producingresults

Pulling taffy and producing tube

Proper tension is a key to success for both processes

By W.B. "Bud" Graham, Contributing Writer

Do you remember going to the county fair and watching candy makers make taffy? As a child I often would watch the whirling motion of the taffy pull machine as it whipped and pulled and whipped and pulled again and again until the candy was the right consistency, texture, and color. As long as the machine speed was constant or accelerating, everything went well. When an inexperienced operator was working, onlookers might be lucky to see the train wreck that followed the wrong speed selection and the embarrassed looks on the candymakers' faces as they scurried about picking up the shredded results.

Tension was at play in a successful folding of the finished taffy, much like the tension needed in tube forming. Although differences exist (taffy is a solid structure whereas tube is hollow), many of the same rules apply to both processes. Forces in the processes bring the material to a plastic state to form the finished product. Achieving desired results, whether making taffy or welded tube, requires attention to tension's role.

Tension and Friction

Two complementary forces–tension and friction–are created at various places on a tube mill. Understanding and controlling these forces can help you control the strip as it passes through the mill.

The rotation of the roll shafts and the tooling mounted on them creates the drawing power, or tension, needed to pull the strip into the tube mill and progressively form it into the desired tubular section. Tension is achieved only when the drive friction is sufficient to transmit the rotational force, or torque, from the rotating rolls to the strip.

Friction is resistance to motion. In welded tube production, friction develops between the strip as it is being formed and the rolls providing the work (rotation) to move the strip through the mill. Friction is the direct result of a load being forced to slide over a surface.

What Develops Friction? In a tube mill, friction is developed by the roll gap and the contours of the successive rolls.

• When the roll gap (the space between the rolls) is set correctly, friction develops between the strip and the rolls. Turning the stand adjustment screws increases or decreases the roll gap. The resulting contour gap between the breakdown tools should be parallel and should match the gauge being formed.

• The strip is flat as it enters the mill. The contours of the rolls force the strip to bend slightly to conform to the roll profile. The strip's tendency to resist changing shape develops friction.

The resistance to bending across the strip's width in the breakdown passes and the resistance to girth reduction in the fin, weld, and sizing passes creates friction by the development of two separating forces (see **Figure 1**). The principal separating force is directly related to the strip's width, thickness, and strength. The secondary separating force is related to the speed at which the strip passes through the mill. In other words, this is the torque required. The sum of these two forces creates the combined stress for the individual driven roll shafts. If the stress exceeds the mill design limits, the roll shafts fatigue and fail.

Conflict Among the Forming Passes. The motor or motors that drive the tube mill develop torque,

Forces Developed in a Tube Mill

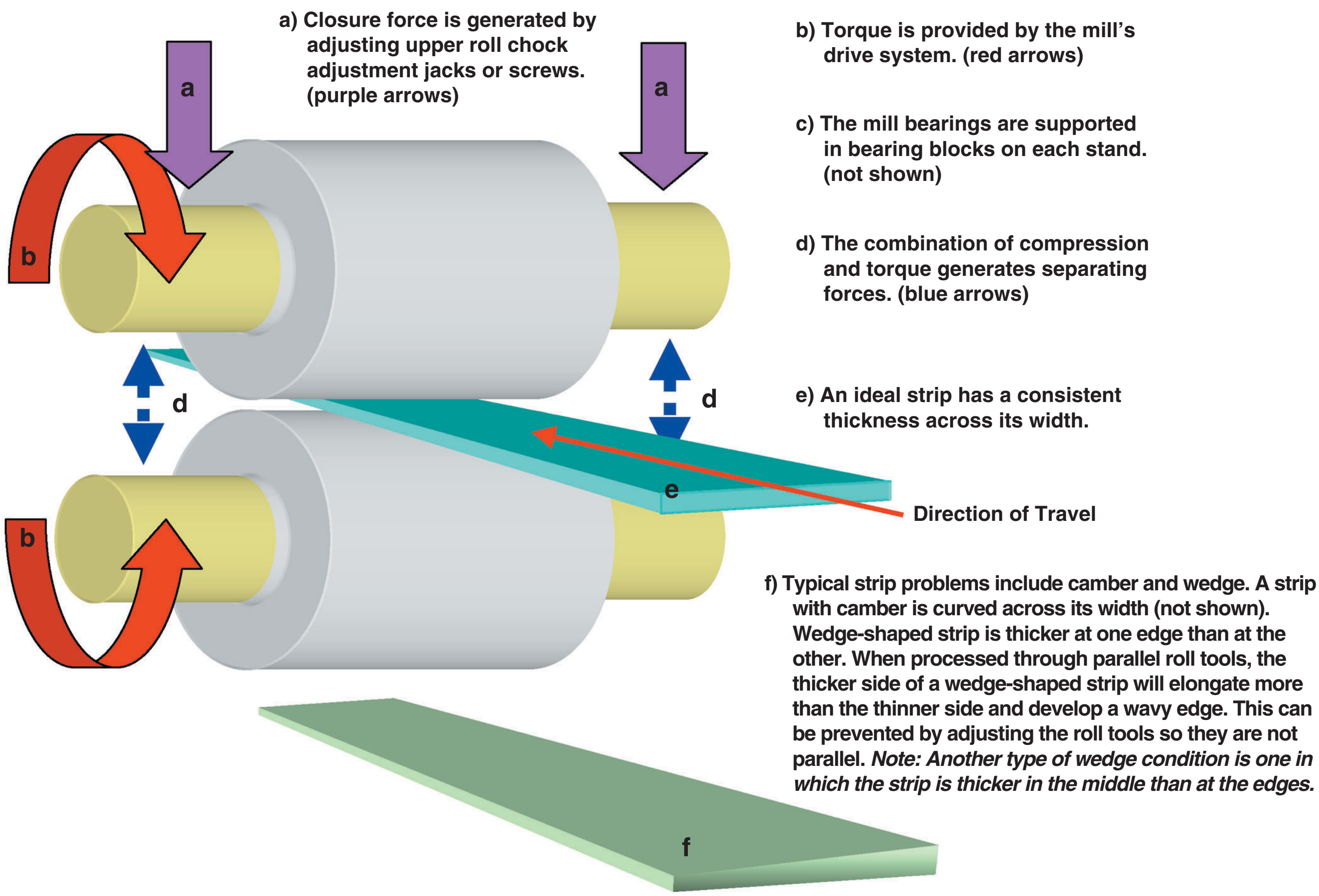


Figure 1

which is transferred through a gear train to the rolls mounted on the tube mill roll shafts. The tube forming process has three simultaneous frictional conditions: forward slippage (drag, or slowing of forward motion), reverse slippage (push, or excess speed), and no slippage (in other words, the speeds match.) This situation is called *roll fight*. Even though all driven rolls rotate in the same direction and at calculated ratios to one another, the material passing through them is not driven at the same drive radius and therefore is pulled by one pair of rolls only to be braked by the next. This spasmodic motion imparts compression and stretch, also known as *stuff* and *stretch*, to the section, which results in strip edge ripples and undulations that make quality welding nearly impossible.

When the resistance to forming is too high and the drive friction too low, the rolls simply spin, or the drive stalls, leaving the material motionless. This could happen when switching from conventional hot-rolled material to pickled-and-oiled or prepainted material; when the new material yield strength exceeds the mill's capabilities; when the girth reduction is too high; or when the speed of a pass is significantly slower or faster than that of its predecessor, resulting in stuff or stretch.

While many types of drive arrangements are used in tube mills, from simple (such as a single-motor setup in which one motor runs the entire mill) to elaborate (such as a system in which individual motors power each driven shaft), this article focuses on universally applicable methods of overcoming the problems associated with too much or too little tension, which can affect any type of mill.

Improper Tension Leads to Improperly Formed Tube

Too much or too little tension can cause any of the five following problems in welded tube production:

1. Problems in handling typical strip shortcomings, such as camber or wedge.

2. Improper strip edge motion that produces poor welds. Pushing the material through the weld squeeze rolls, rather than pulling the material through them, can exaggerate strip shape problems.

3. Folded tube sections in the cooling zone. Too little tension developed by the sizing passes can cause the tube to buckle in the cooling trough.

4. Nonuniform wall thickness in finished tube sections. Too little tension or nonuniform tension leads to stuff, which causes an increase in wall thickness, instead of the more desirable stretch condition in the final sizing passes.

5. Poor overall production speed. Conditions 1 through 4 all contribute to limiting mill speed because as speed increases, stuff and stretch conditions become more erratic.

Wedge and Camber. Sound welds result from bringing the strip edges together so they are at the same height (as seen by looking horizontally across the top of the tube) and parallel to each other (face to face). When strip edges are not in this perfect alignment weld quality suffers, regardless of the welding method.

We know without any doubt every tube mill is fed perfect material–the perfect slit width and gauge, with no camber and no wedge. In addition, each coil is identical to the next in terms of finish characteristics and physical properties such as yield strength and tensile strength. Oops! That was a perfect-world scenario. In the real world of tube and pipe production, the raw material does vary in all of these properties even when it comes from a single supplier. Most tube and pipe producers must work with material not only of different lots but also from different suppliers and different alloys.

Even with a perfectly aligned mill and perfect roll tools and setup, the material might exhibit wedge (see **Figure 1**) or camber, which is curvature across the width of the strip. The tube mill must overcome these faults to achieve a sound weld and suitably finished tube. The limitations for this capability are driven by the mill arrangement, adjustment, and design reduction percentage in the fin passes.

Improper Strip Edge Motions. Strip edge motions such as breathing (opening and closing), rippling, or undulating immediately in front of the weld forge rolls prevent the strip edges from coming together in good alignment. These motions can result from worn rolls, misaligned roll shafts, a poor tooling setup, or mechanical limitations, such as having the transmission in the wrong gear or having insufficient horsepower for the job. When these problems are eliminated, the only ones left are frictional and tension irregularities upstream of the weld forge point.

Managing Wedge, Camber, and Improper Strip Edge Motions. There is no capability in a traditionally designed tube mill to change wedge conditions in the strip. However, the stretch capabilities provided by the fin passes provide a way to reduce both camber- and wedge-induced strip edge deformation to manageable levels. In fact, the fin passes are the only zone in the tube mill where the entire cross section of the strip can be brought to yield before the edges are welded together. Attempting to correct for camber or wedge in the breakdown section only compounds the problem.

The fin passes must provide stretch between the last breakdown pass and the first fin pass and between fin passes to eliminate the effect of camber and wedge. When the material properly fills out the fin passes and the appropriate tension is provided, the length of the fibers along the long axis of the section

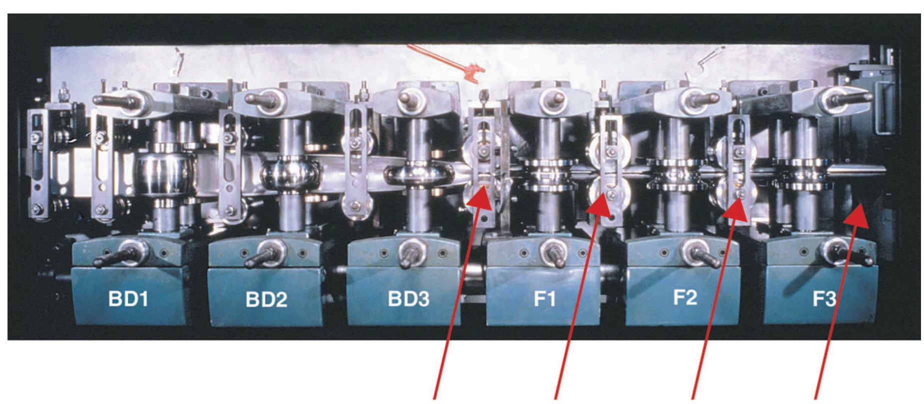


Figure 2

Determine the strip speed between the last breakdown pass and the first fin pass. It may be necessary to temporarily remove the idler stand and rolls. Also measure the strip speed between each fin and pass and between the last fin pass and the weld box. Caution: Stay away from the induction coil. Measure the speed between the sizing passes also.

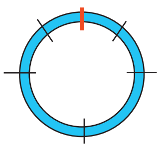
Wall Thickness vs. Process Speed Changes

Girth Calculation % Change (Inches)

Tube OD	4.500	OD Cir.	14.1372	
Tube Wall	0.248			
Wall Thickness / Growth Ratio	33.3%	Thickness	66.7%	Length
Suggested Reduction Per Pass	0.020			
Entering Strip Width	14.045	Skelp Mass	3.4832	Sq. In.
Forming / Welding Speed	78.0	FPM		

Evalutaion of Final Sizing: Wall thickness should be uniform about the circumference for proper Roundness and Straightness control.

Finished Tube Wall



Sample 1			Sample 2			Sample 3		
11:00	Weld	1:00	11:00	Weld	1:00	11:00	Weld	1:00
0.252	0.258	0.248	0.252	0.257	0.249	0.252	0.249	0.250
9:00	6:00	3:00	9:00	6:00	3:00	9:00	6:00	0:00
0.249	0.252	0.250	0.252	0.250	0.248	0.248	0.251	0.251

Tube OD Pi Tape	
Samp 1	4.535
Samp 2	4.530
Samp 3	4.538
Average OD	4.534

Sample 1 Average: 0.2515

Sample 2 Average: 0.2513

Sample 3 Average: 0.2502

Average Wall Thickness: 0.2510

Average Tube ID: 4.033

Tube Mass of Section: 3.3781 Sq. In. (0.7854(D^2 - d^2))

Theoretical Exit Speed: 80.2 FPM

Instructions:
Fill in the green cells with the indicated information. The results of calculations are shown in the yellow cells.

Theoretical Exit Speed = (Skelp Cross Section - (Weld Girth Reduction x Entry Thickness)) x Entry Speed / Average Exit Cross Section

(3.4832 - (0.031 x 0.248)) x 78 / 3.3781 = 80.249

Figure 3

Make a table like this one and fill in the green cells with the indicated information. The results from the calculations are shown in the yellow cells.

may be stretched so they are all approximately the same. When the fibers are of a uniform length and passline heights (bottom line or centerline depending on your mill and tooling arrangement) are maintained, breathing and undulating are eliminated.

A mill's capability to deal with camber- and wedge-associated problems increases with:

• A larger number of forming (breakdown or fin) passes. More breakdown passes provide both progressive bending over a longer distance and more drag for the fin passes to pull against. More fin passes provide more opportunity to correct irregularities caused by camber.

• A larger percentage of total girth reduction.

• A greater speed differential between breakdown and fin passes and from fin pass to fin pass.

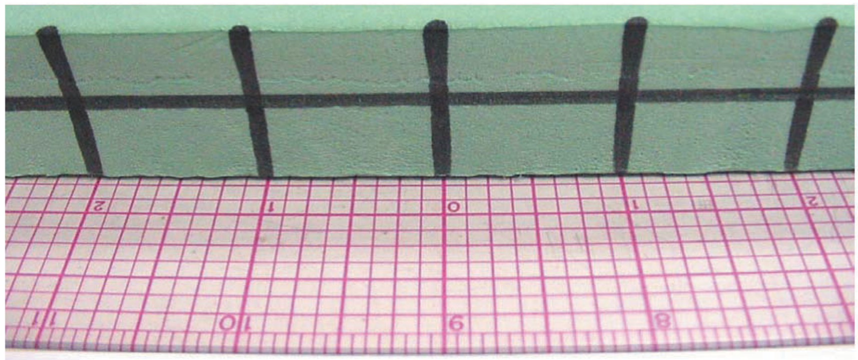
• Increasing the tension exerted by the sizing section through the weld box back to the last fin pass.

Several strategies can help to overcome breathing, rippling or undulating immediately in front of the weld rolls:

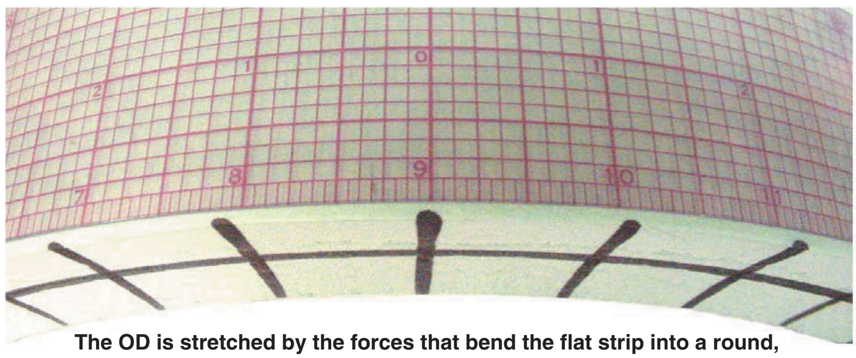
1. Inspect the slit width of the incoming material to ensure that it is proper for the tube being produced. Verify that the slit width variation falls within company standards. Strip widths wider than necessary overload the mill and are more likely to incur edge damage from the breakdown passes. Strip width that is too narrow does not provide sufficient material to fill out the fin passes and thereby reduces their ability to achieve the desired reduction and desirable line tension.

2. Inspect the coil payoff to ensure strip is entering on mill centerline. If the line has a strip accumulator, ensure that the detwist zone has at least one foot of travel distance for every inch of strip width and that the center guide on the last (horizontal orientation) strip stand is used to keep the strip on centerline. A passline change is acceptable as long as the strip is not bent into a radius small enough to permanently set the material.

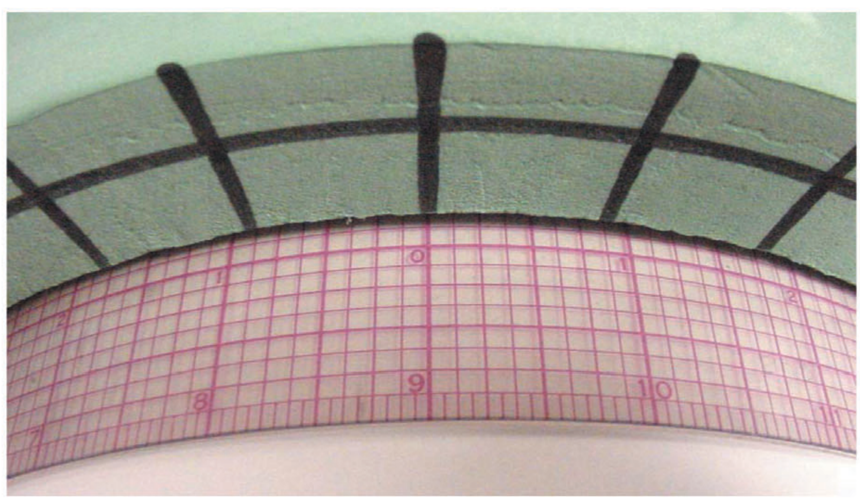
Elongation and Compression During Tube Forming



Before entering a tube mill, the incoming strip's upper and lower edges are the same length. This is the leading edge of a strip that is marked every inch.



The OD is stretched by the forces that bend the flat strip into a round, tubular shape. The OD marks now are more than one inch apart.



The ID is compressed by the same forces that stretched the OD. The ID marks now are more than one inch apart.

3. Inspect and align the entry guide to ensure that strip is aligned with the centerline of the No. 1 breakdown stand.

4. Inspect the passline height for the strip from the first breakdown through the weld box. For most small mills this height (from the mill base to the bottom of the tube belly) will be identical from pass to pass. Small up and down passline changes can stretch or compress strip edge zones so they become uneven and thereby create the condition we are attempting to correct. On larger pipe mills with downhill forming you must ensure that the passline change is uniform and suitable for the mill (horizontal centers) and roll tool design.

5. Ensure that the breakdown passes do not change any observed wedge conditions. The mill should form, but not thin, the material in the breakdown zone. Thinning increases the length of the affected strip zone and creates the ripple condition we are attempting to reduce.

If your setup is thinning the thicker edge more than 0.001 in., increase the roll flange gaps to eliminate the problem. Be sure that roll shafts remain parallel because the wedge condition for the opposite slit mult (a coil slit from the opposite side of the master coil centerline) will be reversed.

Achieve the maximum girth growth in the breakdown zone your mill arrangement and tooling will permit without thinning the strip edges or belly (centerline zone).

6. Verify the physical properties (yield strength, tensile strength, and percent of elongation) for the material are proper for the end use. If the material being processed is highly variable, your only choice (other than changing roll tooling) is to increase the slit width so sufficient girth reduction will occur in the fin passes to overcome the maximum strength material the mill will process.

7. Measure the strip speed from the bottom of the open profile between the last breakdown pass and the first fin pass, between each fin pass, and between the last fin pass and the weld squeeze rolls. (see **Figure 2**). Look for a positive change in strip speed from these measurements. A decrease in strip speed may be caused by undesired friction, which you can reduce by properly applying mill coolant, disconnecting roll shafts from their dri-

ves to reduce roll fight (generally the top rolls in the breakdown passes), changing the ratio of the mechanical coupling to the roll shaft (on single-motor mills), adjusting the drive motors electrically to provide the desired tension between stands (on multimotor mills), and adjusting the stepup in the roll tooling to achieve progressive root diameter increases at each pass.

8. View the forming zone (breakdown and fin passes) from above, looking for abrupt changes in material flow. Eliminate, as much as possible, any abrupt changes in shape by adjusting the side idlers. Flange wipe can lead to pickup (deposition of strip material on the rolls caused by excessive pressure) and create slip/stick conditions that result in retardation of strip speed or intermittent drag conditions that affect weld quality. Figure 2 shows a smooth progression.

Causes of Folded Tube, Nonuniform Wall Thickness, and Improper Production Speed. After the breakdown bending passes, any tube forming troubles can be lumped into one category: mass flow problems that result from uncontrolled tension conditions. Proper tension control is mandatory for optimum welding regardless of the breakdown tool design or welding process.

Foldup in the cooling zone can result from a lack of sufficient friction to transmit the torque available. This condition occurs in mills that perform reshaping in the sizing passes and most often is a result of reshaping in the horizontal plane rather than 45 degrees from horizontal. Foldup can occur anytime the sizing section runs slower than the fin passes.

Wall thickness control in the sizing passes is directly related to proper tension control between the sizing passes. When improper tension is applied, walls thicken and the welding process suffers. Sizing is a volumetric process in which only the outside diameter is controlled by the roll tooling and wall thickness controlled only by the application of tension between the sizing passes.

Don't let the name of the process fool you. The *volume* of material doesn't change; cold working *displaces* the material and lengthens the tube. This is related to the difference in speeds among the roll tooling. If the strip went into the mill and a tube of the same length came out the other end, all of the roll tooling would rotate at the same speed. But this isn't the case. The material's length changes, so some roll tools run faster than other roll tools.

Managing Wall Thickness Consistency and Mill Speed. Finding the proper mill speed will help reduce stuff and stretch, which helps improve wall thickness consistency.

a. Volumetric changes occur between the fin passes and between the individual sizing passes. Simple measurement of diameter by micrometer or caliper is not sufficient to determine what really is going on. A girth measuring tape is necessary to generate useful information on the reductions achieved in the various tension zones. Only a girth measuring tape can accurately measure nonround tube (and remember that there is no such thing as perfectly round welded tube) and convert it to an equivalent round profile for a true reduction measurement. Watch for consistent, uniform reduction patterns.

Refer to "Measuring tube as it grows and shrinks" in the July/August issue of *TPJ*, page 56, for information on the use of girth measuring tapes and how to convert the readings to usable information.

b. Use the girth measuring tape readings to set the roll gaps (not the flange gaps) to adjust for the wear that constantly occurs in the normal life of roll tooling between regrinds.

c. Use girth measuring tape readings to adjust for material physical property changes. Chart the results to make setups easier and thereby improve weld quality.

d. Because the true achieved speed between the fin and sizing passes is difficult to observe, take direct measurements, with the mill in operation, using a digital handheld tachometer that can record peak feet per minute readings. In cases where the horizontal centers are too close or there is danger of entrapment, use an external, noncontact laser Doppler gauge to record the strip speed. Chart your results for future setup adjustment. Look for a consistent velocity increase from one pass to the next. We need to see sufficient tension between the fin passes to eliminate the effect that camber introduces. This means about 1 to 1.5 percent total girth reduction at a maximum in the fin passes.

e. Collect samples between the problem passes and measure the tube wall thickness variation at 1-, 3-, 6-, 9- and 11 o'clock positions so you can chart a true picture of the achieved wall thickness growth. The goal to shoot for should be to limit wall thickening to approximately one-third to one-half the volumetric change between passes by setting the tension to achieve the necessary speed increase to absorb the remaining mass in length growth.

Use a table like the one shown in **Figure 3** to find the right speed.

f. Verify section elongation by scribing pairs of lines (the distance between lines is dictated by the horizontal centers for your mill) on the tube section in front of the sizing mill (see **Figure 4**). Jog the marked section through each sizing pass and measure the stretch between each stand to verify that the setup is correct. When the setup is correct you should observe a progressive stretch between passes proportional to the reduction in the sizing. See the illustration for a similar comparison. This one shows a 2.8 percent speed increase to compensate for the volumetric changes.

Getting the Tension Just Right

Many variables contribute to tension and friction. It's impossible to deal with all of the possible causes at once, so it's necessary to eliminate each of them one at a time. Do not assume the strip has the proper width, tensile strength, or yield strength. Do not assume the mill tooling is aligned. After verifying strip characteristics and the mill tooling alignment, move to the other possible trouble areas. And don't forget that if an adjustment or change accomplishes nothing, return the item it to its original setting before attempting the next adjustment. Finally, record everything. Records make solving the problem the next time easier.

Candymakers didn't always want the right amount of tension. They realized an occasional disaster was good for business because it brought customers to the booth. The tangled mess was part of the show! They sold more candy when it happened and before long it became a scheduled event several times a day.

Tube producers can't afford to do this. Steel costs more than sugar, and mill downtime costs even more. Use the troubleshooting strategies herein and you'll get the right amount of tension and a smooth-running line.

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