A MECHANISTIC SURVEY OF ACCUMULATING, RESONANT, AND SELF-EXCITING SYSTEMS IN WEB HANDLING

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ABSTRACT

Certain problems in web handling can be challenging because they tend to get worse with time. Consider mechanical resonance. The longer you run at resonant vibration conditions, the worse the problem will initially get. Yet the effects of resonance are usually limited because of damping and in many cases are not even perceivable. There are conditions that are much more challenging because they are accumulating or self-exciting. These problems not only get worse with time, they may get *much* worse with time. The response or response rates are ever-increasing and unbounded except by breakdown or shutdown. This paper is a mechanistic survey of some of the toughest problems in web handling including:

Accumulating
- Air Bubbles Behind Nips
- Gage Bands in Wound Rolls
- Loose Lanes in Locked Core Winding

Resonant
- Guide Control
- Tension Control
- Roller Critical Speed
- Wound Roll Vibration

Self-Exciting
- Calender Barring

Interweaving on Simplex Winders
Knots in Wound Rolls
Telescoping on Core Supported Winding
Wound Rolls that Uncoil After Cutover

ACCUMULATING

Accumulating problems in web handling have a response that is initially proportional to time. However, in most cases there are high-order factors that damp out simple textbook expectations so that the response rate decreases and eventually the response itself stabilizes to a certain value. As a consequence, there is the *possibility* that this class of problem might be less problematic. If the limit of the response is acceptable in terms of waste and delay, then there is no practical problem. If not, the mechanics are inexorable and unyielding

Air Bubbles Behind a Winding Nip

Air bubbles can accumulate behind a winding nip as seen in Figure 1. The mechanics of air entrainment was first modeled by Knox and Sweeney for webs approaching rollers [1]. Connolly and Winarski believed that this equation might also apply for simple center-winding [2] and this was verified by Dr Good and others [3-4]. A complete treatment of the state of art of wound roll modeling and measurement can be found in Good and Roisum [5].

These modeling efforts told us that the problem might be worsened by increasing speed, decreasing WIT (web tension and especially nip), increasing smoothness and decreasing caliper. What it did not do was to explain the uneven distribution of air during winding nor describe what has become the de-facto treatment.

That air would be entrained into the winding roll is no mystery. What needs explanation is why the air *might* accumulate behind the nip. Simple theory says that the air should be uniformly distributed through the layers and across the width (with the exception of exhaust at the edges of the wound roll that takes some time). However, the nip can be an obstruction like a dam or squeegee. Consider what would happen if only 99% of the air made it by the nip. That would leave 1% remaining behind, being pushed 'upstream' under the first layer. On the next revolution another 1% might remain behind and so on in an accumulating bubble. Close observation will reveal that the air bubble may not be just under the outer layer but rather the outer several layers because this principle is not confined strictly to the outside wrap.

This process does not usually accumulate indefinitely. Because the air bubble upstream of the nip is at a higher pressure, it is more motivated to get through the nip. Also, air escape on the edges may limit the response, especially for rolls that are narrower. In fact, there may be no accumulation at all. This response is extremely material dependent. The materials most prone to forming bubbles behind the winding nip are thin, have low modulus and have high tackiness. Many specialty films exhibit such a severe response that the operator might have to stop the winder, lance the bubble like a blister, flag the area as defective, and restart. However, at higher speeds, such as seen in the paper industry, we see this problem on two drum winders behind the drums and especially the rider roller even though paper possesses none of the risky web property risk given above. Later the phenomenon was also noted and treated at the reel on the end of the paper machine.

The solution for both of these industries was discovered independently. A wide-shallow grooving had long been used in paper for reasons the designers could not articulate, but it prevented a problem we now know the mechanics of. In the film industry the groove may be called a ‘burping groove’ because it emulated one radical treatment: to momentarily lift the nip to let the bubble through. What happens with this groove is shown in Figure 2. The groove allows freedom for the wound roll layers to deform into the groove and thus form a tiny channel for the air to vent by the nip. The geometry of this groove is critical. Too much groove (width, pitch or depth) and you let too much air in. Too little groove and you have inadequate venting. The geometry that has been found to work is something like 1” wide and perhaps 0.010” deep by as wide of a pitch as practical. The geometry may be first simulated with tape before cutting the rollers or drum.

Gage Bands

An area of relatively higher caliper/gage/thickness will build to a bulge on a winding roll. This bulge can cause many problems. The most common is to stretch the material into yield and thus forming a baggy lane. This mechanics is the most common way to make bagginess in film and foil and is a notable cause elsewhere. The diametral bulge can be quite small; as little as 1/1,000 can be the threshold of pain on some products like dead soft foil laminates or paper. The effect of gage variation on winding stresses is well treated by Good and Roisum [5].

What is not explained here is the tendency for winding to be a self-leveling process. Consider the effects of a nip on a gage band. The nip will bear harder there than elsewhere making it locally tighter and thus smaller than it would otherwise have been. The converse is true of the low spots. For these reasons and other high order mechanisms, gage bands do not tend to grow proportionally but will rather reach a stable absolute size after the wound roll reaches a foot or two in diameter. For these reasons and others, the relative diametral variation on the wound roll is far less than the gage variation that caused the problem in the first place.

This problem is almost entirely a manufacturing issue rather than a winding one. It is true that winding tighter will exacerbate the results. However, winding looser will seldom be satisfying. Thus, all efforts must be made to be able to measure the root problem, gage variation [6], and work to improve web uniformity. Until then we must rely on carefully defined roll-based rejection criteria, i.e. thresholds of pain. The two most common are roll hardness variation (film and especially paper) and roll diameter variation (film). In the paper industry it is the supplier that usually defines the rejection values. In the film industry it is usually the customer.

Loose Lanes in Locked Core Winding

There are good reasons to use slipped core winding when winding multiple slit rolls on the same shaft. As seen in Figure 3, wound rolls build to reflect the incoming relative gage error (though nothing like proportionally for reasons described above). Thus, the high gage roll will build to a bigger diameter. Looking at the side view one will see that the problem, however, is usually on the low diameter roll. The reason is that the low diameter wound roll is turning slower in locked core winding. (The RPM is the same but the radius and thus surface speed is less.) This means that the small roll that is running slower, will be effectively running at a lower draw/strain and thus at a lower tension.

How low is this tension likely to be? Zero. In fact, it is worse than zero. Given time, it will be an accumulating puddle on the floor. Of course long before that happens the system will crash. The only remedy the winder operator has at this time is to increase tension to see if he can pull up the loose lane. It is almost never successful on stiff products. Thus, the motivation to use slipped core winding that allows each roll to turn at the RPM necessary to *in theory* maintain an equal tension. However, there are a great many details and issues with this ‘solution’ that cannot be described here [7]. Suffice it to say that one merely changes one set of problems for a hopefully smaller set of different problems. It should be noted that these problems are not confined to the ubiquitous small duplex rewinders. It also can, on occasion, be seen on large paper rolls on two-drum winders. If the individual roll edges lock together, i.e. turn at the same RPM, the small roll's lane will go slack. Note that if this slackness favors the start of the wind it is for other causes (because the gage variation is yet to build up sufficiently) such as a small diameter core that does not nip up properly. The diagnostic of this problem is that it favors products whose roll ends are fuzzy and the cores are devoid of the polishing that is expected when running diametrally varying rolls together on the same drum.

RESONANT

Resonance is the most common class of the problems discussed here. It is so common that it is ever-present at speeds commonly found in converting. At paper speeds, such as on the winder running 5,000 ft/min, trying to avoid resonance would be like trying to dodge flying bugs to keep the front grill on your automobile clean. However, common does not imply commonly understood. This is one of the most misunderstood areas of mechanics in web machinery.

In any case, the response is very dependent on speed or frequency. At resonance, the magnitude may increase 2-10X depending on the damping. However threatening as this might seem, almost all resonances pass without perceptible problem and most without perceptible notice. The reasons are simple. The forces and energies of vibration are many orders of magnitude less than other forces and energies on the machine such as put in by motors, nips, ovens and so on. Second, the movements are usually quite small, almost always less than the thickness of a human hair (exceptions include guide and wound roll vibration discussed below).

<u>Edge Guide Resonance</u>

The common edge guides include displacement, steering and winder/unwind guides. All are prone to resonance though the winder guides might be riskier because of the higher mass and thus lower resonant frequency. All could be modeled with classical control theory though in practice few are [8]. Risk factors that decrease the propensity or severity of the resonance are also classical:

Mass (in motion) – decrease
Spring rate of system (such as pneumatic/hydraulic cylinder, frame etc) – increase
Backlash/looseness - decrease
Gain (of PID controller) – decrease

In field practice we do not use control theory to calculate the maximum safe gain setting much less the optimum values for the P, I and D terms. Rather, we merely increase the gain knob until the guide starts to hunt. Then we back off slightly. Next we must check that the system not go unstable with a step input such as by waving your hand in front of the sensor. Step inputs occur during splicing and other common operations.

<u>Tension Control Instability</u>

Tension control instability is a most complicated problem. Here again we have a great disconnect between research and practice. Neither the machine builder's drive people nor third party drive integrators use control theory when programming or tuning drives. They use block diagrams to calculate how much effort a motor should be putting out to: change tension, change speed and overcome drag. Something like 98% of the motor's capacity is thus calculated (or measured in the case of drag and sometimes inertia). Only the last 2% of the motor is trimmed by feedback from the ubiquitous dancers or load cells. The tuning of the feedback trim is mostly a trial and error (guided by response) operation.

Unfortunately, in my opinion, drive performance has decreased considerably in the three decades I have worked in the web industries [9]. If this is so, the question to ask is why should that be so given the tremendous improvements in drive hardware and firmware. My conclusion is that few companies are grooming the extremely demanding expertise necessary to program web drives that are among the most difficult motors in any industry [10]. Thus I preach and teach on how to recognize that your drive project and programmer are not doing well [7].

The most common problems are often seen on center unwinds and winders because the challenges are most acute. For example, the inertia of the wound roll changes by orders of magnitude during winding or unwinding. To handle this properly, even at steady state, variable gain known as 'inertia compensation' must be built into the control blocks. This requires a diameter sensor/signal at a minimum as well as possibly a roll width and roll density input from the operator. Another acute challenge is during speed changes. You will often see an 'acceleration offset' on the side of the roll caused when the drive system does not hold tension properly during the challenging speed change. In extreme cases, especially when the roll diameter is small, you may see the operator inch the speed pot up in steps to avoid tension oscillation that may well be severe enough to break him down.

There is so much more I would like to say here but can not due to space limitations. I will close by saying that troubles in this area are so acute as to be near epidemic. My general advice then is to not upgrade your drives unless you have to. They could actually get worse, unless you know for a fact that the programmer is competent in the art and craft. Performance specifications based on tension excursions are one way to avoid new drive and drive 'upgrade' problems [11]. Finally, there is a desperate need for a web drive programming short-course that is under consideration/construction at the time of this writing.

Roller-Frame System Resonances

Roller critical speed is a concept that needs to be buried forever. It has no practical meaning in web handling. A typical simplistic formula used by machine builders assume an infinitely rigid mounting is given below

$$f = \frac{\pi}{2}\sqrt{\frac{gEI}{wl^4}} \qquad \{1\}$$

where

f = natural frequency (Hz)
g = acceleration of gravity = 386 in/sec^2
E = Young's Modulus (lb/in^2)
I = area moment of inertia (in^4) = $\pi(D^4-d^4)/64$
D = outside diameter of roller (in)
d = inside diameter roller (in)
w = weight per length of roller (lb/in)
l = roller 'length' (in)

Critical Speed (ft/min) = 15.71xfxD

Some have observed that this closely resembles the equation for deflection. This led to further nonsense where people calculated or measure the deflection of real rollers that have flexible journals not considered above. Some tried to reconcile that these equations over-predict the real natural frequencies by a factor of perhaps two and thus theorized that it was a half-critical that was responsible. While half-criticals are real, they are not a real problem. The real problem is the assumptions given above.

The reality is quite different than simplistic equations [12]. Rollers are mounted on flexible frames that in turn are mounted on flexible foundations. Field vibration studies have shown time and again that the lowest resonance is usually nearer to one half of what is predicted by the formulas because of this flexible mounting. One study of slitter rollers on a high-speed winder shows two natural frequencies under the approximately 10,000 FPM first critical predicted by simple formula. Thus not only are these formulas incorrect, they are also non-conservative; two quite unforgiveable sins of design.

System resonances are so common, especially on high-speed equipment, because framework is flexible. One might expect much difficulty with vibration when running a 10,000 FPM winder. Yet resonances are almost never noticed, much less so are they a problem. About the only vibration sensitive areas of a well-designed winding machine are load cells and shear slitter blades. (An exception is wound roll vibration described next). The way this demanding machine succeeds is not by trying to avoid resonance; it is impractical to the point of impossible. Success is first achieved by designing stiff/stout frames. Second, we super-balance rollers that are the driving force for vibration. Balance is G 2.5 or better on all rollers (except hard to balance rollers such as bowed roller spreaders) and G1.0 on slitter rollers mounted near load cells. On rare occasions the paper machine will develop noticeable resonances on their tender forming areas. Since major resonances of this kind are few in number they are easily avoided by running at a slightly different speed.

Wound Roll Vibration

The story is quite different with wound roll vibration [13]. This problem can very easily be speed limiting. It can be even worse. Sets of rolls can be thrown from two drum winders resulting in what is most appropriately termed 'a wreck.' Models, field measurement and experience all show that the resonant speed of a winding system decreases as the roll builds. This is because the rotational frequency decreases and because the mass increases. The vibration may be so severe as to cause the winder operator to slow to clear the resonance (because it may be difficult to punch up through). Because the resonant speed decreases the winder operator may have to slow down continuously, often to less than half of the speed they would like to avoid resonance. If they do push the resonance, the roll usually gets out of shape so quickly that the operator may need to slow down even more than they otherwise would have.

What makes this problem so difficult, i.e. nearly impossible to do much with, is that the things that make the most difference are outside of practical control. The driving force is wound roll. The mass in motion is the wound roll. The most flexible relevant spring in the system is the spring rate of the wound roll against the drum. None of these are easily changed. Also, avoiding resonance is usually futile because, as we saw, it changes frequency. Furthermore, even if you could avoid a 1x frequency, the roll is free to form 2 bumps (oval shaped), 3 bumps and so on.

While we know of few effective remedies, we actually know a great deal about the problem as it has had many man-years of study and research. First, the propensity is extremely material property sensitive [14]. High web-web friction (COF) and low bulk (density) are the two most predictive properties. Thus we can anticipate that certain grades will be 'bouncers' such as nonwovens and tissue. To this we can add book, sack kraft, NCR and a few other paper grades on occasion. There are some paper mills who intentionally reduce the COF just enough to avoid winder vibration. (This is a very rare occurrence of Design For Manufacturability used in the web-handling world.) Wound roll vibration on well-designed and maintained winders is seldom a problem on film except when the rolls are exceptionally loose or with tacky materials and even rarer on other materials. One main reason is because the speeds (a very large risk factor) tend to be lower in film and much lower in other industries.

SELF-EXCITING

Self-exciting systems are the most exciting, most often way TOO exciting. Here the response is far more than proportional and is more than mere resonance. The problem feeds on itself in a rapidly increasing self-reinforcing response. Not only does the response increase, the response RATE increases making the problem blow up pretty quickly in most cases. There are few general analogies to this class of problem because even the word 'snowball' is merely accumulative. Once started this problem will not stop. It does not require additional energy to be applied such as the slope of a hill. It supplies its own energy.

Calender Barring

Calender cover barring occurs when elastomeric covers take a set such that there are an integral number of hard and soft bands extending across the width of the roller [15, 16]. The number of 'bumps' per revolution can line up with any one of several system resonant speeds. At that time the problem becomes self-reinforcing. Even though the machine vibrates, the amplitude is not so much as to be speed limiting or cause increased maintenance (aside from the covers). Rather, the deleterious effects are found on the product itself.

The name barring refers a horizontal banding of the (most often paper) web. In the extreme the barring is visible, something like a picket fence. The bar is the relatively higher compressed material. At more modest levels the uneven product is known to cause print variations on the next process and suspected to be a factor in some rare forms of winder vibration.

An analogy of a washboard gravel road may be helpful. We will again use the same analogy for winder vibration [17]. The mechanics requires a deformable element (the road in the case of the washboard and the roller/roll in the case of the calender/winder). The other major element is a spring mass system with a natural frequency. In the case of the washboard it is the car and suspension and in the case of barring and winder vibration is it the machine system. As seen in Figure 4, the problem is initially started by a disturbance that is so small it will never be identified; perhaps a single big gravel stone. This stone causes the car to bump up and then down, digging a slight divot in the deformable gravel surface. The next car traveling at a similar speed and having a similar suspension natural frequency will also find the big gravel stone but also now the slight divot which tosses the vehicle slightly up which then makes a second divot. If all of the traffic has a similar speed and natural frequency, then the surface of the gravel road will be moved to a washboard shape with the spacing an integral number times the wavelength of the suspension's first mode of vibration. The reason that this problem is self-reinforcing instead of mere resonance is that the barring increases the amplitude of the vibration which further increases the amount of compression set on the cover and so on.

So much for theory. What is done in practice? The first thing to do is to grind the cover round again. However, that alone is not enough because the cover takes a compression set at the bars so that it is slightly harder (and perhaps more wear resistant). Putting in this geometrically round yet bumpy cover due to compression set will just set the machine up for another round of vibration. The longer-term fix is to adjust the horizontal position of the calender stack to alter the system's natural frequency enough to avoid resonance at the preferred speed. This approach is more desirable than a production limiting slowing of the machine speed to avoid resonance. Many calender stacks in the paper industry have the provision for this adjustment that is guided by expert vibration modeling and measurement.

Interweaving on Simplex Rewinders

Converting rewinders will take a wide roll and cut it up into many narrower rolls. If this is done on a duplex winder where every other wound roll is on a different station or shaft there is no strong need for spreading and no interweaving whatsoever. However, simplex winder such as two-drums and centerwinds where multiple lanes are running side-by-side on the same shaft have no such luxury. Here it is quite possible that one lane will steer over into its neighboring wound roll and interweave. In paper this is known as tied-up or stuck rolls. It is true that spreading can help a bit because the wider the gaps between the lanes/rolls, the larger the safety factor. Precise mechanical design/maintenance and tension/drive control are also necessary, especially in the paper industry where rolls may be running with only a few hair's thickness between them. Even so, the web itself can steer into its neighbor even if the machine is perfect. The common mechanism here is bagginess on one side of one lane otherwise known as camber [7]. The problem is much more acute with lots of narrow rolls, with thin webs (heavy board will butt up against its neighbor rather than climb over) and with poor quality webs.

While only a few wraps will tie up a pair of rolls, one will see that the problem may become self-reinforcing well after the initial cause, whatever that might have been, is long gone. This is easy to understand with a concave spreader analogy [7]. As seen in Figure 5, when one lane crosses into another, even momentarily, the diameter of that portion of that roll will be relatively larger. We know that a bulge in a roll/roller will cause the web to move toward it in traction. (Traction is almost a given between the layers of the wound roll because of the indefinite 'wrap angle.') This makes the bulge bigger which causes a harder pull and so on. Once a lane crosses over, it tends to get 'sucked' in to its neighbor for quite some time. This forms a pronounced offset on the roll whose lane moved that may end abruptly as it began.

'Knots' on Wound Rolls

An almost identical phenomenon can take place on a single wound roll. Consider a bulge in a wound roll as seen in Figure 6. This may be caused by a number of means including tape at the core, a wrinkle at the core, a wrinkle entering the wound roll, a gage band, anything. I have seen systems so fussy that the operator's only chance for success required starting on a machined metal core using the best care possible to fix the tail to the core.

The results, once started, are a runaway defect. The bulge will pull the material toward it making the bulge bigger. This bigger bulge will pull the material harder toward it and so on in a self-reinforcing pattern. Once started the defect builds more than proportionally so that the only solution is to break down and try to start again. This problem is extremely sensitive to web properties. Thin tacky materials, such as some films, are at most risk because thin means reduced wrinkle buckling resistance and tacky ensures traction. However, I have also seen this on some specialty paper grades. Like many problems of this class, whether the problem ever begins is highly dependent on initial conditions, not unlike an avalanche. The quality of the core and the quality of the taping of the core is most important. Very often a full width tape must be used, instead of individual strips. Even then great care must be taken to make sure the tape and the tail is applied dead flat to a dead flat core.

An analogous defect in the film industry is slip dimples/pimples. Again the defect is self-exciting. Again the defect is very material property sensitive; thin tacky materials are worse. Again the nucleus of the defect is tiny, sometimes unseen. The only difference is that the defect is shaped like a mound instead of being a lane.

Telescoping on Core Supported Winding

There are many defects that go by the name telescoping. Here we will confine ourselves to the most common; telescoping on core supported winding that is also sometimes called cinching or clock-springing. This case is distinguished by J-line movement near the core [18]. The treatments for this well-known problem include winding with maximum taper. After that product redesign should be considered such as reducing roll diameter, increasing core diameter and increasing web-web coefficient of friction. Obviously, this defect can result in the loss of the entire roll if it slides too far sideways to be able to be unwound.

There are two factors that can make this self-reinforcing; one elastic and the other anelastic. The elastic factor is simple. As the roll cinches tighter near the core, the layers compress radially which in turn reduces the pressure on the inside of the roll (just above the layers that have moved). The reduced pressure on the interface between the sliding and stationary layers reduces the torque carrying capacity of the roll so it slides more. (This factor does not apply in the rarer case of nip-induced slippage caused by roll weight born over the core.)

The anelastic factor is similar. On certain tender products the increase interlayer pressure just above the core that was tightened by cinching can cause the product to yield. This causes a permanent thickness reduction and thus reduces interlayer pressure even more. Yielding in the ZD is small or rare, but I have seen it happen on foam egg-carton stock and nonwovens.

Wound Rolls that Uncoil After Cutover

Early in my consulting career I was called to an LWC paper reel that had severe troubles with one extra smooth grade. When the finished reel was cut and center-braked to a stop, it tended to unwind or unzip from the top. Sometimes the defect ruined the outer foot of the large parent roll. This is a large volume of waste and very difficult to slab off and get rid of.

I determined that the problem started when the tail was cut, it had no tension. No tension means no interlayer pressure under the top layer. This in turn meant that the WIT that did exist somewhere further upstream on that layer was relieved because of the tension imbalance (zero on the tail end and WIT on the other) had no resistance to movement. This is because Coulomb friction is zero when the normal force (interlayer pressure was zero). The result was an unwrapping or unzipping of the wound roll from the outside in. This process becomes self-exciting during center-braking. The outer layer and then layers becomes a flywheel that resists slowing down. This is in the direction of loosening which just exacerbates the already-described mechanism.

Slowing the decel rate of centerbraking was not an option for time cycle reasons. Neither was an upgrade. There are a very few reels equipped with a temporary nip applied from underneath to pin the outer layers onto the inner layers just after cutover. So I told the mill that we needed non-Coulomb friction; friction that does not require interlayer pressure. Examples of non-Coulomb 'friction' are adhesives or Velcro. Many paper grades are just fuzzy enough that the layers interlock slightly once they are brought together and are thus non-Coulomb. However, changing grade construction is also not a practical option. Thus I proposed a short blast of a tiny bit of adhesive applied on the outer layer on cutover. This adhesive could be merely water as it would take almost nothing to stop this from getting started. I wrote the report and never heard from them again. The problem was one of selling the solution (the much harder part of problem solving compared with merely figuring it what the problem is and what the options are). The word 'non-Coulomb' friction and spraying water were just not in their vocabulary.

After the visit I did some serious digging and found that a few rare paper machine reels did just that. They sprayed a tiny bit of water to tack down the outer layer just prior to cutover. As fortune had it, I was called back many years later to the same mill for the same problem: uncoiling of parent rolls on certain grades just after cutover. When asked what the problem was I said that the wound roll was unzipping because the tail was too slippery. When asked what to do about it I told them a short blast of water would tack the outer layer to keep this from starting. The mill then asked me "who else has done this?" I was prepared by the culture to be ready for the question and had a reply, if slightly exaggerated. I said "everybody I know who has this problem either adds a nip roller during cutover or blasts a bit of water on the tail." Science provided the explanation but I learned better than share the mechanics. I needed to sell by giving them comfort that it was done elsewhere and it worked.

CONCLUSION

The example problems discussed here are quite varied. They come from a variety of products and processes. However, while the problems themselves may not be familiar to most, the mechanics should be easily recognized once described. We have seen them before, concave spreader principles, resonance, stresses inside nips and inside wound rolls and so on. The troubleshooting challenge is thus not in defining new physics or refining our knowledge of these physics. Instead, the challenge is to determine which of the physics we already know applies to problems that we might have not seen before.

That is not to say that remedy will come easily. These include some of the most difficult problems in our industries. The self-reinforcing problems in particular are quite sensitive to material properties, yet we will find few customers willing to alter the web to avoid these risky properties and thus the problem. These problems may also be extremely sensitive to tiny changes in initial conditions. However, this too is a challenge. It can literally be like determining which gravel stone started the washboard road. Was it too large, did it have a bad shape, or was it just bad luck or was it inevitable?

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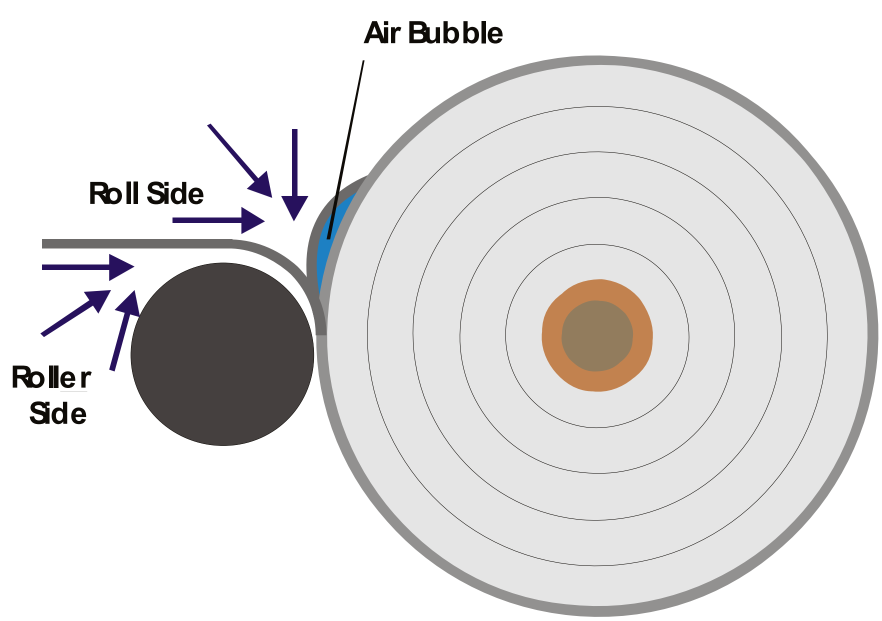

Figure 1 – Air Bubble Behind Winding Nip

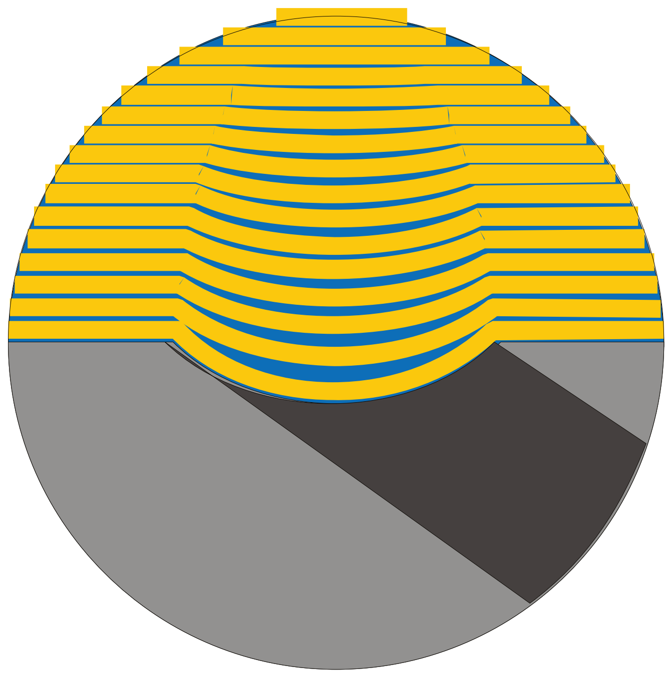

Figure 2 – Venting of Air Over a Wide-Shallow Groove in a Layon Roller

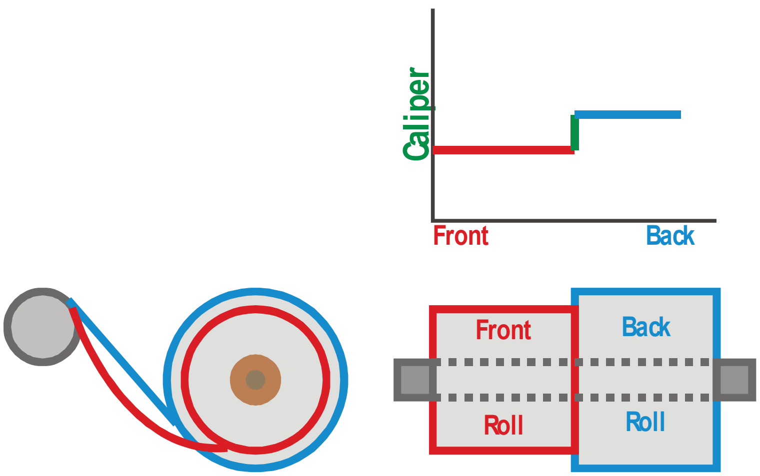

Figure 3 – Gage Variation Causes Slackness on Locked Core Winding of Slit Rolls

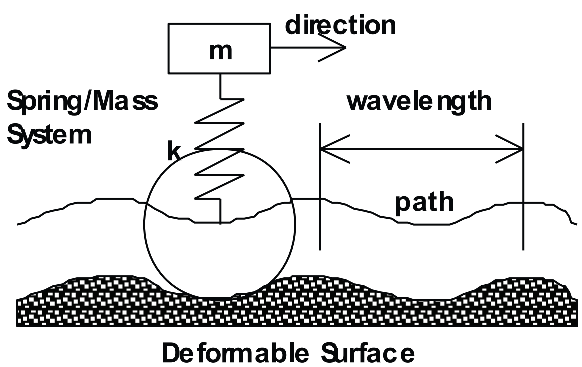

Figure 4 – Daly's Washboard Road Analogy for Winder Vibration

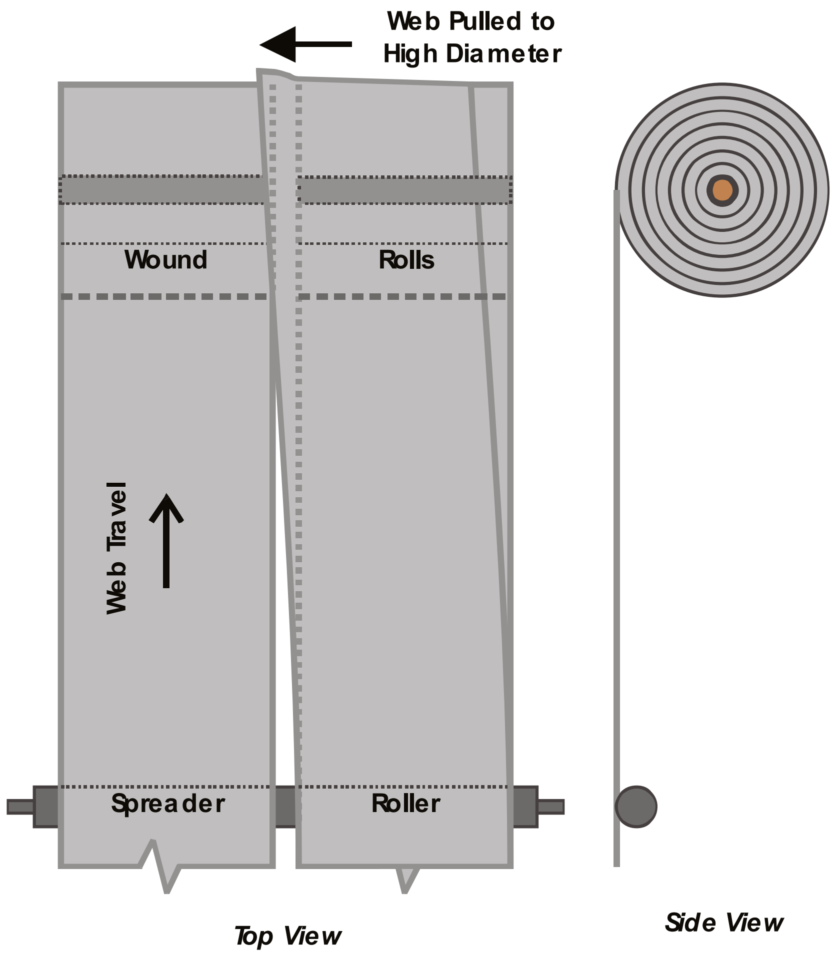

Figure 5 – Self-Excitation of a Slit Lane Crossing its Neighbor

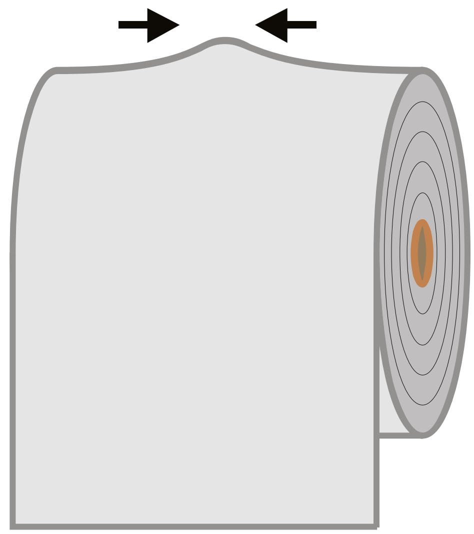

Figure 6 – A Bulge in a Wound Roll Tends to Gather Material

A Mechanistic Survey of Accumulating, Resonant, and Self-Exciting Systems in Web Handling	**D. Roisum**, Finishing Technologies, Inc., USA

Name & Affiliation	**Question**
Volker Traudt, Inometa, Inc.	There are a couple of thousand machines running today close to the critical speed. Theoretically it does not make any sense to use the critical speed of roller to design a machine. But if you have experience with regard to how far you need to stay from the critical speed because of the softness of your frame work and foundations then it works. These machines are running and very few of them are running close to a natural frequency. They are vibrating because of defects and other imperfections.
Name & Affiliation	**Answer**
Dave Roisum, Finishing Technologies, Inc.	You are correct that industry does thrive. But that does not mean they thrive by analysis. It means they have found something that works. I am saying that this calculation doesn't work.
Name & Affiliation	**Question**
Volker Traudt, Inometa, Inc.	We include a 60% safety factor and then hope it will run smoothly. That's really how it's done.
Name & Affiliation	**Question**
Bob Lucas, Winder Science	Philosophically, you have said that the foundations do affect natural frequencies. But if you went and calculated the natural frequency of a roller at 30 Hz and then you went out to the machine and conducted an impulse test on the roller, perhaps you find the frequency is 28.5 Hz instead. Some of the discrepancy is due to the compliance of the bearings. If you modify your calculation to include the stiffness of the bearing perhaps it will produce a result closer to the tested value. Now if you have a poor foundation stiffness too, then you have additional trouble.
Name & Affiliation	**Answer**
David Roisum, Finishing Technologies, Inc.	You are quite right. When I used the term foundation I was describing all the elements supporting the roller including the framework and sometimes bearings. Load cells are notoriously for having low stiffness. In any case, whether you are over predicting natural frequencies by 10 or 50%, I don't care. It is an error and it is not in a conservative direction. It is unacceptable.
Name & Affiliation	**Question**
Bob Lucas, Winder Science	You discussed the impact of grooving patterns on your rider rolls or lay-on rolls. I had an experience where there was some grooving cut on a rider roller for a winder with the idea that this would remove air bubbles behind the rider roll. The thing vibrated badly with a once per revolution vibration. We found that if we narrowed the pitch of the grooves that the vibration was eliminated. The vibration was caused by a hard spot or a ridge on the wound roll.

	Every time the rider roll would rotate one revolution the ridge would contact the land and the groove and would bounce. This produced a once per revolution vibration which was objectionable. If you narrowed the groove pitch for these harder papers, you could eliminate this vibration. I question your explanation of the affect of air. I believe the crucial issue is limiting the air that is entrained, not bleeding the air out.
Name & Affiliation	**Answer**
David Roisum, Finishing Technologies, Inc.	I like your terminology. But again, this is all cut and try, cross your fingers, etc. The biggest mistake I ever made for a client cost them $250,000 because we suggested regrooving the drum. The analysis of three people had indicated the drum needed to be regrooved but it did not work.