What is the Best Tension for My Product?

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ABSTRACT

Tension is the most common control on web machinery. Good tension control is required to reduce waste and downtime. However, before you can effectively design much less operate tension controls, you must know what tension is best for your process and product. You must also know how much variability is tolerable. There are many places you might get answers to tension questions such as these. There are several publications that have suggested tension tables for common materials. Even if your particular material is not tabulated, there are guidelines based on thickness or strength that may work. However, these sources are merely starting points. They do not offer much help in the plant to modify the starting points based on conditions. An analogy is speed limits for automobiles. Posted limits offer little guidance for selecting speeds which best keeps up with fast-moving traffic or which accommodate inclement conditions. This paper offers a progression of ever-better answers on how to set tension for your product and process. It considers all important sources of information such as experience, experiment and, most importantly, economics.

KEYWORDS

Design, Control, Standards, Tension, Optimization

WHY DO WE CARE ABOUT TENSION?

The simple reason is that we care about waste and delay. Tension can have a large effect on waste. Laminating curl, mis-registration during printing, wrinkling and winding defects are just a few problems that are quite tension sensitive. Tension also affects runnability. If the tension is too high, materials can bend, break or neck. High tension web breaks will cause the machine to be shut down, rethreaded, restarted and equilibrium be re-established. If tension is too low, however, the web can wrinkle in nips, wrap rollers or cause many other types of troubles.

There are three big controls on web machines. They are called the TNT's of web handling which stands for Tension, Nip, Temperature (or moisture in the case of paper) and speed. Of these, tension is certainly the most universal because it involves every span of every machine ever built. In cases where nip and temperature are not applicable, tension is also by default the most important. For these and many other reasons, builders and owners of web machinery must care about tension.

WHAT IS TENSION?

Tension is the force applied to the web in the MD (machine direction). Every element that touches the web can change its tension as it proceeds down through the machine. Driven rollers may give the operator some control over the tension. However, undriven rollers also change tension due to effects such as the drag of bearings and inertia (resistance to speed changes). The extent that undriven rollers change tension depend on many machine design details as well as on the web itself. Light weight webs are more sensitive to these so-called idler rollers.

Tension can be reported in three different ways: total force, lineal force and stress. **Total force** reported in units such as lbs, kg or N, is the load applied by the machine and therefore of great interest to machine builders. They will use that force to size rollers so they don't deflect excessively, to size bearings to withstand that load, to size motors as well as select many other mechanical and control components. Total force is also used by operators of machinery which makes ropes, strings and wires as well as profiled products such as diapers. In those machines, 'web width' has little meaning or significance.

However, total force is not the appropriate unit for webs, even though it is commonly found on older machinery. In my opinion, builders and owners of machines using total force as tension units are often careless or lazy. One reason is that total force does not account for web width. An operator moving between machines, or merely changing product width on a machine, would have to learn appropriate tensions for each grade (chemistry and thickness) <u>and</u> each width; a daunting task. However, even if a plant only ran one chemistry, thickness and width, total force would still be inappropriate. That plant would not be able to easily communicate with material suppliers, machine builders and technical people around the world, all of which use lineal force as the lingua franca of web tension. Total force should be only reserved for strings, wires, ropes and other 1-D products as well as highly profile products like diapers.

Lineal force is the force per unit of web width. The units in the English system are lbs/in (lbs per inch of web width) which is most commonly abbreviated as PLI (pounds per lineal inch). Thus a 40# total force applied on a 20" width machine has a 2 PLI tension. In the metric system the most common units are kN/m. If the web width is fixed on a machine, the width is already calibrated into the inputs and outputs the operator works with. If the web width is variable, the width is entered by the operator or remembered by recipe and the division by the current width takes place in the PLC computer. The operator enters the same <u>lineal</u> tension for a 43" web as a 57" web. However, the machine pulls appropriately harder on the wider web without the operator doing any math. Asking an operator to guess at width compensation or to do math is simply not appropriate in this age of computer control.

However, a case might be made for web 'tension' reported with units of **stress**. Here, total force is not only divided by web width, but also by web thickness (caliper, gauge) as well. Thus the stress applied to a 10 mil aluminum sheet that is 50" wide pulled with 1,000 lbs is 1,000lb/50in/0.010in or 2,000 psi. One can then directly compare this tensile stress applied by the machine with readily available textbook values of strength. For example, the above applied stress is 20% of a 10,000 psi yield strength that might be typical for aluminum. With stress as the reporting units, the operator uses the same 'tension' for all widths and thicknesses. The industries that use stress as the reporting units include most metals, a few film companies and most researchers in winding and web handling.

While there are many advantages to using stress rather than lineal tension, there are two serious limitations. First, the thickness of some materials is ill-defined. By that we mean that thickness is unique to a measurement method rather than existing independent of the method. Examples include some foams, nonwovens, textiles and tissue. Materials such as these will yield different measures of thicknesses if you squeeze on them differently with the calipers. However, even materials where thickness is well defined pose issues. What is the thickness? How does it vary? Do we use nominal or actual thickness when reporting stress and so on? Despite the complication, it would not be surprising to see the rest of the film industry move to stress units and perhaps the flat paper grades as well.

HOW IS TENSION MEASURED?

Selecting and setting a tension would not have any meaning unless you can be sure you get what you ask for. In other words, control has no meaning without calibrated measurement. The most obvious means of determining tension is via a roller mounted on **load cells** (1). However, load cells read roller weight and other factors besides the web tension of interest. The designer can, in theory, calculate the zero and gain values required to convert raw load cell readings into proper tension units. However, mistakes in calculation or interpretation can and do happen. From personal experience on a slightly more complicated control, I estimate that half of all nip values are in error by at least 20% and perhaps a quarter are off by more than a factor of two. Thus, design calibrations are merely a starting point and are never adequate unless independently checked.

Field **calibration** of a load cell is usually done by hanging weights on a very flexible strap, wire or rope that is routed along the web run. Figure 1 illustrates a simple example of a calibration setup. This technique can also be adapted to calibrate most dancers and some motors as well. The load cell is first zeroed without any web or weights. Then a weight corresponding to near the high end of the design range is applied and the gain set so that the meter or display reads correctly for that weight. The weight is removed and the zero is rechecked. The full load weight must be rechecked and a mid-sized weight should be checked. The former for repeatability and the latter for linearity. Multiple cells under sectional rollers pose a more challenging setup that will not be discussed here.

A lack of repeatability is as often a setup error as it is an instrumentation error. Friction from any source will scatter the results. This means using a very flexible rope or better yet piano wire if it is strong enough. This also means routing around as few rollers as possible. Obviously you must preserve the ingoing and outgoing web angles of the load cell roller position. However, roller bearings have friction which adds to the uncertainty of the load actually applied to the load cell roller. It is never permissible for the routing to include a driven position as the friction from the gearbox and drive motor would destroy the integrity of the measurement. You can, however, tie off on a driven roller. If a suitable routing can not be made, it must be simulated with pulleys at least for the ingoing and outgoing runs.

Dancers can and should be calibrated in a similar fashion. Here, we hang a few different weights and find what cylinder pressure is required to counterbalance the weighted rope. A curve of tension versus cylinder load is fitted. This curve is then programmed into the PLC so that dancer inputs are in proper tension units of PLI, not psi of cylinder pressure. On equipment without PLC's, you can put a graph or conversion chart next to the pressure gauge or better yet put an overlay directly on the gauge.

Motors are also a poor man's load cell. Most modern motors can compute or estimate the applied torque which translates to tension at the roller's radius. There are widely circulated formulas for tension developed by DC motors given HP, amps, rated amps and other easily obtained inputs. There are problems using estimates like these for DC motors or models for AC vector motors. First, it is possible that the models are wrong, interpreted wrongly or calculated incorrectly. More importantly, these models do not take into account the friction required to power the gearbox and motor itself. No-load motor amps are what are required to turn the motor, gearbox and roller over without a web on it and at the desired speed. Thus, the load on the web is the difference between the current load and what is called no-load motor amps. These and other complications make the tension numbers reported by modern drive moderns suspect unless checked with independent instrumentation. One way to check is to use a weighted rope. However, this weighted rope must be moving slowly to account for friction. This poses extreme challenges for setup, safety and may not be possible for some motors which can not stall for long periods without overheating.

Motors on the endpoints of the line are absolute tension at that point. Motors in the midpoint of a machine determine the tension difference across that position. Here, a motor that is pulling (motoring) decreases the tension of the web as it passes that position. Conversely, a motor that is pushing (e.g., braking or regenerating) increases the tension of the web as it passes that position.

There are other niche methods to determine web tension. One is to calculate it using a measured **web sag** in a long span. A simple formula given web basis weight, web span and web sage readily calculates tension. This method is useful where sag is large and easily measured by instruments such as ultrasonic sensors. Some tissue and nonwovens machines use this technique. Also, it is possible to use ultrasonics and time-of-flight measurements to determine tension. Unfortunately, this is very much a research type method not at all suitable for use in most plants. Tension profile, i.e. variation across the width, is extremely difficult to measure but can be done with some profiling load cells.

HOW IS TENSION CONTROLLED?

The details of tension control methods far exceed the scope of this paper. Here, we will only list the highpoints. The most direct control of tension is by load cell or dancer feedback control of motors. This is *closed-loop* control. If the motor does not pull hard enough as sensed by the load cell or dancer position, it will attempt to make a correction. Obviously, we require calibration of either of these sensors to earn our trust.

The most common *open-loop* control of tension is speed differential control, often inappropriately called draw. Here, we make two adjacent motors turn rollers at a slightly different surface speed. If the downstream motor turns faster, the tension is increased slightly. While the idea of setting a draw and controlling speeds is easy, the effects on the web's tension are enormously complex. The outcome is that we often don't know what is happening to the web at any one time or how it changes with time.

There are numerous mechanical and control details the designers and maintainers of machinery must attend to. However, the process engineers and operators have only two areas of concern. They are: what tension should I run and how close do I have to hold it. Both are potential quality concerns. The problem of the best tension setting is the primary goal of this paper. However, we can make brief mention on the subject of **tension variability**. First, there are wide differences in the tension sensitivities of processes, products and even customers. There are many products where whatever tension variability does exist, does not affect waste and delay significantly. This would include some very tightly controlled machinery. However, it is mostly tolerant products that fall into this situation. Tolerant products <u>may</u> include <u>some</u> construction materials, roofing, rubber and textiles. Here, whatever is currently done is often good enough.

However, other processes are much more tension sensitive. Printing is a good example. Tiny tension variation can cause two colors to go out of register. However, some coaters, laminators and winders are also tension sensitive under certain conditions. In any case, we might do a capability study to determine how much tension varies and how that level of variation affects waste and delay. Obviously this would be a tedious but sometimes necessary study. A quicker but cruder route to an acceptable tension control tolerance is to simply require our machine to behave as good as most. Here, we note that most machines can hold tension to within 5% of setpoint during steady state and to perhaps within 10% of setpoint during modest upsets such as speed changes. These tolerances have to be widened even more if the upsets are larger such as flying splice unwinds, winder roll transfer, closing of nips and other violent events. Many people write tension variation specifications into their quotation requests to protect themselves against machinery that does not hold settings well.

A tension variation standard requires fast acting load cells and high speed data acquisition. This means that you must draw the signal from an unfiltered part of the electronics as filtering can mask the true extent of the variation. This means that analog gauges must be undampened. However, the usual limitation is digital displays. Most PLC's are far too slow to show a variation of interest. Sampling would have to be at least 10 Hz in order to capture many upsets. Some load cells are good enough for this purpose as well as a few high end drive motor controllers. Dancers are not suitable for determining tension variation. A moving dancer means tension might be moving a bit or a lot, you can't easily tell which. A stationary dancer could result from excessive mechanical friction rather than smooth tension control.

BEST TENSION – WHAT YOU ALREADY KNOW

Experience is the best teacher and the best teaching experiences are bad ones. Operators of equipment will vary tension in the course of their duties. If something goes wrong, such as a web break, they will move the tension the other way. Eventually they will feel out the boundaries of trouble at both the low end and high end for each grade and application. Thousands of hours each year on thousands of similar machines tend to find a tension that is somewhere near best. You might think of it as the principle of 'survival of the fittest' applied to tension control settings. Settings that don't work as well don't tend to last as long. Machine builders often accumulate the results of these experiences and incorporate them into standards.

Take this **plant-floor knowledge** and use it. Note what tension the operators prefer. More importantly, ask the operators what tension values causes troubles and what these troubles are at both the high and low ends of the scale. If the tension is too high, for example, the paper might break. If tension is too low, for example, the web may wander unacceptably. Obviously, this 'best' is dependent on grade, machine, position in the machine and other factors.

You can extend this knowledge from one 'grade' to a different grade in some cases. If the grade only varies in thickness, rather than in composition or chemistry, the appropriate tension is proportional or scalable. In other words, the appropriate tension for a new grade is the old grade's tension times the ratio of the thickness of the new grade over the old. This is nothing more than a reiteration that stress is the best measure of pull in most applications.

This rule would, for example, indicate that a product twice as thick should be pulled twice as hard (total pull). However, you will not see tension doubled. More often, operators will only increase the tension by 20% for the thick grades. Similarly, running a material half as thick would indicate halving the tension. However, you will not commonly see tension halved. Rather, operators may only decrease the tension by 20% for the light grades. Why then, does the rule indicate moving tension from 50% to 200% for that range of products when in practice they may only move tension from 80% to 120%. The simple answer is that operators are human beings and human beings tend not to compensate properly for conditions. In the great majority of cases, humans tend to under correct.

Take driving as an analogy. If it rains, the friction coefficient of the tires against the road will be halved. If there are icy patches the friction coefficient will be a quarter of what it would be on dry pavement. Do people slow from 60 mph down to 30 or 15 mph under rainy or icy conditions? Not at all. In fact, they may not even slow down at all. The results are all too predictable for this case of under correcting; more accidents in inclement conditions. The same thing happens on the high end. While 60 mph might be safe on a US highway, it is not so on the German Autobahn. 100 mph might be safer from being rear-ended as that is the norm for the traffic. Yet try going 100 mph. The gas pedal feels like there is a huge coil spring under it. The foot refuses to press down that far because it has little experience there.

Even the most skilled professionals tend to under correct for conditions. Take an aviation mechanic who tightens bolts on an airplane. If the bolt is not tightened enough, it may come loose. If it is tighten too much, it may damage the part or itself. There are torque standards for any application. Even with skill and sensitivity, these most skilled of mechanics will make tightening errors if they do not check their own work. They, and everyone else, will tend to over-torque the little bolts and under torque the big bolts. Thus, instead of a 10-200 ft-lb span for a 1/8" to 1" bolt, they may only span 20-160 ft-lbs.

The moral to this story is to keep an eye on all gauge dependent adjustments and tension in particular. While the operators may have found a good spot for the common grade, they will tend to pull too much on the light material and too little on the heavy material, even if the machine itself has a wider range.

BEST TENSION – WHAT THE MACHINE BUILDERS KNOW

Experience is the best teacher and the best experiences are the bad ones. Just like operators, machine builders will tend to find what works best, or at least some semblance of best. The advantage the machine builders have is awareness of a wider population of applications. The learnings of an operator or process engineer tend to stay in that plant so the population to learn from is quite small. However, machine builders are responsible for dozens if not hundreds of similar machines. Though performance feedback is much more limited, the population to learn from is much larger. Most machinery builders have tables of appropriate tensions for various machines and materials which they commonly supply. Note, however, a single value is always too limiting. The guidelines should be a range where the low end is used for sizing precision or variability and the high end is used for sizing strength.

This accumulated experience of builders is sometimes shared in the form of publication. There are several excellent articles that suggest tensions for common materials (2,3). Interestingly, these values are not dependent on machine. Thus, a certain paper would be tensioned similarly in a coater, laminator, printer and winder. Also, the best of these sources give thickness dependent answers as we would expect if we accept that stress is the best tension guideline. Thus, for example, they might suggest a polypropylene film be tensioned ¼-1/2 PLI per mil of thickness. Occasionally, technical organizations such as TAPPI will accumulate the experiences of an entire industry for materials that they have ample experience with, namely all of the common paper grades.

BEST TENSION – STRENGTH BASED RULES

The above techniques work well for starting points – provided that you or someone has experience with a particular grade. However, what happens if you are making a material which is not tabulated on the charts? What happens if you laminate two materials together making a new composite that certainly will not be tabulated? What happens if you want a second opinion on the charts or your practices themselves?

There are two really simple general guidelines for tensions. One is based on thickness and is restricted to 'normal' webs. The other is based on strength and can be used for almost all webs, though the guideline values might change a bit for webs that are on the extremes of strength. Let us start with a thickness rule that should get you in the ballpark for typical films and papers. It may not work well for odd stuff. It says that a common **tension range is from ½-1 PLI per mil of thickness on paper and perhaps ¼-1/2 PLI on film**. (A mil, or point in the case of board, is 0.001." The word gauge in film means 1/100 of 0.001". Thus, a 50 gauge film is 0.0005" thick.) If we apply this thickness based rule to 3 mil newsprint, we would get a design tension range of 1.5-3.0 PLI. The convenience is obvious, but we probably want to give a better answer if we can.

The next guideline really works for a much wider variety of webs and machines. It says that **webs like to be tensioned at 10-25% of their MD strip tensile strength**. While the purist would argue that yield strength would be preferable, yield stress is far more difficult to get and is not that different from the much more commonly reported peak strength. The appeal here is that nearly everyone knows the strength of their web. If not, they can readily get it by testing themselves or getting the number from a supplier who has a tensile testing machine. Using the previous material, newsprint, we can estimate an appropriate tension range of 1.0-2.5 PLI for a 10 PLI strong newsprint paper. Note the excellent agreement between the two methods. The design range of a machine should thus be from 10% of the weakest grade for precision to 25% of the strongest grade for total force.

Now the caveats. It is risky to use any general rule for really odd stuff. Also, some industries tend to violate these rules in common practice. Textiles and small printers tend to pull noticeably less than the 10-25% range given above. There are also exceptions when at the very light and very heavy ends of the produce range. Thus, for example, tissue may run from 20-40% of its strength. It will not be surprising, web breaks are common because pulling lightly on tissue is not easy when you have brutishly heavy metal rollers to work with. Paper board, on the other hand, may only run 5-15% of its strength. Not surprisingly, path control and flatness can be problems here. The reasoning for the less than expected values for tension is that designing to withstand large loads costs money. Also, it is difficult if not impractical to flatten or stabilize a non-flat or baggy heavy material.

Thus, light materials tend to pull a bit higher and heavy materials a bit lower than the 10-25% of web strength rules suggests. No problem. Simply define the strength based range for appropriate for your material. The concept is that it takes a certain amount of pull, a noticeable fraction of strength, to flatten and stabilize a web through a machine. Conversely, pulling too close to yield or break will increase the incidence of damage or web breaks.

BEST TENSION – LET THE WEB TELL YOU

All of the above methods are a starting point and nothing more. They are in many cases good enough to design a machine with the appropriate range so that the process is not limited. They are in some cases, good enough to run a machine if the product and process are tolerant. We simply select the midpoint of the range. However, if the material or machine is fussy, we may need to modify our starting point to take into account information that is readily available. All we need to do is ask the customer, the web, what it thinks about the applied tension. It will usually tell you.

If the tension is too high, necking, web damage and web breaks may occur. Some wrinkles will show up more frequently at higher tensions. Finally, some winder defects will become more frequent at higher tensions. Conversely, if the tension is too low, the web will skate, wander or flutter through the machine. Path control and registration will degrade. Also, baggy webs may wrinkle more on the entry side of nips at lower tension. Finally, some winder defects will become more frequent at lower tensions.

You will note that all of these troubles have economic impact. You can, for example, assign a waste value in dollars to a roll lost due to telescoping which is usually a low tension defect. You can also, for example, assign a delay value in dollars to a tension web break which is a high tension defect. Thus, there is no real judgment in whether the tension is too high or too low. If the resulting tension sensitive trouble costs money, then it <u>is</u> too high or too low. The only judgment that might be made is if a customer thinks, for example, that a wound roll is wound too tight. Whether it is or it isn't in a functional sense is beside the point. If the customer thinks it is, then it is and it will cost you, even though the costs are less definable. The takeaway is that evaluation of tension is not a judgment call, it is strictly economic. We will build on this in the next and final section to give the best, best tension.

Thus, our starting point tensions are modified by what we see for tension sensitive waste and delay issues. Each situation is different, but the concept and analysis are quite simple. If all you have is <u>only</u> a tight defect or tight defects, back off. If all you have is <u>only</u> a loose defect or loose defects, crank it up. If you have <u>neither</u> tight nor loose defects, leave the knob alone. You are done for now. You have a sweet spot for tension, you found it and you are already there.

The problem is, however, you might have a wholly sweet tension spot. Consider this. Is it possible for the web to be too tight and too loose at the same time? If you think about it for a moment, the answer is obvious. If I have both tight and loose defects appearing while running the same tension setting, the system is over constrained. The simplest example would be baggy edges as shown in Figure 2. A baggy edge is loose. In fact, it is <u>too</u> loose because it wrinkles in front of a nip which costs money. To compensate, the operator increases the tension to try to muscle his way through. However, long before a baggy side is pulled taut, a web break might initiates on the tight side. It is too tight <u>and</u> too loose at the same time.

Being too tight and too loose at the same time is more common than you might think. These defects need not necessarily occur at the same time. They only need to occur at the same tension. When we have both tight and loose troubles, we must use economic optimization to find the sweetest spot. Here, the spot will not be absolutely sweet because that implies there is a tension that yields no tension sensitive defects. Think of it in terms of finding the best place between a rock and a hard spot.

BEST TENSION – THE BEST OF THE BEST: ECONOMIC OPTIMIZATION

A different analysis is required for the not-so-special case of having tight and loose defects at the same level of tension. In cases such as these, we must optimize tension to find the least painful (costly) position between the rock and the hard spot (4). If, as in the previous baggy-break example, we run far too tight we will be put out of business with web breaks. On the other hand, if we run far too loose, we will be put out of business with wrinkling through the nips. We hope that there is a place in between where we can stay in business. Better yet, a place in between where we will do our economic best. We must be quite careful at this point. Best does not mean *zero* defects. If you could have found that position via techniques of the previous section, you would not need this section. Best means *least* defects.

Optimization is simply a mathematical process of finding the minima of a function. We begin by determining what is most important. In business, what is most important is always the same - money. Waste and delay, for example, costs money. This money objective is the y-axis of a graph such as shown in Figure 3. The thing we are trying to optimize for this baggy-break example problem is tension. The thing to be optimized is the x-axis of the graph.

With this setup, we are ready to add in costs. Considering only baggy lanes wrinkling behind the nip, the higher the tension the lower the cost for that type of waste. The baggy curve is monotonically *decreasing* with a concave up shape. This is the approximate shape many plant cost functions. If bagginess was the only concern on that machine, the best or optimum tension would be infinity in this slightly over-simplified example. Even so, answers such as infinity are clearly nonsense. They are nonsense because the analysis misses at least half of the world.

Now consider only simple tension breaks. As we increase tension, the frequency of breaks and thus the cost of downtime increase. In fact, we know from experience that it begins to skyrocket somewhere between ¼ and ½ of the tensile strength. This cost curve will be monotonically *increasing* with a concave up shape. This is the approximate shape many plant cost functions. If breaks were the only concern on that machine, the best or optimum tension would be zero. Answers such as zero (or often even nearly zero) are clearly nonsense. They are nonsense because the analysis misses at least half of the world. (Zero Defects and Six Sigma are but two popular program examples of this type of myopic economic thinking.)

To get a complete picture we must add the costs of low tension baggy waste and high tension breaks. As seen in the figure, the sum has a minima. The minima is the best, best tension to run. It considers everything that is important. It considers that tension is both good (pulls out bagginess) and bad (increases web breaks) at the same time. It is not *either*. It is not *or*. It is not *it depends*. Tension has both good <u>and</u> bad aspects that are simultaneously at work.

The reader at this point is probably going to throw in the towel because the analysis seems to require a lot of information. Indeed, it could in a fully *explicit* technique. You would have to know your process very well, tension sensitivities as well as costs. However, we can get most of what we want with an *implicit* technique that requires very little information. This is what we will do in most plant situations to simply get us an *almost* best answer. Almost best should be better than what we had before because it considers vital information, economics.

Note that at the minima (best place), the incidence of high tension and low tension defects are similar. They are not the same because the minima is where the slopes are equal (and opposite), not the values themselves. Nonetheless, the best place is often close to where the incidence (or costs) of high and low tension problems are equal. Thus, for example, if we had $90K in losses a month due to web breaks and $10K due to baggy web wrinkles, we would back off on tension. Someone might object that wrinkles will increase. Surprisingly, that is what we expect when we are moving in the right direction for this case. On the other hand, if we had $10K losses due to breaks and $90K due to wrinkles, we would increase the tension. The operator will certainly object because they will have to clean up more break messes, but that is what we expect when we are moving in the right direction for that case. We will continue to move toward better which is about where the costs of high and low tension problems are equal.

The biggest objection may come from the manager who tasked you with solving both breaks and wrinkles and you come back with a “we are doing the best we can; we have a bunch of both defects.” Strange as it may sound, however, that is the correct or should I say best answer. To the narrow-minded manager who objects to having both defects because they claim too much loss, we do have a solution. However, this solution can not come from the tension knob because it is truly is as good as it will get. We must move a curve. To move a curve usually means a **redesign of the material or machine**. For this example, we might move the web break cost curve down by buying a tougher raw material or perhaps by aligning our machine or tuning our drives. To move the baggy cost curve down we could simply buy a better quality raw material.

Analysis like this shows us why we can easily get stuck. It is often because our problems are over-constrained and we have not been given enough space to get a complete solution or resolution to them. It is very much a “fix it but don’t change anything” situation. The boss wants to eliminate a problem but limits the allowable moves to something that simply does not have the leverage to do more than minimize the problem. If no outright limits have been placed on the solution process, then it may be simply that your are not enabled with sufficiently powerful options. In any case, we can still do our ‘best’ even if that is not zero defects or troubles. Best is better than guessing.

BEST TENSION – SUMMARY

Start with what you already know. The tensions you currently run will often be in the ballpark of the best answer, but some improvement may be possible. Obviously, best will be grade and machine dependent so there will be a bit of record keeping if you run a lot of products. The more serious effort will require calibrate tensions to a universal set of units. Without calibrated load cells, dancers and other devices, you will simply not know where you are making where you should be even more problematic. In older plants with a lot of machinery this will be something that could occupy a technician for months. Nonetheless, it is necessary if you want to do a good or even adequate job at the vital area of tension control.

Machine builders should also be able to advise you for common materials. You are not restricted to getting information from your suppliers. You might also try their competitors. Articles and trade organizations may also have guidelines for tension. If none of these sources are available, such as with a totally new material, you can estimate the tension range as a fraction of MD strip tensile strength. The great majority of common materials will be run between 1/10 and ¼ of their breaking strength.

All of these, however, are just starting points. Once you have a process you can get better answers by observing tension sensitive defects. You may have to run trials at both the high and low ends to know what problems emerge and at what levels of tension each of the problems begins to show up. If, for example, the web wanders when tensioned less than 1 PLI, then you'd better keep it above 1 PLI. If web breaks soar when tensioned above 2 PLI, then you better keep it below 2 PLI. If at 1.5 PLI you have no wander and no breaks, you are done.

The problem arises when you have high tension and low tension defects occurring at the same level of tension. Then we must use economic optimization to find best. This is a not-so-uncommon situation because almost all of the knobs in our plants have both goodness and badness present at the same time. The simplest way to optimize is to find a tension where the number (or better yet costs) of the high and low tension defects are similar. Better knowledge of cost functions can obviously give better 'bests.'

The reader must take these ideas and apply it in their plant where the issues will be different than the examples we gave here. Perhaps the high tension trouble is necking rather than web breaks. Nothing changes in principle. What are the monthly costs and how sensitive to tension is the necking? Perhaps the low tension trouble is printer registration rather than baggy web wrinkles. Nothing changes in principle. How much does misregister cost and does the incidence change much with tension?

While the reader might want simple answers, they should not expect that simple answers are necessarily good answers. Thus, tables and centerlines are always subject to the question of whether they really are the best. Despite the complexities, the complete picture is not hard to rough out. In fact, good operators already have a good sense of it. What we need to do is to refine their experience by doing some simple costing of defects. Everyone must understand costs in order to know what to work on and how well they are doing their work. Without knowing costs, we can never know what is truly 'best.'

BIBLIOGRAPHY

1. Roisum, David R. *The Mechanics of Rollers.* TAPPI PRESS, Atlanta, 1996.
2. DuBois, G.B. *Selecting Proper Winding Tension for Various Web Substrates.* Tappi J., vol 76, no 5, pp 91-93, May 1993.
3. Jones, J.P. *Determining Tension Values.* Converting Mag., pp 64-72, November 1989.
4. Roisum, David R. *Optimization by Integrating Engineering and Business Models.* TAPPI PLACE, Keynote address, Las Vegas, Oct 26, 2005 (also 8th Int'l Conf on Web Handling, Oklahoma State Univ., June 5-8, 2005 and AIMCAL/CEMA/CMM Shortcourse, Chicago, April 18, 2005.)

Figure 1 – Calibrating a Load Cell

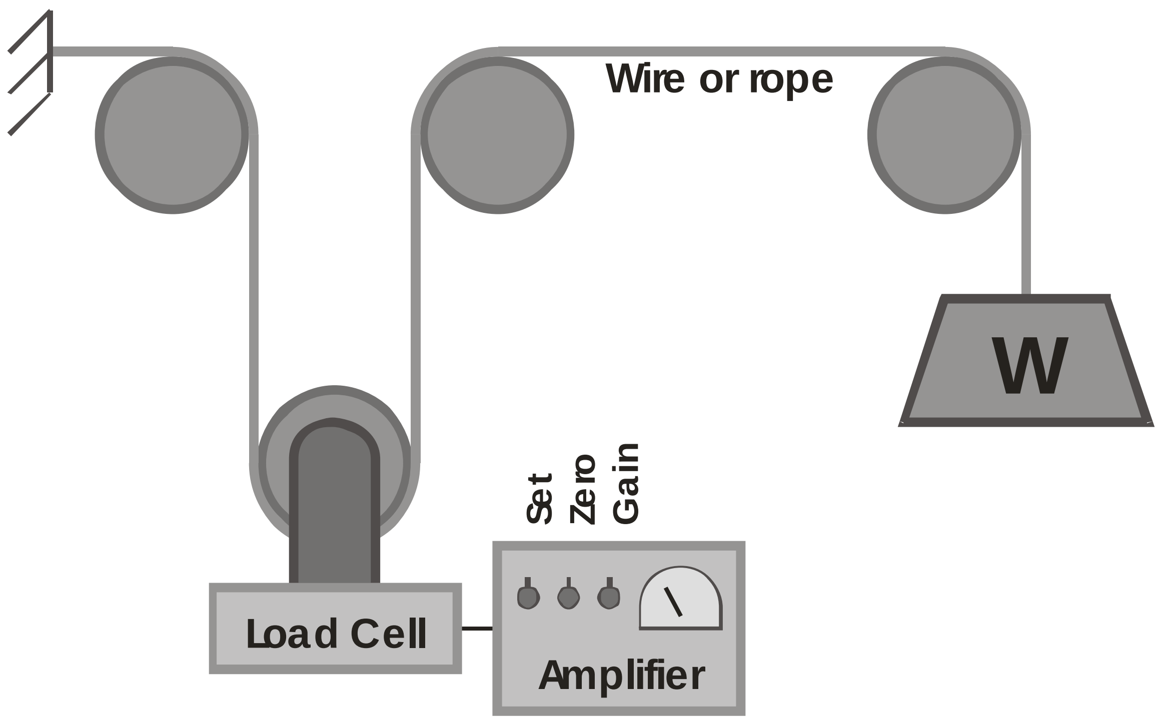


Figure 2 – Baggy Web Wrinkling Behind a Nip

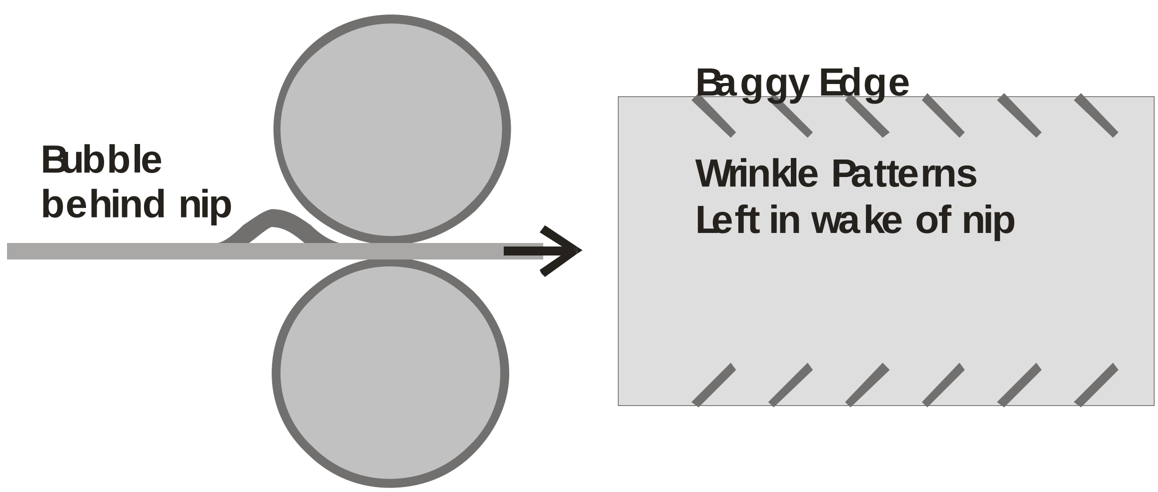
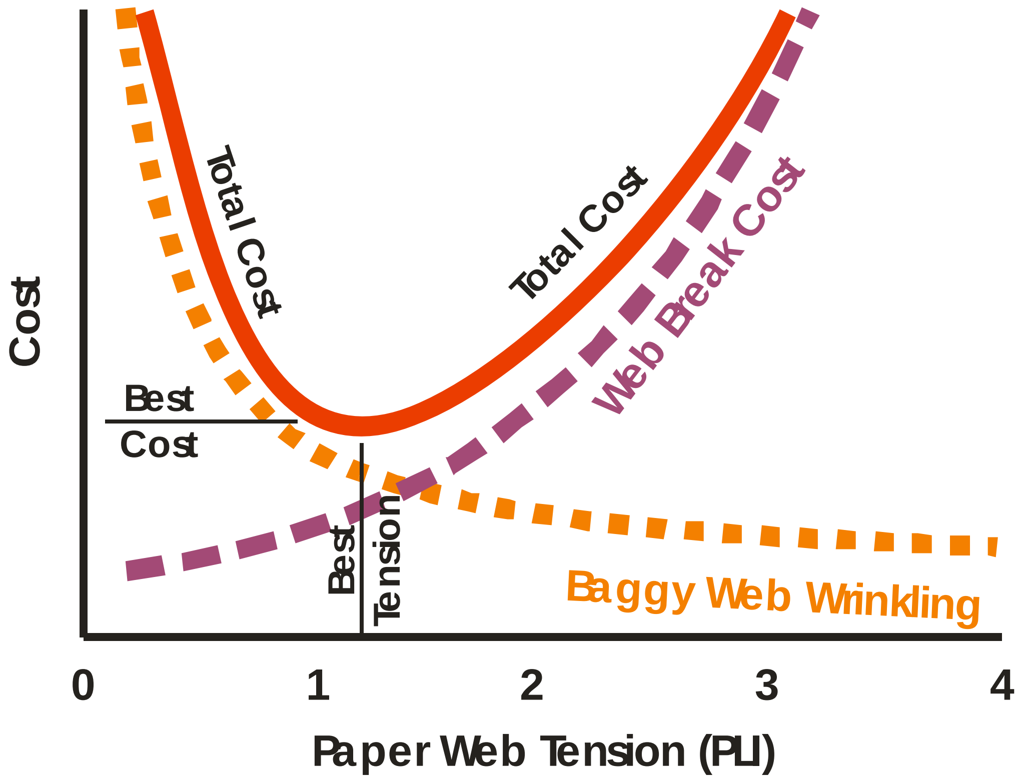


Figure 3 – Optimum Tension



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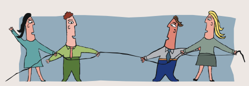
What is the Best Tension for My Machine?

David R. Roisum, Ph.D.
Finishing Technologies, Inc.

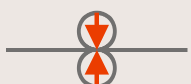
.1

Why is Tension Important?

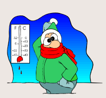
- It is the **most common** of the three important web handling **TNT controls**
  - Tension



  - Nip



  - Temperature



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Why is Tension So Important?

- It is has a large effect on economics of

  - Waste

  - Delay

.3

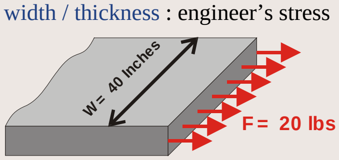
Tension Sensitive Examples

- Flatness: Bagginess & Curl
- Geometry: Length, Width and Thickness
- Position: Path and Registration
- Runnability (Web Breaks)
- Winding: Roll Quality
- Wrinkles

.4

What is Tension?

- Force : rope, string, wire, struts
- Force / width : webs
- Force / width / thickness : engineer’s stress

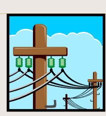


Tension = F/W = 20 lbs / 40 inches
Tension = 0.5 lb/in = 0.5 PLI

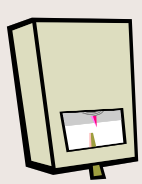
.5

How to Measure Tension

- Web Sag



- Brake Current/Pressure
- Motor Amperage

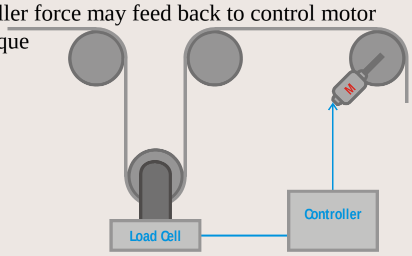


- Dancers that are calibrated
- Load Cells are Best !!

.6

Load Cell Tension Measure/Control

- Roller mounted on a (electronic) force gage
- Roller force may feed back to control motor torque



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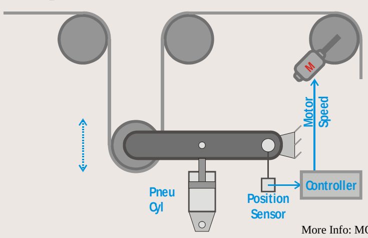
Dancer Control

- Roller on a pivoting arm
- Arm position sensor feeds motor control speed



More Info: MOR pp 16-18

.8

Tension: Setpoint and Quality

Affects the Machine:

- Motor Sizing
- Roller Sizing
- Tension Transducer Sizing

Affects Process, Product and People:

- Somebody has to Set the Tension and live with the results

.9

The 1-2-3's of Setting Tension

1. Starting point based on literature, machine builder guidelines or experience

2. Note whether you have high and/or low tension defects as a result.
   If only high tension defects > reduce tension
   If only low tension defects > increase tension
   If both high and low > optimize

3. Economic Optimization

.10

Tension Setpoint Guidelines - 1

- Common Materials
  - Machine Builder Recommendations
  - TAPPI
  - Literature

- Any Material
  - 0.5-1.0 PLI per mil of **thickness**
  - 10-25% of MD tensile **strength**
  - Best tension is approx. proportional to strength or gauge
    New Tension / Old Tension = New Gauge / Old Gauge
  - If your practice is different from above, find out why

.11

Too MUCH Tension – 2a

- Necking (ductile or rubbery materials)
- Web Breaks (brittle materials)
- Wrinkles
- Wound Roll Defects

- Ten$ion Dependent:
  - Cu$tomer complaint$
  - Rejectable wa$te
  - Downtime$

.12

Too LITTLE Tension – 2b

- Bagginess
- Flutter
- Web path changes
- Printer misregister
- Wrinkles
- Wound Roll Defects

- Ten$ion Dependent:
  - Cu$tomer complaint$
  - Rejectable wa$te
  - Downtime$

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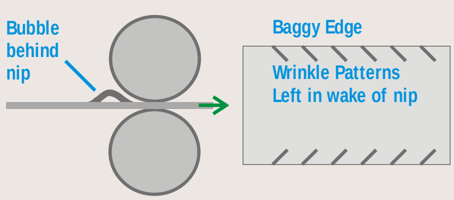
Simple Situations Simple Solutions

- If you only have high tension defects, such as web breaks > back off
- If you only have low tension defects, such as baggy web wrinkling > crank it up

.14

Can Tension Be Too High and Too Low at the Same Time?



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Sticky Situations - 3

- What if you have high tension AND low tension defects at the same time (or at least under the same tension setting)?
- Tension is BOTH good AND bad, at the same time

.16

Solution: Economic Optimization

- Finds the tension that produces the lowest total cost of defects
- Objective function is money

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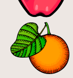
Comparing Apples to Oranges

- You can Compare
  - Apples (web break delay) 
    To
  - Oranges (baggy web waste) 
- When you use Dollars for both 

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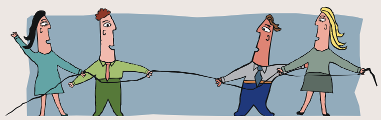
Example Tension Optimization

- What is “Best” amount of tension for a high speed paper printing press?



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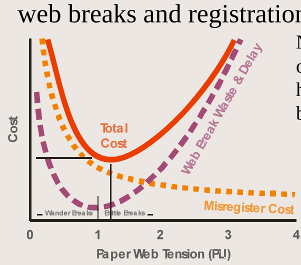
Optimum Tension

- Too Little
  - Registration Waste Increases
    - Bagginess
    - Web wander
  - Web Break Waste & Delay Increase
    - Web crashes into side of machine at very low tensions
- Too Much
  - Web Break Waste & Delay Increase

.20

The Big Picture

- Minimizes total costs by considering both web breaks and registration



Note that economic optimum is slightly higher than web break optimum

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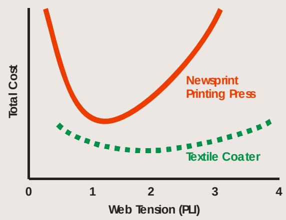
Windows or Sweet Spots

- Some processes are much more sensitive than others



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Summary

- Many Processes are Tension Sensitive
- Picking a Tension
  - Builder or literature guidelines
  - If you have no tension sensitive defects: you are done
  - Let the web tell you; if you have only high or only low tension defects
  - Economic optimization if you have both high and low tension defects at the same time
- Pick an Appropriate Precision
  - 5-10% of setpoint as maximum variability as read by fast acting load cells
- Make the Drive do its Duty

.23

Thank You

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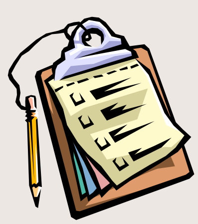

Please remember to turn in your evaluation sheet...

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