

Roller Alignment - Standards

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ABSTRACT

Published roller alignment guidelines are almost nonexistent in the web industries and are largely confined to internal publications of but a few machine builders. Furthermore, those standards were based on what these builders *could* do rather than necessarily what they *should* do; sometimes resulting in excessive maintenance costs. Worse yet, almost all builders are silent on the subject of alignment; at times causing excessive waste and delay due to problems such as mis-registration, web breaks and wrinkling. What this article seeks to do is to define maximum allowable misalignment tolerances based on web handling models and principles.

INTRODUCTION

Most of the rollers in our web industries need to be aligned, and more to the point, realigned. This maintenance process can be quite expensive so we need to determine *if or when* rollers *should* to be moved. While guidelines for alignment tolerances have been published internally by a few machine builders, there are several serious problems with them. First, standards are specific to a very few makes of machinery that are almost totally confined to the paper industry. More problematically, they may not even serve that industry well because the guidelines might be excessively tight for most situations and too loose on a couple of others. These current guidelines are problematic primarily, as we will see, because they are based on capabilities rather than needs. In other words, standards evolved from what we *could* do, rather than what we *should* do. It is the hope that this paper may offer an alternative set of guidelines that are based on both capabilities and needs, as well as one that is not confined to a particular machine, material or industry.

This Roller Alignment Standards [1] paper offers guidelines to *if or when* we should move rollers. Once we decide to move a roller, a companion paper titled entitled Roller Alignment Mechanics [2] outlines *how* we might go about aligning the rollers. However, both questions must be considered in tandem. If, for example, rollers needed to be aligned frequently then that need should be reflected in details of design as well as of maintenance. Conversely, the costs of realignment may in turn affect how tight we set our alignment standards so that some economic balance is achieved. Due to the enormous range of web applications, in this paper we can only discuss a few of the issues for all to consider and perhaps suggest guidelines for some of the more common cases.

ALIGNMENT GUIDELINES – HISTORY IN THE LITERATURE

There are some 66 articles from the Roisum Database [3] containing the keyword root ‘align.’ Of these, the great majority falls into three almost equal-sized and mutually exclusive categories. Let me call them purely practical, intermediate and purely theoretical just for simplicity, though I am sure this will draw criticism for over-simplified labeling. The ‘purely practical’ alignment articles are written primarily by practitioners of the craft of alignment and are published in both conference proceedings and magazines. For the sake of discussion, I will give this mostly craft based knowledge the collective shorthand of what we *could* do. In these articles you will find very practical discussions of the equipment used for alignment, usually optical tooling, as well as a bit about the process of alignment itself. The best of these practical articles are given in the bibliography and are also summarized in my companion paper on alignment [4-18].

The second category is articles written by web handling experts that straddle the ‘practical-theoretical’ range. They border on what we should do, but offer little detail on how to achieve it and little in the way of quantification. To be fair, limitations of the venue, typically magazine columns, preclude much detail of any kind. Also, web products and machinery are so diverse that ‘one-size-fits-all’ recommendations are not to be expected. These practical-theoretical articles are typified and are almost exclusively the domain to the giants of web handling publication; Roisum [20-26] and Walker [27-39].

The third or ‘theoretical’ category primarily stems from research professors and students from the WHRC (Web Handling Research Center) as well as other authors who give papers at IWEB (International Web Handling Conference). These conference papers describe models and/or experimental verification of algorithms that *might* be used to determine maximum allowable misalignment, though they are nowhere near that developed and far from clearly stated. Some papers on seemingly unrelated topics, guiding and spreading, also could be co-opted to build alignment tolerance guidelines. The theoretical category is almost exclusively the province of only three authors: Professor JK Good of the WHRC (and his students and colleagues) [41-45], Dr. John Shelton [46] and Tim Walker [47-48].

We can now see the serious limitations in the literature on such a fundamental and vital topic of roller precisions. Some articles hint at what we *could* do, but with far less detail than would be needed to teach practitioners of the craft. Some articles hint at what we *should* do, but never quite get there. Finally, none even attempt doing both, i.e., giving general algorithms for recommendations that are economical and practical (i.e. not too tight, not too loose). I am reminded of the fable of the three blind men trying to describe an elephant and each gives a totally different picture (by touching only the trunk, feet and tail respectively). It is the quite possibly naive intent of this paper on standards and the companion paper on mechanics to assemble the big picture of the elephant.

What few guidelines exist for roller alignment tends to fall roughly under the following categories as summarized in Table 1 below.

Table 1 – Existing Alignment Guideline Categories

1. none – the great, great, great majority of web companies; builders, buyers and suppliers alike; have absolutely nothing quantitative to say about roller alignment.
2. 1 mil per foot (English) or about 0.1 mm per meter (metric) or 100 microradians – this guideline is sometimes suggested by a very few converting machine builders and a few roller suppliers and some consultants.
3. 2 or 3 mils per 100” of web width, 5 mils max (English) or about 0.02 mm per meter (metric) or 20 microradians – more-or-less standard with builders of large (dry end) paper mill equipment.

We can make a couple of observations about the published guidelines summarized above. First, while most web companies have nothing to say about alignment, this should not be taken to mean it is not important. Rather, it may be that the companies believe current practices are good enough and do not feel the compelling need to write them down (or to be more specific, publish them). Alternatively, it may be that the companies have internal standards that are not published for any variety of reasons. Alternatively, perhaps the companies are totally insecure about recommendations and are thus silent. (This, unfortunately, leaves it to their customers to determine what is affordable/needed when their engineering department could be even more limited). The reader can certainly add to this list, but I don’t think any of this implies ‘best practices.’

When we compare the very few published alignment guidelines, **we find that the culturally distinct paper and converting industries are really not that far apart.** The difference between 0.02 and 0.1 mm/m is not worth fighting about when we consider the truly vast range of machines and materials that these might be applied to. It is literally splitting hairs. For a medium width machine, say 100” or 2.5 meters, it would correspond to a half the (average) width of a human hair (paper industry) or two hairsbreadths (converting). In fact, the variation of human hair between a man’s mustache and his head is not much greater than that. So, for the purposes of this paper, I will summarize that machine precisions

(not just alignment) could be on the order of a hair's breadth. Still, we need to be a bit careful about adopting either too strictly because they might be based on the same set of faulty assumptions and is certainly not going to be appropriate for all situations.

(Allow me to digress for a moment for the many who might doubt that hairsbreadth tolerances are the norm in the paper industry. Rest assured, I have checked this personally on many, many occasions. Nearly every single roller in the paper mill winder (and a few other dry end locations) is almost always just 1 or 2 mils out after an (optical) alignment, and that this accuracy is achieved in 1 or 2 moves and that many/most keep most rollers within a few hairsbreadths without needing to align much more than every year or so. Moreover, these results are achieved by a wide variety of crews from a variety of companies (paper mills, construction companies, machine builders and specialists such as OASIS. Let us resume.)

ALIGNMENT GUIDELINES – SOURCES AND INGOING TOLERANCES

The original sources of these guidelines would be next to impossible to find because many of the authors are long dead. Even if not, we would not be able to determine the evidence or reasoning they used to make these recommendations because they are not articulated. The numbers are given with no explanation of where they came from, how they were derived, what applications or imitations might exist and so on. Given these and many other issues, it would seem that nothing might be said about origin. However, a reflection will yield at least two criteria that must be satisfied by ANY established recommendation. First, it must be practically obtainable. I used the words 'what we *could* do' several times now and that conforms nicely to this idea of practicality. This is not to imply economically desirable or best practices or anything like that. Just, that these recommendations can be obtained without inordinate time and expense in many cases. Second, a recommendation is probably good enough for most situations otherwise it would be quickly discarded. Thus, like any longstanding meme, the standards are regarded as useful by enough people to perpetuate their application for three decades and are still in effect.

So, how can we summarize the origin of these recommendations? Simple, we can without excessive difficulty both measure and move rollers to a hairsbreadth, so a hairsbreadth became the standard where any standard exists. Furthermore, this standard is good enough for most situations. So why go further? Two reasons. **First, it is quite possible that some standards are *TOO* good** and certainly would be so for some applications. Holding unnecessarily tight tolerances is at best distracting, but more importantly is wasteful. Without going into web handling science, which we will do next, a very compelling case of standards being *TOO* good can be illustrated by the two-drum winder, a paper machine component so common that there are literally thousands running in the field right now. Recall, the standard that most of the paper industry adopts for the winder is a hairsbreadth.

Yet, almost all of these 'precision' winders are equipped with a skew adjustable roller inappropriately called a 'guide' roller (because it doesn't guide anything) following the unwind. (Alternatively, the unwind itself may be skewable). In virtually all of these cases, a huge hand wheel crank can and is manually adjusted by the operator without any precision zero or measurement scale to guide him (sorry for the pun). Tellingly, the total range of this adjustment by design is about 2 inches. I have seen on many occasions the winder operators skewing that roll a fair bit of that range with no obvious/immediate penalty. In summary, the alignment standards the machine builders propose is a hairsbreadth yet on the very same machine you will find a roller that can be moved out of alignment by 200 hairsbreadths. This is not mere irony, it could be an indictment of inconsistency if not also overly tight standards in that area.

Now some would argue that a skewable unwind or guide roll can be used to good effect. Nearly identical arguments for skewable rollers are heard in converting (especially in front of a coater/printer head) to compensate for bagginess, wrinkling or other trouble. However, I would ask what is so special about the 1st and 2nd position of a two-drum winder and not the nth roller on that same machine. In converting I would ask why the nth and mth roller should be skewable, but not the 1st, 2nd, or n+1th roller? A further inconsistency is that skewing is taking place in all (web) directions mixing in-plane and out-of-plane misalignments. And if we needed to skew one roller to fix bagginess in the adjacent span or two, the logical progression would be to skew all rollers to conform to the arc that the baggy (cambered) web would

take through the machine; i.e., a banana shaped machine to conform to a banana shaped web. **I find none of these arguments for skewing very convincing;** especially if the skewing is done, as is almost always the case, with non-precise non-zeroed adjustment. **But they do at least suggest that gross misalignments are not only possible, but *perhaps* even desirable in some situations.**

A second problem with current alignment recommendations is that they are single valued. So what that means is that while you can (in most cases) move a roller to a hairsbreadth tolerance, the implication might be that you **MUST** move a roller to hairsbreadth tolerance whenever it exceeds that value. Nonsense, on a whole bunch of levels! Let me just cut to the chase (sorry for the idiom). I propose that INGOING standards for many rollers be just that, a hairsbreadth. If you are determined to move a roller, if you have to move a roller, let's get it to a hairsbreadth because it is easy to do with available alignment methodologies including optical tooling, gyroscopic tooling and so on, in most cases.

HOWEVER, even if we opened up the INGOING alignment tolerances to 10X that, we could SELDOM ACHIEVE THAT reliably WITH HAND TOOLS such as levels and tape measures, at least under many conditions. Without doing surveys of a truly vast range of equipment and cultures and without doing gage R&R studies, I can only offer one fact and one general personal observation in this regard to hand tools. FACT: there is no 'squaring' tool in your toolbox, so alignment in two planes of every roller can not in general be performed. Here, we are guided by the maximum that it doesn't matter how many rollers (and directions) you get right. **All that matters is how many rollers you *don't* get right** (or, more precisely, get good enough). Now the personal OBSERVATION with many caveats. That is that people who use hand-tools do so at big big big big big big big risk of being too sloppy; even with the best of intentions and instruments. Of course, we must be open to the suggestion that *sometimes* hand tools are good enough and *sometimes* hand tools are even the best choice for very specific situations.

In short, **I propose that *ingoing* alignment standards be on the order of a hairsbreadth,** that alignment be obtained with suitable instruments and procedures (such as optics but not hand tooling in many or most cases) and that this is good enough for most situations. In other words, when you move a roll, such as on installation, maintenance or rebuild, you move it to a hairsbreadth, what we can do easily (most of the time). The remainder of this paper will focus on establishing the **much much harder AND perhaps more important question of *outgoing* standards, when *should* you move a roller** because it is causing an economic problem directly associated with its misalignment. This recommendation will be based on web handling science and it necessarily must vary greatly with the application.

TWO TYPES OF MISALIGNMENT

First, we need to define misalignment. Misalignment is the geometrical error between the axes of two or more nominally parallel rollers. (We consider the case of offset centerlines in the Roller Alignment Mechanics paper.) Moreover, misalignment must be specified in two different directions that need not be parallel. **The coordinate system that makes sense in web handling is the directions that correspond to in-plane twisting and out-of-plane bending.** We will show shortly that **tolerance to out-of-plane twisting is about 100X that of in-plane bending.** This knowledge of the night and day difference in tolerance between the two is **essential to understanding all guides and some spreaders.** However, this knowledge **can also reduce the costs of machine design and maintenance** in ways we will discuss shortly.

Unfortunately, this web handling view of misalignment, while essential knowledge for anyone working with web machines and a view that is solidly backed by both science and experience is a very very awkward coordinate system. **The in-plane / out-of-plane web handling coordinate system is awkward** if for no other reason than it moves with every span in the machine. It is also awkward because it is span centric instead of roller centric. **So instead, we use a much more convenient coordinate system of level and square.** Level being with respect to gravity. Square is usually with respect to a datum called an 'offset centerline' that we described in the Mechanics paper. Unfortunately, this measurement centric view of misalignment also **has severe limitations. It will treat in-plane and out-of-plane problems the same,** yet we know without any doubt that the resulting issues are quite different in both character and magnitude.

Also, insisting every roller in a machine be level may not solve any problems whatsoever if EVERY roller in the machine had precisely the same out-of-level. This situation can be approximated if you had an extremely stiff frame mounted on a crooked floor or when a foundation settles somewhat evenly on the backside.

PRACTICAL APPLICATIONS OF THE WEB HANDLING VIEW OF MISALIGNMENT

Figure 1 shows stresses on the web for pure in-plane twisting. As shown, the stresses are highest at the edge so weak or brittle webs could suffer more damage there. What is not shown is that there are compressive CD stresses generated in the open span. If these were excessive, one would see an MD trough develop there that might cross the downstream roller as a bulge. Web handlers have long known, however, that this direction of misalignment is extremely tolerant, perhaps 100X that of in-plane bending.

Thus we make use of that to be able to guide (move the path) the web sideways in a very compact arrangement called the displacement guide. (Papermakers should take note here that this knowledge that is nearly universally applied in converting has not been utilized by the paper machine builders to guide their felts, wires and other clothing, and that is much to their disadvantage.) In Figure 2 we see that the span 1-2 of a displacement guide is in pure twist. From decades old science we know that we can misalign rollers a lot, yet with little risk.

Figure 3 shows an accumulator where we might apply similar understanding. Knowing that the web is extremely intolerant to in-plane bending, we know that the rollers must be leveled quite precisely. Leveling is by far the easier direction to measure and thus is much less effort than squaring. However, consider that many accumulators are 'timed' during their stroke by either chains or gear racks. If these are not precision components (or are worn), the rollers will be out-of-level during large portions of the accumulator's stroke, even if it were aligned at one end, say the more critical bottom end (because the spans are short and that is sometimes the running state). The result is the common trouble of throwing of a momentary diagonal wrinkle when the accumulator stroked up or down.

Conversely, the web is very tolerant to out-of-plane twisting so that squaring might not ever be needed beyond using a modicum of care during manufacturing of the accumulator's frame. We can consider applying this knowledge to other machine components that have similar geometries. One example here is the dryer cans found on most every paper machine. Here, the spans are *almost* in pure twist. Thus, only level is indicated in most cases. Exceptions that indicated an additional squaring *might* be diagonal wrinkling, distortion of a stretched edge or path control. However, my read/opinion is that the few occasions where these troubles occur are due to other causes that have the same results.

Before we move to in-plane bending, we must remind ourselves of the normal entry law that is essential for determining the path of the web when both rollers are in traction (the common state, hence the alias of common would be 'normal'). The web bends to meet the downstream roller at a right angle, hence the term 'normal' meaning perpendicular. From guiding mechanics developed by Shelton over four decades ago and more recently summarized in the Mechanics of Rollers book [51] we know that the curvature or bending is greatest at the upstream roller and the path straightens to meet the downstream roller. The net result is precisely the shape of a cantilever being bent by a load at the tip corresponding to the CD force imposed on the web by the downstream roller.

Now to the order(s) of magnitude more fussy in-plane bending. There are four risks to this direction of misalignment as shown in Figure 4. The first is that the outside of the curve is stretched, possibly to the point of yield or break. The second is that the inside of the curve may go slack or even into compression. The third is that the web may be forced to diagonal wrinkle on the downstream rollers as seen in Figure 5. These three failure modes will be the basis of the science-based standards suggested in the following sections. The final risk is well known but will not be discussed here and that is the path of the web is shifted.

Now despite these risks, we can bend the web sideways and do so safely IF we use science as is best exemplified by the steering guide shown in Figure 6. Here, we must give the web a long enough path to make the bend. This tends to be on the order of 3-5 web widths (plus or minus an order of magnitude depending on the details of the application) of entering span length. This is so long that application is limited to things like air float dryers and some accumulators in the strip-steel industry. The next span can be quite a bit shorter because it is in pure twist.

TWO (OR MORE) TYPES OF FAILURE MODES

There are at least two roller misalignment failure modes that are well enough documented by web handling sciences. They are wrinkling and web breaks. While there are many other risks for roller misalignment, they will not be detailed here simply because the documentation is not nearly so mature. For example, it is well known that a crooked printing press will exacerbate wrinkling, web breaks (paper) AND misregistration. The registration problem is compounded by tension control variation. However, the color-to-color registration problem in printing is just a subset of a much bigger class of problems we could call path control problems. Path control problems would on a winder, for example, show up as wound roll edge quality problems and, in the case of two-drum rewinders, increase the risk of 'stuck' or 'tied-up' rolls. Extreme path control problems may even allow the web to go off the edge of a roller or even run into a side frame, such as happens on occasion on most air float dryers as just one example.

Since wrinkling is a more widespread problem and is also better documented, we will deal with that case first. The classic misalignment wrinkle has three characteristic features as was seen in Figure 4:

1. Excessive in-plane (tram, parallel) misalignment as perhaps verified by Pi-tape
2. Diagonal wrinkle on one edge pointing to the narrow side of parallel
3. The wrinkle (*may*) 'walk'

Note that there can be other causes for a diagonal wrinkle at the edge of the sheet such as roller diametral variation and a baggy or tight edge. That is why we would verify the cause by direct measurement of insufficient parallelism using a Pi-tape or tramping stick. Also note that problems are additive in that diagonal wrinkling due to misalignment could get worse if, for example, you also had a baggy/tight edge as well.

Brittle web breaks are confined to, well, brittle materials such as most paper grades, cellophane, foil and a few others. It is particularly a problem and most studied in newsprint printing presses. Here, we know that web breaks are proportional to the second or third power of tension depending on the grade as seen in Figure 8 [52]. Thus, very small increases in the tension setpoint can have a profound reduction of runnability. To this well-studied phenomenon we must also note that tension is skewed by rollers that have parallel misalignment as shown in Figure 4. If a roller pair is misaligned at the 'critical angle', the angle at which the inside edge just goes slack, the tension at the outside edge is doubled. This nearly undetectable (tactile and visually) misalignment could thus increase web break rates 4-10X at that span. Of course, a tight edge (i.e., bagginess or camber) superimposed onto the outside edge would make things even worse.

STANDARDS BY CALCULATION OR MODELING

The first analytical model of **wrinkling** was derived by Prof J.K. Good of the Web Handling Research Center at Oklahoma State University [42-43]. It was soon verified experimentally by Gelbach and Kedl of 3M. This remarkable application of web handling science was completed soon after the center was formed in the mid 1980's and is the foundation of all related work since. The application centers on a plot of tension (specifically MD stress) versus parallel misalignment as seen in Figure 7. On this plot is an odd shaped failure curve. If you are to the left of this curve, you will not have a wrinkle crossing a roller. If you are inside this curve you have two possible moves to clear the wrinkle. The first move would be to

change tension. Curiously, either up or down might get you clear of wrinkling. Dropping the tension to clear the wrinkle is easily explained by web handling: you may not have enough traction on the downstream roller and in slippage the normal entry law is not enforced. Since you are now sliding, the sharp bend of web path that was the cause of all the trouble in the first place is simply not present. The possibility of clearing the wrinkle by increasing tension is harder to explain with rigor; so we will just say that sometimes you can muscle your way through some problems.

While tension should always be your first move, because every web machine has a tension knob available, it might not be enough. Many limitations of web and/or machine might preclude you from getting outside of the failure curve with tension alone. Thus, the second and final move would be to align the roller pair. How close? To at least completely clear the right hand side of the failure curve at any and every tension. Since this critical angle can be calculated, we have the possibility of science-based design of maintenance standards, at least with regard to wrinkling over non-parallel rollers.

While the equations to do this are not daunting, they would be intimidating enough so that the potential industrial customers of this approach would be extremely few; i.e., near zero. It is fortunate that Rheologic has come to our aid and automated the calculations for us. The roller misalignment module is only one of nearly a dozen useful tools in the commercial TopWeb program [53]. By just entering a few basic and easily found parameters, such as geometries and web modulus, the program will calculate the critical angle for misalignment wrinkling as well as a slack edge. An input/output screen for this module is given in Figure 9. Other outputs from this module include the amount of entrained air (for smooth rollers and webs), forces and stresses. Other modules include drive/tension control, spreading and winding.

Since this program is so easy to use, we might expect that some people might calculate maximum allowable misalignments for each and every roller in their plant. This is not so unreasonable as it might first sound since the calculation is far faster and cheaper than moving a roller unnecessarily (and presumably cheaper than not moving a roller when you should and taking waste and delay for your complacency). However, our culture is slow to adopt and our expectations of calculating/designing rather than guessing would probably be met by disappointment. Fortunately, we don't need to do every web condition for every roller. The reason is that the critical angle does not vary enormously for a given machine. Instead, all we need to do is to take a worst-case web (thin and stiff) running on our line or in our plant and a worst-case roller geometry (wide web on a short span). To this we add a healthy safety factor and we have an outgoing (maximum allowable) misalignment for the entire plant that should not be overly conservative in most cases.

STANDARDS BY MEASUREMENT

Of course, calculation might not be for everyone. A better and faster method for determining appropriate misalignment tolerances for a specific situation can be done by experiment. (Indeed, the best computer 'program is in fact the real world.) The brute force method would be to carefully (by that I mean safely and precisely) move a target roller in the in-plane direction while a critical web is running. At the onset of either a slack edge or a diagonal wrinkle the value of the threshold-of-pain in terms of out-of-parallel can be measured. This would be, appropriately, conservative as combinations of in-plane and out-of-plane or pure out-of-plane would be less risky. Alternatively, you could let normal variation do the experiment for you. That is wait until it is clear that one span is causing a misalignment related problem and carefully measure the lack of parallelism there. Of course, either of these methods absolutely requires a thorough understanding of web handling mechanics otherwise one will be just guessing that the misalignment was too great when perhaps some other factor, such as web bagginess, was the major cause.

THE NEED TO APPLY A GENEROUS SAFETY FACTOR

There are many reasons that we need to apply a generous safety factor for the case of roller misalignment. First, distinctly different problems add and accumulate to the same end result. So as is the case of brittle

web breaks; excess tension can come from the sum of nominal web tension, tension variations from drive control errors, bagginess, stress concentrations (flaws in the material) in addition to mere misalignment. In the case of shear wrinkles; bagginess, roller diametral profile errors and other factors add to the problem and thus conspire to make wrinkles at misalignment angles less than predicted for a perfect world.

A second reason for a conservative safety factor is that you don't want to just clear failure. This leaves no room for the roller moving on its own. Recall from the companion paper that foundations and framework move for a variety of reason. If you just clear the wrinkle today, you might be into wrinkling the next season due to changes in soil moisture/temperature that pushes foundations around.

A third reason and most important reason for a conservative safety factor is for reliability. These models and experimental verifications were based on immediate failure. We don't want do break/wrinkle within one second, one minute or maybe not even in one day (86,400 seconds). Reliability is why Beloit Corporation sized bearing lives so conservatively, a L10 of 50 years. It was not that the machines had a life of 50 years, some are in service even a century later. It is because we want reliability to be high enough in year one because there are thousands of bearings on the machine. While a stochastic design is much harder than a deterministic one, we are obliged to at least consider that the real world is more complicated and these complications often conspire to make troubles more frequently than if the world was simple; having but a single cause for any problem.

So what kind of well-studied safety factors can be found in our industry? I can think of two. The first is overstressing rotating elements, i.e., roller components. Here, Beloit Corporation had internal standards for all commonly used metallurgies. These safety factors varied from as little as 4 to as high as 8 depending on the metal alloy. So while the engineers accounted for all sources of bending and torsion to which calculated stress concentration factors would also be factored, the engineer could not know all things. Possible overloads by the customer and corrosion and other complications would reduce reliability/safety unacceptably unless a safety factor was applied. The second safety factor is on web tension. Remarkably, almost all webs and machines run a tension that has a safety factor of 4-10 on ultimate strength. A much more detailed but specific study is a web break rate as the 2nd or 3rd power of tension as seen in Figure 8 [52]. With these three quite disparate but similarly sized safety factors we might be emboldened to apply something similar to critical misalignment angles for end slackness and diagonal shear wrinkles. We might go as little as 4 for slow non-demanding processes such as might be found in some corners of converting to as high as 8 for industries such as paper, glass and steel where there is no such thing as a little problem.

So, how might this end up for a demanding situation. Given a thin high modulus web (paper) on a 100" wide machine, shear wrinkling would be expected at 20 mils of out-of-parallel misalignment. This is 200 microradians. Apply a safety factor of 8 for this demanding industry and you get a maximum allowable (outgoing) misalignment of 2.5 mils, precisely what is the 'standard' already taught by the large paper machine builders. Furthermore, take the 200 microradians and divide by a super sloppy safety factor of 2 for converting (who might or might not run a thin stiff web) and you get 100 microradians. Thus, the basis of my first attempt at a misalignment classes given in Table 2 similar to the format that was published for deflection in my roller book.

Table 2 – Proposed Alignment Standards

<u>Class</u>	<u>Value</u> microradian	<u>Application</u>
A	< 20	Optical and other alignment tooling, brittle webs such as ceramic coated
B	20	Metals, paper
C	100	Converting general
D	1000	Rubber, textiles
F	> 1000	Ribbon, rope, string

Of course, there will be exceptions to any rule. Some will ignore guidelines entirely for any number of reasons, such as we don't need to. If you *know* you don't need such tight tolerances based on economic

evidence of minimal cost of alignment related problems, then by all means don't waste time and money. It would be an interesting point of logic who owned the burden of proof here: the one making the claim that alignment is good enough (the grandfather fallacy) or the one seeking to change status quo (the newer is better fallacy). However, one situation is well-grounded in web-handling science. If the web is in pure in-plane twisting, we could safely loosen up one Class.

Some will say we can't do that; meaning we don't *want* to do that. I have no reply because data seldom changes cherished beliefs. Some will say we can't do that; meaning it *can't* be done because no one in our industry can do it. **Narrow rollers** are one example; take spools as an extreme. You will find that any of these allowable angular tolerances would not be achievable on a roller a few mm or even a few cm wide because the measurements and movements are below our threshold of, well, measuring and moving. However, even if you could measure and move these small absolute distances, cutting cylinders to that accuracy might not be practical and it would do little good to accurately align a roller whose cylindricity or other parameter was even larger.

Finally, I will admit that **it is possible to move rollers into closer alignment and make alignment related problems worse**. I have done this on many occasions. The reason is not that aligning is not good or even needed. The reason is that grossly misaligned rollers force the web into sliding which is tolerant. However, get the rollers a little closer to alignment and the crooked roller can bite in, forcing the web into the arc (as determined by the normal entry law valid in traction), that is the root cause of most of the problems. Fortunately, making problems worse by moving rollers in the correct direction is rare with best alignment practices and is confined to super-stiff webs such as metals. Most cases of making problems worse (while still moving in the correct direction) are with sloppy alignment practices.

CONCLUDING REMARKS

Previous quantitative guidelines for alignment standards are limited at best. In this paper we showed the drastically different directions of in-plane bending and out-of-plane twisting must be considered. We also showed that web handlers have long been able to calculate thresholds of pain for certain common misalignment problems, namely web breaks and wrinkling. We also, hopefully, made a convincing case for a conservative safety factor on any failure mode. The net result of all of this is proposal for a set of alignment classes that vary from 20-1000 microradians depending primarily on the properties of the web. These correspond nicely to best practices for alignment already in use in many companies and can be a guide for others who have not yet considered this most important roller precision topic. Those who are willing to do more work might cut the economic corner closer by calculation or experiment based on their own specific conditions. This optimum level of maintenance considers the total costs of recurring precision realignment and the recurring costs of misalignment such as web breaks, wrinkles and mis-registration.

BIBLIOGRAPHY

1. Roisum, David R. *Roller Alignment Standards*. AIMCAL 2012
2. Roisum, David R. *Roller Alignment Mechanics*. AIMCAL 2012
3. Roisum, David R. *A Century of Web Handling Literature*. 11th Int'l Conf on Web Handling, June 2011.
4. Allen, George Jr. *Optical Tooling for Paper Machines*. TAPPI Engineering Conference, pp 595-599, 1994.
5. Allen, George Jr. *Across-the-machine baselines as the alignment reference for freestanding paper machines*. Tappi J., vol 78, no 11, pp 224-225, November 1995.
6. Boggs, R.E. *Rotating Machine Misalignment: The Silent Disease but not the Symptom* Tappi J., vol 73, no 12, Dec 1990.
7. Busch, Sebastian. *Inertial Measurement of Roller Parallelism - A new approach to solving an old Problem*. TAPPI PLACE Conf, Las Vegas, September 26, 2005.

8. Chinick, Harold P. *Aligning 'Difficult-to-Check' Rolls*. Paper Trade J., pp 56-58, Jun 1985.
9. Dalsanto, Tim. *Staying inside the lines*. Converting Magazine, vol 25, no 7, pp 34-36, July 2007.
10. Dunn, James and Allen, Donald and Carter, Michael and Pepin, Stephen and Leonard, William. *Precision Alignment of Winders*. TAPPI J, vol 79, no 6, pp 67-71, Jun 1996
11. Dunn, Jim M. and Pepin, S. and Allen, D. and Leonard, W. and Carter, M. *Precision Alignment of Winders*. TAPPI Finishing and Converting Conf. Proc., San Diego, CA, pp 119-124, Oct 15-18, 1995.
12. LeBel, Gary A. *Optical Diagnosis for Misalignment*. Converting Magazine, pp 46, 48,50, November 1993
13. LeBel, Gary A. *Improving Dryer Section Runnability through Optical Alignment*. Tappi J., vol 77, no 5, pp 285-288, May 1994.
14. LeBel, Gary A. *Paper Machine Alignment*. Papermaker, pp 12-14, Dec 1994
15. LeBel, Gary A. *Proper Machine Alignment Can Boost Productivity*. Paper Film Foil Converter, vol 73, no 11, pp 72-79, November 1999.
16. Sasikumar, Arun. *Inertial Roll Alignment for Diagnosing and Preventing Web Handling Problems*. Applied Web Handling Conf, AIMCAL AWEB, Charlotte, May 7-10, 2006.
17. Tannan, Jan. *Roll Alignment*. Paper, Film & Foil Converter, vol 82, no 1, pp 42-45, January 2008.
18. Woo, C. *The Advantages of Inertial Roll Alignment Device in Eliminating Web Handling Issues* . 11th Int'l Conf. on Web Handling Proc., Web Handling Research Center, Oklahoma State Univ, June 13-15, 2011
- 19.
20. Roisum, David R. *What Causes Diagonal Shear Wrinkles?* Converting Magazine, Web Works column, pp 22, June 1994.
21. Roisum, David R. *How Can I Align My Machine?* Converting Magazine, Web Works column, pp 24, November 1995.
22. Roisum, David R. *The 10 Commandments of Web Machine Design*. CEMA Conf, The Coating and Laminating Process, March 27-28, 1996.
23. Roisum, David R. *Why would I want to skew rollers?* Converting Magazine, Web Works Column, vol 24, no 9, pp 86, Sept 2006.
24. Roisum, David R. *Alignment: New Machinery Installations*. Converting Magazine, vol 25, no 5, pp 44-46, May 2007.
25. Roisum, David R. *How closely do I need to align my machine?* Converting Magazine, Web Works Column, vol 26, no 2, pp 72, February 2008.
26. Roisum, David R. *When do I need to align my machine?* Converting Magazine, Web Works Column, vol 26, no 3, pp 64, March 2008.
27. Walker, Timothy J. *Going With The Parallel Flow*. Paper, Film & Foil Converter, vol 77, no 8, pp 20, Aug 2003.
28. Walker, Timothy J. *The Long and the Short of Web Bending*. Paper, Film & Foil Converter, vol 77, no 9, pp 26, Sept 2003.
29. Walker, Timothy J. *When Rollers Fight, Webs Lose*. Paper, Film & Foil Converter, vol 78, no 4, pp 26, April 2004
30. Walker, Timothy J. *Tracking Wrinkles: Part I*. Paper, Film & Foil Converter, vol 78, no 5, pp 26, May 2004.
31. Walker, Timothy J. *Tracking Wrinkles: Part II*. Paper, Film & Foil Converter, vol 78, no 6, pp 36, June 2004.
32. Walker, Timothy J. *The Signs of Shear Wrinkle*. Paper, Film & Foil Converter, vol 78, no 8, pp 22, Aug 2004

33. Walker, Timothy J. *The Secret Strain*. Paper, Film & Foil Converter, vol 80, no 1, pp 30-31, Jan 2006
34. Walker, Timothy J. *Twist and Shout*. Paper, Film & Foil Converter, vol 81, no 1, pp 12, January 2007
35. Walker, Timothy J. *Don't Get Bent out of Shape*. Paper, Film & Foil Converter, vol 81, no 1, pp 12, February 2007
36. Walker, Timothy J. *Support Your Rollers*. Paper, Film & Foil Converter, vol 81, no 9, pp 12, Sept 2007
37. Walker, Timothy J. *How Much Misalignment is Trouble?* Paper, Film & Foil Converter, vol 83, no 1, pp 12, Jan 2009.
38. Walker, Timothy J. *How Much Misalignment is Trouble?* Paper, Film & Foil Converter, vol 83, no 2, pp 12, Feb 2009.
39. Walker, Timothy J. *Wrinkling of Foils*. Paper, Film & Foil Converter, vol 85, no 8, pp 9, Aug 2011.
- 40.
41. Beisel, J.A. and Good, James K. *Analysis of Trough Formation and Lateral Steering of a Web Due to a Tapered Downstream Roller*. 8th Int'l Conf. on Web Handling Proc., Web Handling Research Center, Oklahoma State Univ, June 5-8, 2005.
42. Gehlbach, Lars S. and Good, J. Keith and Kedl, Douglas M. *Web Wrinkling Effects of Web Modeling*. American Control Conf. Proc., Minneapolis, June 1987.
43. Gehlbach, Lars S. and Good, J.K and Kedl, Douglas M. *Prediction of Shear Wrinkles in Web Spans*. Tappi J., vol 72, no. 8, pp 129-134, Aug 1989
44. Good, J. Keith and Beisel, JA. *Buckling of Webs in Web Processing Machines Resulting from Roller Misalignment*. WHRC Report, date uncertain
45. Good, J. Keith and Beisel, Joseph A. *Calculations relating to web buckling resulting from roller misalignment*. TAPPI J., Dec 2006.
46. Shelton, John J. *An Initially Straight Moving Web with a Slack Edge: Steady State Behavior Caused by Roller Nonparallelism Greater than Critical*. ASME Winter Annual Meeting, Anaheim CA, Nov 1992.
47. Walker, Timothy J. *Wrinkling and Spreading of Wide Webs*. Applied Web Handling Conf, AIMCAL AWEB, Rochester, May 17-20, 2010.
48. Walker, Timothy J. *Wrinkling at Nip Rollers*. Applied Web Handling Conf, AIMCAL AWEB, Rochester, May 17-20, 2010.
49. Webb, D.D. *Prediction of Web Wrinkles due to Misalignment of a Downstream Roll in a Web Span*. MS Thesis, WHRC, OK State Univ, Dec 2004.
- 50.
51. Roisum, David R. *The Mechanics of Rollers*. TAPPI PRESS, 1996.
52. Roisum, David R. *Runnability of Paper, Parts I & II*. Tappi J., vol 73, no 1, pp 97-101, January 1990 and vol 73, no 2, pp 101-106, February 1990.
53. Rheologic. TopWeb II web handling computer program. http://www.rheologic.co.uk/tw_case/index.html

FIGURE 1 –WEB STRESSES IN PURE OUT-OF-PLANE TWISTING

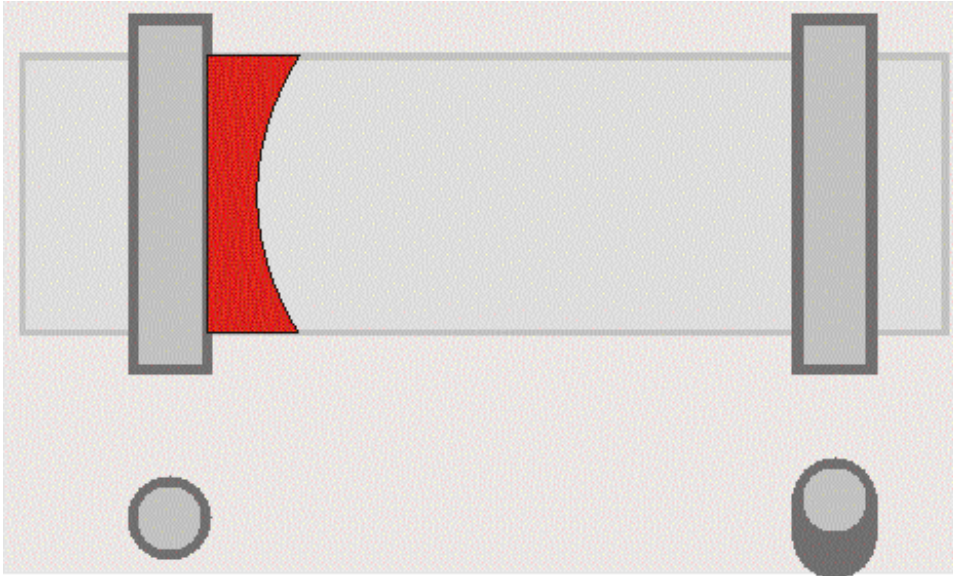


FIGURE 2 –THE DISPLACEMENT GUIDE

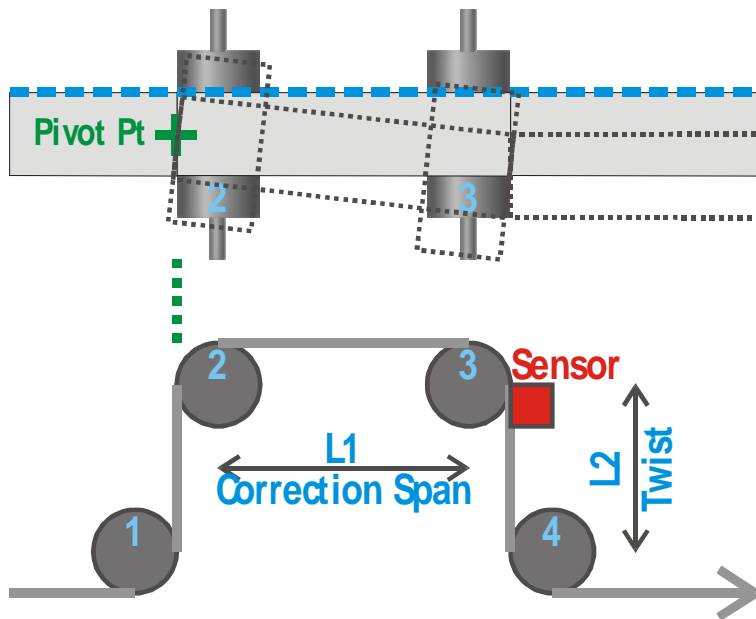


FIGURE 3 –THE ACCUMULATOR

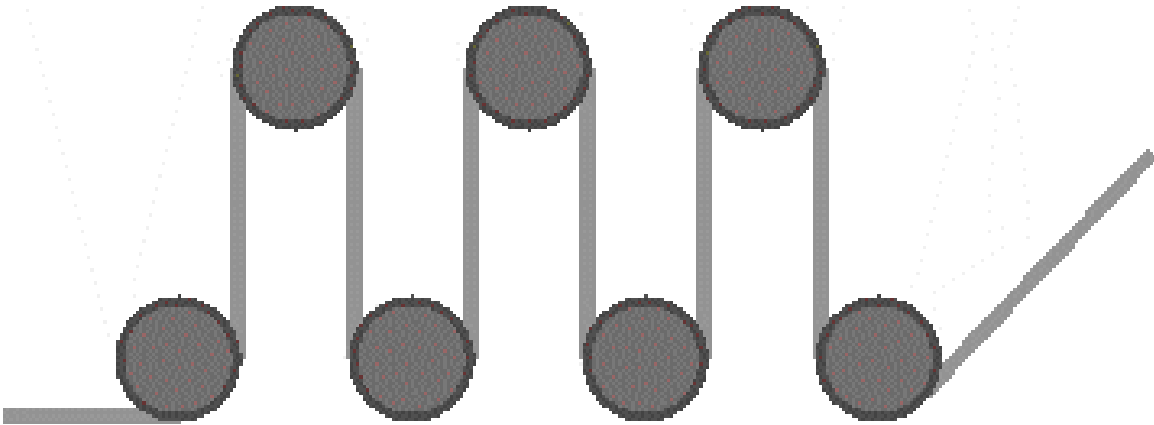


FIGURE 4 –FOUR RISKS OF IN-PLANE BENDING

- **Physics:**
- **Normal Entry Law:**
 - Web enters a roller in traction at a right (normal) angle
- **Explains**
 - Guides
 - Roller Misalignment
 - Spreaders
 - etc
- **Can Cause**
 - Web Breaks
 - Slack Web
 - Wrinkles
 - Path Change
 - etc

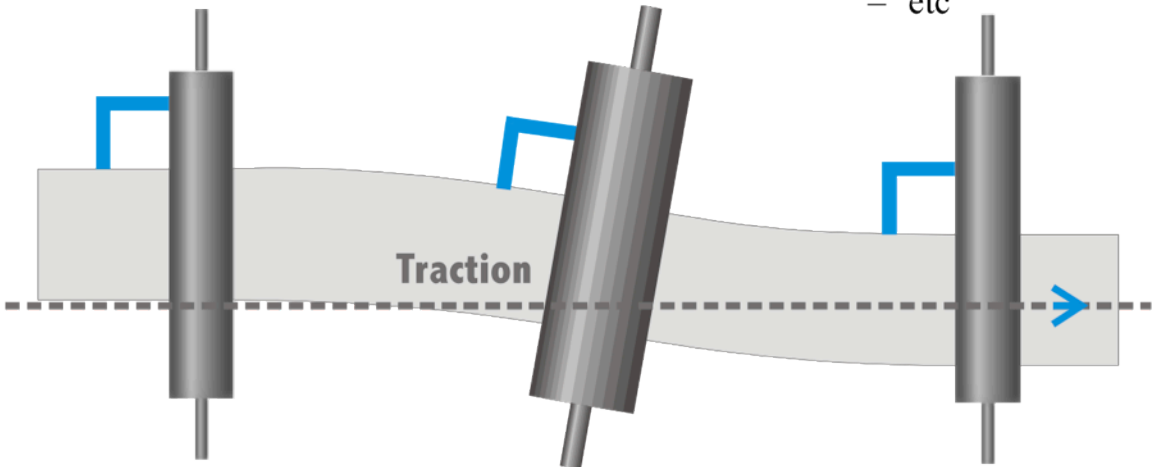


FIGURE 5 –PARALLEL OR TRAM MISALIGNMENT WRINKLE

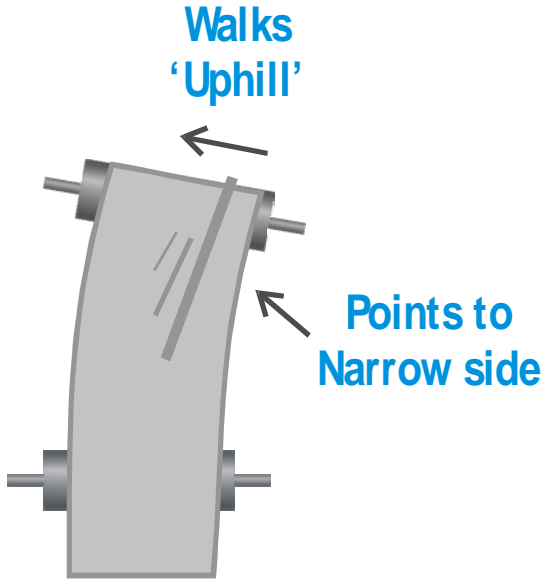


FIGURE 6 –THE STEERING GUIDE

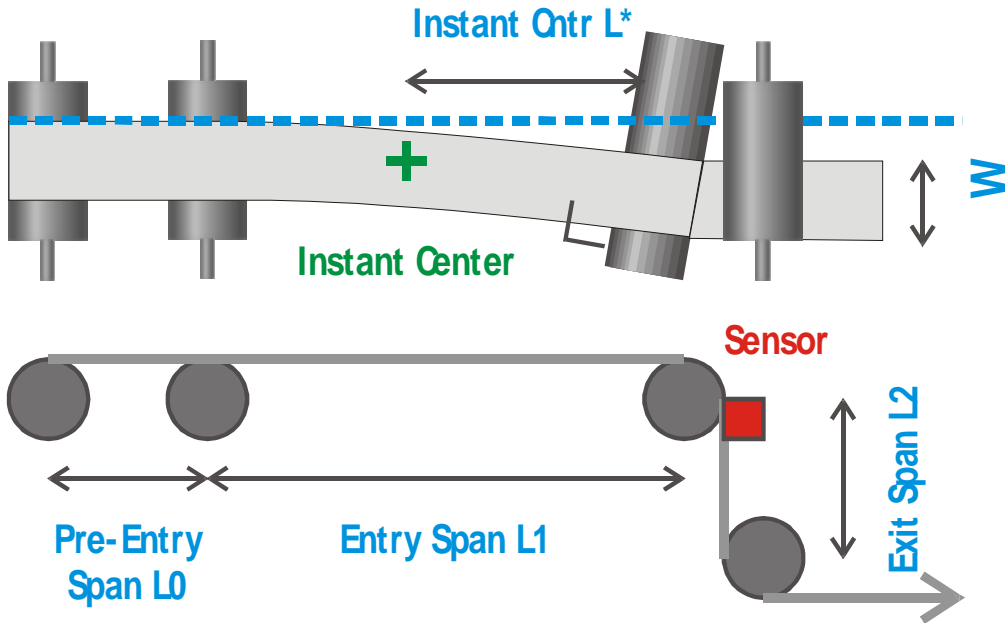


FIGURE 7 – PARALLEL MISALIGNMENT AND WRINKLING

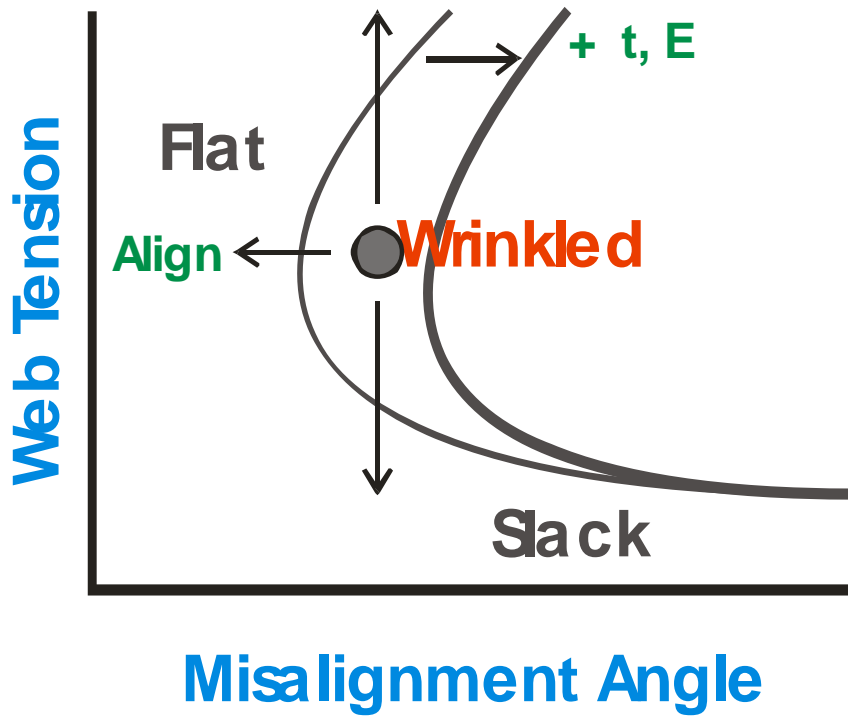


FIGURE 8 – WEB BREAK RATE AS A FUNCTION OF TENSION

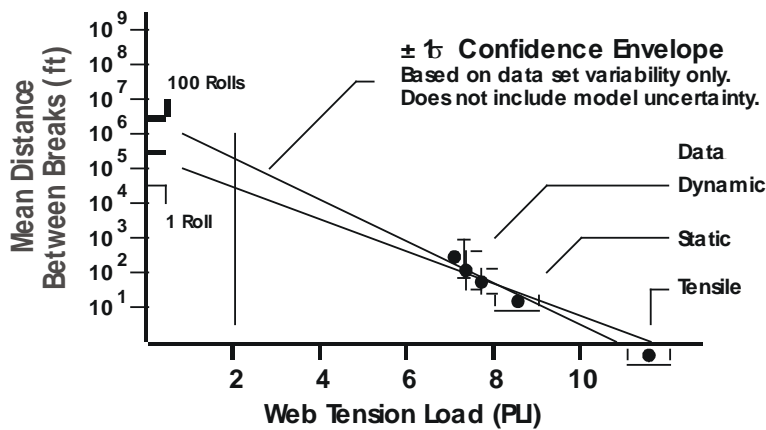


FIGURE 9 – MISALIGNMENT/TRACTION MODULE FROM TOPWEB 2

Slip & Alignment | Rolls | Torque & Inertia | Web guidance | Lamination | Web path | Bowed rollers | Helix Illusion | Concave Rollers

Input Data

Wrap deg: 90.0

Friction coefficient: 0.30

Torque N-m: 0.00

Brake Drive

Diameter mm: 120.0

Radius taper μm : 0.0

Roller roughness μm : 0.0

Web roughness μm : 0.0


Span m: 1.00

Misalignment μm : 1000

Expansion %: 0.0

Aniso. 2.0

Wrap

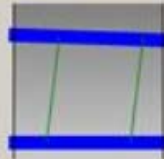


100.00%

Span

Misalignment: 0.001rad
0.057deg

Taper: 0.000%



Calculated data

Air gap: 1.50 μm

No slip:

Slack edge: Slack edge

TD offset from Misalignment & Taper: 0.0 μm Friction limited

Poisson shrinkage: 204.5 μm

TD Force: 3.65e01 N

Friction force: 0.00e00 N

Tension force on roller: 2.12e02 N

Max Tension: n/a

% Increase: n/a

% of Yield: n/a

Horizontal sag: 0.6 mm

Vertical tension: 0.7 N/m

MD Wrinkle Wavelength: ~-0.09m

MD Wrinkle Amplitude: -

Type 1 Shear wrinkle angle: 6.9°

Speed m/min: 10.0 Tension N/m: 150 Web width mm: 1000 Thickness μm : 50.0 Web: PET

Modulus GPa: 4.40 Poisson ratio: 0.30 Density kg/m³: 1400 Web length m: 3950 Yield strength MPa: 95.0

15.3 kg
3.00 MPa