EXPERIMENTAL STUDY OF WINDING ZONE DYNAMICS

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ABSTRACT

The elastic nature of plastic films and the rotational inertia of rolls, spindles and drives cause a film handling line to exhibit the characteristics of a dynamic system. This dynamic response can be observed by measuring on-line variables such as tension, roll velocity or dancer motion. Because of the dynamic behavior, a variety of control systems are employed to keep tensions and velocities in bounds. For purpose of control and isolation, a film line is divided into separate zones. One of the most difficult zones to control is the winding zone.

This paper describes an experimental study conducted on an existing film line where the winding zone was experiencing large tension variations at certain speeds. An experimental technique was developed to measure the natural frequency of the zone. The natural frequency was found to vary with package diameter and film thickness. Using FFT analysis on the winding tension signal, the resonant excitation was identified as the winding spindle frequency. A computer model was used to predict the transfer functions and natural frequencies for the zone. Very good agreement was obtained between the predicted and measured natural frequencies.

In addition to explaining the source of the large tension variations during winding, this study also provided a better understanding of the dynamics of a winding zone and the possibilities for resonant conditions. With these tools, alternate solutions to the problem could be evaluated.

NOMENCLATURE

e	Dither voltage amplitude

E	Dither voltage signal
T	Web Tension
t	Time
ΔV	Velocity variation
V_o	Average velocity
V_1	Vacuum roll velocity
V_2	Winding velocity
ω	Spindle angular velocity
ω_d	Dither frequency
ω_n	Natural frequency

BACKGROUND

In a plastic film line, each zone has its own dynamic characteristic depending on length, number of rolls, and type of tension or velocity control. One of the most interesting and difficult to analyze and control is the winding zone. This is particularly important because good tension control is needed for the winding process. For example, in center winding a tension variation of ± 10% is normally required for good package formation. Excitations in this zone are either transient, such as a turret rotation, or periodic, such as idler roll eccentricity or package runout.

An additional complication arises because the dynamic characteristics of the zone change during the winding process. The inertia and radius of the package increase and the angular velocity of the spindle and drive system decrease as the package builds. The rate of change of these parameters is greater at the beginning of the package than at the end.

The winding zone on a semiworks film line was known to experience large tension variations under certain running conditions. Since this line typically winds film of different thicknesses and at different speeds, good tension control is difficult to maintain. Measurements revealed significant tension variation during winding. A typical trace taken during winding (Figure 1) showed a well defined frequency and evidence of beating.

PROBLEM DEFINITION

The winding zone on this line is a typical design with a vacuum roll providing the infeed and a loadcell for feedback tension control. Figure 2 shows the layout of the rolls and the web path. Measurements were taken of vacuum roll velocity, idler roll velocity, tension and spindle velocity. Two different film thicknesses were tested. They will be identified as Film A and Film B.

The data in Figure 1 shows a peak-to-peak variation in tension of 53%. Frequency analysis of the data (Figure 3) showed two distinct frequencies at 0.85 Hz and 1.05 Hz. The data also showed that the spindle rotation was at 0.85 Hz. Thus it appeared that the rotation of the spindle was driving the large tension variations. Since the amplitude of the tension variations decreased as the winder slowed down, it was suspected that the zone was passing through a resonant condition. This event occurred at different frequencies depending on film thickness and package size. Thus, it was decided to experimently determine the zone's first natural frequency for the two films at different package diameters.

MEASUREMENT OF ZONE NATURAL FREQUENCY

Measurement of natural frequencies in vibrational systems is a well known technique discussed in reference books (Ref 1). For a film line, however, the measurement must be done while the line is running. A technique developed by the author (Ref 2) involves inserting a low amplitude, variable frequency (dither) signal into the drive and measuring the film tension response. In this case, the following scheme was used:

1) insert the dither signal into the vacuum roll drive

$$E = e \sin \omega_d t$$

2) measure winding zone tension
3) set dither amplitude low (1-3% full speed)
4) sweep frequency from 0.2 to 20 Hz
5) take FFT analysis of the tension signal continuously
6) plot the results in a "waterfall" format

The natural frequency is defined as the frequency where the tension signal reaches its peak amplitude. This scheme was repeated for each of the films and at different times during the winding cycle to determine the effect of package inertia and diameter.

Figure 4 shows a plot for this type of experimental analysis. One hundred continuously taken FFT records are plotted on a skewed axis. The frequency range was 0 to 10 Hz. The apparent height or amplitude is the actual tension variation at each frequency measured in "lbs peak-to-peak". For this test, the dither was set for a 3% peak-to-peak variation of the vacuum roll velocity. For the records shown on the plot, the dither starts at 7 Hz and ends at 0.3 Hz. Frequencies from the vacuum roll or idler rolls are constant and appear as lines at the skew of the plot. The winding spindle and drive appear as skewed lines at the rate of the package buildup. The test must be run quickly so that the buildup is small. The dither signal's skew is determined by the sweep rate of the frequency generator. Note that the second harmonic of the dither can also be seen on the trace and causes a tension variation.

The natural frequency is identified by locating the peak amplitude from the dither curve and finding the record number in which appeared. That record can be recalled and the frequency identified precisely. This process was repeated for Film A and Film B at several different times during the winding cycle.

COMPARISON OF RESULTS

Several methods are available to model winding zone dynamics and predict the natural frequency (Ref 3,4). In this case, an in-house software program was used to compute the transfer functions for the zone. The peaks in the curves represent the natural frequencies. Figure 5 shows a typical plot from 0.01 to 40 Hz and reveals three natural frequencies. For this problem, the lowest frequency is the one of interest. The program was run several times for Film A and Film B (different thickness) and at several different package diameters.

The results for Film A are shown in Figure 6. The modeling predicted a first natural frequency of 1.1 Hz which decreased slightly with package diameter. The three data points agree quite well with the model results considering the number of parameters required to do the simulation. Similarily, the results for Film B agree with the measured results as shown in Figure 7. In this case, four measurements were taken. The core diameter was 11 inches and the final package size was normally 20 inches. The increasing package size causes an increase in inertia and a slight reduction in natural frequency.

PREDICTION OF RESONANT CONDITIONS

The resonant phenomenon requires a dynamic system with a discrete natural frequency and a periodic excitation with a frequency which is near the system's natural frequency. In this analysis, the excitation is the velocity of the winding package and has the form,

$$V_2(t) = V_o + \Delta V \sin \omega t$$

where the velocity variation (ΔV) is caused by either package runout or angular velocity variation of the spindle. The frequency (ω) is equal to the angular velocity of the spindle which decreases as the package builds. Resonance occurs when the excitation frequency approaches the system natural frequency,

$$\omega \to \omega_n$$

If this occurs, large variations in tension will occur and the amplitude will appear beating between the two frequencies, as shown in Figure 1.

This analysis is plotted in Figure 8 for the winding zone problem under discussion. The measured natural frequencies for both films are plotted along with the rotation frequencies of the spindle at three different line speeds (200, 250, and 350 FPM).

From Figure 8, Film B will experience large tension variations early in the package when winding at 250 FPM. Whereas, Film A will experience problems when the package diameter reached 14 inches. To avoid resonant or near resonant conditions for these two films on this winder, all speeds between 200 and 350 FPM should be avoided.

CONCLUSIONS

Severe tension variations were observed on a semiworks winder while winding two specific films in the 200 to 350 FPM range. The problem was identified as a resonant condition (beating) in the winding zone tension which was excited by the variation in package velocity. To make this identification required measurements of tension and velocity, a technique to measure zone natural frequency and modeling of the winding zone dynamics. The results confirmed that resonant conditions will exist in the zone for both films with speeds between 200 and 350 FPM. The only difference would be the package size when it occurred.

Avoiding this speed range was suggested as the solution to the problem. Based on the understanding of the problem and the computer modeling, other solutions could be considered:

a) reduce the inertia of the spindle and drive system to increase the natural frequency
b) modify the web path to change the natural frequency
c) change the feedback control algorithm to add damping and shift the natural frequency
d) consider an alternate type of tension control, such as dancer position feedback

The benefit of a good dynamic model is that each of these modifications can be evaluated without having to make hardware changes. For item d) however, a change to the model would be required since the dynamics of a dancer system would alter the zone dynamics.

The fundamental conclusion from this work is that dynamic modeling was used to support on-line measurements of tension and velocities. Together they provided understanding of the problem and helped identify possible solutions.

ACKNOWLEDGEMENTS

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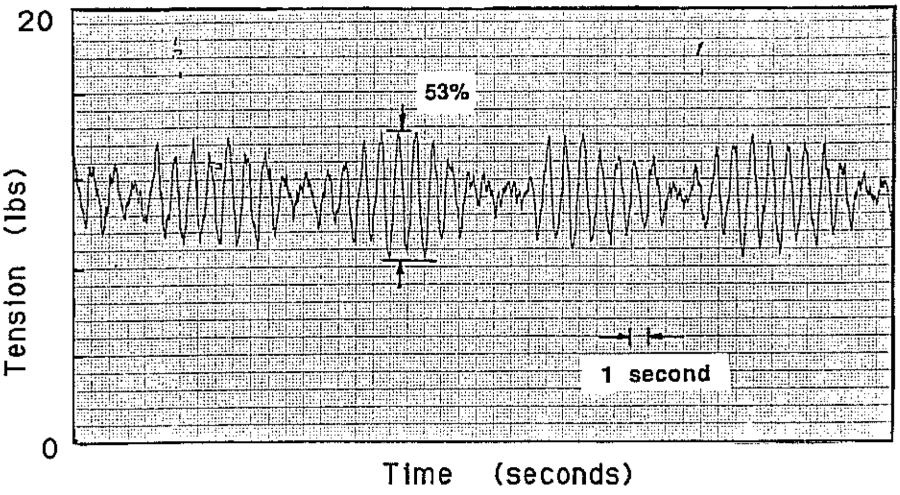

Figure 1. Time Trace of Winding Tension Variation

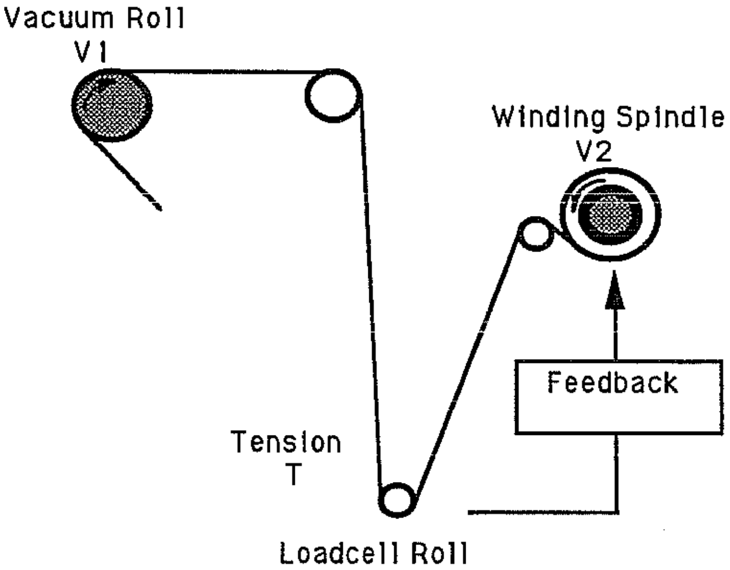

Figure 2. Layout of the Web Path for the Winding Zone

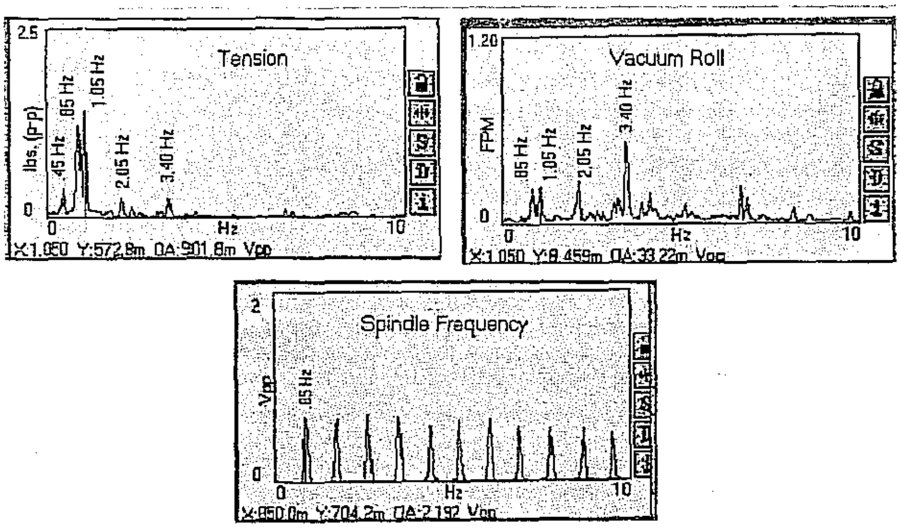

Figure 3. FFT Analysis of Tension, Velocity and Spindle Signals

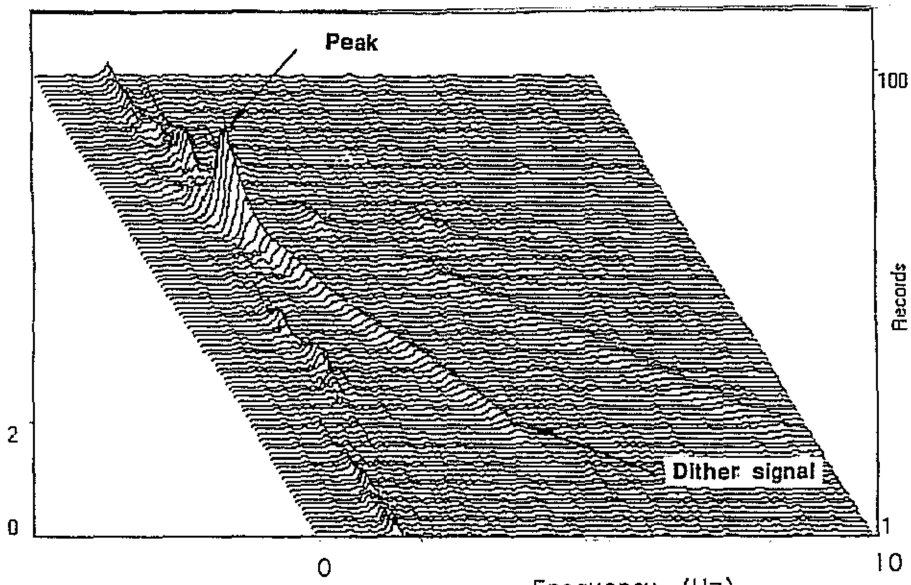

Figure 4. Waterfall Plot for Winding Zone Tension

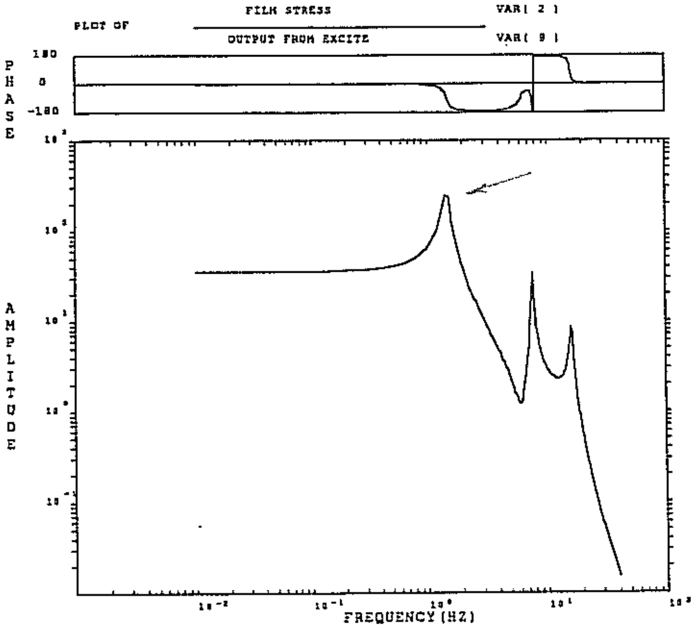

Figure 5. Transfer Function for Winding Tension

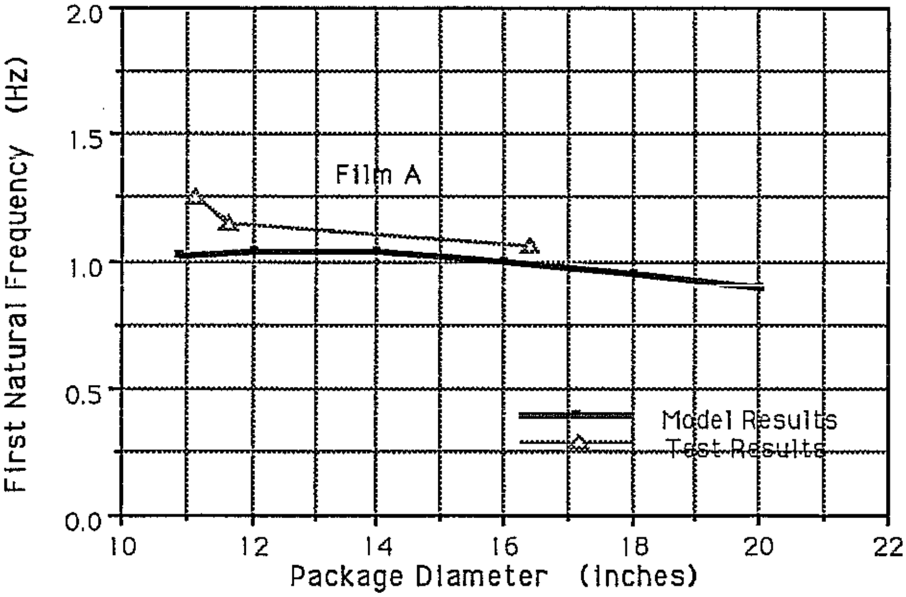

Figure 6. Comparison of Predicted and Measured Natural Frequencies

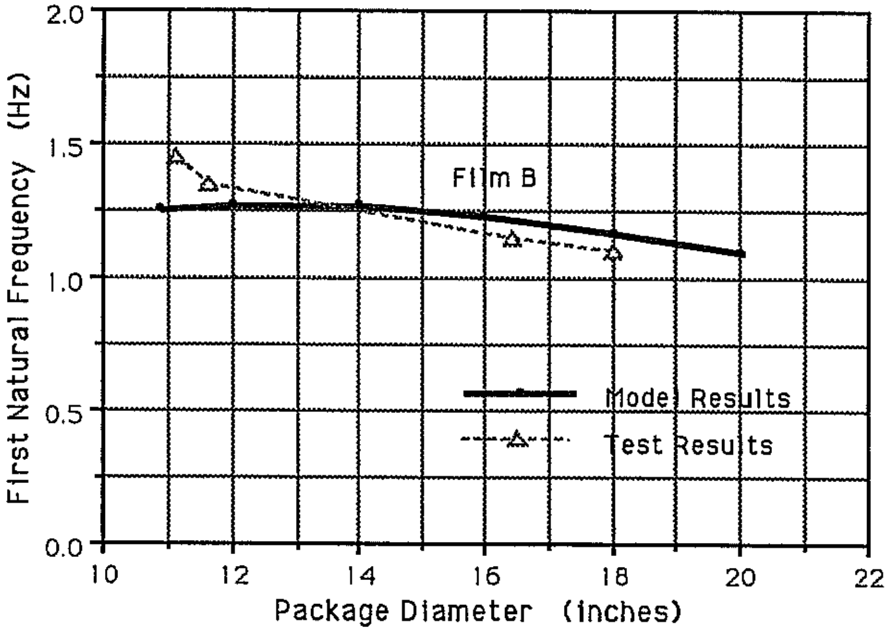

Figure 7. Comparison Between Predicted and Measured Natural Frequencies

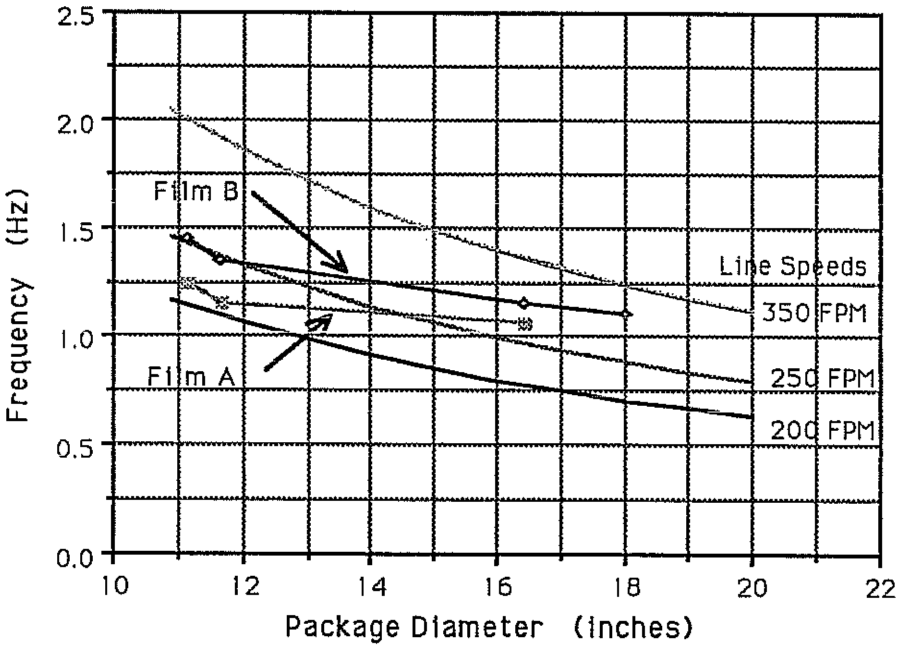

Figure 8. Prediction of Resonant Conditions Using Measured Natural Frequencies for Film A and B

Question - You suggest to avoid the specific kit range 200 to 350 FRM range. Is that specific, is that specific to your plan or is that general, where did you get this number that can be changed depending upon the radius of your rollers and your lines maybe the particulars of the disturbance. How do you select those speeds?

Answer - Speed recommendations are for these two films, if there were a 3rd film you would have to develop the same criteria. That is correct because the range is dependent upon the parameters of the system. This is not a general recommendation, it is just for this specific problem that we were addressing at the plant.

Question - Depending on quality of the roller, in case you have a defect in the quality of either roller upstream, it will generate a disturbance, it will give us a difference frequency, in the sense of a disturbance frequency then it will aggravate the tension variation.

Answer - Disturbances from rolls or from the vacuum roll drive will be constant frequency throughout the winding cycle. Yes it is possible that it might be parked right on the natural frequency or it may pass right through there. I have not seen that case, but it is quite possible. The worst thing is for the spindle frequency, not only the spindle but the motor and the drive for the spindle because they sweep through frequencies so they are sweeping down so they have a much more likely hood of exciting resonance than either roll or the constant velocity of the vacuum.

Question - Would you care to comment on the techniques disclosed this morning versus avoiding the speed range the gentlemen Valmet trying to change speeds to run through the various resonance frequencies?

Answer - It's a possibility. It's not something that we typically do, as you know. Yes it is possible because you can use that same curve to identify a speed, or suddenly increase speed in one range and then drop back down. Yes, it is possible to configure a winding speed profile to get you around the resonance condition. It is viable but I don't know how practical it is.

Question - The speed signal you are using on the vacuum roll, is it the speed on the motor detector signal, or is it directly measured on the surface of the roll?

Answer - The vacuum roll velocity is measured directly on the surface of the roll.

Question - What kind of equipment did you use for this?

Answer - I can only tell you that it is an optical tach with additional computer equipment to go along with it. The rest of it is proprietary.

Question - Have you noticed in the wound roll itself any indication of it going through a resonance.

Answer - A few things we observed. One thing is the tension pulsing. The second is the number of times we had telescoping occur at that time. The tension is dropping very low on the down cycle and then back up so, a number of times we observed not telescoping but "Sluffing" where the sheets slide off and then you go back on again when you go through it. You actually can look at a package and can go back and determine at what diameter this occurred.

Question - This was a phenomenon of the system, so it wouldn't have mattered if it was a torque control winder or a clutch system. It was really characteristic of the web links and the tensions and the inertia, not the control loop?

Answer - The experiment results or the modeling results? The results were a function of all of what you just mentioned because it is an on-line experimental technique to determine transfer functions or natural frequencies for that zone. If you changed the control system or you changed a couple of the idler rolls, you have to re-do the experimental study again. It is the characteristazation, the rotational equivalent, the web handling equivalent of the shake table. The difference is that everything is running. The worst thing is when I pass a frequency through one that is already there. I lose mine. I sometimes have to have some blanks in the transfer functions because of the overlap, so I try to get the amplitude a little higher than anything that is there, so I can't do it if there is a lot of background noise caused by the other elements.

Question - I have a question concerning your FFT Analysis of Spindle frequency. There are peaks from lower to higher frequencies with the same amplitudes, what causes these peaks? Is it a non-surging winder as on Figure 3 in the paper?

Answer - Refer to the Peaks in the Bottom Figure. Once per rev pick-up, so it is a spike everytime the spindle goes around, you get a pulse. When you do a FFT of a Pulse you get all frequencies from the fundamentals on.

Question - The model surprised me because the resonant frequency goes up at the beginning. That really surprised me; the web length is getting shorter faster than the roll is building. What makes the resonance frequency increase with roll diameter?

Answer - The inertia of the roll package is not only the package inertia but all the inertia that is reflected forward. It is
J (of the roll) + J reflected that is the armature of the motor, the gearing shaft, forward.
It is actually J/R^2 and that in fact sets smaller for a short period, then gets bigger.

Question - Is natural frequency independent of line speed?

Answer - Yes, there is a small effect of V, but by and large it is independent of line speed.