Crepe Blade Vibration Monitoring for Improved Efficiency and Asset Protection

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ABSTRACT

Tissue manufacturers are continually challenged to achieve higher levels of productivity and quality. As a result, operators often work with conditions such as higher machine speeds and lower sheet moisture levels that increase the probability for developing chatter. A machine experiencing chatter often leads to lost production, increased maintenance, and capital expenditures. Currently, operators rely on detecting the presence of chatter when sheet defects occur or by observing the characteristic periodic marks that form in the Yankee coating. In severe cases where the vibration energy is high enough, the doctor blade can penetrate through the coating making direct contact on the Yankee dryer surface resulting in costly damage. Avoiding this state requires detecting the onset of chatter and alerting operators of the impending negative condition. To address this, Nalco partnered with SKF®, a supplier of condition monitoring equipment, to develop an early chatter warning system. The technology is based on indirect doctor blade vibration monitoring using a customized user-friendly intuitive software module. An overview of the monitoring technology is presented along with case studies that illustrate benefits and knowledge building this tool offers for improved asset management.

INTRODUCTION

The occurrence of chatter on Yankee dryers is a well-known problem that tissue manufacturers strive to avoid, but often find themselves struggling with, due to the demand for higher quality products and optimum machine efficiency. This combination tends to stress the creping operation, thereby placing the process on an operating trajectory favorable for developing chatter. Several review papers by Archer et al.[1,2], Alessandrini et al.[3], and Corby[4] describe the different mechanical and operational conditions that promote chatter formation. Identifying the conditions favorable for chatter is the first step in developing best practices to minimize the problem. However, complete elimination of chatter is not easily achieved even when best practices are followed, because the creping operation is complex and dynamic. Consequently, attaining optimum machine runnability and asset protection requires the combination of best practices coupled with an online monitoring system that provides continuous real-time feedback to detect the onset of chatter.

Chatter formation is a vibration phenomenon caused by the crepe blade tip oscillating relative to the dryer surface plane. Under normal operating conditions, i.e., no chatter present, the creping doctor blade tip rides in the coating and experiences minimal out of plane movement, as illustrated in Figure 1A. Critical forces acting on the blade tip are tangential resistance and normal (loading) force. As the tangential resistance increases, e.g., coating becomes hard; the amplitude of the blade tip movement can increase because of the "stick-slip"[1] phenomenon. Continuous operation at this condition increases the risk to develop chatter marks that appear as cross directional (CD) defects in the coating and/or dryer surface, as illustrated in Figure 1B. Sheet defects from chatter also occur and appear as multiple holes in the machine direction, or develop a lace-like appearance, thus negatively impacting product quality. Under severe chatter conditions, when the doctor blade penetrates through the Yankee coating and makes direct contact with the dryer surface, horizontal, CD, grooves in the metal can form. Chatter marks formed in the metal is an irreversible process and can only be repaired by conducting a costly regrinding operation. Therefore, it's imperative to avoid this condition by detecting the onset of chatter early enough to perform the necessary corrective actions.

Despite the impact chatter can have on production, asset maintenance, and depreciation, tissue manufacturers have limited options for chatter detection. As a result, machine operators often rely on audible sound changes or visual inspection of the sheet quality and/or Yankee dryer surface as a first indication that chatter is present. Taking this hands-on approach is both, subjective and inconsistent, making reliable and early detection of chatter difficult. Thus, identifying chatter using these manual approaches lacks sensitivity and detection in a real-time manner. Consequently, the effectiveness of corrective actions taken is reduced, thereby increasing the risk of forming irreversible chatter damage on the dryer surface.

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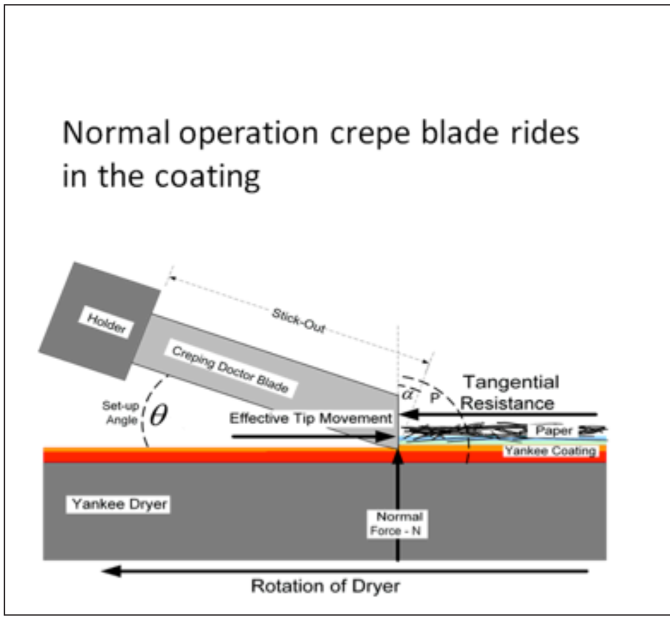

Figure 1A – *Detailed view of the creping operation showing the different forces and important setup conditions affecting crepe blade vibration.*

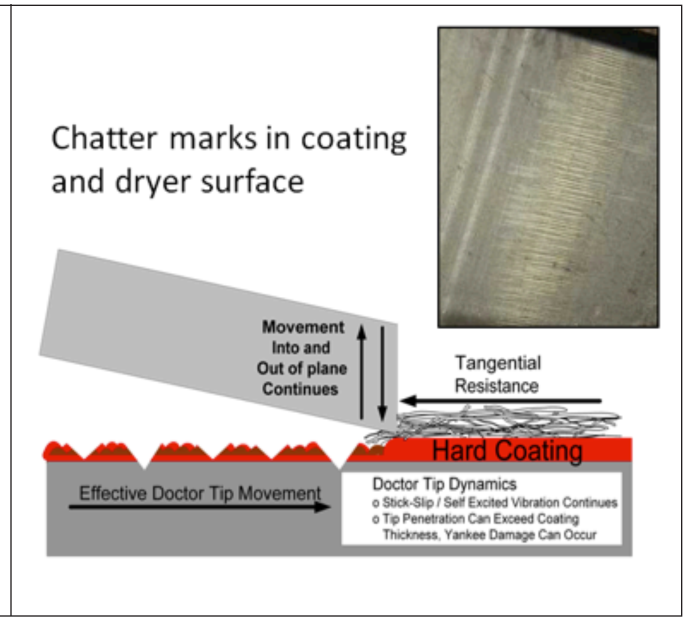

Figure 1B – *Illustration showing development of chatter by the out of plane movement of the creping blade.*

Nalco Early Warning Chatter Detection System

To address the need for an Early Warning Chatter Detection (EWCD) system, Nalco partnered with SKF to combine expertise in both the Yankee coating and process with conditioning monitoring, maintenance and asset management. At the core of the EWCD platform is the SKF hardware and software technology that is industry proven for conditioning monitoring applications covering a diverse range of industrial markets such as pulp and paper, energy, aerospace, and transportation. These applications typically focus on bearing fault detection or other lower speed rotating elements, whereas the EWCD system is tailored for crepe blade vibration monitoring. This distinction is critical for the following reasons:

1. Crepe blade vibration is dynamic compared to bearing monitoring due to the multitude of process conditions such as blade age, basis weight, furnish, coating chemistry, crepe blade setup, production rate, moisture level, etc., that will impact vibration energy transferred to the creping blade.
2. Crepe blade vibration exhibits a cyclic behavior, i.e., the vibration energy can vary over a minimum and maximum range for short or long time spans.
3. In cases where chatter develops the vibration frequencies of interest are higher than other rotating elements on a paper machine.

The functionality of the EWCD platform addresses these points using a time and intensity based alarming strategy. Additionally, EWCD is designed to be user-friendly requiring minimum training for machine operators to use. Data analysis and reporting is streamlined to eliminate the need for consulting vibration experts unless specific problems or troubleshooting is required.

The basic setup for crepe blade vibration monitoring requires installing piezoelectric accelerometers in close proximity to the crepe blade, as shown in Figure 2. Accelerometers have a small footprint (26 mm dia. x 30 mm height) allowing retrofit installation on different creping system designs. The sensors are well suited for crepe blade monitoring because they cover a wide frequency range (from 1 to 2 Hz up to 20 kHz[5]) and are immune to dusty and moist environments. In addition, the sensors are operational at temperatures > 250°F using standard commercial devices. A minimum of two accelerometers is recommended to cover front and back side zones of the dryer to identify side-to-side differences in both vibration frequency and amplitude. For larger Yankee dryer widths, additional sensors can be added for better zone coverage. Signal collection from the accelerometers and tachometer is made through water tight cabling and connections between the sensors and the SKF Multilog IMx-S conditioning monitoring hardware. The SKF Multilog® IMx-S can be mounted on the plant floor near the machine to minimize sensor cable lengths. Data transfer from the SKF Multilog IMx-S hardware to a dedicated computer running the EWCD software for alarming and reporting uses a standard CAT5e cable. Complete system installation is typically achieved during a single maintenance shutdown.

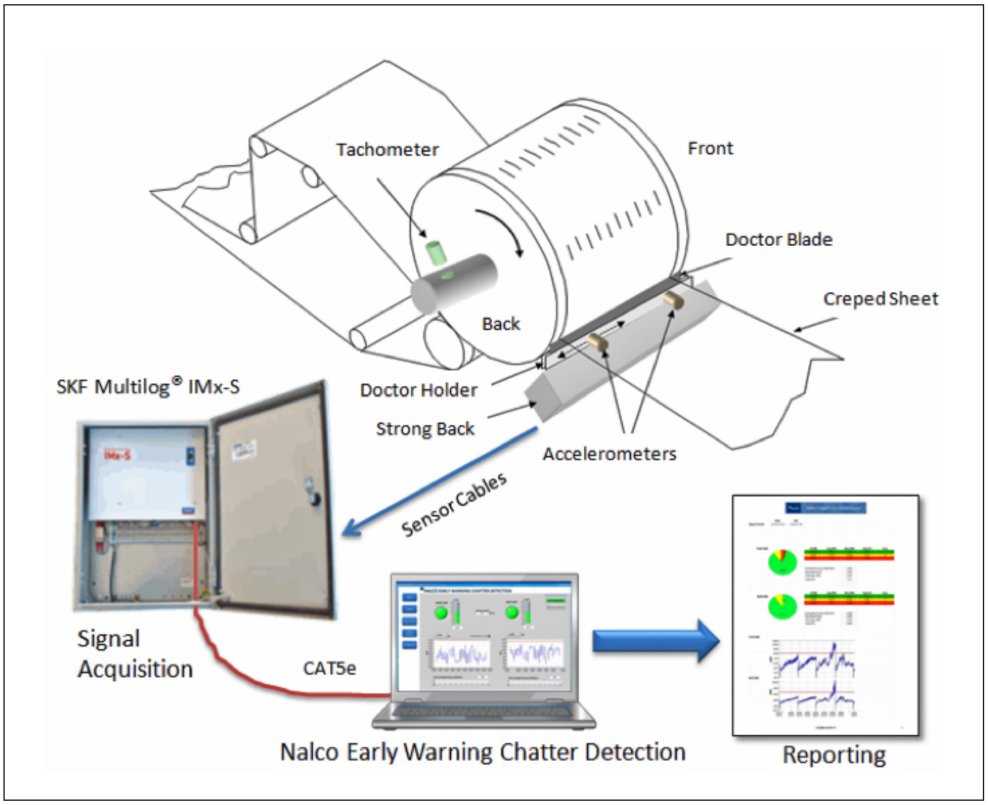

Figure 2 – *Basic setup for the early warning chatter detection system.*

EWCD HMI KEY FEATURES

The EWCD HMI (Human Machine Interface) software is composed of different layers (or screens) used in collecting and transferring information, as shown in Figure 3, with the arrows indicating the directional flow of information. Central to the HMI is the Alarm layer which is the primary viewing screen for operators to observe the current vibration state of the process. The peripheral layers labeled Configurator, Alarm Setup, and Band Analysis are used to define sampling conditions such as sensor channel, display trend length, sampling rate, etc., as well as setting the alarming parameters. Vibration data collected in the Alarm layer is stored in a MS SQL database for later use in setting the alarm parameters utilizing the Alarm Setup and Band Analysis layers, or to generate a summary report.

The HMI layers are intuitively designed, allowing the user to quickly navigate through the different layers to analyze data or adjust alarming parameters. Before setting the alarm parameters, baseline data collection over an extended period of time, e.g., life of a felt, production run for a specific grade, etc., is required. Baseline data collection is critical to establish the characteristic vibration signature (frequency spectrum) produced for a given machine. Factors affecting the vibration signatures from different

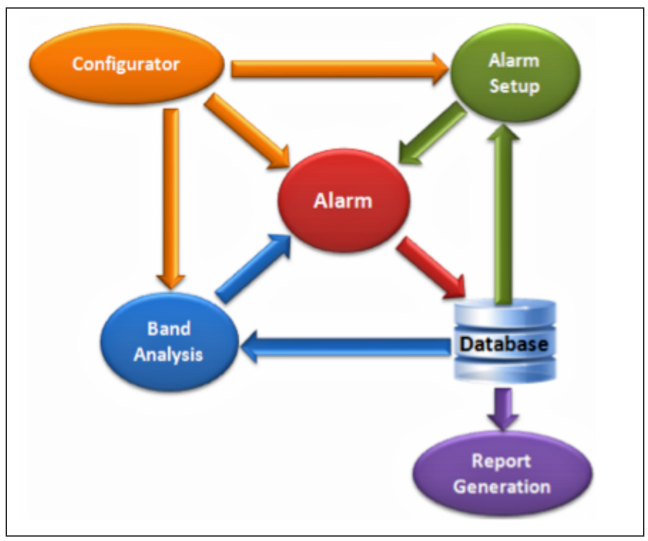

Figure 3 – *Flow chart for the early warning chatter detection software showing the different layers and direction of data collection and transfer.*

Yankee dryers include mechanical design differences in the creping hardware, mechanical and process operating conditions, and vibration sensor mounting location. Nevertheless, common features in the vibration signature are observed from different machines.

A useful tool in the EWCD HMI is the Band Analysis layer for vibration frequency spectra analysis. This layer is used for both baseline data analysis and general data analysis to examine changes in the vibration frequency spectra and identify correlations to process operating conditions. The frequency spectrum collected from the creping process is complex containing broad spectral bands. If chatter is present the overall vibration energy will increase as well as the appearance of new broad spectral bands at high frequencies. Machine vibration sources such as pumps, felts, and rollers are at lower frequencies and have minimal contribution in the frequency range where chatter appears.

Alarming is not made on the frequency spectra but rather the overall gRMS (root mean square) value from the vibration spectra or a band gRMS value from a selected frequency range. The BAND ANALYSIS layer allows the user to recreate trends corresponding to user selected spectral regions of interest (ROI). Figure 4 shows an instantaneous vibration frequency spectrum in the top plot with four spectral regions labeled A, B, C, and D. The lower plot shows the reconstructed trends for each ROI over a 12.5 hour period. Results from this analysis show how the trend varies depending on the spectral regions with differing degrees of sensitivity to process changes. From the simulated trends ROI C exhibits the highest sensitivity to process changes, e.g., at 07:30 ROI C rapidly increases to a higher value relative to the other ROI trends. During this time period the machine experienced a sheet moisture level drop, which increased the tangential resistance on the crepe blade due to the harder coating. This example illustrates the importance of selecting spectral ROI for trending to enhance the sensitivity and response of the monitoring system for early detection of changes that stress the creping process.

Despite these numerous factors affecting the vibration signature for a given machine, common trends are still observed. For example, the ROI trends C, D, and to a lesser degree B shown in Figure 4, and the baseline overall gRMS trend shown in Figure 5, display a characteristic saw tooth pattern resulting from the crepe blade aging. When a new crepe blade is installed, some of the coating is removed, thus reducing the tangential resistance and the observed gRMS. As the crepe blade ages its efficiency to remove coating from the surface decreases due to blade tip wear, resulting in the tangential resistance increasing, which in turn increases the observed gRMS. With periodic changes in either the creping or cleaning blade, a macro cyclic behavior in the gRMS trend is produced forming the characteristic saw tooth pattern. The cyclic behavior observed is one key feature that differentiates crepe blade vibration monitoring from traditional bearing fault detection.

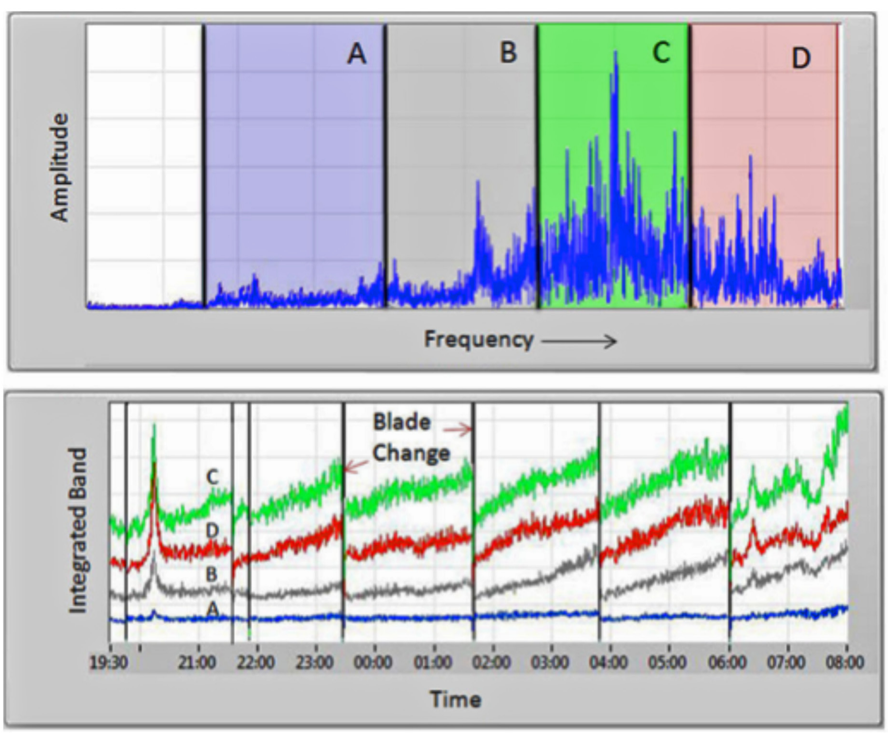

Figure 4 – *Top plot shows a frequency spectrum collected from the EWCD system with user selected markers indicating frequency bands A, B, C, and D used in recreating the trends shown in the lower plot. Blade changes are indicted on the lower plot by the vertical lines.*

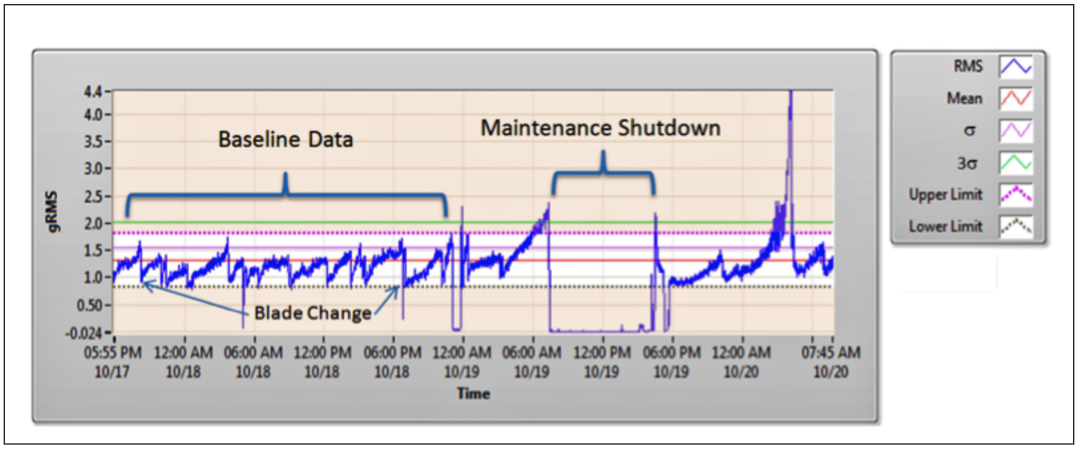

Figure 5 – *Trend showing outlier data in shaded region that is removed in the alarm level calculation. Baseline data spans a minimum and maximum range of 1.082 and shows the effect of blade changes that appear as a sharp drop in the gRMS value.*

For a tissue machine operating under normal conditions, i.e., no evidence of chatter, the natural variation in the gRMS trend defines a minimum and maximum range for the gRMS value. The alarming strategy developed in the EWCD HMI is based on first determining an nσ (ex. n=3) alarm level calculated from baseline data collected with outliers removed. Generally, outliers will appear in baseline data collected over several days and are easily filtered out using upper and lower limits in the Alarm Setup layer of the EWCD program. For example, outlier data occurs when the creping blade is disabled for maintenance procedures resulting in the gRMS trend value approaching zero. Alternatively, a transient jump in the gRMS can also occur driven by a process operating condition change, e.g., startup after maintenance shutdown (sheet moisture decreases). These different features are highlighted in Figure 5 with the outliers in the shaded area of the plot.

The second step in the EWCD alarm strategy is to define a threshold value to alert operators whether a Level-1 (Yellow) or Level-2 (Red) alarm event occurred. If the gRMS value is > nσ the following condition is triggered in the EWCD HMI:

$$\int (RMS - n\sigma)dt = \begin{cases} < n\sigma * threshold = Level - 1\ (Yellow) \\ > n\sigma * threshold = Level - 2\ (Red) \end{cases} \quad \text{Eq. 1}$$

where a Level-1 (Yellow) signals a cautionary state and a Level-2 (Red) alarm is a critical state. When a critical Level-2 (Red) alarm is active an inspection by the operator following a decision tree is the recommended action. The integrated value in Eq. 1 represents the excess vibration, i.e., the vibration energy above the nσ setting over an integrated period of time. This value is also tracked over time and displayed on the Alarm layer as the cumulative excess vibration.

Implementing this alarm level switching strategy reduces false positive alarms as well as indicating shifts in the mean gRMS trend. For example, a gRMS spike with short time duration will not necessarily trigger a critical Level-2 alarm unless the switching condition is met. Similarly, a gRMS value slightly > nσ will trigger a Level-2 alarm if the gRMS value stays above nσ for an extended period of time. In this case, the Level-2 alarm may not be critical, but rather indicating an overall shift in vibration energy occurred. Process changes such as grade, furnish, or production, can cause shifts in the overall gRMS that require the alarm parameters to be readjusted.

The visual display on the EWCD HMI alarm layer provides operators with a clear indication of the current vibration state of the machine. An example screen shot of the EWCD Alarm layer is shown in Figure 6 for an installation using two accelerometers mounted near the front and back side of the creping doctor. The EWCD system can accommodate up to four accelerometers if needed, e.g., wide Yankee dryers > 200 inches can benefit with the addition of a third or fourth sensor to enhance the sensitivity by reducing the zone coverage required for each sensor. For each sensor an alarm level indicator is displayed to show the vibration state of the sensor based on the alarming strategy. A green display indicates the vibration energy is below the alarm level and operating in its normal vibration range. Vibration energy exceeding the alarm level will trigger the alarming strategy to indicate either a yellow cautionary state or a critical red condition. The current gRMS value is reported on a color coded bar plot linked to the alarm level along with a digital display. Plot display options include the gRMS trend with the alarm level or current vibration frequency spectra for each sensor. In addition,

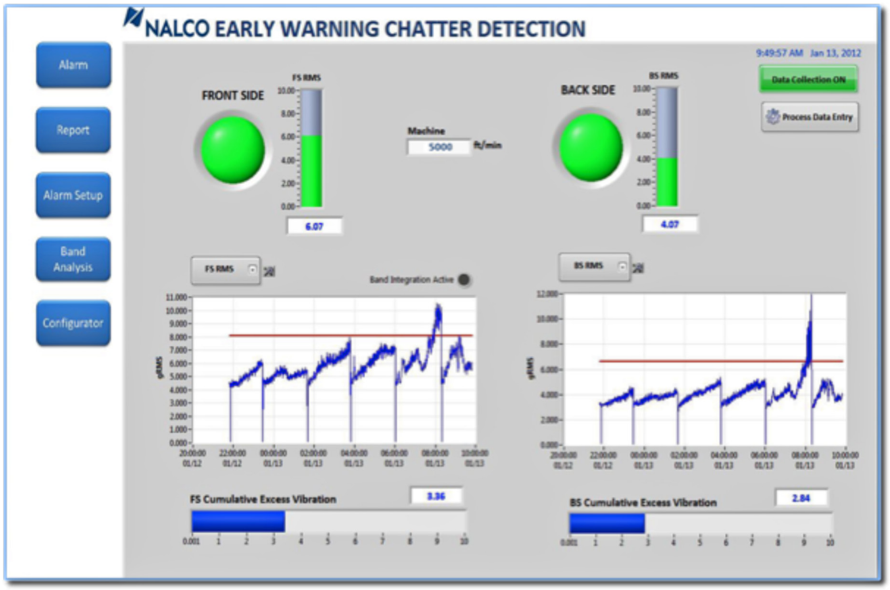

Figure 6 – *Sample Alarm layer HMI displays the current vibration alarm condition and historical gRMS trend or current frequency spectrum.*

the cumulative excess vibration determined from Eq. 1 is displayed to provide an overall indication of the historical level of vibration above the set alarm level. Lastly, a process data entry option is available to track changes in operating conditions, mechanical setup changes, comment on atypical events, and indicate whether chatter is visually observed in the coating. Data entered in this form can be later extracted with the report generation and used to identify trends or conditions leading to chatter, establish a better understanding of operational procedures that stress the creping operation, or alert operators that alarm level adjustment is needed due to a change in operating conditions.

The EWCD HMI also includes a report generation feature to provide a summary of the vibration data and alarm events collected over a user selected time period. Results reported in this layer are reduced to a simple format allowing the user to quickly assess the machine operating performance with regards to the severity and frequency of alarm events. This streamlined approach provides a first level screening to evaluate vibration energy changes related to either operating conditions or procedures. Conclusions drawn from this screening process may indicate required machine maintenance, reevaluation of operating procedures, or may warrant conducting a detailed analysis of the vibration data, e.g., identification of characteristic vibration frequencies, to identify the problematic source.

To highlight the different features in the report generation layer a sample screen-shot is shown in Figure 7. The screen is divided into sections depending on the number of measurement points. In this case, reporting is made for sensors mounted near the front and back side of the creping doctor for data collected over 9 hours where at 08:00 an alarm event occurred. The pie chart on the left hand side shows the analysis results reported as the percentage of time the machine operated within an acceptable vibration level (Green) and time spent in the cautionary Level-1 (Yellow) and critical Level-2 (Red) states for the selected time period. Machines operating with a high percentage of time in a critical state are at risk of irreversible chatter occurring. Additional information on the alarming frequency, i.e., number of times an alarm event occurred, and a breakdown of the average gRMS values with standard deviations for the alarm events are displayed on the right side. This breakdown provides a higher level of analysis useful in evaluating the severity of the alarm events, based on the magnitude of the mean and standard deviation. The horizontal bar plots for each side report the cumulative excess vibration for the selected time period. This gives a quick indication on the side-to-side differences and severity of the vibration. An additional visual check is also provided by displaying the gRMS trend plot and alarm level settings. Optional markers displaying where a Level-1 or Level-2 alarms occurred are also available on the trend plots.

Another optional reporting feature allows comparing the categorized reduced alarm event data collected at different time periods. Alarm event comparison is useful to evaluate how changes in operating conditions or procedures may have negatively or positively affected the vibration on the creping doctor. For example, comparisons can be made for different grades, changes in coating chemistry, furnish changes, or even to evaluate operating procedures from

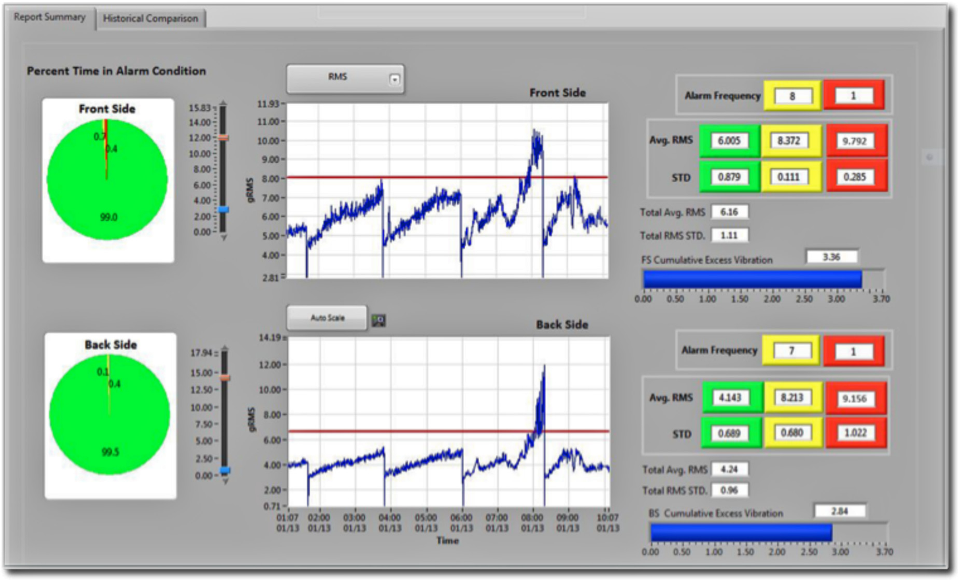

Figure 7 – *Report generation layer to summarize the gRMS vibration measurement quantities collected over a user selected time period.*

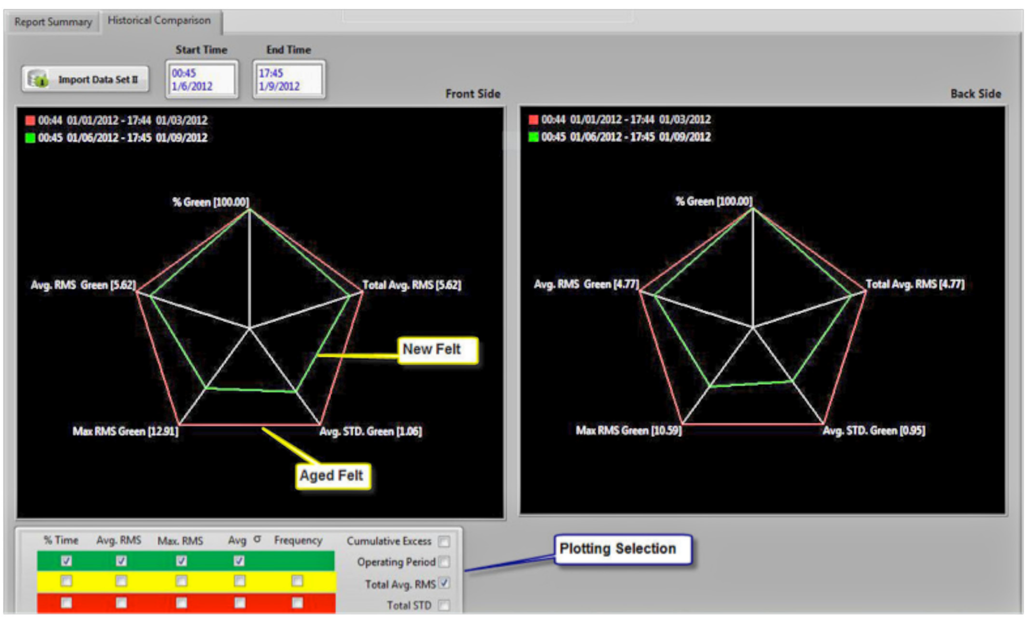

Figure 8 – *Radar plot illustrating changes in selected variables for data collected 3-days before and after a felt change.*

different shifts. The historical comparison is displayed using a radar chart to identify striking differences and commonalities. An example is shown in Figure 8 for data collected 3 days before and after a felt change. The user has the option to select which quantities to plot for comparison. In this example no alarm events occurred, but the average gRMS, standard deviation, and maximum gRMS values for data collected with an aged felt are all higher compared to the new felt data for both the front side and back side sensors.

All data displayed in the report generation layer can be exported to a formatted EXCEL file for printing and distribution or used for further analysis. An option is available to include a higher level of detail in the EXCEL report that includes all captured alarm events and process data entries. Captured alarm event data includes the timestamp when the event occurred, duration of the alarm event, average gRMS for the alarm event, standard deviation, maximum gRMS, and the cumulative excess vibration.

APPLICATION NOTES

This section presents a number of examples illustrating how the EWCD system was used to identify the onset of chatter. The examples demonstrate the sensitivity and response of the system to various mechanical, operational, and chemical changes that stressed the creping operation. Detection of the crepe blade vibration increasing and/or becoming unstable in these examples allowed operators to intervene early and perform the necessary corrective actions to minimize the severity of these chatter events.

Detecting Mechanical Runnability Problems

In the first example, a customer was experiencing a high frequency of sheet breaks along with trim plugging problems. The customer also had a EWCD system installed and observed unusual gRMS trends that showed a high level of instability on the back side of their machine. Time periods when the back side sensor gRMS stability became poor are shown in Figure 9. Here the gRMS trend shows the characteristic decrease when a new creping blade is installed followed by a gradual increase. However, the peak to peak value of the gRMS trend varied significantly at different periods, as indicated on Figure 9. The runnability problems experienced and the instability in the gRMS trend motivated operators to inspect the back side of the machine. This led to discovering a failed tube in the doctor blade holder resulting in poor profiling of the creping doctor and inefficient vibration dampening. After adjusting edge profiling screws and installing a shim behind the crepe blade, the gRMS signal peak-to-peak variation decreased by a factor of 5. In addition, the rapid gRMS increase observed after a blade change was reduced and stabilized Furthermore, the sheet break and trim plugging problems disappeared after conducting the temporary repair. With the improved runnability blade life also increased and ran >5 hours before a scheduled maintenance shutdown, at which time the tube was replaced. Prior to the repair blade changes averaged < 2 hours.

Moisture Variation

Dynamic changes in the tissue machine operating conditions during a startup are common and require careful attention to stabilize the process to minimize the potential for chatter. In this example, a sudden drop in sheet moisture occurred during the startup period after a felt change. The reduction in moisture hardened the coating resulting in more tangential resistance at the doctor blade. The gRMS trend shown in Figure 10 demonstrates the vibration effect when the sheet moisture content dropped. In the startup phase, a balance between the hood temperature and stock flow to the machine is critical. For example, if the hood temperature is ramping up faster than the desired stock flow, the sheet moisture content will become too low causing the coating to harden. Furthermore, sheet moisture content is often not measured during the startup period because the scanner is not yet operational. In this case, the EWCD can provide additional insight on the dynamic changes taking place. Here the EWCD alerted operators the gRMS level had reached a critical state. By taking the appropriate corrective action, which was to increase the stock flow, the sheet moisture level increased, and the overall gRMS level was reduced, thus averting a potential chatter event.

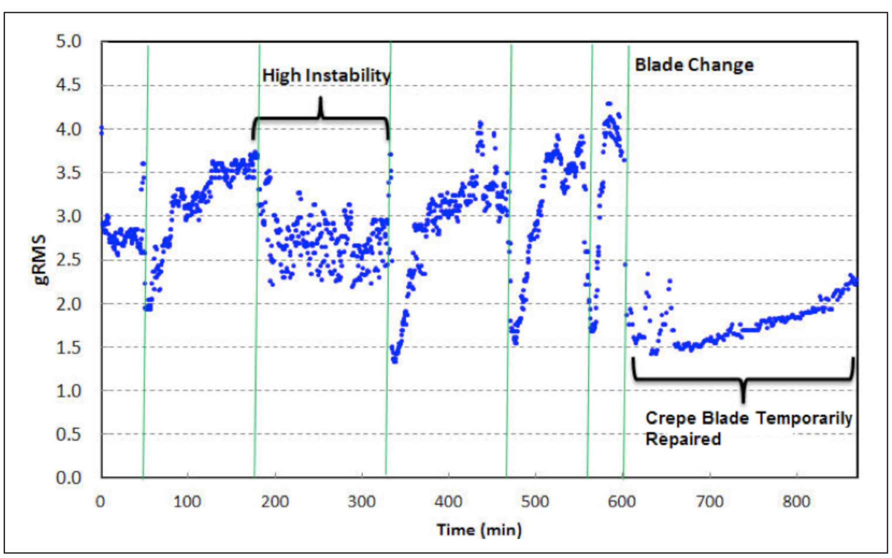

Figure 9 – *Trend exhibiting instability related to the crepe blade holder malfunctioning.*

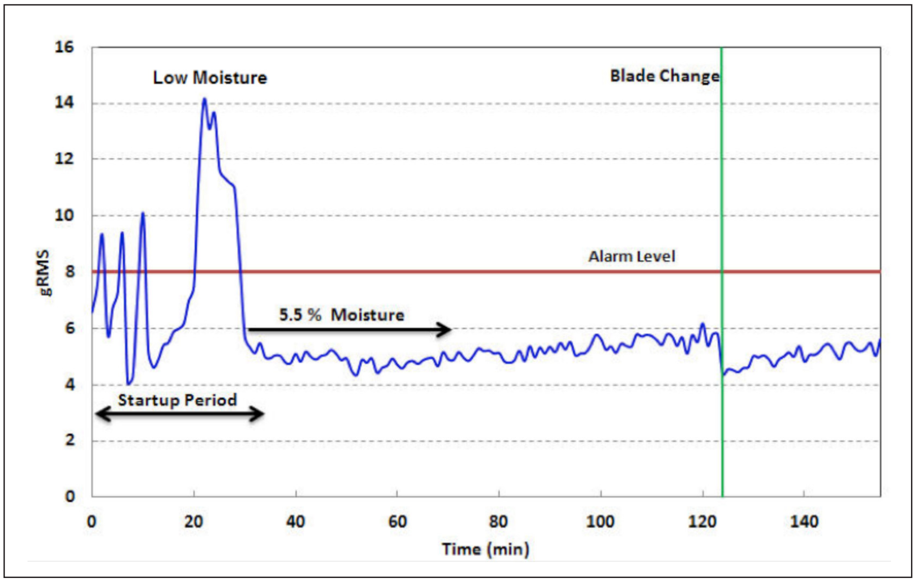

Figure 10 – *Effect of sheet moisture on crepe blade vibration during a startup operation.*

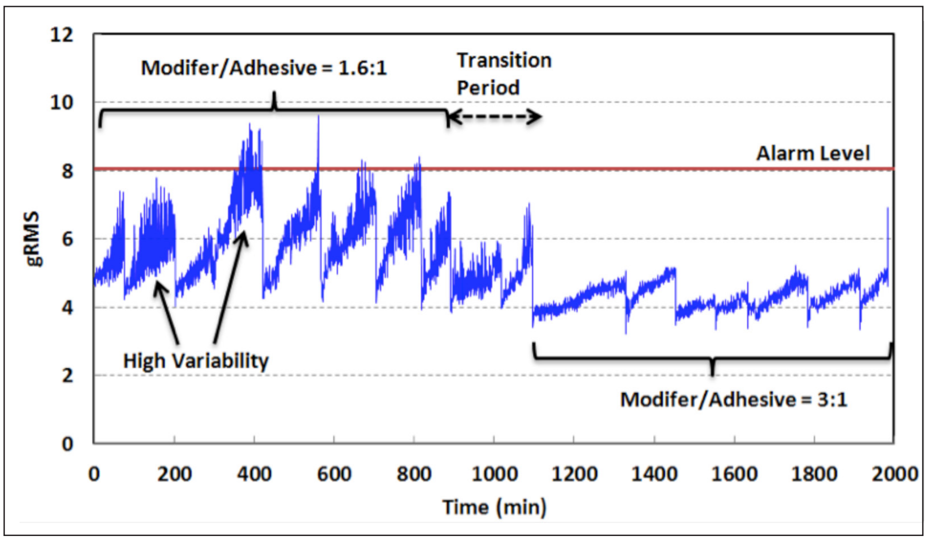

Figure 11 – *Effect of coating chemistry modifier/adhesive ratio on vibration stability and amplitude.*

Coating Chemistry Impact on Vibration

Coating hardness is also sensitive to the modifier or release/adhesive ratio, and if not adjusted properly can lead to chatter conditions. In this example, the modifier/adhesive ratio was adjusted off the optimal centerline value of 3:1 by the operator in an attempt to solve an on-going quality control problem. The operator adjusted the modifier/adhesive ratio down to 1.6:1 and improved the quality, but the change also hardened the coating. Figure 11 shows the gRMS trend operating at the different modifier/adhesive ratios. At the lower modifier/adhesive ratio the gRMS amplitude and variability significantly increased as a result of operating with a harder coating. At this condition micro chatter was visually observed in the coating near the front edge of the sheet. The EWCD system alerted operators of the problem leading to an adjustment of the modifier/adhesive ratio back to the centerline value. As shown in Figure 11, the overall gRMS level and variability decreased along with eliminating the sheet edge chatter. Additionally, the rise in gRMS observed significantly decreased after adjusting the modifier/adhesive ratio

CONCLUSIONS

1. The EWCD HMI provides an intuitive user-friendly environment that engages operators to improve management of the creping operation. Navigation through the different HMI layers is streamlined to develop alarm levels, select optimal vibration frequency bands for alarming, and summarize the results to track how the vibration on the creping operation changes over time.
2. The EWCD is a sensitive and fast response monitoring system to capture changes in operating conditions that can stress the creping operation. This provides additional insight to evaluate operational practices and their effect on the creping operation.
3. Early detection of events stressing the creping operation allows operators to intervene quickly and perform the necessary corrective actions to maintain runnability. Additionally, the EWCD system provides asset protection by minimizing the severity and duration that the creping operation is exposed to critical vibration levels.
4. Implementation of the EWCD vibration system is not restricted to creping process design constraints. The technology can be retrofitted to any creping system with flexibility in the number and location of the measurement points. Installation is straightforward typically done in less than one day during a maintenance shutdown.

REFERENCES

1. Archer, S., Grigoriev, V., Furman, G., Bonday, L., and Su, W., "Chatter and Soft Tissue Production: Process Driven Mechanisms," Tissue World Americas Conference, March 11-14, 2008, Miami Beach Florida.
2. Archer, S., Furman, G., and Von Drasek, W., "Yankee Surface Chatter," Tissue World 2011, Nice, France, March 2011.
3. Alessandrini, A. and Pagani, P., "Chatter Marks: Origin, Evolution and Influence of the Creping Doctors," Tissue World 2003, Nice, France March 2003.
4. Corboy, W., "Vibration Induced Yankee Surface Wear- An Overview of Chatter," Tissue World 2003, Nice, France March 2003.
5. Goldman, S., Vibration Spectrum Analysis: a practical approach, New York, Industrial Press Inc., 1999.

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