New Insights into Calender Barring Prevention

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Abstract

A computer simulation of calender barring has been constructed which sheds new light on the phenomena. The characteristics of the paper feedback mechanism are examined in detail and it's interaction with corrugated roll wear and forced excitation are discussed.

Introduction

Calender barring results in caliper variation causing a resultant quality loss. It can occur with or without the corrugation of calender rolls. This problem has baffled many paper mills for years. Although much research has been performed, it is still a poorly understood phenomena.

Calender barring has been a long-standing concern at Abitibi-Price's, Alma mill. Since approximately 1989 calender barring has occurred on PM #9 and PM #10. This problem results in increased maintenance costs and effort associated with frequent changes of calender rolls in order to maintain paper quality.

A number of vibration studies had been performed attempting to identify the cause and develop solutions to this problem with little success. In 1995 Abitibi-Price's Alma mill funded work to conduct a more comprehensive investigation of the problem. The goal was to develop a thorough understanding of the calender barring phenomenon which would lead to feasible and definitive solutions.

The approach was to develop computer models of the barring phenomenon which matched measured data and predicted the range of barring symptoms which have been observed at Alma and other mills. This paper presents a brief overview of the current understanding of the calender barring problem resulting from this modeling effort.

Calender Barring Background

Calender barring has been studied extensively over the past thirty years [1-15] yet a consensus understanding of the problem has not been reached except, possibly, by a very few "experts" in the field. The reason a common understanding eludes the paper making industry is that calender barring is an extremely complex phenomenon which exhibits a multitude of different and sometimes seemingly contradictory symptoms.

A very large number of parameters have been observed to influence barring behavior including:

- roll diameter
- roll offset
- number of rolls in stack
- roll grinding practices
- nip load
- paper moisture content
- roll temperature
- machine speed

- basis weight
- breaker stack open or closed
- grit content of paper
- press section vibrations
- flow instabilities at wet end
- use of swimming or cc rolls
- nip relief
- external vibration sources

Subtle changes in any of these parameters can often eliminate or initiate barring, or change the amplitude and frequency at which it occurs. Much of the work conducted on calender barring has been near-term-solution focused, attempting to identify straightforward causes which can be dealt with to cure the problem. Since it is nearly impossible to isolate and identify the effects of the influencing parameters independently it is easy to draw false conclusions regarding causes and possible solutions.

There is general agreement that there are two main mechanisms which cause barring in calender stacks, self excited stack vibration due to regenerative feedback between nips through variation in paper caliper, and regenerative wear of calender rolls causing roll corrugation. The work conducted in this study provides a clearer understanding of these mechanisms, the interaction between them, and the resulting calender barring symptoms. Hopefully this understanding will allow practical solutions to the problem to be developed.

Approach to Calender Barring Problem Study at Alma, PM 9

The approach followed in this work was to develop a comprehensive understanding of the mechanisms through which calender barring occurs through computer modeling. A literature search was conducted in order to utilize the existing knowledge and experience base. Based on this background research, experimental testing conducted at Alma, and the authors' experience in dynamic systems and self excited vibration, a computer model of the Alma PM#9 was constructed which predicts barring behavior.

Modeling of Calender Barring

Stack dynamics

The rolls in a calender stack behave as masses connected by springs. The effective stiffness results from the characteristics of the paper being compressed in the nip. The stack has resonant frequencies at which it is particularly susceptible to vibration excitation. In the neighborhood of these resonant frequencies the stack vibrates in a particular shape or displacement and phase relationship between the rolls. Because of the predisposition of the stack to vibrate at it's resonant frequencies, self-excited vibration occurs at or near resonant frequencies.

There are two self-excitation mechanisms which occur in calender stacks. These are the paper feedback mechanism and the regenerative roll wear mechanism.

Paper Feedback Mechanism

Any infinitesimally small deviation in paper bulk or basis weight entering a nip will cause a variation in nip load which will excite the stack. Because the stack vibrates in mode shapes, this vibration causes the entire stack to vibrate, resulting in variation in nip gaps in all nips. Under certain conditions of stack configuration and operating parameters the stack will vibrate such the preceding nip imparts a variation in paper bulk which, when it enters the next nip, re-enforces the stack vibration, causing self sustaining vibration and barring.

Regenerative Roll Wear Mechanism

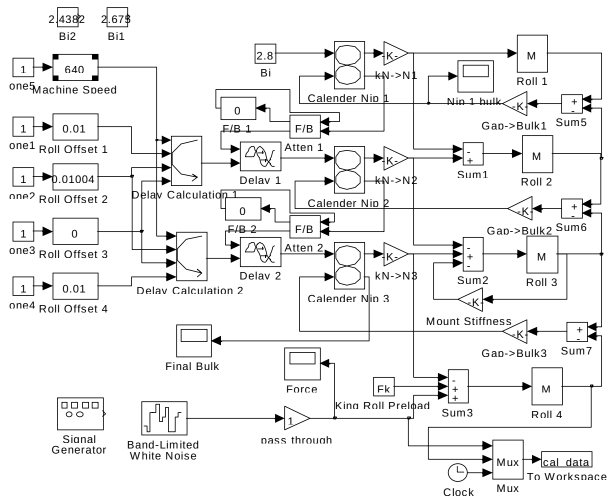

Figure 1: Simulation Model Block Diagram

The second regenerative mechanism which exists in the calender stack is regenerative roll wear which results in roll corrugation. This is the same regenerative wear mechanism which has been studied in relation to machine tool grinding and turning processes [16]. A similar mechanism is responsible for 'washboarding' on road surfaces.

All other conditions being equal, calender roll wear is proportional to nip load. Any microscopic roll surface irregularity (a high spot or a low spot) will result in a variation in nip force when the irregularity enters the nip. The variation in nip force excites the stack modes and causes vibration of the rolls which in turn causes variation in the nip load. Under certain stack conditions there are frequencies at which the stack vibration resulting from the irregularity passing through the nip will cause the nip load to vary such that when the irregularity re-enters the nip the wear process causes it to grow. This regenerative wear process is only stable for an integer number of corrugations occurring around the circumference of the roll.

Stack Simulation Model with Paper Feedback Model

Figure 1 shows a Simulink™ block diagram model of the Alma PM#9 calender stack which predicts barring due to the paper feedback mechanism. The most challenging task in generating this model was developing a model of in-nip paper characteristics which predicts realistic caliper variation and dynamic nip load as a function of roll vibration. The "Calender Nip" blocks accomplish this utilizing an inverted form of the calendering equation and research results of Browne [17] which relate in-nip to permanent paper strain. The nip blocks calculate instantaneous exiting paper caliper and nip load based on instantaneous entrance paper caliper and nip gap.

The "Delay Calculation" and "Delay" blocks implement the paper transport delay between successive nips. This is based on machine speed, roll diameter and roll offset. The "Roll" blocks model the roll mass characteristics, apply linear or quadratic viscous damping forces, and calculate the roll position (nip gap) based on the nip loads generated in "Calender Nip" blocks.

During operation of the simulation model both the machine speed and the offset of each roll can be adjusted to determine the effect of these parameters on barring behavior. Each of the blocks on the left of the system block diagram labeled "Machine Speed" and "Roll Offset" expand into a slider bar control to adjust these parameters.

Illustrative Results of Initial Simulation

The simulation may be used to explore the effect of varying most calender stack and paper furnish parameters. In addition to machine speed and roll offset, the roll masses and diameters, the number of rolls, and which roll is solidly attached to the stack frame may be changed. Paper characteristic effects are handled through the calendering equation parameters. The effects of two readily controlled parameters, machine speed and roll offset, are illustrated below.

Effect of Change in Machine Speed on Barring

The simulation model was run for a system which matched Alma PM#9 in terms of configuration, roll masses, roll offsets, and roll diameters. Nominal values were used for the paper calendering equation parameters which correspond to TMP paper. These were utilized because they were available in the literature. For more accurate results the calender equation parameters for the paper being run at Alma should be used.

The following results were obtained without the simulation model being tuned to exhibit the same resonant frequencies as the PM9 stack. Because of this the simulation barring frequencies do not match the frequencies observed on PM9.

The sheet entering the first nip has a bulk of 2.8 cc/gm with no variation. Any barring observed is thus due entirely to self excited vibration, with no effects attributable to variation in sheet properties entering the first nip.

Figures 2 and 3 show the time and spectrum plots of paper caliper variation for the machine running at a speed of 655 m/min with offsets of rolls one through four of 0.01, .0.0, 0.01 and 0.01 meters.

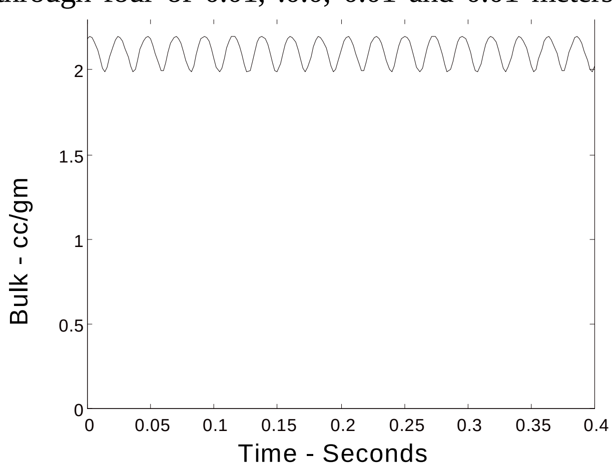

Figure 2: Paper Caliper Variation - 655 m/min

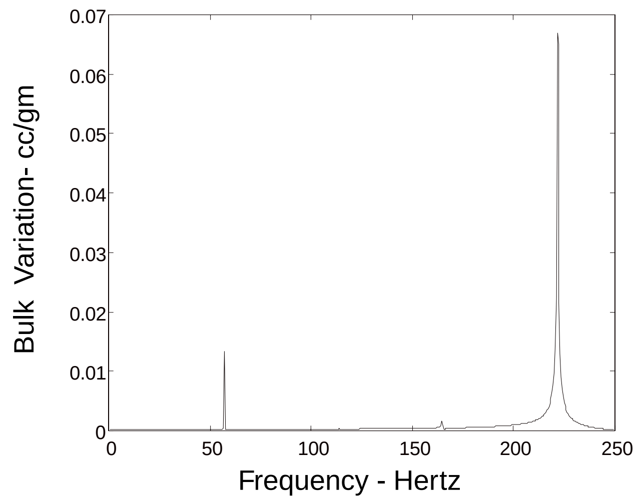

Figure 3: Caliper Spectrum - 655 m/min

For these conditions barring is occurring primarily at a frequency of approximately 220 Hertz. When the machine speed is increased to 675 m/min (Figures 4 and 5) barring disappears completely and the sheet exiting the calender stack has no variation in caliper. Since similar scales have been maintained in order to compare between figures, the caliper spectrum in Figure 5 is not visible. Figures 6 and 7 show the barring behavior with the

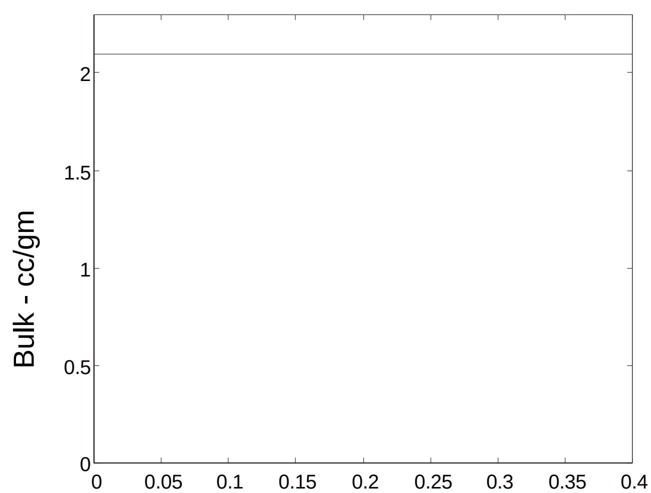

Figure 4: Paper Caliper Variation - 675 m/min

machine speed increased to 685 m/ min. Barring is occurring at a lower frequency of approximately 175 Hertz.

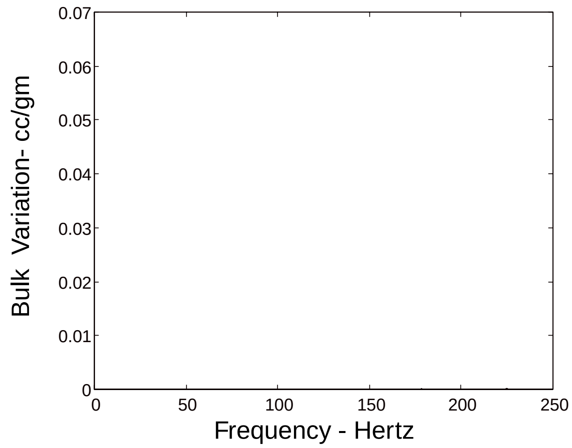

Figure 5: Caliper Spectrum - 675 m/min

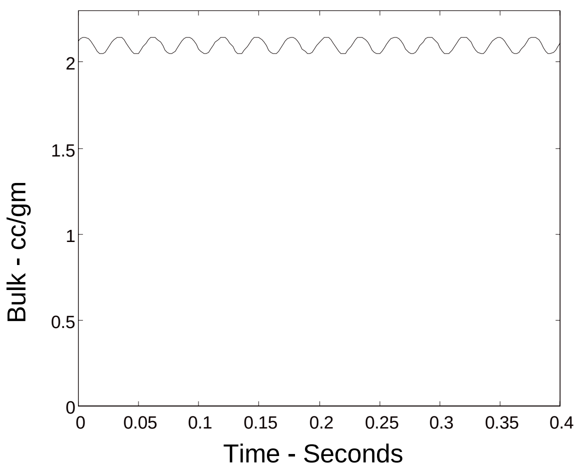

Figure 6: Paper Caliper Variation - 685 m/min

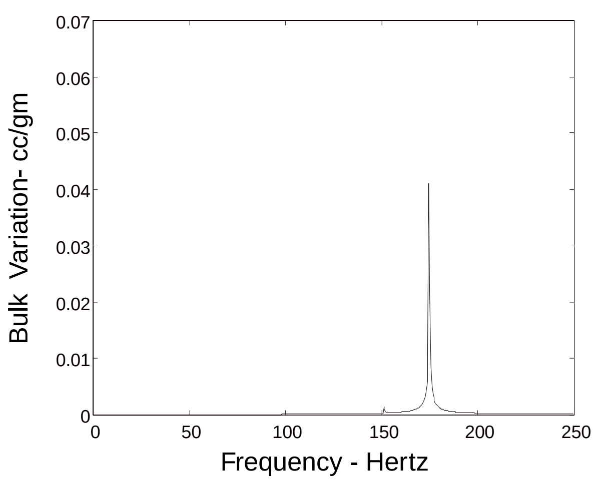

Figure 7: Caliper Spectrum - 685 m/min

Effect of Change in Roll Offset on Barring Behavior

With the machine operating at 685 m/min the barring is as shown in Figures 2 and 3. When the offset of roll three is changed to -0.01 meters from 0.01, the barring is totally eliminated and there is no noticeable caliper variation, similar to Figure 4 and 5.

Effect of Regenerative Feedback on Stack Dynamics

Barring caused by regenerative caliper variation feedback has been looked at as an "all or nothing" phenomenon. In other words, if the stack is not experiencing paper barring due to regenerative feedback, regenerative feedback was not considered to be having an effect. The simulation work performed indicates that this is not the case at all.

The dynamic characteristics of a system are often defined and illustrated with frequency response functions (FRFs). FRFs are a measure of the magnitude and phase of the vibration response of a point on a system due to a dynamic force applied at a specific point on the system. FRFs are a function of frequency and location. To determine the effect of regenerative feedback on calender stack dynamics, the simulation model was run at a condition where barring was not occurring. A dynamic force was applied to the King roll and the vibration response of the roll was stored. The FRF between the force signal and the roll vibration was calculated.

Initially, the feedback mechanism was eliminated by artificially removing any caliper variation in the paper between successive nips. The resulting FRF is shown in Figure 8. The four peaks evident in the FRF are the four modal resonances of the calender stack.

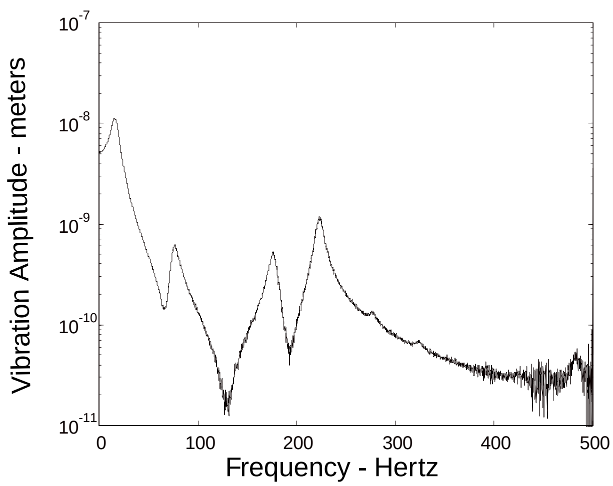

Figure 8: Stack Dynamics Without Effect of Regenerative Feedback

Figure 9 shows the same FRF with the effects of regenerative paper feedback.. As shown, this makes a significant difference. A number of feedback resonances are superimposed on the stack without paper feedback. The amplitude of the FRF at these frequencies (note the logarithmic amplitude scale) is an order of magnitude higher than the open loop response shown in Figure 8. The implication of these feedback resonances is significant in two respects.

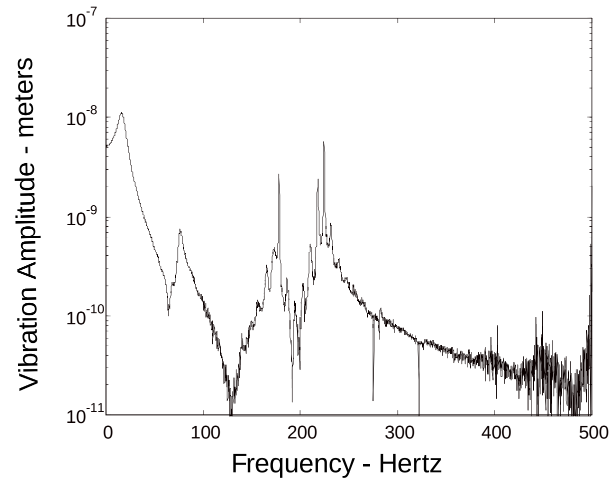

Figure 9: Stack Dynamics With Effect of Regenerative Feedback

First, the regenerative roll wear which causes roll corrugations is a function of the dynamics of the calender stack. The paper feedback resonances undoubtedly exacerbate the corrugation wear process. This interaction between the two barring mechanisms has not previously been considered in the literature.

Second, the feedback resonances make the system extremely susceptible to external excitation which may occur at these frequencies. For instance, if there is vibration from a dryer gear mesh frequency entering the calender stack at a frequency matching one of the feedback resonances, the stack will be excited and paper barring may occur. Since the feedback resonances are extremely lightly damped and narrow in frequency, very small changes in the frequency of the disturbance or the resonance will cause the barring to stop or start.

Solutions to Calender Barring Which May be Investigated using Simulation Model

The simulation model must be tuned to match the characteristics of the calender stack and paper furnish of interest. Calendering equation parameters and the relationship between in-nip and permanent paper strain must be determined for the paper furnish of interest. An experimental modal analysis of the stack must be conducted while the machine is running in order to accurately determine the stack natural frequencies.

Once the computer model accurately reflects the physical reality of the calender stack it may be utilized to evaluate a wide range of possible solutions to the calender barring problem.

Various stack configurations could be investigated, evaluating different combinations of roll offset, number of rolls, roll diameters, and position of rolls in the stack in order to arrive at a configuration which is most robust to barring.

Since barring is highly dependent of machine operating parameters, various schemes to tune operating parameters to avoid barring could be investigated. Both stack vibration and/or roll corrugations could be monitored to determine if barring was regenerative (increasing) or destructive (decreasing) and machine speed, for instance, could be perturbed slightly to prevent regenerative roll wear from occurring.

More innovative solutions such as adding passive dampers between roll bearing housings, on-line offset adjustment, or active vibration control may also be investigated using the computer model.

Conclusions

A computer model of a calender stack which incorporates the paper feedback mechanism causing calender barring has been developed which predicts observed barring symptoms. Work is progressing to tune the model and evaluate potential solutions to barring experienced at Abitibi-Prices Alma mill.

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