Winder Vibration Related to Set Throw-outs

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ABSTRACT

Throwing a set out of a 2-drum winder has been a problem since winders became shaftless, and worsens with increasing winder speed.

This paper presents a case study of solving the problem of roll throw outs through modeling and vibration analysis. The predominant level of vibration occurred at set rotational frequency, greatly increasing at 718 mm diameter. Included in the study are 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 imparts eccentricity into a roll while being wound. The model shows there is no roll eccentricity until the wavelength of the variation is equal to the set circumference, at which point there is a step change in eccentricity. This model explains some of the effects seen in the case study.

INTRODUCTION

As described by Olshanski [1], a roll of paper being wound has no translational momentum, therefore the velocity of the roll as it is thrown from the winder, must come from the conversion of the roll's rotational momentum to translational momentum. This conversion of momentum is initiated by vibration in the rolls. The vibration may increase slowly, or can have a sudden start from an impact type of event, like a snap-off. With sufficient vibration amplitude, the roll may start rocking to the extent that the outside corner of the roll is forced against the side of a neighbouring roll at a smaller radius. This causes a difference in velocities at the point of contact, which can convert the rotational momentum into translational momentum, which may then throw the roll out of the winder pocket. At other times there may be excessive vibration but the roll does not get thrown, because this vibration is predominately translational rather than a rocking of the rolls. In shafted winding, the shaft prevents the rolls from vibrating independently thus preventing roll wobble during vibration, as well as restraining the roll translationally, preventing throw outs.

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 leads to an understanding of the many important factors contributing to vibration, and potentially aids in leading to design changes in the winder itself.

Hakiel [4] has presented a sophisticated model of 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.

In addition there are a number of people knowledgeable in roll throw outs, with many years of experience in dealing with all kinds of winding problems. Both Lucas [5] and Helen [6] have unpublished trouble-shooting procedures for roll throw outs. These focus on reducing the vibration excitation force, and reducing vibration transmissibility. A quick summary of their recommendations include properly functioning winder controls, rolls built with a good wound-in-tension profile, uniform paper, a coefficient of friction (CoF) less than 0.5 for the paper, straight cores all of uniform diameter in each set, core tips cut straight and square noting that metal tipped cores are more problematic than fiber cores, properly functioning winder with good alignment and balance, use of direct acting hydraulic rider rolls to reduce rider roll bounce and to ensure a more uniform load to keep the set in the pocket, spreader and slitters aligned with the cores, and any 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 properties of the set being wound. Often when a roll throw out occurs, a number of these factors contribute to the problem.

Set Eccentricity Modeled from Caliper Variation

Current winding models assume uniform paper properties. The measurements taken for this project led to the speculation that machine direction 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 MD caliper variation was created. This model treats paper as a rigid material, with no elasticity to allow the paper to compress radially or stretch lengthwise. The red curve 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 remains uniform as the roll continues to build. There is some high frequency oscillation in the eccentricity however.

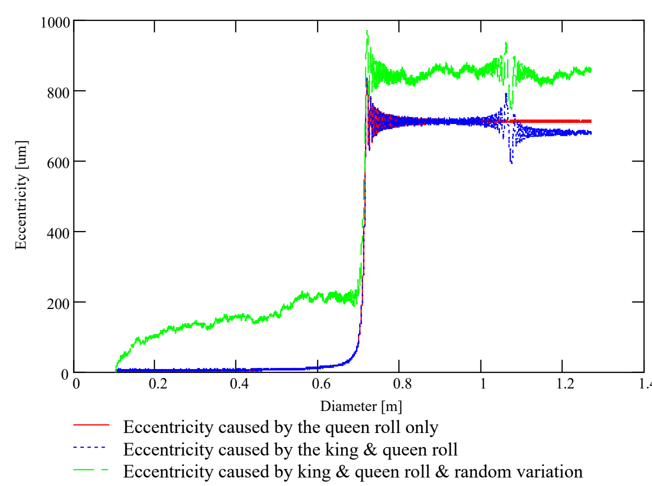

Figure 1 The eccentricity as a function of time

The blue curve shows what happens if the king roll also causes caliper variations. Up to the king roll diameter there is no difference in eccentricity between the two cases. At the king roll diameter there is a marginal decrease in eccentricity with further high frequency oscillation. When some random caliper variation is added there is only slightly more eccentricity that builds most rapidly at small diameters as shown by the green curve.

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. Additionally, when the diameter of the king roll and its amplitude of caliper variation are changed, the model shows that the eccentricity could have increased as opposed to the decrease shown in this example.

CASE STUDY

The Beloit model L winder is a typical 2-drum shaftless winder and has had problems with sets being thrown out. Many of the sets have been thrown out at just over 700 mm diameter coinciding with increased vibration, which led to the speculation that caliper variation in the paper caused the vibration. On occasion, throw outs have also occurred 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.

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, 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 roll. 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 cause the roll to bounce out of the winder pocket.

The paper on this machine had a CoF of 0.67 to 0.7, with an average value of 0.68, significantly higher than the recommended value. Friction is predominantly an effect that occurs at the fiber level. 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 reduce the friction on this machine. PCC increases the friction in paper. Possibly the PCC content was overriding the effect of the soaps used in recycling. PCC content was varied, but when used within the range required for acceptable optical properties, the CoF was not affected.

Frequency Response Function (FRF) Measurements

Frequency response function measurements were performed while the winder was stopped, using a modal hammer on the winder drums without paper and on the rider roll and core chucks with a set in the pocket and at a variety of diameters to determine the resonances present.

Since the winder was stopped for these 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.

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.

None of the high amplitude operating frequencies matched the resonant frequencies. This indicated that resonance was not a problem.

Operating Measurements

To determine the vibration characteristics during winding, the vibration was measured on the rider roll beam and the core chucks during operation. Measurements were also taken from the bedroll bearing housings to determine if there was a problem with the bedrolls. One pulse per revolution tachometer signals from the core chuck and back drum were included to correlate the vibration with rotational speeds. The vibration on the core chucks and rider roll beam was measured with triaxial accelerometers on the drive and tending sides. From this data the nature of the vibration was determined by plotting the vibration as spectral maps. The spectral maps clearly show that the vibration associated with the set rotational frequency was the dominant vibration. The vibration occurring at the set running speed was plotted as a function of time, set diameter and vibration frequency.

The vibration on the winder bedrolls was less than 1 mm/s, thus not considered a problem.

The initial measurements of winder vibration had different characteristics than later measurements. The high vibration levels often occurred over a broad diameter range. During one measurement period the vibration first appeared at approximately 450 mm diameter and increased in level until the roll reached 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.

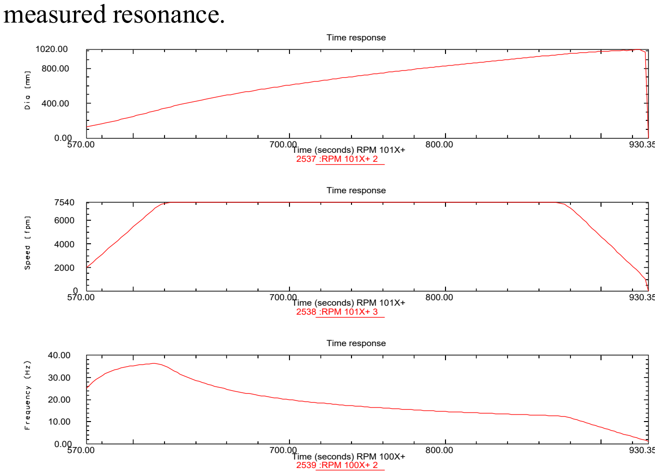

Figure 2 Diameter, winder speed and set rotational frequency as the set builds

An eccentric roll would be expected to cause high vibration levels on the core chucks but, as it is round, to have minimal effect on the vibration of the rider roll. Unbalance caused by eccentricity will have some effect on the rider roll. For later measurements the winder speed and set rotational speed is given in Figure 2 with a spectral map in Figure 3, and the vibration at the set rotational frequency in Figure 4. 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 slightly but stayed much higher than the initial vibration level. The tending side vibration level ranged in peak amplitude from around 20 mm/s to 50 mm/s for the different sets measured.

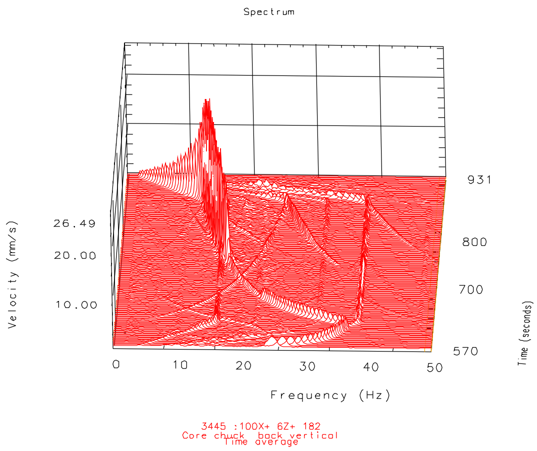

Figure 3 Spectral map of drive side core chuck vibration over time

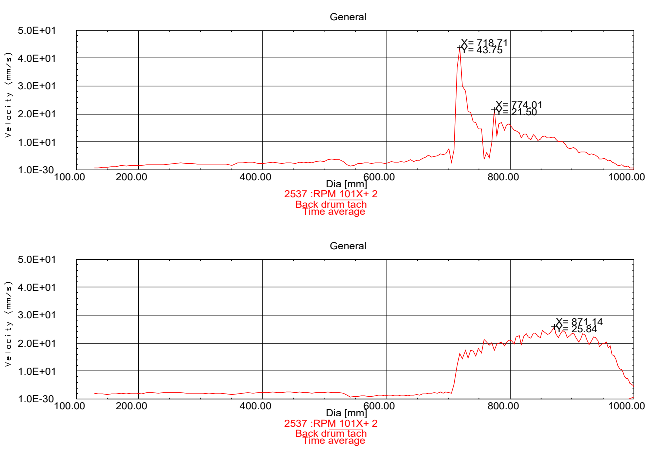

Figure 4 Vibration of tending side (top) and drive side (bottom) of core chuck vs. diameter

The vibration on the drive side core chuck increased to 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 matches the prediction of the eccentricity model.

The rider roll had some vibration present, all under 2.5 mm/s. Its likely source is set unbalance caused by roll eccentricity. This vibration level peaked at 719 mm, but on the tending side had a secondary peak at around 760 mm, the bedroll diameter.

Taking the commonly accepted standards for vibration severity for rotating machines where vibration under 1 mm/s is considered very smooth and over 10 mm/s very rough, often the core chuck vibration was up to 5x worse than the 10 mm/s limit. This vibration level is easily noticed visually.

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 caused by 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.

It is clearly evident that decreased winder speed reduced the vibration level of the core chucks. When the winder speed was then increased, the vibration level increased. 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.

With the measurements on many sets 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

Samples for TAPIO measurements were taken during the vibration measurements. The results showed a clear caliper variation at the calender intermediate roll rotational speed. Caliper variation in the paper is predominately due to the last nip. 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, it has also been verified in a mill. Thus the king and queen roll rotational frequencies will be the primary frequencies present in the paper.

With the intermediate calender rolls, specifically the queen roll being implicated in the problem, measurements were taken on the calender stack to determine the possible source of the problem.

Table 1 The rotational frequency at 4404 fpm

Roll	Diameter	Calc Rotational Frequency	Measured Frequency
Top roll	704.9262	10.119	
5th roll	710.946	10.033	10.033
4th roll	711.1492	10.030	10.029
3rd roll	711.5048	10.025	10.025
Queen Roll	710.438	10.040	10.038
King Roll	1067.054	6.685	

The rotational frequency of the calender rolls is shown in Table 1. With such closely spaced frequencies, zoom measurements were performed to distinguish the vibration contribution from each of the intermediate rolls, as shown in Figure 5. The vibration contribution due to the queen roll was the highest, with the second highest contribution due to the 5th roll. Amazingly, the vibration of the 5th roll was the highest in the king roll. The contribution of the 4th roll was the lowest, with the contribution of the 3rd roll at an intermediate level.

With the frequencies of the rolls being very 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 their vibration is in phase or out of phase, known as beating. When the vibration adds there will be a higher caliper variation than when it subtracts. 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, hence they will be additive for about ¼ of this time or 35 seconds. The amount of caliper variation and thus 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 data must be collected at least for one complete beating cycle for accurate vibration or caliper measurement, and preferably for a few. Most predictive maintenance measurements as well as Tapio measurements do not collect information for this length of time.

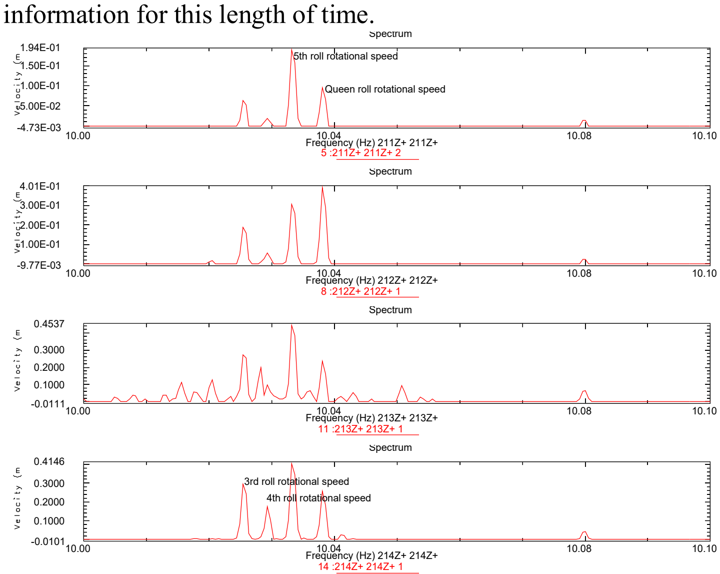

Figure 5 Zoom analysis on the queen roll with the peaks labeled with the associated roll speed

Operating deflection shapes were calculated for the calender rolls and support framing as shown in Figure 6. The vibration amplitude is much higher on the drive side frame with a machine direction rocking, pivoting about the floor. This raised concern that the frame was not tightly bolted down, but the bolts available for checking by the millwrights were tight.

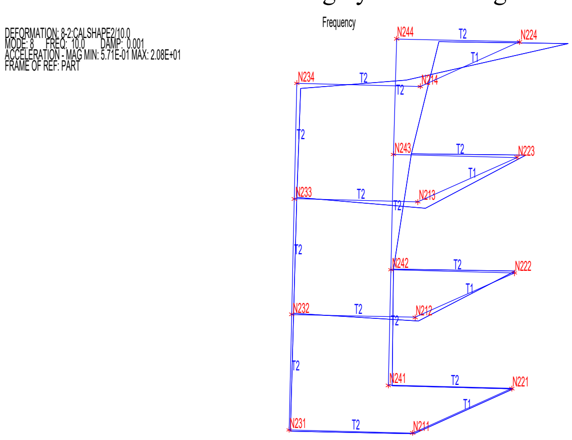

Figure 6 Calender Shape at queen roll rotational frequency of 9.875 Hz

Vibration 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 on both the tending and the drive side. 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 significant 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 remaining at a constant level until the winder is decelerated. This vibration on the drive side matches the eccentricity predicted by the eccentricity model.

The variability in vibration from set to set can be explained by the phase relationship between the vibration caused by closely matched diameters on the intermediate calender rolls.

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.

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 study, 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.

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