Nip Impressions

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ABSTRACT

A nonuniform nip is nearly synonymous with a nonuniform product. Uneven nips are also a common cause of web handling waste such as wrinkles, web breaks and other troubles. There are many causes for nonuniform nips. However, all are readily detectable by using nip impression paper. Nip impression paper is an indispensable tool for process and product troubleshooting as well as for nip roller system maintenance. This technique is good, fast and cheap. There are few good alternatives.

KEYWORDS

Nip, roller, pressure, uniformity, quality, safety

WHAT IS A NIP IMPRESSION?

A nip is the pressure between two rollers that are forced together. A nip impression is a measure of the uniformity of that pressure. The pressure profile is sometimes referred to as a footprint. It can be measured in many ways. The simplest is to make sure that there is pressure everywhere across the width. This can be done by shining a light through the nip. Light escaping through a gap between the rollers tells us that there is no nip there. However, even if there is contact everywhere, the pressure may still be quite uneven. A better approach is to measure the width of the footprint. If the width is uneven, the pressure profile must also be uneven. However, measuring nip widths accurately can be difficult if the width is narrow. Also, as we will see, nip width variations are not a very sensitive measure of nip uniformity. The very best measure of the nip is to measure the pressure profile directly. Both nip widths and nip pressures can be measured with paper thin products often referred to as nip impression paper, even though some are these products are made of plastic rather than paper. Nip impression paper behaves like carbon or carbonless paper which turns color when a sufficient pressure has been applied such as by typing or writing with a pen. Nip impression paper is an indispensable tool for machine PM or process troubleshooting.

AN IMPORTANT SAFETY NOTE

Nip impressions, like most maintenance procedures, require people to be in proximity of a potentially hazardous area, namely, the nip. Thus, every one involved must take every precaution to ensure safety of their people. The most important precaution is to never enter the area until the drive and machine have been locked out and tagged out and the nip mechanically blocked open. Another requisite precaution is to limit the procedure only to those who have been trained and tested in machine safety in general and taking safe nip impressions in specific.

WHY IS A UNIFORM NIP PRESSURE IMPORTANT?

Our motives to measure nip pressure uniformity are to improve product quality and reduce customer complaints and waste. A nonuniform nip is nearly synonymous with a nonuniform product for a variety of forming processes from paper making to rubber calenders. The same is true for many converting processes including calendering, coating, laminating and printing. Finally, web handling can suffer with more wrinkles, web breaks and other troubles if the nip is uneven. The very few applications where nip uniformity is less important may include some extremely thick webs or light loading of high modulus materials.

WHAT CAN MAKE A NIP UNEVEN?

There are many factors that can make a nip uneven. Perhaps the most universal is roller deflection. As seen in Figure 1, rollers in nip will bow apart in the middle making the nip there less than on the ends. This behavior is inescapable because it is determined by immutable laws of physics. The amount of bending can be calculated and can even be countered with techniques such as crowning. Even so, it is possible to make errors in calculation or machining that may be difficult to detect without checking the nip uniformity. It is up to the machine designer to make judgments about roller diametral sizing to avoid excessive deflection. A similar design issue is thin shell wall deflection, as seen in Figure 2, which again causes the pressure in the middle to be less than the ends. In this case, crowning or other compensations are seldom successful.

Less than perfect maintenance is also a source of nip pressure variations. As seen in Figure 3, a roller's diameter varies across the width. This variation can be defined either as pk-pk, station-to-station or taper. Also, the radius of the roller may vary around the circumference. This variation is called TIR for Total Indicator Runout. Another maintenance source is roller misalignment as seen in Figure 4. Alternatively, rollers might be aligned but still have a side-to-side error because the force on one side is greater. Cover hardness is but another source of nip pressure variation.

HOW DO I KNOW IF MY NIP PRESSURE IS UNIFORM?

The brute force method to check a nip would be to check all of the possible causes of an uneven nip such as given above. However, this is the hard way to get things done. Many of the checks, such as roller diametral and shell wall sizing, involve calculations that would be difficult and time-consuming at best. Even if you did take the time, how would you know if you did it right? Even more crucial is how would you know if a given deflection was too much?

Many of the checks involve measurements that would be difficult and time consuming at best. You would need calipers for diameter, dial indicators for TIR, theodolites for alignment, force gages for loading systems and cover hardness measurements. Even if you did take the time, how would you know if you did it right? Even more crucial is how would you know if a given variation was too much?

The simple alternative and the first line of defense is to use nip impression paper. If the width and/or color come out uniform, you no longer need to concern yourself with the nip. It is uniform. Equally useful is that if width/color does not come out uniform, the nip impression will almost always direct you to the exact cause. At most you may need to only do one calculation or measurement and then only for verification. Using nip impression paper is good, fast and cheap. There are few good alternatives.

There are two methods of using nip impression papers; static and dynamic. As seen in Figure 5, the static technique 'stamps' the paper while the dyamic technique 'rolls' the paper through. Either one or both can be put on the same paper sample. Both can typically be done in less than a half an hour.

THE STATIC NIP IMPRESSION

The static nip impression is used when you primary objective is to get nip width rather than pressure or roller TIR. The nip width footprint is obtained by closing the nip momentarily on the paper. The steps are as follows:

1. Open the nip
2. Lock out and tag out the machine
3. Lock out and tag out the drives
4. Mechanically block open the nip
5. Cut a sheet of nip impression paper corresponding to the width of the rollers
6. Label the sheet with date, machine #, nipped roller set name, roller ID #'s, crown values, cover hardness, front side / back side
7. <u>Center the paper under the nip</u>. This may require two technicians and tape to hold the paper in place.
8. After all people are safely distant from the nip, the nip block is removed.
9. All personnel are cleared from the machine
10. Locks and tags are removed
11. The operator makes a last visual inspection of the nip area and yells "Clear Nip"
12. While observing the nip area, the operator closes the nip

13a. The nip load is set at a running or test value and held for 10 seconds

14. The nip is opened
15. Lock out and tag out the machine
16. Lock out and tag out the drives
17. Mechanically block open the nip
18. Remove the nip impression paper
19. Inspect the nip footprint for the uniformity of the footprint

Gaps in the line indicate that any product with similar thickness/modulus will have zero pressure there. If a thick or flexible product is to be run, you can do the nip impression on top of the web product. However, the most important measure of uniformity here is the width of the footprint line. Footprint width is measured with a ruler (if wide) or a magnifying reticule if narrow. Width measurements might be taken every couple of inches or so across the width, or up to a dozen CD (cross direction) positions or as best serves the application or study.

While the static nip impression is most convenient, it is unfortunately insensitive. The nip load ratio is the square of the width ratio because pressure also increases with nip width for a given roller set. Thus, a 2:1 ratio of maximum to minimum line width is in reality a 4:1 variation in nip load. While the static technique is insensitive, the dynamic technique can be hypersensitive.

THE DYNAMIC NIP IMPRESSION

The dynamic technique is preferable to the static in three situations. The first is if your objective is to measure pressure. The second is if your objective is to measure the effects of roller runout or TIR. The third is if your objective is to maximize the sensitivity of the measurement. With the dynamic technique, the pressure profile is obtained by rolling the nip paper through the nip. The dynamic technique differs from the static in only a couple of steps, namely, 7 and 13. All steps, however, are repeated here for convenience.

1. Open the nip
2. Lock out and tag out the machine
3. Lock out and tag out the drives
4. Mechanically block open the nip

5. Cut a sheet of nip impression paper corresponding to the width of the rollers
6. Label the sheet with date, machine #, nipped roller set name, roller ID #'s, crown values, cover hardness, front side / back side
7. Position the paper at the leading edge of the nip. This may require two technicians and tape to hold the paper in place.
8. After all people are safely distant from the nip, the nip block is removed.
9. All personnel are cleared from the machine
10. Locks and tags are removed
11. The operator makes a last visual inspection of the nip area and yells "Clear Nip"
12. While observing the nip area, the operator closes the nip

13a. The nip load is set at a running or test value and held for 10 seconds

13b. While observing the nip area the operator jogs the drive to run the paper through the nip

14. The nip is opened
15. Lock out and tag out the machine
16. Lock out and tag out the drives
17. Mechanically block open the nip
18. Remove the nip impression paper
19. Inspect the nip footprint for the uniformity of the footprint

Obviously, roller runout can not be completely checked using the technique given here because the width of the paper is usually far smaller than the circumference of the roller. Nonetheless, it may well be a representative sample. If you feel the need to document the entire circumference at some location you can run the paper through with the lengthwise direction with the paper oriented in the MD (machine direction). Now, you will have a complete revolution but not a complete width. Use the technique most suited to the problem you are trying to troubleshoot.

INTERPRETING THE COLOR, LOAD RANGE AND NIP WIDTH

The pressure curve for the nip impression paper is shown in Figure 6. There are two values of most interest. The first is the onset of color which begins at the threshold pressure. This pressure is well above zero for most products. The second is the saturation pressure. At this value, the paper will be completely colored. If the color of your nip impression is white, the load range of that paper product is too high for that application and nothing can be learned. If the color of your nip impression is completely colored and saturated, the load range of the paper is too low. Here, however, you can at least learn something. Here, the nip pressure at least as high as the saturation value is present across the entire width. You can not, however, make a quality or uniformity statement. If, for example, the paper saturates at 500 PSI, the impression would appear uniform (completely dark) even if the nip pressure varied from 500 to 5,000 PSI.

The most sensitive measure is if the paper turns out partly colored, grey if you like. The intensity of the paper can be matched like a color chip to calibrated pressures, if provided by the supplier. In any case, you can use a standard or special web brightness meter to quantify the color and thus pressure.

One subtlety of a nonzero threshold pressure is that the actual nip width is wider than the width of the impression. This has two implications. First, the calculation of peak pressure based on nip width and nip load will be compromised. Second, crown correction formulas given below assume the real value of nip width is known. While these are limitations, they are seldom an issue except in certain niche situations.

HOW DO I KNOW IF I HAVE DONE THE MEASUREMENTS WELL?

If you have a clear imprint, you probably have done the measurements well. However, here are some conditions that indicate problems with the measurement.

1. No coloration – load range of the paper is too high for this application
2. Completely saturated color for dynamic technique – load range is too low for this application

3. The paper puckers or wrinkles – paper not squared and mounted carefully
4. Paper, particularly two-component products, slips or shears during the procedure.
5. High temperatures that damage the nip impression paper.
6. A repeat of the procedure does not yield similar results.
7. Results are incompatible with other measurements or knowns.

HOW DO I KNOW WHAT CAUSES MY NON-UNIFORM NIP?

The causes for a non-uniform nips given above are usually quite easy to determine by looking at the nip impression results. Figure 7 shows how the static and dynamic nip impression footprint color intensity can vary with common sources of problems. Only in a couple of cases might the source be ambiguous. One example is that thin wall deflection and under crowning look similar. However, in the thin wall case the gradient (change) on the ends is extremely high while the under crown tends to vary smoothly and gently across the width.

HOW DO I KNOW IF NIP NONUNIFORMITIES ARE A PROBLEM?

The easiest way to troubleshoot the nip is to match the shape of the problem to the shape of the nip profile (2). This is something like matching fingerprints on a door knob to a suspected burglar. For example, if the CD (cross-direction) location of a web steak or web defect lines up with a band in the nip impression, you may expect that the diametral variations were responsible. Supporting evidence would be if the width of the streak/defect lane is within a factor of two of the width of the nip impression band. If so, the next step would be to replace or regrind the offending roller(s).

Your problem might also be smile or frown shaped. By this I mean that the ends are better, worse or different than the middle. Check the nip impression. The static nip impression footprint might be concave (hourglass) or convex (barrel) shaped. The dynamic nip impression would be darker on the ends than the middle or vice versa. If the nip impression were similarly shaped, you may be suspicious of a causal connection. Take care, however, because many elements of web machines are similarly shaped. All you have established so far is that the nip is a candidate, not necessarily a cause. The next step would be to verify a crown/deflection mismatch by calculation (1) or by varying the load to see if the nip impression shape changes. Another technique is bias the loads on the side, so one is higher than the other, to see if the problem moves correspondingly. If so, the next step would be to crown, if the error were modest, or rebuild to a larger roller, if the error were severe.

WHEN SHOULD I DO A NIP IMPRESSION?

Nip impressions can be done for troubleshooting, maintenance or PM's. The application for troubleshooting was discussed above. The application for maintenance would be to check rollers as they are taken out and put into service. The former is to establish a 'threshold of pain' and the latter is a sanity check to make sure the loading system and roll grind are in good shape.

However, the big opportunity and the one that most people miss is PM (preventative maintenance). In other words, don' wait until the customer complains about streaks in the product. Don't wait until QA does a thumbs down before changing the rollers. Do nip impressions before the roller wears out and the customer complains. You can use service history to estimate a frequency that might be appropriate. If for example, a roller tends to last one year between grinds, do a nip impression every quarter at a convenient down time. If, on the other hand, you only get a month, then you might look at doing a nip impressions every week. This frequency allows you to get ahead of the problem. Often to the point of predicting when the roller will need changing, long before it even needs changing. This allows you to plan downtimes, spare parts and maintenance. Proactive instead of reactive.

WHICH ROLLERS SHOULD BE CHECKED?

Any nipped roller which has worn out in the past or is expected to wear out would be candidates for nip impression PM's. Any nipped roller which is a process roller (calendering, coating, laminating, printing etc.) should be done on occasion because they are the heart of the machine and process. You should do this even if you are not aware of a problem caused by nip uniformity. You may just discover why you product is uneven (which it almost certainly is). You should do this on any transport nip (pull rollers, winders etc.) if puckers, wrinkles or web breaks are troublesome at that location.

OTHER NIP IMPRESSION PRODUCTS AND TECHNIQUES

We already mentioned the sources of nip uniformity problems and the tools that would be required to check them directly. We have concluded that nip impression paper is almost always better, faster and cheaper. Nip impression paper may be paper, film or foil. The non-foil products may be either one-part or two-part products. The two-part product has a separate sheet for the dye and the blank or the dye and developer sheets. The one part products are slightly easier to handle. The products also differ in their useful load ranges. Foil has the lowest threshold while paper has the highest. Film spans the middle pressure ranges. Finally, there are at least two commercial electronic nip sensors as well as a number of others that have been used for special R&D projects. The costs of these products vary enormously. Film is highly engineered and is thus very expensive. The electronic nip sensors are even more complex and include sensors, instrumentation, computers and software and are thus outrageously expensive.

There are a number of ad hoc ways to check nip uniformity. Using feeler gages, one might measure the profile of gap. However, this technique is very time consuming to profile, doesn't consider deflection and is very insensitive for hard nips. In other words, a tiny variation in a metal-metal gap can represent a huge variation in pressure, especially for products thinner than 10 mils or so. Another technique is to nip strips of shimstock or product in various places across the nip. Using a force gage, one can measure the variation require to pull the strips out. Again, this technique is time consuming. It is also not suitable for nip loads much above 10 PLI which preclude almost everything but winders. Some people put sticky notes into both sides of a static nip and then measure the distance between the pairs. Finally, some people make up a sandwich of grease inside a plastic bag. The nip width can be measured by the area where the grease has squeezed away. The use of such techniques makes me shake my head in disbelief. Why people would improvise such crude methods to check rollers which cost thousands if not hundreds of thousands of dollars?

HOW TO CUT AND CORRECT A CROWN?

An initial crown is usually cut to a value either determined by long and studied experience or by calculation (1). The calculation is simply the sum of the bending deflections of both rollers caused by gravity and the loading system. In either case, errors of omission or commission can make the crown inappropriate for the loading as seen in Figure 8. One can correct the crown by two crude but simple approximation techniques. The first is to alter the loading until the nip impression is flat and uniform. This presumes that the equipment is capable of reaching those loads, but does not require saleable product. The corrected crown would be the present crown multiplied by the load ratio. Specifically,

$$NewCrown(mils) = OldCrown(mils)\frac{CurrentLoad(PLI)}{FlatLoad(PLI)}$$

The challenge here is that most people will not readily know the nip load in appropriate units of force or force/width. Most machines give nip cylinder pressure in PSI and are not calibrated as they should be to PLI (kN/m in the Metric system). Contact the machine builder or an engineer to get loads in the correct units for use for product and process design.

The other technique is to measure the nip width at the roll ends, We, and the roll center, Wc. The crown deficiency is calculated in a consistent set of units as:

$$C = \frac{\left(We^2 - Wc^2\right)\left(D_1 + D_2\right)}{2 \times D_1 D_2}$$

where:
C = Diametric crown deficiency (positive if too little crown, negative if too much crown)
We = Nip width on the roll ends
Wc = Nip width at the roll center
D1 = Diameter of roller 1
D2 = Diameter of roller 2

These techniques give an approximation for the value or magnitude of the diametral difference for the crown. They say nothing about the shape. The shape is a best convenient fit for the beam deflection. While one could use a parabola, the convention is to cut the crown as a 70 degree cosine as seen in Figure 9. Cutting an accurate crown is something that will tax the best numerically controlled grinders.

The bottom line is that we will use the nip impression paper technique to determine whether the crown is correct. The resulting width or color will tell us the direction we need to move as was given in Figure 7.

CALCULATING PEAK NIP PRESSURE, NIP LOAD OR NIP WIDTH

If you know two of the above, you can calculate the third. One application would be to get peak pressure or stress to select the right nip impression paper product or to engineer contact stresses. Another application would be as a sanity check for nip load values. Specifically,

$$\sigma_c = 1.277 \frac{N}{W}$$

where,

σ_c = peak nip pressure or stress (lb/in^2, psi, or N/m^2)
N = lineal nip load (lb/in, PLI or N/m)
W = actual nip width (in or m)

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Figure 1 – Roller Beam Deflection

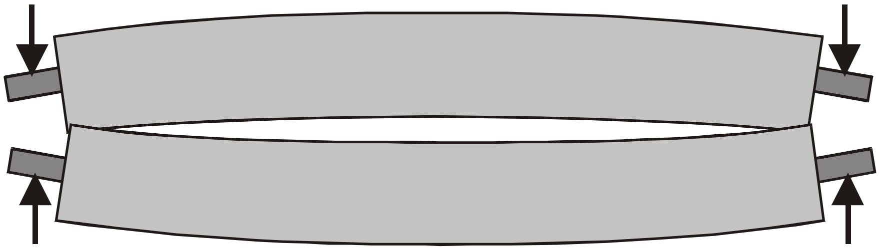


Figure 2 – Roller Thin Wall Shell Deflection

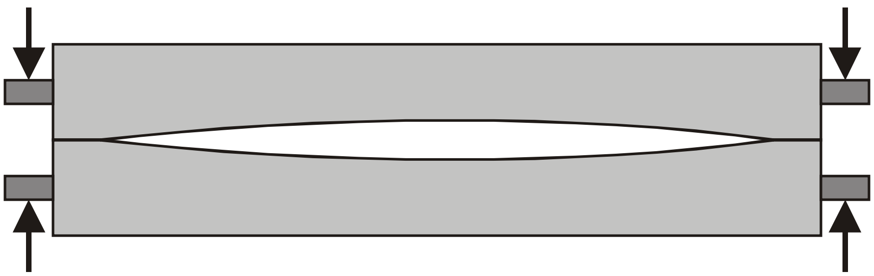


Figure 3 – Cylindricity Error

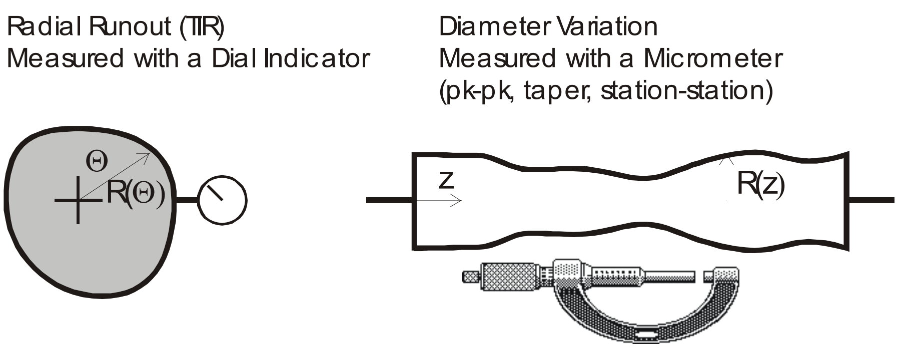


Figure 4 – Roller Misalignment

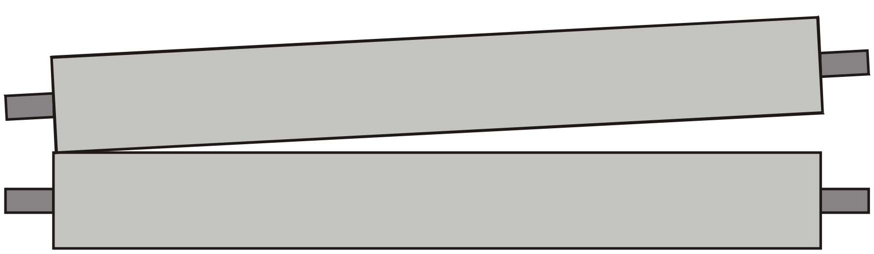


Figure 5 – Static and Dynamic Nip Impression Techniques

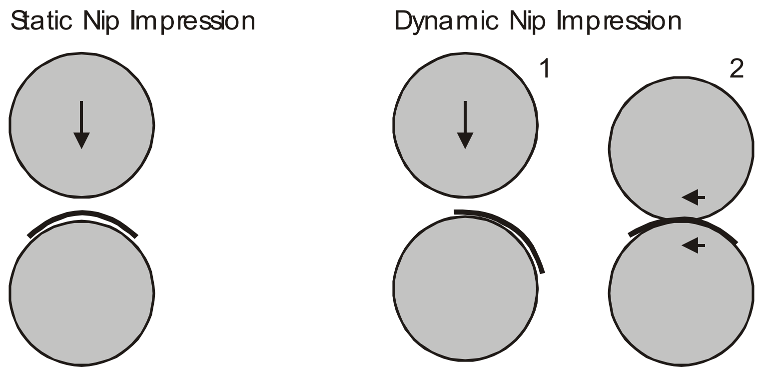


Figure 6 – Nip Impression Paper Color Curves

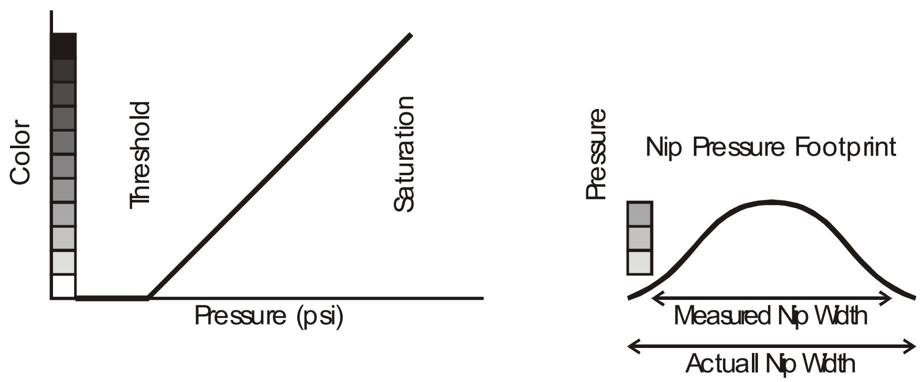


Figure 7 – Reading Nip Impressions

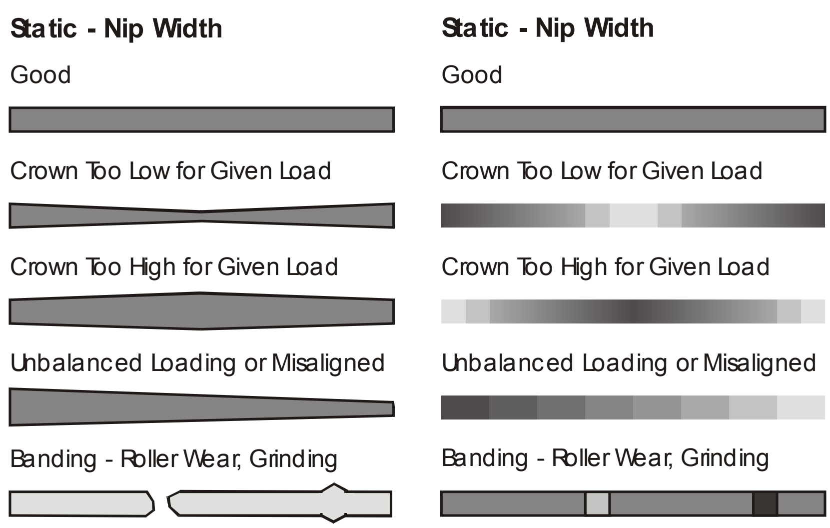


Figure 8 – Crown Errors

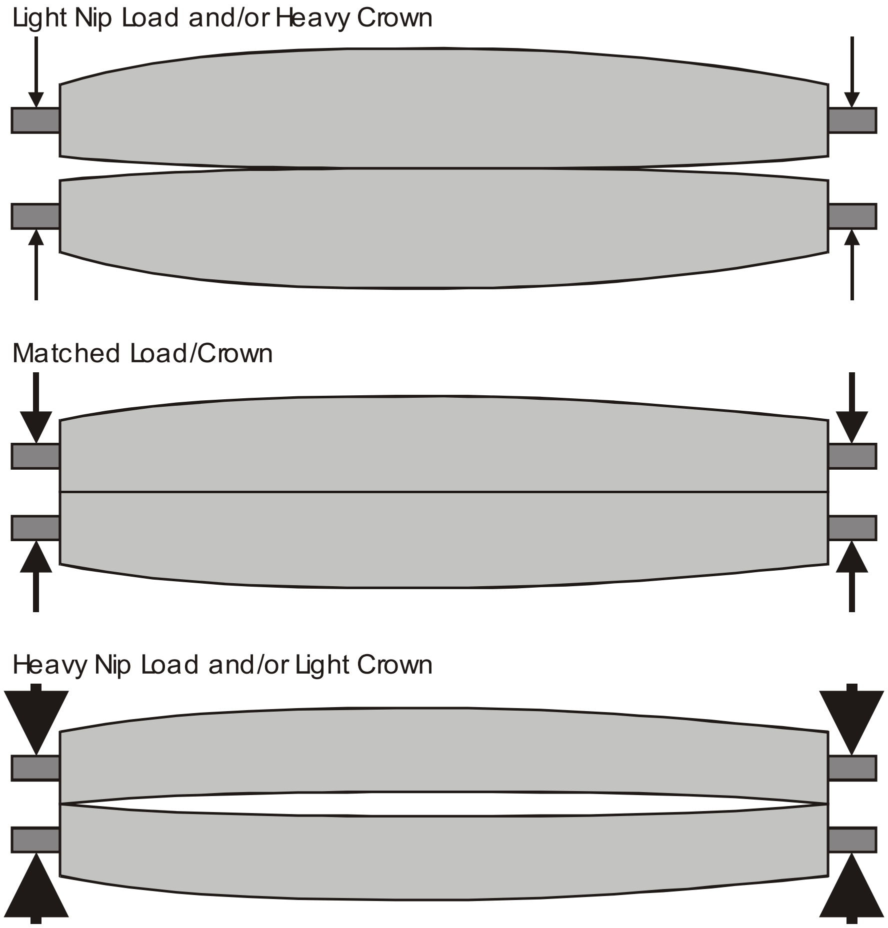
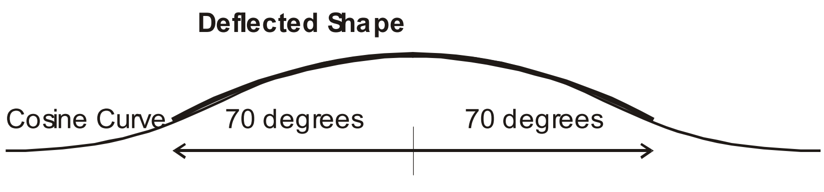


Figure 9 – 70 Degree Cosine Approximation of Crown Shape



SAFETY

Nip impressions, like many maintenance procedures, require people to be in proximity of a potentially hazardous area, namely the nip. Thus, every one involved must take every precaution to ensure safety of people in the area. The most important precaution is to never enter the area until the drive and machine have been locked out and tagged out and the nip mechanically blocked open. Another requirement is to limit the procedure only to those who have been trained and tested in machine safety in general and nip impression methods and nip impression safety in specific.

Nip impressions should not be taken unless all people involved have been trained and tested in machine safety and nip impression safety.

Nip impressions should not be taken unless all people involved can and will take all precautions such as listed here.

There are at least two hazards represented by the nip. These hazards can maim or kill if proper precautions are not taken. The first hazard is closing the nip which may pinch a body part. The nip is closed in both the static and dynamic technique. Everyone should be aware that the nip loads generated by cylinders are easily enough to crush and kill on most machines. On wide paper machines and metal mills, the nip load can easily exceed 10 tons. However, even narrow converting machinery can deliver dangerous nip loads. Everyone should be aware that nips do not open suddenly like an elevator door when contacting a body. Rather, the nip load will be developed so fast as to exceed human reaction time. You will be crushed long before anyone can open the nip, even when using a 'dead man switch'.

The nip should not be closed until the operator has made certain that all personal are clear. This would include both people involved with the maintenance as well as those visitors which may stray into the area.

The nip should not be closed until the operator has a clear view of the entire length of both sides of the nip. If the entire length of one/both sides can not be seen from the operating panel, the operator will use one/two helper(s) as an extra set of eyes. The helper will stand in an area with good visibility but which is clear of the machine. A single thumb up is the universal 'All Clear' signal and should not be used for any other meaning.

The nip should not be closed until the operator has loudly yelled "Closing Nip" and waited for at least 5 seconds.

The second hazard is jogging the drive which is used only in the dynamic technique. This step has an even higher potential hazard because the driven nip will often be able to pull a person into the nip. Everyone should be aware that the torque loads generated by most drives are easily enough to pull a person through the nip. On wide paper machines and metal mills, the torque load can easily exceed 1000 lbs. However, even narrow converting machinery can deliver dangerous torque loads. Everyone should be aware that drives do not stop suddenly. Rather, even at thread speeds the human reaction time is so slow that at least one foot of material will be entrained before the drive stops.

The drive should not be engaged until the operator has made certain that all personal are clear
The drive should not be engaged until the operator has a clear view of the entire length of both sides of the nip.
The drive should not be engaged until the operator has loudly yelled "Drive On" and waited for at least 5 seconds.

There are three time periods which are most hazardous. They are when people may be in proximity to the nip. They are:

1. Mounting the paper – Step 7
2. Engaging the nip and drive – Step 13

3. Removing the paper – Step 18

Special attention and diligence and focus are to be maintained everyone at these times. Side conversations and other duties should cease at these times.

No access to the machine is to be allowed unless it is locked out, tagged out and the nip mechanically blocked open.

Consult your plant and machine builder for lockout tag out procedures for your machine.

The nip must be blocked open when personnel are inside the machine.

The best place to block is usually with a pin through a hole on a point provided by the machine builder. It is safest to block both front and back of the machine. If not provide by the OEM, you might design spacers to go between the nip if the nip opening is not large such as on a winder. The spacers must be slightly narrower than the maximum opening of the nip. A slight taper on the spacer block will prevent it from dropping through a nip with a vertical web run.

<u>Other Safety Tips</u>

1. **Think about and plan every move** before you make the move. Do not rush anything. Do not do anything that does not seem right or violates safe practice. You are ultimately responsible for your safety and the safety of those around you.
2. **Watch out for your buddy** to make sure he/she is also acting in a safe and predictable manner. Report anyone whose behavior and actions put someone at risk. It is better to be a fink than be party to an accident. The former is forgivable, the latter is forever.
3 **Keep nonessential people out of the area** when performing any maintenance including nip impressions.
4. Make sure all guards, interlocks, controls, signage and other **safety elements** are in place and operating correctly. Consult your machine builder and your safety department if you have any concerns.
5. A **dead man's switch**, activated by lifting and depressing the foot, is an extra layer of safety when in the proximity of the nip. Here, the operator must maintain a specific amount of pressure on the foot pedal. Any changes will immediately stop the drive and open the nip. The switch is usually a supplement rather than a replacement to other switches such as pull cords and mushroom buttons.
6. Nips should never move quickly. A rule of thumb is 10-20 second **nip open and closing time**. This is fast enough to notice movement, but may be slow enough to get out of the way. The speed of opening and closing is usually adjustable by flow control valves. Consult the machine builder if you have any concerns.
7. Watch out for the **nip loading mechanism** itself, such as cylinders and arms, as they may also present a pinch hazard. Be familiar with the machine and consult you machine builder if you have any concerns.