

Vacuum Tension Rolls: How They Work & Where to Use Them

By Lee Fennema, Webex, Inc.

Introduction

Vacuum rolls are relatively simple devices with very beneficial characteristics. The use of vacuum rolls is growing with increases in line speeds, quality levels, and safety awareness. Traditional applications include moving a web between coater and dryer and facilitating high speed line operation, but an interesting variety of other uses are possible as well. Two related products, vacuum belts and vacuum chill rolls, have additional unique characteristics that can be quite valuable in certain situations.

Description and Terminology

There are many ways to design a vacuum roll. The essential elements are a rotating shell through which air can pass, and a way to evacuate the inside of the shell. In addition, it is usually desirable for noise, efficiency, and functional reasons to establish a vacuum zone that approximates the area of the roll which is wrapped by the web.

Terminology

Figure 1 shows a typical vacuum roll, highlighting key components. In this case the shell is driven and rotates around a stationary center-tube which serves to evacuate a vacuum zone. Figure 2 shows the stationary vacuum zone that is established within the shell. The vacuum zone angle is a little less than the web wrap angle to help ensure that the web wrap is correctly maintained. Similarly, along the width of the web the vacuum zone is a little less than the web width. Figure 2 also shows the forces at work on the roll, which will be discussed later.

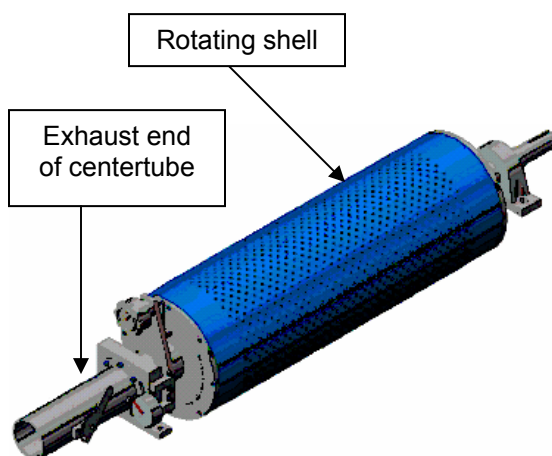


Figure 1

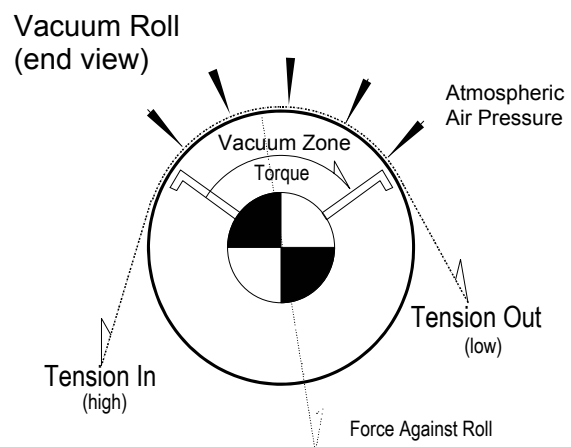


Figure 2

Shell

The shell may be made of a porous material, or by using porous inserts in a steel shell. Special concerns for this approach are the typically higher vacuum requirements and a tendency for porous material to gradually plug up with dirt.

More often the shell is steel, or possibly aluminum or cast bronze, with a large number of holes drilled to allow the passage of air, as seen in Photograph 1. A composite shell may be preferred for its lower inertia if, for example, the vacuum roll is on a moving assembly. As discussed later, a variety of coatings and coverings may also be used on the shell.

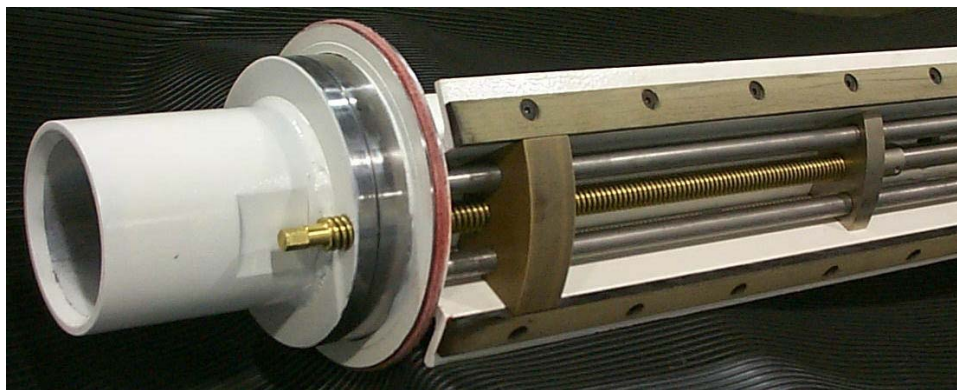


Photograph 1

Evacuation

A blower is used to remove air from the shell, but unless mounted within the shell it needs a way to communicate with the inside of the shell. The two complications in accomplishing that are the shell's rotation and the vacuum zone. A variety of schemes are used including rotary unions, special porting systems built into the end covers of the shells, and stationary center-tubes that also serve as shafts inside the shell.

Assuming a vacuum zone is to be established, it is set just a bit smaller than the area wrapped by the web. Generally, the wrap angle is fixed, although even this may need to vary if multiple web paths are needed. When web width varies, it is helpful to have adjustable width decking of the vacuum zone, rather than "taping off" the unneeded holes in the shell as some users do. See Photograph 2 for one common means of changing internal decking to match web width.



Photograph 2

How Does a Vacuum Roll Work?

In simplistic terms, a vacuum roll pulls a web down onto the roll with sufficient force to create good traction between web and roll. But how does that really work?

As with standard rolls, the normal force of the web against the roll results in frictional forces that oppose web slippage. In vacuum roll operation, the normal force has two components.

The first component is the resultant force produced by web tension, as with a simple roll. This part of the normal force depends on Tension In and Tension Out.

The second component of normal force is produced by the pressure difference between the atmosphere and the vacuum at the interface between web and roll. This second component is by far the larger part of the normal force for most vacuum rolls. Furthermore, the normal force component produced by the pressure difference does not depend on web Tension In or Tension Out.

How can the normal force from pressure difference be maximized? Taking atmospheric pressure as a given, the objective is to minimize pressure between the web and the shell of the roll. The enemy in this case is boundary air, dragged in by the surfaces of both the moving web and the rotating shell. This air needs a means and motivation to escape.

1. Vacuum level is important. The lower the pressure inside the vacuum roll, the more likely air will move away from the web-shell interface into the evacuated interior of the roll.
2. An escape path for the air is also necessary. The shell holes are the obvious portion of the path, and more holes per unit area make the escape path shorter. But the air also needs a good way to reach the holes. Grooves running from hole to hole are one way to accomplish this. A bumpy surface, which provides gaps for some air movement between web and shell, is another approach. A wire mesh over the shell is yet another way to “spread” the vacuum.

The normal forces, made up of a large component due to pressure difference and a smaller component due to web tension, produce frictional forces that oppose web slippage. The actual forces that result will also depend on the coefficient of friction between the web and the shell surface.

What Are the Useful Characteristics of Vacuum Rolls?

Five characteristics of vacuum rolls may be useful, depending on the application.

1. It is inherent in the design of a vacuum roll that it only touches the web on one side.

2. A vacuum roll can sustain larger tension differentials than other technologies that perform a similar function. Large normal forces are developed via pressure differential to greatly increase friction between web and roll.
3. Similarly, a smaller wrap angle can be used to reach a required tension differential than would be required with competing technologies.
4. Extremely low tensions are not a problem for vacuum rolls since the normal force from differential pressure does not depend on tension.
5. Vacuum rolls can remove boundary air even at high line speeds. A well-designed vacuum roll facilitates rapid removal of air from the interface between web and roll.

Where and Why Should Vacuum Rolls Be Used?

The two basic functions of a vacuum roll are tension isolation, by sustaining a tension differential, and web metering. While both of those functions can be accomplished in other ways, using a vacuum roll allows the designer to take advantage of one or more of the desirable characteristics listed in the previous section.

Following are some practical ways in which machine designers and users have chosen to apply vacuum rolls.

1. Transporting Wet Webs – This takes advantage of single side contact, and is a traditional application for vacuum rolls. In this case, a nip roll or “S” wrap simply cannot be used because the web is wet on one side. Photograph 3 shows a vacuum roll located between coater and dryer.



Photograph 3

2. Replacing Nip Rolls – While initially a bit more expensive, vacuum rolls have nonetheless proven popular as replacements for nip rolls. Vacuum devices may be considered more desirable for one or more of the following reasons.
 - Safety is improved by eliminating nips, a potential source of injuries. This factor alone has led some web processors to specify vacuum rolls wherever possible.
 - Scrap is reduced by preventing scratches, imprints, wrinkles, and slippage caused by nip rolls.

- Operator time is saved by eliminating nip adjustment for web thickness, providing better access for web threading, and avoiding the need to manually close nips before starting a line.

3. Replacing Other Pull Rolls

- Improved line layout may be possible because less wrap angle is required than for other technologies. Care must be taken, however, to ensure sufficient tension differential for the application.
- Higher line speeds are possible due to removal of boundary air that otherwise may cause a pull roll to lose traction.

4. Handling Lightweight Film – Moving light weight film through a coating line is very challenging with traditional driven rolls. The positive grip and control of a vacuum roll, even at very low tensions, helps minimize stretching and web breaks. In this application, a helically seamed mesh covering may be used to prevent web deformation by the shell holes. For especially sensitive webs a seamless screen can also be employed.

5. Controlling Tension in a Floatation Dryer – Achieving low tensions through a floatation dryer is another traditional application for vacuum rolls, shown in Figure 3. A typical layout would have vacuum rolls before and after the dryer to isolate tension. Less frequently, a vacuum roll may be placed between dryer zones to help stabilize and guide the web.

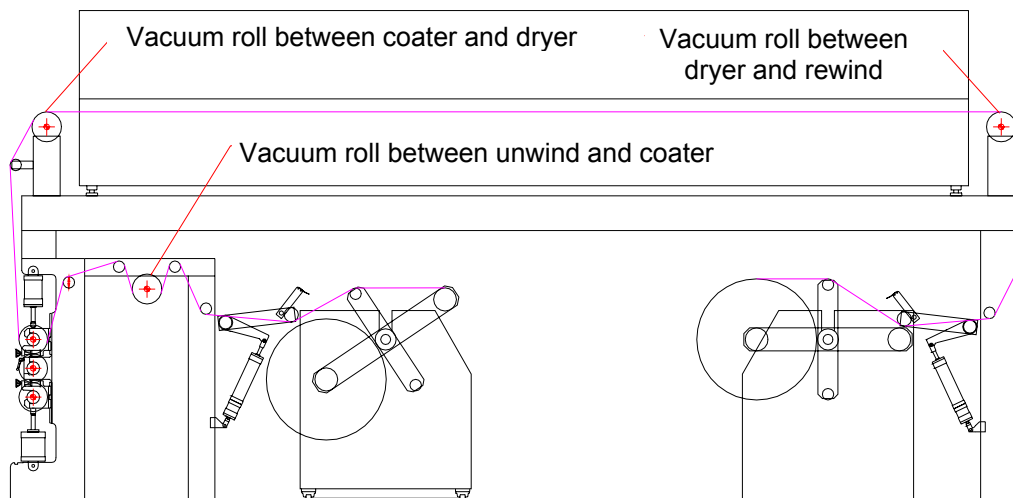


Figure 3

6. Guiding Webs – Gaining popularity is the use of vacuum rolls as part of a web guide. This takes advantage of the vacuum roll's ability to keep a good grip on the web even as path adjustments are being made by the guide. At the same time, the vacuum roll can replace a nip roll or "S" wrap.

7. Dealing with Web Breaks – When a web break occurs, vacuum rolls remain functional. At a minimum, this can keep most of the web in place so less threading is required to restart the line. In more sophisticated applications, a vacuum roll can be used to initiate an alternate path when a web break is detected.

8. Releasing Web from a Tenter Frame – The ability of a vacuum roll to provide a very low tension on the inlet side makes it ideal for controlling web tension at a tenter chain release point. The web is stabilized for edge trimming and tension upsets are prevented from traveling upstream. See Figure 4.

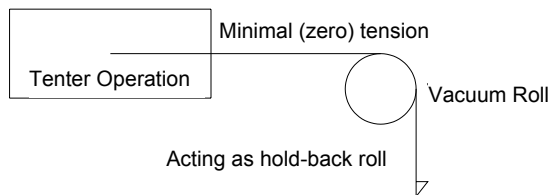


Figure 4

The remaining examples fall into the web metering category. The emphasis is on the ability of a vacuum roll to prevent slippage while measuring out a desired length of web and feeding it into a process step.

9. Implementing a Short-Term Loop Accumulator – Figure 5 shows two vacuum rolls being used to accumulate a length of web in the process lines, like bag production, may use a recurring start-stop operation. If the web can only be touched on one side, the vacuum rolls still allow a start-stop process section to be isolated from the balance of the line. The inlet vacuum roll continuously feeds into the loop, while the exit vacuum roll meters material into the process step intermittently. The reverse is done on the other side of the process step.

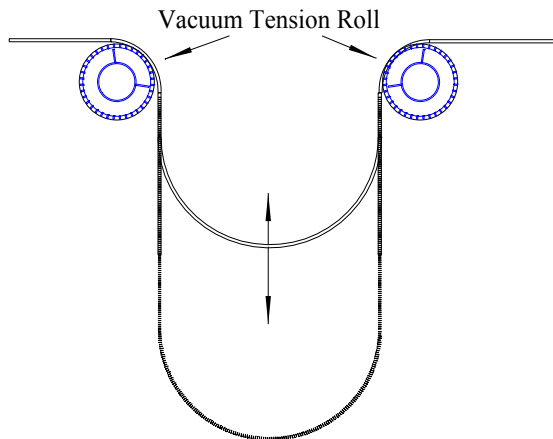


Figure 5

10. Establishing a Constant Loop – Process lines in which an abrasive or bulky material like sand or reflective particles is added to a web may use a constant loop. This allows excess material that did not adhere to be removed from or fall off the loop in a position below important machine components, reducing repairs.

11. Metering and Drawing a Web – Certain processes require both precision metering and a constant pull. Figure 6 shows a vacuum device metering the web, then holding it while another device pulls it with constant tension.

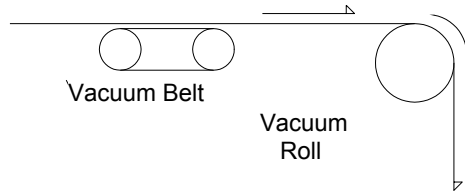


Figure 6

Vacuum Belts

Figure 7 depicts a vacuum belt, as does Photograph 4. As shown, a vacuum box is contained inside the belt. The box top is made of engineered plastic over which the belt can easily slide, and holes in the top communicate with holes in the belt. As air is removed from the web-belt interface, the web is pulled into close contact with the belt surface.

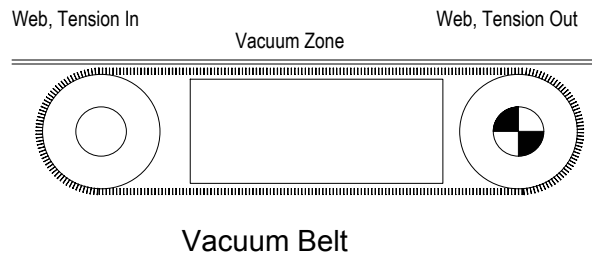
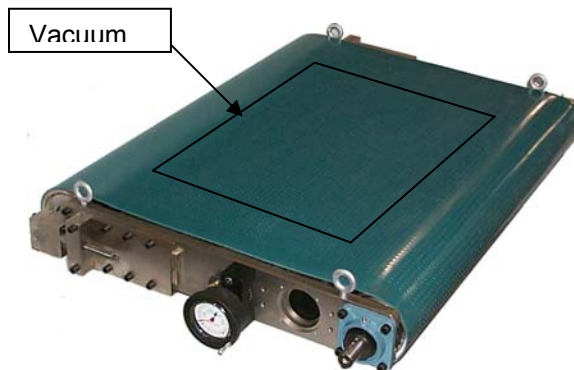


Figure 7



Photograph 4

As with a vacuum roll, the normal force of interest is caused by the air pressure differential. The belt surface may be rubber to provide a good coefficient of friction so that the normal forces cause frictional forces that oppose web slippage. Width decking of the vacuum box is helpful if multiple web widths will be run.

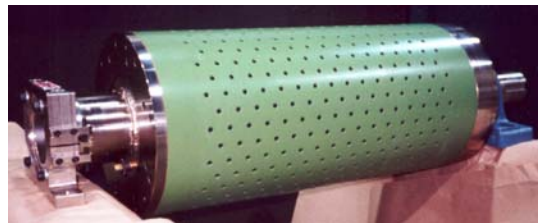
The key characteristics of a vacuum belt are that it can accommodate a near-zero wrap angle and it can be stretched lengthwise to increase the tension differential that can be sustained.

The most obvious benefit of a vacuum belt is that it gives new flexibility to machine designers in establishing a web path and tension zones because of the near-zero wrap angle required. Experimental use has also been made of vacuum belts for drawing a coating further into a substrate.

On a cautionary note, the belt should be considered a wear item and access to the unit will be needed in order to change the belt when needed. The belt can be designed for replacement without removing the unit by using hidden laces or cold or hot belt lamination.

Vacuum Chill Rolls

Photograph 5 shows a vacuum chill roll, which provides the benefits of a vacuum roll and also allows heating or chilling of the substrate. In this design, a rotary union is used to communicate with channels through the shell, so that heated or chilled fluid can be circulated. Since the web is pulled into intimate contact with the roll, the heat transfer is more effective than with a chill roll for a given wrap angle.



Photograph 5

An ideal location for a vacuum chill roll is at the end of a dryer as part of a web guide. The unit can then be used for tension control, web guiding, and initial cooling of the web.

Design Considerations

Vacuum roll manufacturers generally take on the burden of doing all needed calculations and applying experience to arrive at a suitable vacuum roll specification. The machinery builder or user will need to provide the manufacturer with the following parameters.

1. Maximum and minimum web width
2. Wrap angle
3. Substrate types and thicknesses
4. Line speed
5. Tension and tension differential ranges
6. Orientation of the center of the vacuum zone
7. Operating environment, including web temperature, air temperature, explosion-proof requirements, clean room considerations, elevation, and electrical power available

In addition, any special considerations with regard to the substrate, how the roll is to be driven, where it is to be mounted, or locations of adjustments or connections should be discussed. For vacuum chill rolls, details of the required heat transfer will also be required.

With that information in hand, the vacuum roll manufacturer can respond with a quotation including specifications for the vacuum device. A vacuum system comprised of an exhaust connection from the roll, a vacuum gauge, an airflow control valve, the necessary tubing, and a blower, can also be specified.

Examples:

Vacuum Roll

Customer Requirements	
Mounting	Drive outside of frame
Web wrap angle	30 degrees
Web width range	57" to 62"
Web thickness range	4 mils to 10 mils
Web material	Paper
Maximum line speed	1000 fpm
Web tension	75 to 120 lbs
Hazardous environment	Yes
Recommended Vacuum Roll	
Nominal diameter	12.75"
Face width	68"
Vacuum zone width	Fixed at 55"
Vacuum zone angle	Fixed at 20 degrees
Shell holes	Staggered pattern of 3/16" diameter holes
Roll temperature not to exceed	140F
Tension differential	0.75 PLI
Blower requirement	315 CFM @ 44" W.G.
Roll surface	Tungsten carbide traction / release

Vacuum Chill Roll

Only the information pertinent to providing sufficient heat transfer for the application is shown here.

Customer Requirements	
Web wrap angle	90 degrees
Web width	24"
Web weight	40 lbs paper
Ream size	3000 sq. ft.
Maximum line speed	500 fpm
Specific heat	0.35 BTU / lbs-ft-°F
Incoming web temperature	180F
Outgoing web temperature	90F
Water inlet temperature	55F
Coefficient of heat transfer	150
Recommended Vacuum Chill Roll	
Nominal diameter	13.75"
Face width	31.5"
Vacuum zone width	Fixed at 20"
Vacuum zone angle	Fixed at 80 degrees
Shell holes	Staggered pattern of 3/16" diameter holes
Water flow rate	20 gpm
Water pressure drop	20 psi
Chiller size requirement	2.1 T
Roll surface	Chrome

Conclusion

Designers have chosen to use vacuum devices in a wide variety of ways in web processing lines. The key to creative application is an understanding of the unique characteristics of vacuum rolls, belts, and chill rolls. While vacuum rolls have a long history, machine designers and users continue to find new ways to use them.