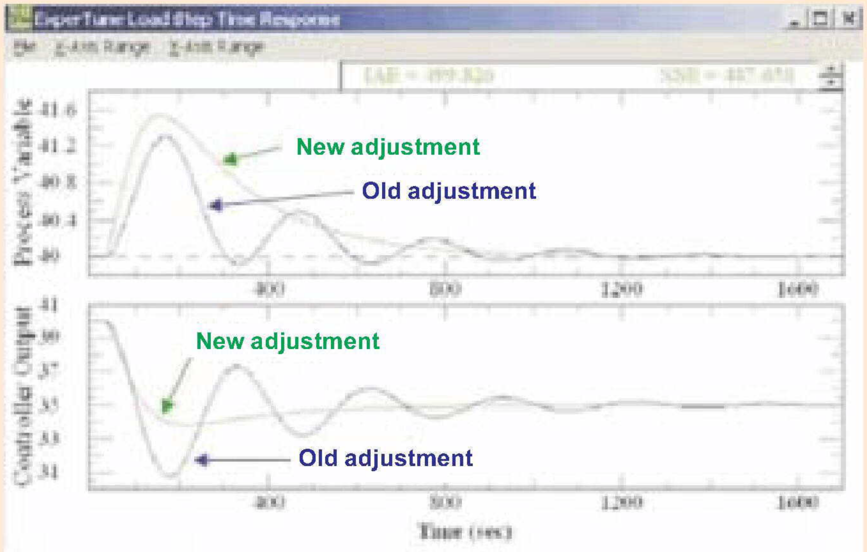

Figure 10. Response of the system to the load and set point variation, using the old parameters (blue) and the new ones (green).

The control loops have significant impacts on the variability of the final product. In this case, tools such as the spectral power density can quickly identify the source of oscillation problems. Based on the knowledge of the main periods of oscillation it is possible to know whether the oscillation is caused by vibration, loop adjustment, interactions between loops or mechanical problems (hysteresis, restrain).

If the identified problem is related to loop adjustment, using models of these loops allows calculating, in a few minutes, the PID adjustments yielding the best results considering both load and set point variations, and the process response to these variations can be simulated as well.

The presented results demonstrate the potential of economic gain in using the monitoring, evaluation, diagnosis and loop tuning software.

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