Camber, The unkind Curve

Understand how Camber can be handled in a typical Tube Mill:

By W.B. “Bud” Graham, Contributing Writer

Ok, were going to talk about curves. Not the one seen in a ball game but the ones you encounter in the slit to width strip you convert into welded tube. The most commonly encountered strip shape problem is camber. Camber is the deviation (curve) of a strip edge from a straight line. Slit to width strip should be a uniform width so the camber measurement (distance between the inner curve and the imposed straight line) is taken over the entire length of the concave side. A camber measurement is stated as a deviation from the straight line over the length of the curved section. For hot rolled coil the mill supply upper limit is typically ½” in 20 feet.

The second and third strip shape problems are; Edge Wave, deviation vertically from the horizontal plane (a sinusoidal wave) and Center Buckle, deviation of the center section of a strip from the horizontal plane of the strip edges. Camber, Edge Wave and Center Buckle are all examples of the same problem: unequal strand length across the strip width. All three strip shape problems occur because of internal stress left over from the initial rolling, improper slitting / rewinding or strip handling into and out of the strip accumulator system. Camber results when there is

a length variation across the strip (creating a right or left curve), Edge wave occurs when only the edges (one or both) become stretched longer that the center of the strip. Center Buckle is the reverse problem; the center of the strip is stretched to become longer than the edges. In welded tube production strip shape problems cause forming and weld problems. Fortunately the tube mill Fin forming passes can reshape the strip and reduce camber and edge wave to manageable levels. Center buckle is the hardest strip shape problem to overcome in the tube mill. Strip with obvious Center Buckle should be rejected, see the last illustration for details.

I am often asked how much camber is permitted in slit to width strip for welded tube production. The answer is: it depends! When I say it depends, I am referring to the relationship between the wall thickness and the tube OD you are producing, in other words, the t/d ratio. The easy to form range is between 3 and 8 percent t to d ratio. The mill is most capable in dealing with Camber and Edge Wave when making tube within this range. When we operate below 3% or above 8% the capability of the Fin passes can be compromised, not by their limits, but because it become all that more difficult to achieve a quality mill setup from end to end.

How do the Fin Forming passes overcome typical camber and edge wave strip shape problems? The Fin passes perform their function by (outer girth trapped by the roll contour, strip edge trapped by the fin blade)

compressing 100% of the crossection to a plastic deformation state AND simultaneously stretching the open section. The Fin forming passes act like a mini continuous tension leveling line.

To illustrate the capability of the Fin Forming passes we need to understand the nature of the observed camber. Here is where curves come in. The illustration shows the effect of camber on slit coil. The calculations compare the curvature; the length of the curved arc to a straight line (cord) and the capability of the fin passes to tension level the section.

For our example we illustrate ½" camber in 20 feet. (See image #1) The calculated radius of the curve is 14,400.25 inches (1,200 feet); the length of the curve is 240.0028 inches. The difference between the curve length and the 20-foot (240 inch) measurement base is 2.8 thousands of an inch. This means that we need to bring the section to a plastic condition and stretch the section between the fin passes by 0.00002894 (2.894E – 05) inches ever inch (travel thru the tube mill) to eliminate the camber condition.

The capabilities of the fin passes to perform this feat are dependent upon:

1. **The use of the proper strip width and the related quality issue of consistent slit width control.**

2. Good tool condition (proper roll stepup, top and bottom roll root, proper radius and proper fin blade usage)
3. Proper mill alignment. All shafts parallel to one another (all bottom shafts must be in the same plane and the weld box at proper height) and all shaft shoulders in line (breakdown thru final sizing) to a maximum deviation of 10% of the minimum gauge processes.
4. Proper mill setup. Proper rolls and spacer installed and adjusted to the roll setup charts (flange gaps and Pi-Tape reading confirmation of achieved reduction).
5. Proper drive control (all shafts powered, no freewheeling permitted except for free floating fin blades) so tension may be applied between the breakdown and the fins and between the fins and sizing zones.
6. Friction reduction caused by excessive lubrication (Pickled and oiled material) can reduce the capabilities of the roll tooling. Operation with prepainted or coated material or polished surfaces may also impact roll / mill capabilities.

The illustration shows a 4" root diameter roll set with 0.010" stepup (Stepup - increase in roll root diameter from F1 to F2 and F3). With a 0.010" stepup (and proper mill drive trim) the fin passes will provide a stretch of 0.314" between passes at 100% efficiency. In the real world stretch is limited by the frictional bite at the roll face to between 25 and 33 %

efficiency or a maximum stretch of 0.0419 inch per roll revolution, based on the 4" root. The cumulative stretch is 0.8004 inches over the 20-foot section. The fins can easily accommodate a ½ inch camber in 20 feet!

When we use the same calculations to illustrate edge wave capabilities we see a completely different picture as edge wave conditions tend to be created over shorter distances. For our example we will use a 1/2" wave height over a 36-inch length. (See image # 2) This illustration shows a high likelihood of good operation as we have sufficient stretch capability to overcome the edge wave condition. An edge wave condition tends to be repetitive over long distances so we need excess capacity to handle the varying workload.

The third example shows the effect of an edge wave condition with a shorter distance between crests. This example would fail as we need a 0.0781-inch stretch over the 12-inch distance and the fins are only capable of 0.040-inch stretch. The strip will pileup in the breakdown and fins. Short duration waves, even when the height is low, are far more difficult to deal with. Center buckle is s prime example of this condition as well; this is why we suggest that center buckled material should be rejected.

Learning to play the curves and your mill / tooling capability limits will make you a better tube producer!

To learn more about the Fin passes refer to two earlier printed articles, "Solving the Mystery of the Fin Passes, part 1 and 2".

Bud Graham is president of Welded Tube Pros, P.O. Box 202, Doylestown, OH 44230, 330-658-7070, fax 312-896-5696, budg@bright.net, www.weldedtubepros.com. He also is the chairman of TPA's Tube Producers Council. Welded Tube Pros is a consulting engineering firm serving the needs of welded tube producers. If you have a specific question or would like to see an article on a particular problem, please contact the author or TPJ.

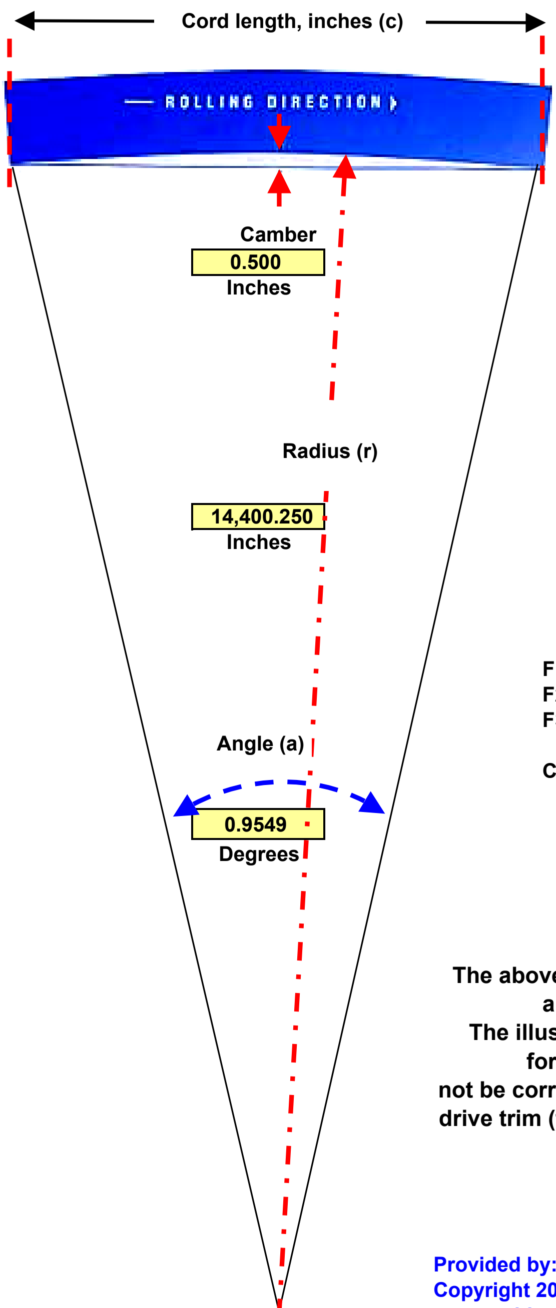
Attachments:

Image #1 - Camber

Image #2 - 36" crest W 0.500" height

Image #3 - 6" crest W 0.375" height.

Camber Effect and Fin Stretch Correction - Camber 0.500" in 20 feet



6.371 Strip Width, Inches

240.000 Inches 1/2 Cord = 120.000 Inches

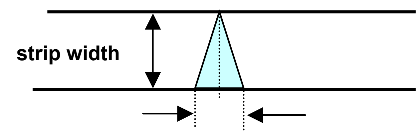
camber (h), inches 0.500 Inches

Radius, (r) = (c^2 + 4h^2) / 8h 14,400.250 Inches

Angle (a) in radians =
(ASIN(1/2 Cord / radius))*2 0.0167 radians angle (a)

Degrees angle (a) =
DEGREES(J9) 0.9549 degrees angle (a)

Length of the Arc, l
(radius* 2 * PI())/ 360*degrees of arc 240.0028 Inches



2.894E-05
Inch per inch of Cord length
Crossectional Area that must be
Stretched to compensate for camber

0.00018435
Cubic Inches

Cord Length
240.000 Inch

Length of Arc
240.0028 Inch

Safety Factor
2.5

Minimum length correction to reduce Camber condition
0.0069 Inch in the cord length
2.894E-05 Inch per inch of Cord length

Fin Pass work rolls
Root Diameter 4.0000 Inch
Progression 0.0100 Inch, (stepup in diameter from pass to pass)

		Cir. Inches	Ft./ Rev.	Cir. Difference, Inches
F1 Root	4.0000	12.5664	1.047	0.0000
F2 Root	4.0100	12.5978	1.050	0.0314
F3 Root	4.0200	12.6292	1.052	0.0314

Note: this does NOT take into account the line speed difference between the BD and FIN passes

Cumulative stretch per revolution @100% Effect. 0.0628 Inch / Revolution

Wall Thickness / Length Growth RATIO

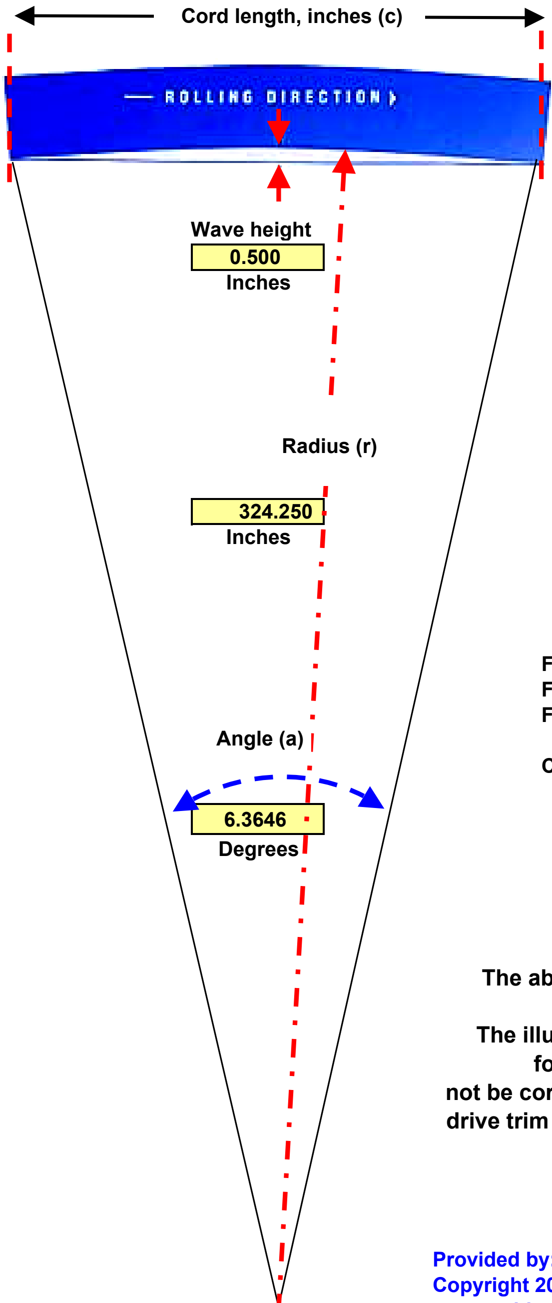
Thickness	Length
33.0%	67.0%

Adjusted Stretch capacity based on build condition
0.0421 Inch per roll revolution

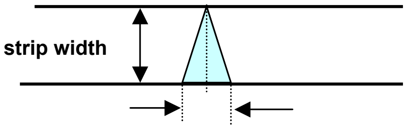
Cumulative correction over wave length (crest to crest / roll Cir)
0.8040 Inch

The above calculation illustrates typical strip Camber of 1/2" in 20 feet and the capability of a three pass fin forming section to apply sufficient stretch to reduce the camber to a manageable working condition for welded tube production.
The illustration assumes that strip width is sufficient to fill the #1 Fan pass and that full engagement continues thru the Fin forming section. Compression in the Fin passes must exceed the elastic limit of the material or strip camber will not be corrected. Attempting to operate with insufficient strip width, improper mill setup, worn roll tooling and / or improper mill drive trim (failure to pull from one zone to another) will reduce the capability of the fin passes to perform their intended function.
Insufficient compression creates wavy strip edges and poor edge to edge alignment.
Failure to adequately compress the section in the fin passes is the primary cause of weld faults.

Edge Wave Effect and Fin Stretch Correction - 36" crest W 0.500" height



6.371	Strip Width, Inches			
36.000	Inches	1/2 Cord =	18.000	Inches
	camber (h), inches		0.500	Inches
	Radius, (r) = (c^2 + 4h^2) / 8h		324.250	Inches
	Angle (a) in radians = (ASIN(1/2 Cord / radius))*2		0.1111	radians angle (a)
	Degrees angle (a) = DEGREES(J9)		6.3646	degrees angle (a)
	Length of the Arc, l (radius* 2 * PI())/ 360*degrees of arc		36.0185	Inches



1.286E-03

Inch per inch of Cord length
Crossectional Area that must be
Stretched to compensate for Edge Wave

0.00819189
Cubic Inches

Cord Length
36.000 Inch
Length of Arc
36.0185 Inch

Safety Factor
2.5

Minimum length correction to reduce Edge Wave condition

0.0463 Inch in the cord length
1.286E-03 Inch per inch of Cord length

Fin Pass work rolls

Root Diameter	4.0000	Inch
Progression	0.0100	Inch, (stepup in diameter from pass to pass)

		Cir. Inches	Ft./ Rev.	Cir. Difference, Inches
F1 Root	4.0000	12.5664	1.047	0.0000
F2 Root	4.0100	12.5978	1.050	0.0314
F3 Root	4.0200	12.6292	1.052	0.0314

Note: this does NOT take into account the line speed difference between the BD and FIN passes

Cumulative stretch per revolution @100% Effect. 0.0628 Inch / Revolution

Wall Thickness / Length Growth RATIO

Thickness	Length
33.0%	67.0%

Adjusted Stretch capacity based on build condition
0.0421 Inch per roll revolution

Cumulative correction over wave length (crest to crest / roll Cir)
0.1206 Inch

The above calculation illustrates Edge Wave of 1/2" in 3 feet and the capability of a three pass fin forming section to apply sufficient stretch to reduce the wave to a manageable working condition for welded tube production.
The illustration assumes that strip width is sufficient to fill the #1 Fan pass and that full engagement continues thru the Fin forming section. Compression in the Fin passes must exceed the elastic limit of the material or strip camber will not be corrected. Attempting to operate with insufficient strip width, improper mill setup, worn roll tooling and / or improper mill drive trim (failure to pull from one zone to another) will reduce the capability of the fin passes to perform their intended function. Insufficient compression creates wavy strip edges and poor edge to edge alignment.
Failure to adequately compress the section in the fin passes is the primary cause of weld faults.

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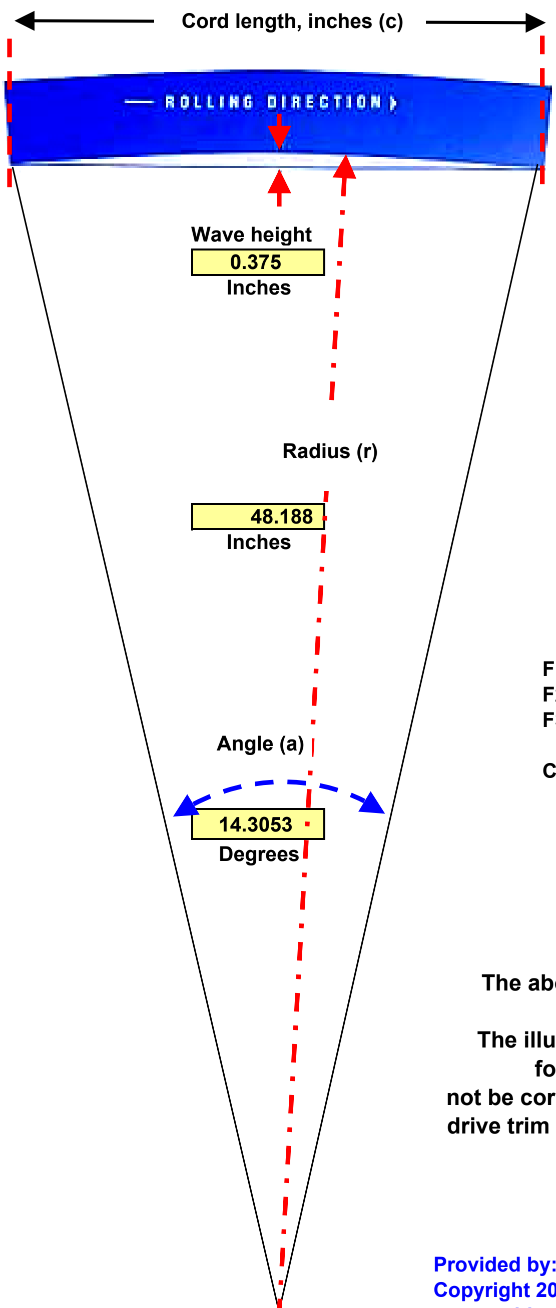
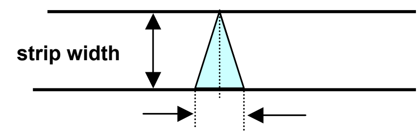
Edge Wave Effect and Fin Stretch Correction - 6" crest W 0.375" height



6.371	Strip Width, Inches			
12.000	Inches	1/2 Cord =	6.000	Inches
	camber (h), inches		0.375	Inches
	Radius, (r) = (c^2 + 4h^2) / 8h		48.188	Inches
	Angle (a) in radians = (ASIN(1/2 Cord / radius))*2		0.2497	radians angle (a)
	Degrees angle (a) = DEGREES(J9)		14.3053	degrees angle (a)
	Length of the Arc, l (radius* 2 * PI())/ 360*degrees of arc		12.0312	Inches



6.505E-03

Inch per inch of Cord length
Crossectional Area that must be
Stretched to compensate for Edge Wave

0.04144551

Cubic Inches

Cord Length

12.000 Inch

Length of Arc

12.0312 Inch

Safety Factor

2.5

Minimum length correction to reduce Edge Wave condition

0.0781 Inch in the cord length

6.505E-03 Inch per inch of Cord length

Fin Pass work rolls		
Root Diameter	4.0000	Inch
Progression	0.0100	Inch, (stepup in diameter from pass to pass)

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Note: this does NOT take into account the line speed difference between the BD and FIN passes

Cumulative stretch per revolution @100% Effect. 0.0628 Inch / Revolution

Wall Thickness / Length Growth RATIO

Thickness	Length
33.0%	67.0%

Adjusted Stretch capacity based on build condition

0.0421 Inch per roll revolution

Cumulative correction over wave length (crest to crest / roll Cir)

0.0402 Inch

The above calculation illustrates Edge Wave of 3/8" in 1 foot and the capability of a three pass fin forming section to apply sufficient stretch to reduce the wave to a manageable working condition for welded tube production.
The illustration assumes that strip width is sufficient to fill the #1 Fan pass and that full engagement continues thru the Fin forming section. Compression in the Fin passes must exceed the elastic limit of the material or strip camber will not be corrected. Attempting to operate with insufficient strip width, improper mill setup, worn roll tooling and / or improper mill drive trim (failure to pull from one zone to another) will reduce the capability of the fin passes to perform their intended function. Insufficient compression creates wavy strip edges and poor edge to edge alignment.
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