PUMPLETTER
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DESIGNING THE DIAPHRAGM

The Heart of AODD Pumps

When designing and developing original component, the opportunity presents itself to put as much forethought into what can be done to optimize items such as the part's cost or life expectancy. However, an engineer can achieve both goals by designing manufacturability. This achieves the most competitive part price for several reasons: improved scrap rate, lower capital tooling cost and the use of the most suitable materials. Bringing all of these concepts together will ultimately produce a superior diaphragm having the greatest life-cycle potential.

Several areas of importance would need to be discussed to offer a comprehensive guide to diaphragm design. In this Pumpletter we will focus on those areas most important to manufacturability: Flange Design, Bead Geometry, Height to Bore ratio and proper Material Selection.

Flange Design determines the success of the seal between diaphragm and hardware with couple of design options. One with a flat/gasketed flange which is more difficult to control the compression of the material when compared to beaded flange. Often, proper compression of flat-flanged parts can only be determined through trial and error while hardware design for beaded flanges is a quantifiable value; to maintain a good seal that hardware should produce 20% - 30% volumetric compression of the diaphragm's bead – higher compression will likely damage the part.

Although it does not incorporate the use of a bead, a flat flange may include a series of small, concentric V-Ribs (either on the hardware or on the diaphragm) to increase seal success. Molding V-Ribs on a flat flange typically does not affect the part manufacturability and eliminates many of the quality issues related to beaded diaphragm.

Bead Geometry is very important not only in the functionality it provides as a seal, but also in how complex the manufacturing process becomes. During molding, a poorly design bead increases the potential for quality problems such as trapped air or flow/knit lines that affect seal compression and increase the scrap percentage. Some designs also make the parts more difficult to trim increasing scrap or tooling costs.

Height to Bore Ratio describes the relationship between the diameters of the convolution base to the overall convolution height. Typically, this ratio is set at a maximum of 1:1. Although larger ratios have been achieved before, it becomes much more difficult and relies heavily on a specific fabric style (more on this point will be discussed with Material Selection). When determining the Height-to-Bore ratio, the engineer should also consider the resulting draft angle of the sidewall. Although there is no recommended minimum, the draft angle should be as large as the hardware will allow – this maximizes diaphragm life while minimizing manufacturing difficulty.

Material Selection often requires the knowledge and experience of the diaphragm supplier. Specifying the best choice of materials not only ensures the longest possible life of the diaphragms, but often unnecessary cost can be avoided by not overdesigning for the application.

The elastomer choice is critical when considering the environment in which the part will operate, and will often override considerations taken for manufacturability. Relevant elements include: chemical contact, abrasive hardware or medium, applied loads and health or federal regulations.

If conditions allow, the elastomer will be selected for manufacturability based on its flow characteristics, cure system/rate, gasket/fabric adhesion and the ease of cut (generally described by Durometer). Fabric choice can increase/decrease the difficulty involved in manufacturing the diaphragm. Knit fabrics are more difficult to predict because of the dissimilar stretch characteristics in each thread direction. For diaphragms with large height-to-bore ratios, a fabric with an open weave (larger thread spacing) must be used to allow the fabric threads to realign themselves when formed. The engineer should keep in mind that shaping fabric essentially forces an initially square structure into a round structure.

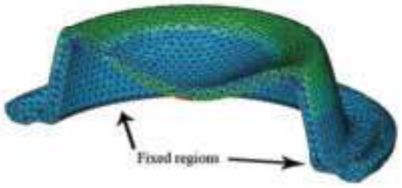
The burst strength of the fabric, environmental compatibility and abrasion resistance will also help to define viable options. As can be imagined, materials with the most capability and highest quality fetch the highest prices – thus selected materials should be capable of meeting only the necessary requirements.

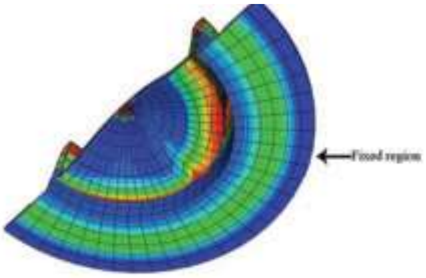
Taking advantage of the opportunity to properly design a diaphragm for manufacturability in the initial stages minimizes lead-time, decreases tooling costs, maximizes production efficiency and yields the highest quality product possible.

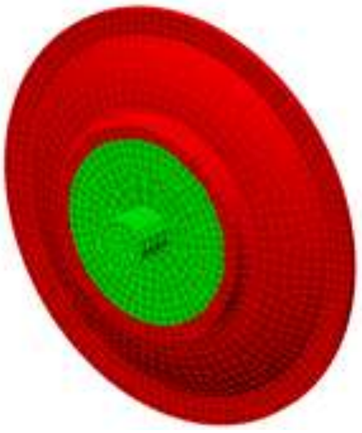
Initial Design Considerations

- Keep the convolution width as wide as safely possible.
- Provide enough space in the hardware to ensure smooth diaphragm movement.
- Whenever possible use a thinner and/or a more flexible material.
- Keep the stroke requirements as small as possible.

Neo-Flex Diaphragm Cross-Section







FABRIC REINFORCEMENT – A Skeletal System for Diaphragms

One of the most common questions in diaphragm design is at what pressure is fabric reinforcement required? The most common answer is that 5 PSI to 10 PSI in differential pressure is the threshold for requiring fabric in a diaphragm. In fact, the answer is not that simple. There are many areas of the application that must be considered before a true determination can be made.

First, we need to consider the role of the diaphragm in the proposed system. The diaphragm converts one type of energy into another. It will take pneumatic or hydraulic pressure and convert it into mechanical force to perform a task or, conversely, take a mechanical force and convert it into ether a pneumatic or hydraulic force. The pneumatic or hydraulic force will react with the weakest link in the system. If the diaphragm's ability to resist stretching is the weakest link, the diaphragm will simply blow-up like a balloon, absorbing all the energy put into the system instead of transferring it onto the piston.

Preventing Stretching with Fabric varies from compound to compound. It will also vary in the same formula from batch to batch due to mixing variations as well as thickness variations. A homogeneous diaphragm will also become stretched out over time due to pressure being applied repeatedly much like a balloon that has been blown-up and deflated many times. To inhibit this stretching, fabric is molded into the diaphragm with a layer of elastomer between it and a high pressure. When the pressure is applied to the diaphragm, the elastomer pushes against the fabric, which resist stretching, resulting in the force being transferred onto the piston and on down the line to the work to be done. Once fabric is introduced into the diaphragm, the role of the elastomer is reduced to plugging the holes in the fabric and sealing the flange. The fabric becomes the skeletal system for the diaphragm supplying all the strength to resist streaking and transferring the energy to the piston.

Fabric reinforced diaphragms comes in two types: Single Coat & Double Coat

- **Single Coat**
    - The single coated diaphragm has the elastomer on the high pressure side of the diaphragm and the fabric on the low pressure side
- **Double Coat**
    - The double coat has elastomer coating on both sides of the fabric.

Fabric, like elastomer, has to be in the correct environment with regards to heat, chemical resistance and strength. However, it also has to be able to be formed correctly into the geometry of the diaphragm. With research, an engineer will develop the criteria requiring the selection of a particular fabric for the application's environment. The ability to form a fabric, however, is a product of its weave.

When to design a Single Coat or Double Coat Diaphragm?

Elastomer is what is used to form a sealing barrier between the system pressure and the porous fabric enabling the diaphragm to convert the pressure into a mechanical force. Fabric is the reinforcing member of a diaphragm, but because it is porous and in order for it to support the high pressure of an application, it needs to form a seal. This explains why all diaphragms need elastomer on the high-pressure side of the diaphragm. But some diaphragms have elastomer on both sides.

Neo-Flex Double Coat Diaphragm Design with Fabric Reinforcement

Here are some of the most common reasons that elastomer is needed on both sides of the diaphragm.

First, in double acting system the pressure differential flips back and forth in a system resulting in a need to seal the fabric from both sides in order to convert pressure correctly in both directions. This means that both sides are at times the high-pressure side. There are also occasions when a pressure reversal can happen during a system failure. If the diaphragm is coated only on the high-pressure side, during the system failure the pressure reversal will blow the fabric off the diaphragm causing a rupture. In many cases this rupture could result in a dangerous situation such as leaking harmful materials into atmosphere or into other areas of the application.

Second, there are occasions where high-pressure is only on one side of the diaphragm but the low-pressure side may have high enough pressure to cause a leak path on the fabric side of the diaphragm. The fabric face is not an ideal sealing surface given that the fabric itself is made up of twisted threads, which can allow the gas or fluid on the low-pressure side of the diaphragm to seep out of the flange area of the hardware. Again, this leak could result in a hazardous scenario.

A *Third* possibility exists when a caustic material that the fabric cannot withstand is present on the low-pressure side of the diaphragm. As the fabric degrades it loses its tensile strength. Once the fabric's tensile strength degrades to the point where it can no longer withstand normal operating pressures it will result in failure of the diaphragm and the system.

Finally, if the application's hardware has a rough finish then this will abrade the fabric to a point where its tensile strength is reduced and it can no longer support the pressure in the system. The additional layer of the elastomer on the diaphragm will not eliminate the wear but will extend the life of the diaphragm. The loss of the elastomer does not weaken the diaphragm's ability to function.

The selection of the fabric's weave is a balancing act

A fabric's ability to be formed is determined by the spacing of the threads on the fabric. As the fabric is formed, the threads in the fabric are pulled to fit the new geometry. Since the threads do not stretch, they must change their orientation at some point to keep from folding on themselves, resulting in a pleat. This change in orientation takes place along the axis that runs 45 degrees to the plane of the threads or the bias area of the fabric. As the fabric is pulled, the open squares (interstices) formed by the threads in the bias area collapse to a point where the threads hit one another. At this point, the fabric can no longer be pulled without forming a pleat. The conclusion here is that the more open the weave the deeper it can be drawn.

As mentioned earlier in this article, once fabric is introduced then the elastomers job is only for sealing the flange and plugging the interstices in the fabric. The key point is that fabric has holes in it formed by the spacing between threads. It also stands to reason that the lower the thread count (threads per inch) the larger the interstices formed between threads. When the elastomer is introduced, the interstices are closed forming the seal. However, in between the threads there is only elastomer holding onto fabric preventing a leak. If the cross section of elastomer is too thin in relation to the openings in the fabric, blow-through will occur. This is when the pressure in the application actually blows a piece of rubber through the fabric resulting in a small pinhole leak.

Conclusion

The final design of any diaphragm is equally critical to its application and the manufacturing process. Whether your application requires a single-coated or double-coated diaphragm, it is important to optimized materials design, for both elastomer and fabric.

Tolerances of Fabric Reinforced Diaphragms

One of the most misunderstood areas in development of a fabric-reinforced diaphragm is dimensional tolerance. In regards to rigid objects or assemblies, such as metals or plastics, the dimensional tolerance may be relatively straightforward. Since these materials are homogeneous, it is a matter of applying a certain value for shrinkage when designing a tooling for these objects. This is a time-tested method and works very well for those particular industries, providing reliability and consistency in product dimensions.

Many times, design engineers apply similar tolerance methods to diaphragm designs, assuming it is like any other rubber part. Fabric-reinforced diaphragms are a unique product, incorporating both a seal and reinforcement in one structure. Plastic or metal shrinkage techniques do not apply directly to a manufacturer of fabric-reinforced diaphragms. If this point is considered throughout the product design process, a better understanding of the diaphragm's role and its capabilities within the hardware will be achieved.

It is important to note that fabric-reinforced diaphragms which are designed with round or circular convolution are neither round nor circular in the finished product. Given that a reinforced diaphragm is produced from a woven or knit fabric with elastomer coating on one or both sides, there is an intricate interplay of shrinkages and stresses between the fabric and elastomer when a reinforced diaphragm is molded. The elastomer tends to have a uniform shrinkage, while the fabric does not. The fabric is an anisotropic material; it stretches more on the bias of the weave and shrinks more in the direction of the weave. Additionally, the fabric may impart a residual stress that may affect a reinforced diaphragm's dimensional stability.

Add some other features, such as a molded-in fiberboard gasket on the flange, PTFE cladding, or metal inserts, and soon there is an even greater amount of interplay between the stresses. Additionally, a reinforced diaphragm tends to relax over time. The convolution height may decrease and hole size may also change

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