Potential Use of High Frequency Demodulation to Detect Suction Roll Cracks While in Service

Thomas Brown P.E.

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Ask paper machine maintenance departments about the worst failures they have experienced, and a large number of replies will involve suction roll shell failures. Roll failures can result in considerable damage to surrounding parts and typically take days to repair. Often, the mill spends months correcting the collateral damage problems caused by the failure after the machine is returned to service. Losses are many times counted in the millions of dollars.

Mills are trying to extend the life of fabrics, felts, roll covers, and virtually every component of a paper machine. Because of the need for cleaning and the huge potential for loss, suction rolls are one of the remaining components that are removed, inspected, and overhauled at fixed time intervals. Fortunately, equipment manufacturers are developing seal strips that run longer, showers to keep suction boxes cleaner longer, and covers that run longer between grinding. However, evaluation of suction roll shell condition remains crucial to preventing catastrophic failure.

Recent experiences at a mill producing publication papers point to a method for monitoring suction roll cracks while in service called high frequency demodulation. Detecting cracks while rolls are in use would support the push to extend roll run times. Such a method would provide an additional level of monitoring that could augment, but not replace, detailed non-destructive examinations done during overhauls or when the machine is shut down.

SUCTION ROLL INSPECTION METHODS

Suction rolls may be inspected using methods described in the TAPPI technical information paper titled “Guidelines for Non-Destructive Examination of Suction Roll Shells” (TIP 0402-19). This document provides a framework for inspecting suction roll shells and determining fitness for service when they have been removed from the machine. The described methods include visual, dye penetrant, borescope, eddy current, and acoustic emission evaluation. However, these methods are time based and are usually governed by the need to remove the roll from the machine for cleaning, seal strip replacement, and grinding of the shell.

Monitoring technologies have been developed and continue to evolve to assess the condition of various components on a paper machine. Bearing vibration monitoring is an example of a method that can be used while the machine is running. We no longer open up bearings and inspect them visually while a machine is shut down. An ability to monitor suction roll shells while in service would help in the drive to extend time between overhauls. In the event of a crack developing between inspections, detection of roll shell cracking in operation would help reduce downtime by allowing a planned outage and avoiding the collateral damage from an unexpected catastrophic failure.

HIGH FREQUENCY DEMODULATION

The use of high frequency demodulation offers a potential method for monitoring suction roll cracks while rolls are in service. Various versions of high frequency demodulation technology have existed for many years. As more field experience is gained, guidelines have developed that assist the vibration analyst in improving the diagnosis of machinery deterioration. Likewise, vendors continue to improve high frequency demodulation products, making them valuable tools for finding and monitoring machinery faults.

High frequency demodulation is a three-step process that separates low amplitude signals caused by impulse or impact events from lower frequency modal vibration associated with machinery faults. The demodulation process begins when the vibration signal from an accelerometer is sent through a high pass filter to remove the lower frequency modal vibrations normally associated with rotational speeds.

Next, the signal is passed through a peak-to-peak “envelope detector” or full-wave rectifier to identify the repetition rate of the impact. This creates a signal that contains both a high and low frequency. Finally, this signal is fed to a low pass filter to remove the high frequency part of the signal. The resulting signal is displayed in the conventional amplitude versus frequency fast Fourier transform (FFT) format.

The major equipment vendors for high frequency demodulation use different filter and detection methods to process the signal. Because of these differences, a conservative approach is recommended where additional and possibly unnecessary data are gathered until a greater understanding of the problem is reached. It cannot be claimed which vendor’s system is most effective, but only that there is much to be learned about high frequency demodulation and its application in the pulp and paper industry, as the following example illustrates.

ANALYZING A COUCH ROLL FAILURE

A recent example points to the potential of high frequency demodulation for monitoring suction roll cracks while rolls are in service. The suction couch roll in this case was in a high-speed gap former producing publication papers at speeds in excess of 4,000 fpm. The face length of the roll is 329 in. and the outside diameter is 55 in. An online vibration monitoring system had recently been installed on the machine that monitored more than 600 points. The couch roll was monitored in the horizontal, vertical, and axial directions using velocity and high frequency demodulation.

Taken from the couch roll, the four spectra in Figures 1 through 4 illustrate the potential of using high frequency demodulation for detecting suction roll cracking. Figure 1 is a velocity spectrum, taken September 15 when there was no observable fault in the roll. Also from September 15, Figure 2 shows a demodulated spectrum using a high frequency bandpass filter of 500 Hz to 10Khz. Figure 3 is a velocity spectrum and Figure 4 is a demodulated spectrum, both of which were acquired October 29 just prior to removal of the roll from service for a cracked shell.

The October 29 velocity spectrum in Figure 3 shows a high second order peak and appearance of multiple low amplitude orders. However, the high frequency demodulated spectrum taken at the same time shows a much clearer pattern developing in which the second as well as higher orders are much better defined. Table 1 shows the overall amplitude increases. From September 15 until October 29 when the suction roll shell was removed due to cracking, the increase in overall amplitude of the demodulated signal was greater than the overall velocity signal increase. The increase in overall amplitude of the demodulated signal is significantly greater than the overall velocity increase.

TABLE 1
Amplitude Comparison

Date	Velocity		Demodulated	
	Overall	**Sync**	**Overall**	**Sync**
September 15	.034	.029	.052	.019
October 29	.045	.037	.202	.153

Comparison of these spectra shows the change began about a month before failure and was readily evident in the demodulated spectrum before indications could be found in the velocity spectrum.

Initially, the demodulated spectrum showed the increase in orders and there was a slight second order increase in the velocity spectrum. We were uncertain how to interpret the demodulated spectrum. In our experience, high frequency demodulation was primarily used for early detection of bearing faults. We knew that a cracked rotor would generate orders due to asymmetry, but thought that it would only apply to the velocity spectrum at lower frequencies.

Surprisingly, we soon learned otherwise. The roll developed a longitudinal crack that resulted in an unscheduled outage to change the roll. The orders generated by the cracked shell appeared first in the high frequency demodulated spectrum before becoming evident in the velocity spectrum. The change in overall values was greater and the appearance of orders occurred sooner! Based on this experience, we believe that high frequency demodulation might provide early warning of cracked suction roll shells.

The experience with this couch roll indicates that the amplitude modulation of the high frequency signal can identify roll cracking with greater definition before it becomes evident in the velocity spectrum. Thus, we should expect to see structural defects in high frequency demodulated spectrums before they become evident at lower frequencies.

Questions remain as to which vendors' filter and detection methods are most effective, but there are two important factors that influence the results obtained using high frequency demodulation. Mounting of the accelerometer is paramount and selection of the correct filters can still be a process of trial and error.

Stud mounted accelerometers give the most repeatable and reliable high frequency demodulated data. High frequency demodulation was first implemented at the publication papers mill in this example using hand held data collectors and magnet mounted accelerometers. However, it was difficult to gather meaningful data because the amplitudes varied substantially from survey to survey. High frequency demodulation was just used as a secondary tool to confirm a diagnosis made from the modal vibrations associated with rotating speeds. When an online monitoring system was installed with permanent stud mounted accelerometers, the value of high frequency demodulation was realized because the variability due to different accelerometers and, most importantly, the mounting was eliminated.

The horizontal direction provided the best response to the crack in this situation. The roll was monitored in three directions of the tending and drive side of the machine. Horizontal, vertical, and axial accelerometers were mounted on a common block attached to one of the bearing cover bolts on both sides of the roll. At this time, it cannot be said if one direction will be more sensitive to shell cracking than another. If directional stiffness is used as a guide for positioning an accelerometer, then the direction with the lowest stiffness, which in this case was the horizontal direction, should be used.

Selection of the filter ranges and bands is where the science weakens and the art of vibration analysis takes hold. If a filter range is selected that does not include the energy of the high frequency impact, then the deterioration can be missed. When using band pass filters, it is better to err on the side of too many filter bands. Likewise, the high pass filter cutoff frequency should be chosen so that it does not exclude the impact energy. In either case, it is very important that maximum frequency of the spectrum display is not greater than the minimum frequency of the filter.

FACTORS IMPACTING SHELL MAINTENANCE

Advances in the shell metallurgy coupled with better understanding of the mechanisms that lead to deterioration and failure have made failures of suction roll shells less likely today than in the past. The duplex stainless steels that dominate shell material in the market today are more resistant to general and localized corrosion, especially when compared to bronze shells, and have higher resistance to crack propagation.

Even with these improvements, monitoring of suction roll shells is an important part of equipment monitoring because of the potential for huge losses. Activities to insure continued reliability of suction roll shells play an important part in minimizing the potential losses and insuring greater reliability.

As mentioned earlier, monitoring demodulated spectrums of suction roll shells should not be considered as a substitute for regular inspections as outlined in TAPPI TIP 0402-19. High frequency demodulation has the potential to become another tool in the toolbox needed for today's businesses to improve reliability of paper machines by allowing detection of an impending shell failure before it shuts the machine down unexpectedly. In the same way, vibration monitoring of bearings is important, but it is not a substitute for monitoring lubrication contamination.

The TAPPI inspection guideline covers six significant topics. Briefly, these are:

Shell cleaning and visual examination.
Written inspection procedure
Examination and interpretation of the results by trained and qualified people
- Penetrant testing
- Acoustic emission testing
- Metallographic examination

Examination frequency
Documentation
Pre- and post-grinding inspections

In the event that a crack(s) are discovered that cannot be removed by grinding, the mill's only practical option in many cases is to monitor the cracks while a shell is procured. If a shell must be run with a crack, more frequent monitoring to determine the rate of crack growth as recommended in TIP 0402-19 must be done. In this situation, monitoring demodulated spectrums may provide warning of rapid crack growth prior to failure.

In addition to examination of the shell and monitoring the demodulated spectrums, there are other events that can occur on a paper machine that affect suction roll shells. Operational changes may improve the performance of the machine at the expense of reliability. When the load on a suction roll shell is increased either from an increase in vacuum or loading (pli), a thorough evaluation of the shell should be completed. Likewise, changes in wet end chemistry should be followed by increased diligence of suction roll shell conditions. Unfortunately, the effects of these changes on suction roll shells may take months or even years before becoming detectable.

Unexpected events may also cause damage leading to shell cracking. If the seal strip shower water is not turned on, the localized heating caused by the seal strips rubbing on the bore of the shell may result in thermal cracks developing on the inside of the shell.

Also, unexpected mechanical damage to a shell caused by catastrophic failure of other machine components such as felts, roll covers, showers, etc. can send pieces through a fully loaded suction roll nip. The localized damage to the roll may serve as a crack initiation site.

In addition, procedures used to clean suction roll shells may damage them and lead to premature failure. Cleaners that are corrosive to the shell should be avoided. This includes products used to clean the shell as well as those used to clean felts on the machine. If holes in the shell are plugged, tools such as twist drills that can create a sharp notch should not be used to clean them. The notches created can initiate corrosion fatigue cracks.

FAILURE POSTMORTEM

The failed couch roll at the publication papers mill was manufactured in 1986 from a duplex stainless Alloy KCR-A682. This alloy was one in a progression of alloys developed by roll manufacturers to combat corrosion fatigue. Newer alloys that have greater resistance to corrosion fatigue have replaced it. However, there are a significant number of rolls made from the earlier generation of stainless alloys and bronze still in service.

The roll in this example went from no vibration evidence to failure in 34 days. If we had recognized the significance of the information in the demodulated spectrum, a planned outage could have been scheduled that would have minimized the collateral damage. Fortunately, the collateral damage in this case was expensive but relatively easy to correct; two new forming fabrics were ruined and required replacement.

After the cracked roll was removed from service, it was calculated that it had operated 2,816 days or approximately 1.1×10^9 cycles since first installed. After its removal, we sectioned an area through the crack. In addition to the main longitudinal fracture, there were numerous other fracture sites. Additional analysis determined that corrosion fatigue was the cause. Also, the roll had not been examined using dye penetrant or acoustic emission in its entire history. This lack of data complicates development of the theories to explain what was seen in the demodulated spectra.

A “spare” roll was placed in service while a new shell was fabricated for the cracked roll, and what occurred with it is also interesting. This roll eventually operated 1,899 days or approximately 7.6×10^8 cycles as calculated from its first installment. When the new shell made from Alloy 86 arrived, it was assembled and installed, and the spare roll, which had operated 920 fewer days than the original roll, was removed and penetrant tested. Two cracks were found.

Several questions come to mind when considering this data. Did the chemistry of the wet end change? Were both the original and the spare rolls cracked before being placed in service after the last rebuild? If so, what was the crack growth rate before signs were seen in vibration spectrums?

5191 Country Lane, Duluth, MN 55810 • Voice 218-729-4646 • Fax 877-585-8982
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SUGGESTED MONITORING STRATEGY

How should suction roll maintenance change in light of the findings at the publication papers mill? Since this is one event, we need to collect additional information regarding suction roll failures. If the experience and data from other failures supports our evidence, then one can consider using this monitoring technique for suction rolls while in service. In the meantime, vigilance using proven non-destructive examination (NDE) methods must continue. In the event that one is able to detect incipient failure while in service, one should still continue to inspect suction rolls while they are out of service.

A suggested monitoring strategy would consist of the following activities:

1. Complete a baseline non-destructive examination of suction roll shells. The preferred method is water washable fluorescent dye penetrant. Test the rolls using acoustic emission.
2. Use a permanently mounted accelerometer to monitor the roll. In our example, the horizontal direction provided the best results. We used a bandpass filter with a range of 500 Hz to 10 kHz, an f_{max} of 12,000 cpm, and 800 lines of resolution with 1 average. Adjust these values to match the speed of the roll being monitored. The couch roll in this example was running at approximately 297 rpm. It is important to use a permanent accelerometer mounting. In my experience, temporary mounting causes substantial variability in the data.
3. Check suction rolls for cracks when they are removed from service in accordance with the TAPPI guidelines. If cracks are found and no other alternative to running the roll exists while a new shell is ordered, increase the frequency of NDE inspections and monitoring with demodulated spectrums.

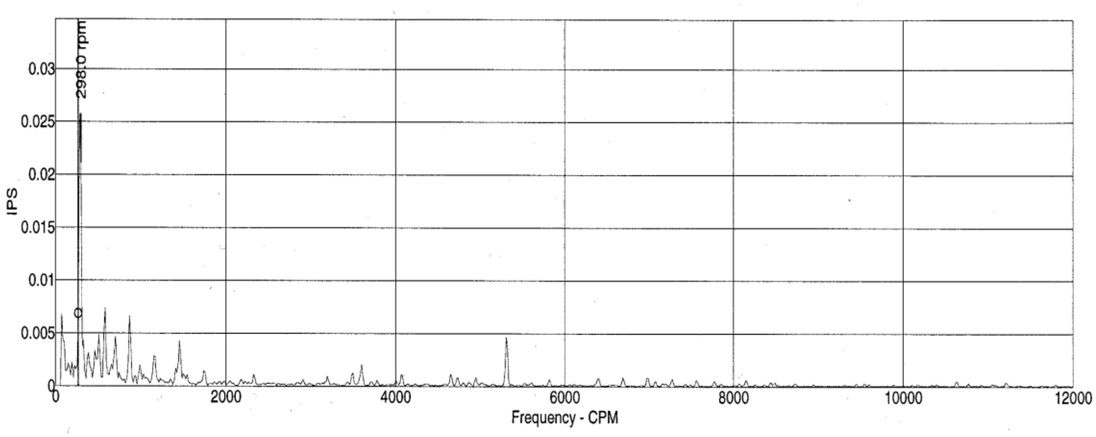

Figure 1
The Sept 15 velocity spectrum showed no faults

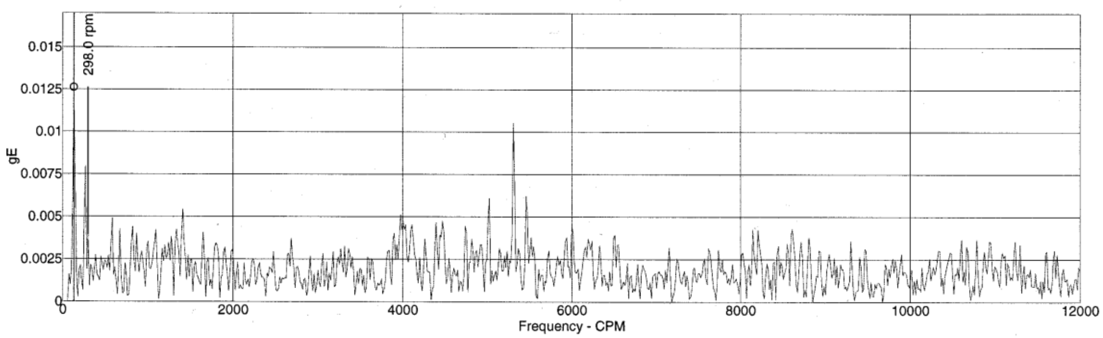

Figure 2

The Sept 15 demodulated spectrum also showed no faults

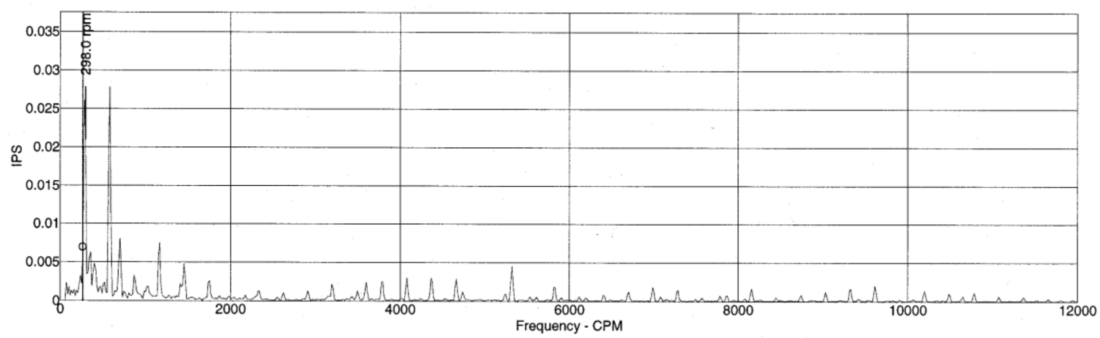

Figure 3

The October 29 velocity spectrum shows low level harmonics and very little increase in amplitude.

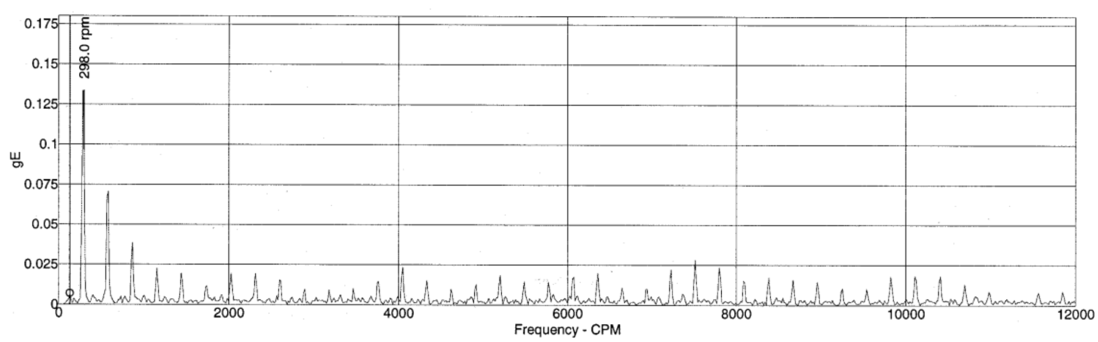

Figure 4

The October 29 demodulated spectrum showed well-defined harmonics and an increase in amplitude

Figure 5
Suction roll with triaxial accelerometers

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