Winder Vibration Related to Set Throw-outs

Jake Zwart
Spectrum Technologies and LSZ PaperTech
1075 Milborough Line, R.R. 1
Millgrove, ON L0R 1V0

Walter Tarnowski
NorskeCanada
PO Box 70 Crofton, BC V0R 1RO

ABSTRACT

Throwing a set out of a 2-drum winder has been a problem since winders became shaftless. It is a problem that tends to get worse as winder speed increases.

This paper presents a case study of relating winder vibration to roll throw outs. It was found that the predominant level of vibration is related to the set rotational frequency, and that the vibration increased greatly when the set diameter slightly exceeded the diameter of the queen roll in the calender. Included in the study are the other significant factors that put this winder at risk for throw outs.

A computer model was developed to show how sinusoidal caliper variation induced in the paper affects the eccentricity of a roll when it is being wound. The model shows that there is no effect until the wavelength of the variation is equal to the circumference of the roll being wound and at this diameter there is a step change in eccentricity. This model explains some of the vibration effects seen in the case study.

INTRODUCTION

Roll throw outs have been a problem since two drum winders became shaftless. The best source of information for an existing paper mill is a paper written by Olshanski [1]. He gives a general description of the problem, with background in the types of vibration that can occur. This paper gives a trouble-shooting procedure that a mill can use to try and resolve a throw out problem.

A mathematical description of the factors influencing paper vibration in the pocket of a winder is given by Jorkama [2] and Olsen & Irgens [3]. This is very important for understanding the vibration in detail, which leads to an understanding of the many important factors contributing to vibration, and potentially aids in leading to design changes in the winder itself.

In addition there are a number of people knowledgeable in this field, with many years of experience in dealing with all kinds of winding problems. Both Lucas [4] and Helen [5] have unpublished trouble-shooting procedures for roll throwouts.

Winding models such as that presented by Hakiel [6] have become sophisticated in modeling the process of building a roll of paper, taking full account of the elastic properties of the paper. These models give the roll structure as a function of radius and assume paper is uniform in the machine and cross directions.

WINDER ROLL VIBRATION

A roll of paper, as it is being wound has no translational momentum. The velocity of the roll when thrown from the winder comes from the conversion of the rotational momentum of the roll to translational momentum. This conversion of momentum is initiated by vibration in the set [1].

There can be many causes for the initial vibration [1,4,5]. Some of the more important factors are listed below. All winder controls must be functioning properly, the roll must be built with a good wound-in-tension profile, and the paper itself must have a coefficient of friction less than 0.5 and be uniform as it comes from the paper machine. The cores must be straight and all cores in a set must be of uniform diameter. The tips of the cores must be cut straight and square. Metal tipped cores give more problems than fiber cores. The winder itself must be functioning properly with good alignment and balance. Direct acting hydraulic rider rolls reduce rider roll bounce, ensuring more uniform force to keep the set in the pocket. Spreading and slitter alignment with the cores' ends are additional factors that can lead to roll throw outs. A resonance within the winder system must not coincide with a rotating frequency for any length of time. The winding system includes the mechanical properties of the winder and the set of paper being wound. Often when a roll throw out occurs, a number of these factors contribute to the problem.

Vibration Theory

The vibration level of an object is determined by the excitation force exerted on the object, and how easily the object vibrates. Usually rotating shafts or impacts causes the excitation force. Sometimes the excitation force comes from physical changes in the object itself, such as diameter variations of a cylinder, caused by the existing vibration. When this self-excited vibration is present the existing vibration acts to increase the amplitude of vibration over time. Examples of self-excited vibration are the washboard effect on a gravel road, press barring and calender barring.

Another possibility is a paper roll that starts rocking, causing the outside edge of the roll to be forced against the neighbouring roll. A slight difference in the peripheral velocities of these adjacent rolls, due to the rocking, can act as an additional excitation force, probably being the force that ultimately throws the roll out of the winder pocket. While one or both of these forces are undoubtedly present when a roll is thrown, it is quite possible that they are not present until that time, and thus these effects are not visible in the vibration measurements.

Logically, then, there are two main things to look for in resolving any vibration problem, one being the excitation source(s) and the second being a resonance to amplify the excitation forces. In addition, look for complicating factors such as a self-excitation mechanism.

Set Eccentricity Modeled from Caliper Variation

Current winding models do not incorporate non-uniform paper properties. The measurements taken in the case study discussed below led to the speculation that caliper variations were the source of consistent increased vibration levels on the core chuck at a specific diameter. To confirm this speculation a model of roll eccentricity caused by caliper variation was created. The main assumption in this model is that it treats paper as a rigid material, in other words there is no elasticity to allow the paper to compress radially or stretch tangentially. The results in Figure 1 show that the set eccentricity is not affected by sinusoidal caliper variations until the set circumference reaches the wavelength of caliper variations (set diameter reaches the diameter of the roll that imparted the caliper variations). At this point there is a dramatic increase in eccentricity that does not diminish as the roll continues to build. There is some high frequency oscillation in the eccentricity however.

The second curve shows what happens if the king roll also causes caliper variations. Up to the king roll diameter there is no difference in eccentricity. At the king roll diameter there is a marginal decrease in eccentricity with more high frequency oscillation in eccentricity. The addition of some random caliper variation is given by the curve with the highest level of eccentricity showing that there is only slightly more eccentricity that builds most rapidly at small diameters.

A number of additional trials were modeled with much larger diameter sets. At each integer multiple of the diameter of the first step change in eccentricity, another step change occurs, almost always increasing the eccentricity.

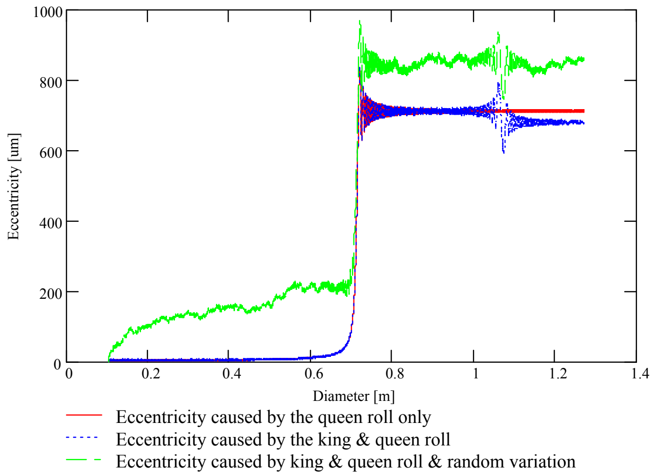

Figure 1 The eccentricity as a function of time

CASE STUDY

The Beloit model L, a typical 2-drum winder on paper machine 3 at Crofton has had problems with sets being thrown out. Many of the sets have been thrown out at just over 700 mm diameter, which led to the speculation that there might be a caliper variation in the paper that caused the high vibration level. In addition, they have occurred on a number of occasions at much smaller diameter. These were described as being caused by pop opens. This report will focus on the problem associated with the larger diameter set throw-outs. A brief history of events is given in Table 1.

Friction

It is clear that the interlayer friction of paper [1,4,5] is an important contributing factor in roll bounce problems. Once an initial bounce occurs with sufficient impact to cause a dent in the surface of the roll, internal pressure acting from the interior of the roll tries to push it out. For the dent to be pushed out, however, the layers of paper near the surface of the roll at the dent will need to slip against each other. If the friction is above 0.5 [1] the dent will not push out of the paper. When this dent reaches a subsequent nip it acts as a vibration exciter. This self-excitation mechanism can then act to increase the vibration level and, in the end, cause the roll to bounce out of the pocket.

Table 1 History of events related to roll throw outs

Date	Event
Prior to Mar 2001	sets only thrown out on metal tipped cores
Mar 10-14, 2001	queen roll change
Mar 22, 2001	set thrown with Japanese metal tipped core
April 26, 2001	complete stack change, rolls 1-5
Aug 7, 2001	set thrown with plain cores
Oct 10, 2001	set thrown with plain cores
Nov 3, 2001	complete stack change
Early June 2002	set thrown

The friction of the paper produced from the paper machine at Crofton has a CoF of 0.67 to 0.7, with an average value of 0.68, which is significantly higher than the value quoted in the literature.

Friction is predominantly an effect that occurs at the fiber level, and with the addition of soaps in a recycling plant, the fibers tend to become slippery, reducing the CoF with increasing recycled content. The addition of up to 40% recycled furnish did not affect the friction at Crofton. Possibly the PCC content was overriding the effect of soaps used in recycling. PCC content was also varied, but when used within the range required for acceptable optical properties, the variation did not affect the friction.

Frequency Response Function (FRF) Measurements

Frequency response function measurements were performed with a modal hammer on the winder drums without paper and on the rider roll and core chucks with a set in the pocket to determine the resonances present. The rider roll FRF measurements were taken at set diameters of 500 mm, 700mm and 1000 mm. The core chuck FRF measurements were only done at 1000 mm set diameter, as their natural frequency was not expected to be a function of the set diameter. All FRF tests were done while the winder was stopped.

The frequency response functions ¾ of the way to the drive side of the front drum is shown in Figure 2. This shows that a resonance exists in the 22 to 25 Hz range, with the vertical direction having a slightly higher resonance due to the bearings being stiffer in this direction. The rider roll results, Figure 3, show that there is a natural frequency of about 12.5 Hz and 23 Hz on the rider roll at all the diameters tested. The core chucks, Figure 4, have their own separate natural frequencies. The response of the core chucks is fairly flat from 20-60 Hz, with a lower response at around 10 Hz.

Since the winder was stopped while taking the driving point FRF measurements, the dynamic characteristics that change during rotation, due to gyroscopic effects, were not taken into account. These effects are not expected to have a large impact on results.

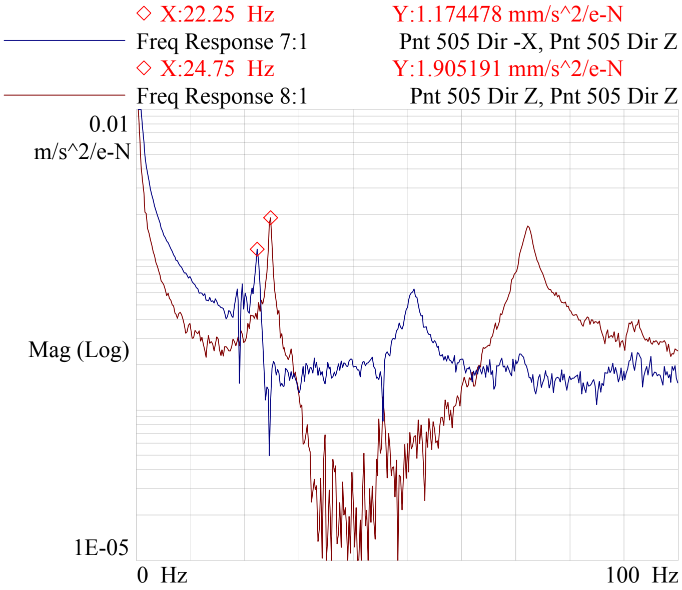

Figure 2 Front drum frequency response functions showing resonance.

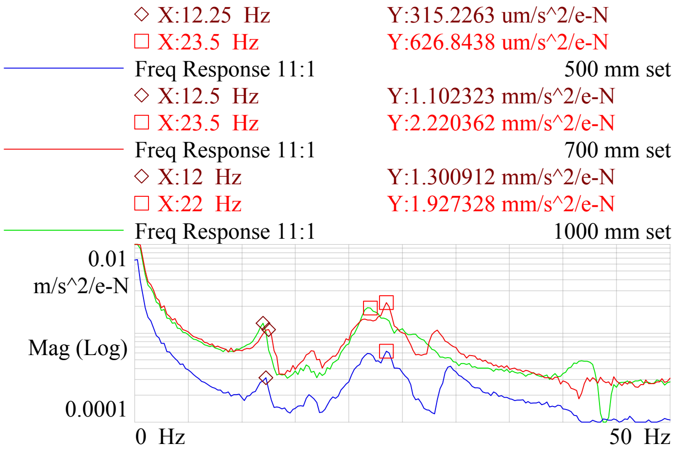

Figure 3 Driving point FRF on the tending side of the rider roll

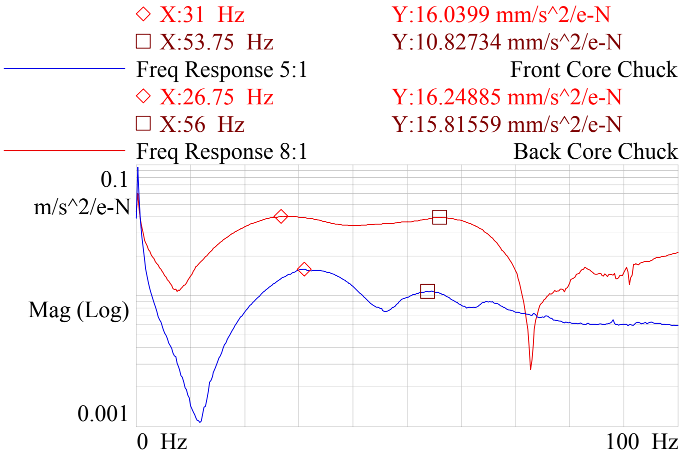

Figure 4 The core chuck FRFs at 1000 mm set diameter

The nature of the frequency response measurements taken from the rider roll only accounts for the translational rigid body modes of the individual paper rolls in the winder. The impact testing will not excite the rotational rigid body modes of the rolls. These will be a function of the width of the rolls in the set. It may well be that these unmeasured rotational rigid body modes are important in determining whether a roll will be thrown out.

Operating Measurements

To determine the vibration characteristics of the winding sets of paper, the vibration was measured on the rider roll beam and the core chucks during operation. In addition, measurements were taken from the bedroll bearing housings to determine if they were causing a problem. The vibration data was collected as time history files with the results calculated later. Included with the data was a 1 pulse per revolution tachometer signal from the core chuck and back drum. The vibration on the tending and drive side core chucks was measured with triaxial accelerometers. The vibration occurring at the top of the rider roll beam on the drive and tending side was measured in the same manner. From this data the nature of the vibration was determined by plotting the vibration as a spectral map. The spectral maps clearly show that the vibration associated with the set rotational frequency was the dominant vibration. Additionally the vibration occurring at the set running speed was plotted as a function of time, set diameter and vibration frequency. In summary, the time history file was processed into a set of spectra, which was plotted to determine the sources of the vibration content. The frequency information at the set rotational speed was then extracted and replotted a number of different ways.

Winder Bedroll Vibration

The vibration on the winder bedroll bearings on the drive side was measured, to determine if the bedrolls could be a potential source of vibration. A typical example measured while a set was building is shown in Figure 5, which shows the vibration is very low, less than 1 mm/s, and not a cause for concern.

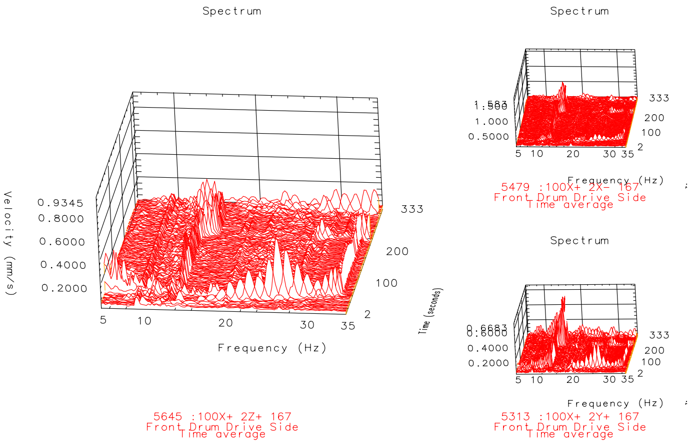

Figure 5 The vibration in three directions on the drive side of the front drum

Core Chuck and Rider Roll Vibration Measurements

The initial measurements of winder vibration seemed to have somewhat different characteristics than later measurements. The high vibration levels often occurred over a broad diameter range. Over one measurement period the vibration first appeared at about 450 mm diameter and increased in level until 570 mm diameter. The frequency of this vibration did not correspond with the measured resonance frequencies, indicating that it came from an external source or a non-measured resonance.

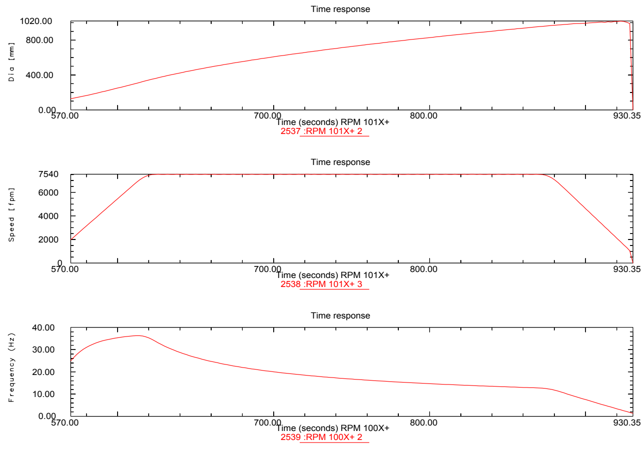

Figure 6 Diameter, winder speed and set rotational frequency over time

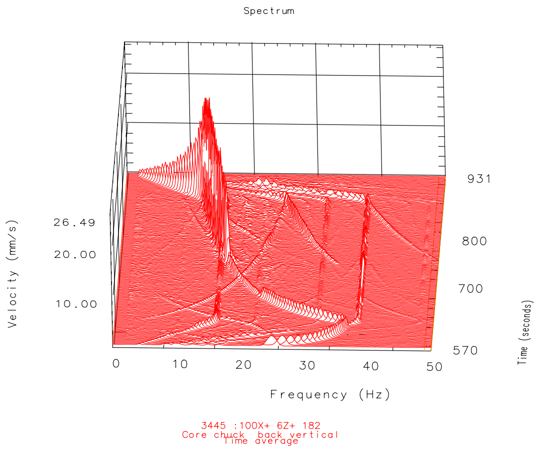

Figure 7 Spectral map of drive side core chuck vibration over time

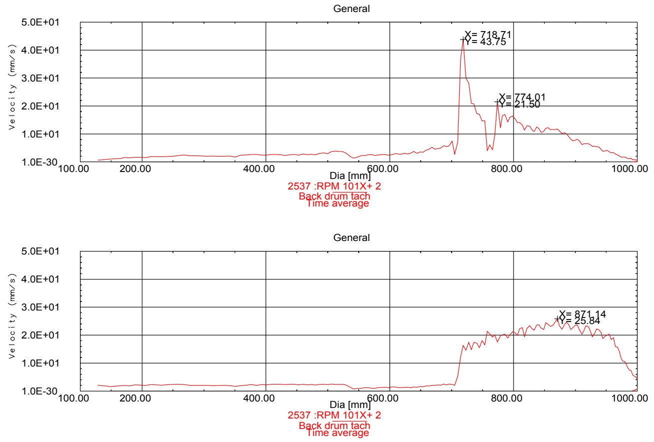

Figure 8 Vibration of tending side (top) and drive side (bottom) of core chuck vs. diameter

An eccentric roll would be expected to cause high vibration levels on the core chucks but have little effect on the vibration of the rider roll. Since this vibration also is present in the rider roll, it is coming from the winder rather than the paper.

A typical example of vibration is shown in Figure 6, Figure 7, and Figure 8. The vibration on the tending side core chuck remained quite low until the set reached 719 mm diameter, at which point the vibration level increased greatly. At times the vibration level dropped off to previous levels, while at others times, as in this example, the vibration level dropped off from the peak value but stayed much higher than it was initially. The tending side vibration level ranged in peak amplitude from around 20 mm/s to 50 mm/s for the different sets measured.

The vibration on the drive side core chuck increased to a much lower value of 18 mm/s as compared to 44 mm/s on the tending side core chuck at the same diameter. While the tending side core chuck vibration began to decrease at this point, the vibration of the drive side core chuck continued to increase very slightly until the winder speed started decreasing. This residual effect corresponded to the model where the eccentricity remains unchanged with a sinusoidal caliper variation. The rider roll had some vibration present, all within 2.5 mm/s. This vibration level peaked at 719 mm, but on the tending side was also present at around 760 mm diameter.

Taking the commonly accepted vibration levels for rotating machines where vibration under 1 mm/s is considered very smooth and over 10 mm/s very rough, we see that often the core chuck vibration was much worse than the 10 mm/s limit. This vibration level is easily noticeable visually.

Trials

A number of trials were performed to determine the effect of different conditions on the vibration level. A summary of the results is shown in Table 2.

These results show great variability in the vibration levels, for no apparent reason. They also show that the vibration level was greatly reduced when the speed was reduced, especially around 719 mm, the diameter at which high vibration occurs. The vibration due to the eccentricity after this speed remained as a background vibration. Reducing the speed to 6000 fpm did reduce the vibration levels.

There did not seem to be any additional vibration reduction effect at 719 mm diameter when accelerating through this diameter region. This is additional confirmation that resonance was not involved.

General Observations

At low vibration levels, such as that experienced by the rider roll, often the vibration was higher at a set diameter of 760 mm. This is because there was some vibration due to the bedroll rotational speed. The algorithm used for plotting the vibration is not able to distinguish the vibration from the different sources but attributes all vibration at the given frequency to the reference tachometer source.

Table 2 Results of trials held for varying speeds

Name	Condition	Speed	TS vib	DS vib
Win13_02a	constant speed	7740	34	9
Win13_02d	constant speed	7740	46	17
Win13_02e	constant speed	7740	36	7
win13_03a	constant speed	7540	16	17
win13_03b	constant speed	7440	44	26
win13_03c	constant speed	7030	19	6
win13_03d	@ 650 mm reduce speed to 5000 fpm – increase after 710 mm	7540	4	11
win13_03e	@ 610 mm reduce speed to 5000 fpm – increase after 710 mm	7540	4.5	9
win13_04b	@ 640 mm reduce speed to 6000 fpm – increase after 710 mm	7840	26	43
win13_04c	@ 640 mm reduce speed to 6000 fpm – increase after 710 mm	7840	6	18
win13_05a	accelerate through 710 mm – start deceleration at 640 mm	7840	3.5	7
win13_05b	accelerate through 710 mm – start deceleration at 620 mm	7840	18	18
win13_05c	accelerate through 710 mm – start deceleration at 630 mm	7840	36	14

It is clearly evident that decreased winder speed reduced the vibration level of the core chucks. This is consistent with the vibration being driven by the roll eccentricity, where the displacement does not change with rotational speed, but the vibrational velocity will increase linearly with rotational speed.

At times when the vibration level had increased to a high level it seemed to stay at that high level. When the winder speed dropped the vibration level dropped also. If the winder speed then increased, the vibrational level also increased.

With all the measurements indicating that the vibration increases dramatically at 718 mm, the diameter of the intermediate calender rolls, measurements were performed to determine if the calender rolls were imparting a caliper variation in the sheet.

Caliper Variations TAPIO Measurements

TAPIO Measurements were taken during the vibrations measurements and the results are shown in Table 3.

A consistent caliper variation problem is evident at about the queen roll rotational frequency. The caliper variation from the stack has increased since the stack was last changed. The caliper variation is much higher than normal or desired. The vibrations measured at the winder were consistent with the paper eccentricity model developed above.

Table 3 Paper MD caliper variations

Date	Location	Amplitude	Frequency
Oct 10, 2001		1.33	9.422
Late Oct, 2001 after stack change		0.47	9.97
June 2002	Tending side	0.93	9.33
June 2002	Drive side	1.15	9.33

Calender Vibration Measurements

With the intermediate calender rolls, specifically the queen roll being implicated in the problem, measurements were taken on the calender stack itself to determine the possible source of the problem. Caliper variation in the paper is predominately due to the last nip. Thus the king roll and queen roll rotational frequency will be the primary frequencies present in the paper. Previous nips may put an equally great caliper variation into the paper as it comes out of that nip, but this variation is calendered out in subsequent nips. Not only is this phenomenon consistent with the calendering equation, but it has been measured in another mill.

The rotational frequency of the calender rolls is shown in Table 4. With such closely spaced frequencies, zoom measurements were performed to distinguish the vibration contribution from each of the intermediate rolls as shown in Figure 9. The vibration contribution due to the queen roll was the highest, with the vibration of the 5th roll the second highest contribution. Amazingly the frequency due to the 5th roll was the highest in the king roll vibration. The contribution of the 4th roll was the lowest, with the contribution of the 3rd roll at an intermediate level.

Table 4 The measured and calculated rotational frequency at 4404 fpm

Roll	Diameter	Rotational Frequency	Measured Frequency
Top roll	704.9262	10.11856	
5th roll	710.946	10.03288	10.033
4th roll	711.1492	10.03001	10.029
3rd roll	711.5048	10.025	10.025
Queen Roll	710.438	10.04005	10.038
King Roll	1067.054	6.684606	

With the vibration of the rolls being this closely spaced, and with the upper rolls having a significant contribution to the king and queen roll vibration, the amplitude of vibration will vary depending upon whether the vibration is in phase or out of phase. When the vibration adds there will be a higher caliper variation than when it subtracts. This phenomenon is known as beating. Taking the queen roll and 5th rolls as examples, the complete phase relationship from being in phase to out of phase and back in phase takes 140 seconds, so they will be additive for about ¼ of this time or 35 seconds. The amount of eccentricity imparted into the set will be significantly higher while the vibration is in phase as compared to out of phase. It also means that, to get an accurate picture of the caliper variation, data must be collected at least for one complete cycle and preferably for a few.

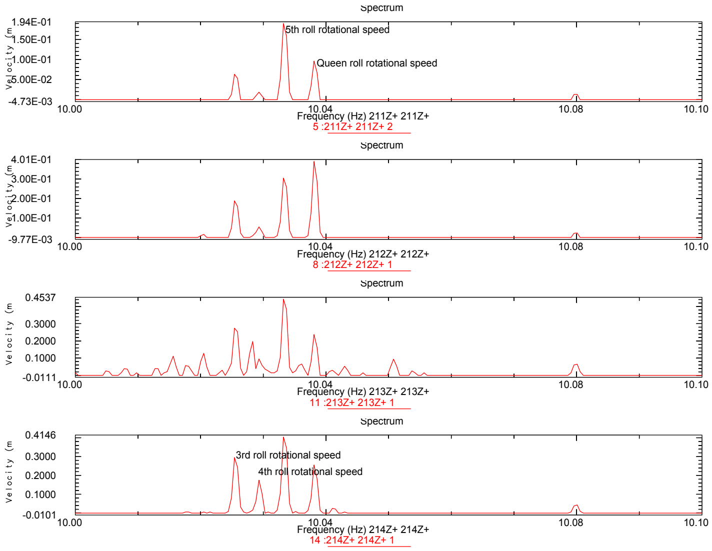

Figure 9 Zoom analysis on the queen roll with the peaks labeled with the associated roll speed

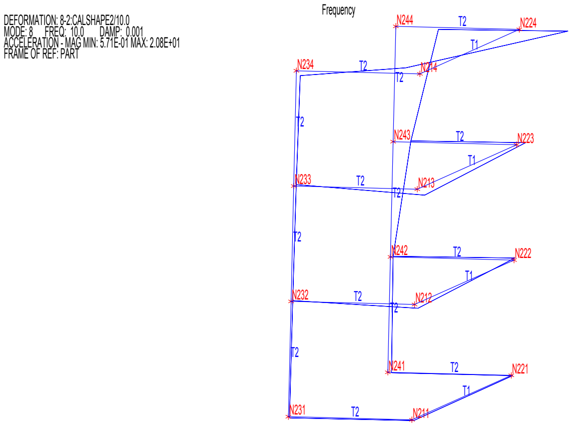

Figure 10 Calender Shape at queen roll rotational frequency of 9.875 Hz

Operating deflection shapes were calculated for the calender rolls and support framing with the results shown in Figure 10. The interesting point to note is that the vibration is much higher on the drive side frame with what appears to be a machine direction rocking, pivoting about the floor. This caused suspicion that the frame was not tightly bolted down but the bolts available for checking by the millwrights were tight.

Probable Excitation Mechanisms

The caliper variation of the sheet caused by the queen roll in the calender stack is the cause of the high vibration starting at 718 mm set diameter. This matches the queen roll diameter allowing for a little over 1% paper stretch from the calender to the winder. The vibration at this diameter on the core chucks is much higher than at smaller diameters, but there is variation in the amplitude. During some measurements taken from the tending side, there was little vibration except at this diameter. The vibration pattern is quite different on the drive side, where the vibration starts at 718 mm diameter and then remains until the set is complete and the winder is decelerated. This vibration on the drive side matches the vibration predicted by the eccentricity model.

Clearly there are similarities and differences in the vibration from each side of the winder. One possible cause for the differences is the differing axial loading on each core chuck. With the drive side being used as a reference for the axial position, it has a much higher load than the tending side core chuck. There may also be a difference in the caliper variations from the tending side to the drive side of the machine or a difference in the paper profiles or winding, from the tending to drive side.

In the early measurements taken, there was an increase in vibration level from 450 to 550 mm diameter. The source of this variation cannot be determined from the vibration measurements. What is known is that it occurs at the rotational speed of the set, is not related to the measured resonance, and has a larger effect upon the vibration measured on the rider roll as compared to the core chucks. This would leave the possibilities mentioned in the literature, [1,2,3], such as core problems, core tips, and at times paper profiles. It may also be related to possible roll resonances that could not be excited by impacting the rider roll.

The excessive core chuck vibration may put sufficient force on the rolls to cause the roll to rock enough that inter-roll forces cause a throw-out. Replacing the current pneumatic core chuck raising cylinders with hydraulic units will add substantial damping and reduce the vibration. Reducing the mass of the core chucks will also reduce the forces.

SUMMARY

As noted in the introduction, winder roll throw-outs can have many sources. Often a number of sources contribute together to lead to the roll being thrown out. In this case, the main suspected sources are caliper variations in the machine direction causing set eccentricity, along with the high friction of the paper.

A model of set eccentricity caused by sinusoidal caliper variations was used to help confirm that the caliper variation is a source of core chuck vibration.

REFERENCE

1. Alexis Olshansky, TAPPI JOURNAL February 1997; Vol.80; No. 2 - Roll Bouncing
2. Marko Jorkama, TAPPI JOURNAL January 1998; Vol.81; No. 1 – The Role of Analytical Winding Dynamics in Winder Design
3. J.E. Olsen, F. Irgens, JOURNAL OF PULP AND PAPER SCIENCE, August 1999, Vol.25; No. 8 – Dynamic Analysis of Two-Drum Winding
4. Robert Lucas, Causes for Unstable Winding on Two-Drum Winders, Internal Document GL&V
5. Pekka Helen, Roll Throw Outs, Internal Document Metso
6. Z. Hakiel, TAPPI JOURNAL January 1987; Vol.70; No. 5 – Nonlinear model for wound roll stresses