Rolling Diaphragm Seals Stay Strong Under Pressure

Diaphragm seals use a clever principle to form a frictionless leak-proof seal

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OCT 07, 1999

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When pneumatic or hydraulic pistons repeatedly slide inside of cylinders, they rely on fluid power to transmit force. It's no secret that the total force couldn't be transmitted without a tight seal. But rough-and-tumble environments and heavy-duty applications can destroy most seals. And when designs require low friction, high cycling, or high fluid pressure, O-rings or die-cut seals simply don't hold up. In these situations, rolling diaphragms are often the only option. Unfortunately engineers may not know the advantages of rolling diaphragm seals or be aware of precautions to take when designing hydraulic or pneumatic systems that use them.

Rolling diaphragms are basically pressure vessels with a variable volume and flexible sidewalls. They move with almost no friction because the seal between the cylinder and piston is maintained by a rolling action rather than a sliding one. The seals are made of fabric-reinforced molded elastomers, making them tough and versatile. They also are less prone to leaking and hysteresis than other sealing methods, such as U-cups, O-rings, metal bellows, and die-cut diaphragms. Diaphragm seals can withstand pressures up to 6,000 psi over temperature ranges from –65 to 600°F. Plus, they need no maintenance or lubrication.

Diaphragm seals are used in industries that require high performance in harsh environments, such as the automotive, aerospace, medical, and food and water-processing industries. Advantages of rolling diaphragms include accurate, repeatable positioning, long stroke lengths, and no spring rate, which refers to forces caused by rubber trying to return to its molded position.

The center portion of the diaphragm fits over the top and part of the sides of the piston. The outer portion presses against the cylinder wall. A semicircular "convolution" in the diaphragm runs between the piston and cylinder wall. As the piston moves up and down, this convolution rolls with the piston. Mounting hardware tightens onto the flanged edge of the diaphragm. A variety of flange configurations are available depending on the application. Most diaphragms have an elastomer coating only on the high-pressure side (above the piston) and fabric on the low-pressure side (adjacent to the piston).

Rolling diaphragms withstand high pressures because of the way loads are distributed on them. Most of the diaphragm surface area contacts the piston head. This transmits the bulk of the load (a function of the fluid pressure) to the piston. The short, semicircular length of the diaphragm between the piston and cylinder wall, called the convolution, is the only part of the diaphragm carrying a load.

The convolution carries only a small portion of the load because fluid pressure is evenly distributed over the entire diaphragm and the convolution comprises a small portion of the diaphragm's total surface area.

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Lengthening diaphragm life

To maximize the life of diaphragm seals, designers need to know what problems to look out for. Common problems that lead to early failure include machining flaws, abrasion against piston hardware, back-pressure, and circumferential compression.
It's obvious that a metal barb from a carelessly machined piston or cylinder will tear apart even the toughest diaphragm in a few cycles. But even small burrs or slightly sharp edges that repeatedly contact the diaphragm will rapidly tear the material.

Improperly finished hardware can also wear away at diaphragms. When pressure is constantly applied then relieved, the diaphragm rubs against supporting hardware. If the surface of the hardware is too rough, it can abrade the fabric and cause early failure. Hardware surfaces that contact the diaphragm generally should be no rougher than 32 μin. Higher cycling applications may require 16-μin. finishes.

Although diaphragms do not need lubrication, if abrasion is a concern, the diaphragms may be coated with molybdenum disulfide to reduce friction. Pistons may also be coated with Teflon, or with an elastomer. The elastomer will reduce abrasion by preventing the diaphragm from shifting.

Quick failure also occurs when the diaphragm sidewall contacts itself, locking the two rubber surfaces together while the piston continues to travel. This jams the sidewall between the piston and cylinder wall and tears the elastomer and fabric. This is usually caused by either backpressure or misaligned pistons.

Pistons normally stay centered at high pressures because the pressure is the same all around them. However, at low pressure, gravity can take over and pull the piston to one side. The piston then jams the sidewall into itself. This can be avoided with a bushing that keeps the piston centered throughout its stroke.

Backpressure also causes jammed sidewalls. Diaphragms are designed to support a high-pressure differential in one direction. If pressure becomes higher on the low-pressure side of the diaphragm, the sidewall collapses and the diaphragm jams and fails.

Because most diaphragms work within closed actuators, there must be a means to adjust for changes in fluid volumes above and below the diaphragm. Designers use vent holes for this. The holes must be sized so they allow enough fluid to pass through in the time it takes to stroke the diaphragm. Designers should be aware that this time changes when the device carries a higher load or cycles more rapidly.

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Circumferential compression is another cause of failure. This happens at the top of the diaphragm's stroke. Slack in the diaphragm sidewall bunches up around the piston and forms an axial fold in the sidewall. Repeated folding at the same location eventually breaks a thread and then ruptures the elastomer. Circumferential compression is often called "four cornering" because fibers in the support fabric are woven in a square pattern and folds occur at four-point patterns in the fabric.

Eventually, circumferential compression happens in all diaphragms, but there are a few ways to slow its onset. The first method is to only use the bottom half of the diaphragm's stroke so that only the top of the sidewall compresses around the piston. The top of the sidewall has the tightest fit around the piston so there will be less slack in this portion of the stroke. This will create folds that are not as sharp as they are at the top of the stroke.

A double-tapered diaphragm also reduces circumferential compression while letting the diaphragm travel through its full stroke. Sidewalls on standard "top-hat" diaphragms are parallel to the flange and piston radii. Double-tapered designs, however, have narrower diameters at the bottom of the sidewall. This reduces excess material in the area and relieves circumferential compression.

The same effect can be obtained by molding the diaphragm as an offset preconvoluted or involuted diaphragm in the full-up position. This puts the total amount of working sidewall at the piston circumference, virtually eliminating circumferential compression.

The final means of reducing circumferential compression is with a tapered piston, which simply increases the piston circumference as the sidewall circumference increases. This is the least desirable method because tapering the piston circumference decreases the effective pressure as pressure rises, and increases the effective pressure as pressure drops.

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