Vacuum Pull Rolls
Design and Applications

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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.

There are many ways to design a vacuum roll. The critical component and design criteria of the vacuum roll are:

1. Rotating shell through which air can pass.
2. A method to evacuate the inside of the shell.

In addition, it is usually desirable for noise, efficiency, and functional reasons to establish a vacuum zone. The vacuum zone is the area of the roll that is determined by the web width and wrap angle. A typical vacuum roll (Figure 1) highlights the items mentioned above. In this case, the shell is driven and rotates around a stationary centertube which is connected to an exhaust elbow and 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 1 – Critical components
Figure 2-Vacuum zone angle

Figure 3 locates several of the components and their location on the vacuum pull roll.

Figure 3 – Identification of vacuum roll parts

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.

The most common material for the shell is mild steel. It is possible to manufacture the shell from other materials, such as, aluminum, cast bronze, stainless steel or composite, in lower inertia applications. The shell has a means of air flow, most commonly a drilled hole pattern. (Figure 4) As discussed later, a variety of coatings and coverings may also be used on the shell.
To create a vacuum a blower is used to remove air from the shell. Unless mounted within the shell the blower needs a way evacuate the inside of the shell. Due to the fact that the shell is rotating and an established vacuum zone needs to be maintained there are a variety of solutions to the evacuation problem. A variety designs including rotary unions, special porting systems built into the end covers of the shells, and stationary centertubes are used to accomplish this evacuation. Illustrated in Figure 5, a centertube configuration with adjustable deckles (for adjusting the length of the vacuum zone) is shown.

When designing the vacuum roll it is important to establish a vacuum zone. The vacuum zone area is based on the wrap angle and web width. It is sized to be slightly smaller than the maximum wrap angle and web width so a good contact seal is made between the material and the roll. Typically, the wrap angle is fixed. If the web width
varies, it is helpful to have adjustable width deckling of the vacuum zone. This allows the zone to be adjusted as material widths change.

A vacuum roll pulls a web down onto the roll with sufficient force to create good traction between web and roll. 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. This part of the normal force depends on Tension In and Tension Out. (Figure 6)

![Figure 6 - Resultant Force diagram](image)

\[ \frac{Th}{Tl} = e^{\mu \Theta} \]

Figure 6 – Resultant Force diagram

Th – Higher Tension Zone (any units)
Tl– Lower Tension Zone (same units)
e – Base of Natural Logarithm (~2.718)
\( \mu \) - Coefficient of Friction
\( \Theta \) - Wrap Angle (Radians)

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. 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. Five characteristics of vacuum rolls may be useful, depending on the application. It is inherent in the design of a vacuum roll that it only touches the web on one side. 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. Similarly, a smaller wrap angle can be used to reach a required tension differential than would be required with competing technologies. Extremely low tensions are not a problem for vacuum rolls since the normal force from differential pressure does not depend on tension. 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.

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.

![Figure 7 – Wet Web Transportation](image)

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 lightweight 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 8. 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 8 – Floatation Dryer](image)

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 9.

![Figure 9 – Tenter Frame](image)

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 10 shows two vacuum rolls being used to accumulate a length of web. Some 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 10 – Accumulation Loop](image)

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.
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. While vacuum rolls have a long history, machine designers and users continue to find new ways to use them to improve their processes.