Diaphragm Design Manual

Your Technology Specialist simrit®

Simrit leads the industry in the design, testing, and production of dynamic seals, whether they are homogeneous, fabric-reinforced, or insert molded. Simrit supplies high quality product into the Small Engine, Automotive, Irrigation, Gaseous Fuels Regulation and other markets and has worked diligently to develop the elastomers required to meet these industry's regulatory bodies (e.g. UL, NSF, FDA, etc.)

We are particularly adept at working alongside the design team at the prototype stage and using Simrit's quality and manufacturing systems, which are certified to ISO 9002 and QS 9000, you can be assured that your design will result in a highly reliable production product.

Using Simrit's in-house diaphragm testing lab, our engineers can validate the design before, during, and after production has begun to continually improve the product. Each piece of testing equipment is built around a specific customer application to provide results that are easy to interpret and immediately beneficial to our customer's engineers. From life cycle testing to failure mode analysis our engineering team can meet your challenge.

Simrit's production area uses the latest in manufacturing techniques to turn the designs into a production reality with a standard industry-leading lead-time of two weeks. Simrit supports a variety of inventory methods and customer order practices to make the decision to manufacture your product with Simrit an easy one.

The Simrit Team

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The Diaphragm Engineering and Design Manual is intended to be used by engineers for the purpose of developing new or improved rubber diaphragm designs and evaluating material and/or process alternatives. Any other use of the Diaphragm Engineering and Design Manual is strictly prohibited without written permission from Simrit. All efforts have been made to provide comprehensive and accurate data. No warranty is expressed or implied.

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Introduction

The elastomeric diaphragm is a versatile dynamic seal that eliminates many of the limitations of other sealing methods.

Elastomeric diaphragms do not leak, offer little friction and can be constructed for low-pressure sensitivity. With optimal material choices elastomeric diaphragms can withstand wide temperature and pressure variations without maintenance or lubrication.

Diaphragms are available in shapes ranging from flat to deep-drawn formed styles.

Selecting the right geometry and materials for the application are only part of the equation. The diaphragm's associated assembly hardware is equally if not more important for improving its useful life.

When embarking on the design of a device that will incorporate an elastomeric diaphragm seal as part of its assembly, please use the *Quick Start* checklist and the *Quick Reference Tabs* as your road maps to a robust design.

This manual has been organized into five main sections:

Materials
Diaphragm Styles
Selected Design Topics
Glossary of Terms
Technical Flyers

For your convenience, the manual also includes an Engineering & Application Data Form, which is on the last page, which can be used by you for your own design work or can be submitted to our Engineering Group, should you desire guidance in your diaphragm design.

Design Guideline – Initial Design Considerations – See Technical Flyer "Design for Manufacturing" Page 62

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

The "Quick Start" Check List

1. ☐ What is the diaphragm device's basic function?
  a. Regulator – Pressure typically on one side.
  b. Pump – Pressure typically on both sides.
  c. Other.
2. ☐ What are the environmental conditions? – **See Page 44**
  a. Temperature range.
  b. Humidity range.
  c. Ozone.
  d. Other.
3. ☐ Which elastomer should be used? – **See Pages 11–14, 15**
  What fluid will contact the diaphragm?
    i. Passive – Such as distilled water or air
    ii. Aggressive – Such as gasoline or solvents.
4. ☐ Which fabric should be used, if any? – **See Pages 14–15, 27, 30 & Technical Flyer Page 57**
  What are the pressure requirements?
    i. Under 5 PSI – Fabric reinforcement may not be required.
    ii. 5 to 10 PSI - Fabric reinforcement will be application dependent
    iii. Above 10 PSI – Fabric reinforcement will be required.
    iv. Pressure differentials must be accounted for.
    v. Pressure spikes must be accounted for.
5. ☐ Which construction style should be used? – **See Pages 17 & Technical Flyer Page 59**
  a. Pressure or aggressive media on one side?
    i. Should use a one side coated part.
    ii. May use a two side coated part.
  b. Pressure or aggressive media on both sides?
    i. Should **not** use a one side coated part.
    ii. **Must** use a two side coated part.
  c. What Is the expected stroke length?
    i. Short to medium? – Can use single or two side coated
    ii. Long? – Must use one side coated
6. ☐ Which diaphragm shape should be used? – **See Pages 16-24 & Technical Flyer Page 55**
  a. Short stroke – Flat, Low Convoluted or Shallow Draw.
  b. Medium stroke – Shallow Draw, Convoluted or Drop Center.
  c. Long stroke – Deep Draw / Top Hat.
7. ☐ What is the expected cycle rate?
  a. Test________________
  b. Use________________
8. ☐ What is the expected cycle life?
  a. Test________________
  b. Use________________
9. ☐ How will the diaphragm device be assembled? – **See Pages 34-37**
  a. Bolted piston and flange.
  b. Riveted piston and flange.
  c. Spin crimp or swage.
  d. Sonic welded.
  e. Housing:
    i. Injection molded plastic.
    ii. Stamped or formed metal.
    iii. Machined plastic or metal.
10. ☐ Any additional hardware considerations?
  a. Return springs required? – **See Page 30**
  b. Positive stops required? – **See Page 31**
  c. Piston design? – **See Pages 34**
  d. Diaphragm care? – **See Pages 35**
11. ☐ What style of flange will be needed? – **See Pages 38-43**
  a. Flat.
  b. Beaded.
  c. Gasketed.
  d. Combination.
12. ☐ Any special specifications or requirements?
  a. FDA.

   b. UL.
   c. ASTM.
   d. Internal.
   e. Other.

13. ☐ Tolerances – This area is often overlooked but is extremely important. Please review the information and the chart provided on **pages 44-46 & Technical Flyer Page 60** before completing your design.

Formula 1 – The Diaphragm's Designed Fabric Tensile Strength – page 15

$$Fabric\ Tensile\ (Design) = \left(\frac{Convolution\ Width\ x\ Burst\ Pressure}{2}\right)$$

Formula 2 - Blousing Flat Diaphragms for Stroke (reference Figure 1) – page 18 and 19

$$OD = Bore\ Diameter + 2\ x\left(S - \left(\frac{Bore\ Diameter - Piston\ Diameter}{2}\right)\right)$$

$$where\quad S = \sqrt{(Half\ Stroke)^2 + \left(\frac{Bore\ Diameter - Piston\ Diameter}{2}\right)^2}$$

Formula 3 – Half Stroke for Convoluted Diaphragms – page 21

$$Convoluted\ Half\ Stroke = 2\ x\ Height - (Convolution\ Width + 2\ x\,(Flange\ Radius))$$

Formula 4 – Height Calculation for Convoluted Diaphragms – page 22

$$Convoluted\ Height = \frac{1}{2}(Convolution\ Width + 2\ x\,(Flange\ Radius) + Flange\ Thickness + Half\ Stroke)$$

Formula 5 – Height Calculation for Deep Draw Diaphragms – page 24

$$Deep\ Draw\ Height = Half\ Stroke + (Flange\ Thickness + 2(Flange\ Radius) + 1.56(Conv.\ Width) + SF)$$

Formula 6 – Half Stroke for Deep Draw Diaphragms – page 24

$$Deep\ Draw\ Half\ Stroke = Height - (Flange\ Thickness + 2(Flange\ Radius) + 1.56(Conv.\ Width) + SF)$$

Formula 7 – The Diaphragm's Designed Effective Area – page 29

$$Effective\ Area\ (Design) = \left(\frac{Piston\ Diameter + Cylinder\ Diameter}{4}\right)^2 x\ \pi$$

Formula 8 – Calculating Sidewall Tension – page 31

$$Total\ Tension(T) = \frac{.25\ P}{COS\ \alpha} + \left(D_1 + \frac{(D_2{}^2 - D_1{}^2)}{D_2}\right) = \frac{Lbs.}{in}(of\ Bore\ Circumference)$$

Where: D_1 = the piston diameter in inches, D_2 = the bore diameter in inches, P = the pressure in PSI, and a = the angle of the sidewall **from the vertical.** Note:

$$\alpha = Tan^{-1}\left(\frac{\left(\frac{(D_2 - D_1)}{2}\right)}{h}\right)\ where\ h\ is\ the\ height\ of\ the\ convolution\ at\ \max\ stroke$$

Formula 9 – The Diaphragm's Designed Burst Pressure – page 31

$$Burst\ Pressure\ (Design) = \left(\frac{Fabric\ Tensile\ x\ 2}{Convolution\ Width}\right)$$

Formula 10 – The Piston Skirt Length for Best Diaphragm Support – page 34

$$Piston\ Skirt\ Length = \left(\frac{Convolution\ Height + Half\ Stroke}{2}\right)$$

Cylinder Diameter	.25 / .99	1.00 / 2.50	2.51 / 4.00	4.01 and Up
Safety Factor (SF)	0.06	0.10	0.12	0.14

Materials

Compatability Chart

Common Name			Nitrile	EPDM	Hydrin	Neoprene	HNBR	Fluorocarbon	Simriz	Silicone	Fluorosilicone	Teflon^{TM}
Polymer Composition			Butadiene Acrylonitrile	Ethylene Propylene Diene	Epichlorohydrin ethylenoxide	Chloroprene	Hydrogenated Acrylonitrile Butadiene	Fluorinated Hydrocarbon	Perflouronated Hydrocarbon	Polysiloxane	Fluorvinyl Methyl Siloxane	Hexafluoro-propylene
ASTM D2000 Classification			BF, BG, BK	CA	DK, DJ	BC, BE	-	HK	-	FC, FE, CE	FK	-
Physical Properties Room Temperature	Durometer Range (Shore A)		20-95	30-90	40-90	20-95	45-95	60-90	60-90	5 to 90	35 to 80	-
	Tensile Strength, PSI		3000	2500	2500	3000	6000	2000	3200	1500	1400	-
	Elongation, %		600	600	350	600	500	300	250	1000	480	-
	Compression Set		B	B-A	A-D	B	A-B	B-A	B	B-A	B	-
	Resilience		B	B	C-A	A	B	C	A	D-A	A	-
	Permeability Coefficient**		0.18	6.4	.17/.66	0.89	-	0.20	-	200.0	37	-
	Electrical Resistivity (Polymer)		D-C	A	B	C	D-C	B	A	A	B	-
	Creep, Drift or Strain Relaxation		B	C-B	B	B	B	B		B		-
Mechanical Properties	Impact Strength		C	B	C-A	B	A	B	A	D-C	D-B	-
	Abrasion Resistance		A	B	C-B	A	A	B	A	A-B	D	-
	Tear Resistance		B	C	C-A	B	A	B	A	A-B	A-B	-
	Cut Growth		B	B	B	B	A	B	A	C-B	C-A	-
Temperature Data	(Hot) Tensile Strength % Decrease	at 212°F	-50	-50	-45	-50	-	-70	-	-10	-	-
		at 350°F	-75	-80	-65	-70	-	-90	-	-40	-	-
	Hot Elongation	at 212°F	-30	-20	-45	-35	-	-30	-	-30	-	-
		at 350°F	-57	-50	-60	-45	-	-60	-	-50	-	-
	Heat Resistance	at 5 hrs, °C	190	200 to 220	220	180	230	>300	-	>300	-	-
		at 70 hrs, °C	150	170 to 180	150	130	180	280	-	275	-	-
		at 1000 hrs, °C	120	130 to 140	130	100	150	220	-	180	-	-
		Strain Relaxation at 212°F	B	C-B	C-B	B	A	B-A	-	A	-	-
		Heat Aging at 212°F	B	A	B-A	B-A	A	A	A	A	A	-
		Flame Resistance	D	D	B-D	B-A	A	A	C	A	-	-
	Low Temperature	Stiffening, °F	+30 to -20	-20 to -50	0 to -10	+10 to -50	-	+10 to -10	TR10 = 0 to -4C	-60 to -180	-	-
		Brittle Point, °F	-40	-90	+5 to -10	-85	-	-65		-90 to -180	-	-
	Glass Transition	Tg, °F	-20	-55	-26 to -45	-45	-30	-18 to -50	+23	-120	-90	-
	Compression Set	at -20°C	45	20	-	50	-	50	-	10	-	-
		at Room Temperature	8	4 to 8	-	10	-	18	-	2	-	-
		at 120°C	55	20	20	30	30	20	-	3	-	-
Environmental	Weather-Sunlight Aging		D	A	B	B	-	A	A	A	-	-
	Oxidation		B	A	B	A	B	A	A	A	-	-
	Ozone Cracking		C	A	A	A	-	A	A	A	-	-
	Radiation		B	B	-	B	-	C-B	B	C-B	-	-
	Water		A	A	B	B	-	A	A	A	-	-
	Steam		C-B	A	B-C	B	B	B	A	C-B	-	-
General	Alkali Dilute / Concentrated		B/B	A/A	B-D	A/A	A/B	A	A/A	A/A	-	-
	Acid Dilute / Concentrated		B/B	A/A	B/C	A/A	A/B	B/C	A/A	B/C	-	-
	Ketones, Oxygenated Solvents		D	B-A	C	C	NR	NR	A	B-C	-	-
	Chlorinated Hydrocarbons Degreasers		C-B	NR	A	D	C	A	B	NR	-	-
	Aliphatic Hydrocarbons, Kerosene, etc.		A	NR	B-A	C	A	A	B	D-C	-	-
	Aromatic Hydrocarbons, Benzol, Toluol, etc.		B-A	NR	B-A	B	C	A	B	NR	-	-
	LP Gases, Fuel Oils		A	NR	A	B	A	A	B	C	-	-
	Swell in Fuel C at 70h, Room Tempurature, %		25	-	30	-	65	5	-	-	-	-
	Alcohols		C-B	B-A	C-B	A	A	C-A	A	C-B	-	-
	Brake Fluid, Non-Petroleum Base		NR	B-A	D	C	-	C	B	A	-	-
	Synthetic Lubricants - Diester		B-A	NR	B	D	A	A	A	NR	-	-
	Animal and Vegetable Oils		B	B	A	B	-	A	A	A	-	-
	Taste		C-B	B	B	C-B	C	C-B	C	B	-	-
	Odor		B	B	B	C-B	C	B	B	B	-	-
	Non-Staining		D-C	B	B	B-A	-	C-B	B	A	-	-
	Bonding to Rigid Material		B-A	C-B	C-A	B-A	A	C-B	C	B-A	-	-
Specific Applications	Hydraulic Fluids	Petroleum Base	B-A	NR	A	D-C	-	A	A	NR	-	-
		Water Glycol	C	A	B	B	-	A	A	A	-	-
		Silicate Ester	B	B-A	B	B	-	A	A	NR	-	-
		Phosphate Ester	D	A (300° +)	NR	C	NR	B-A	A	B	-	-
	Lubricating Oils	High Aniline (190°+)	B	NR	A	B	-	A	A	C	-	-
		Low Aniline Point	A	NR	A	A	-	A	A	B	-	-
		Swell in ASTM IRM903 at 70 hrs, %	5 (100C)	>140 (70C)	10 (150C)	80 (100C)	15 (150C)	2 (150C)	-	50 (150C)	-	-
	Refrigerants	Ammonia	B	B	NR	A	-	NR	A	A	-	-
		Fluorinated	R-11, 12, 13	R-12, 13, 22	R-12, 22 12	R-11, 12, 13, 21, 2	-	R-11, 12, 13	-	NR	-	-
		Methyl Chloride	NR	D	NR	NR	-	B	B	NR	-	-
	Refrigerant + Oil	Fluorinated	R-11, 12	NR	B-A	R-11, 12, 22	-	R-11, 12	-	NR	-	-

**Permeability Coef.-Nitrogen, 10^{-8} cm^2, sec^{-1}, atm^{-1}

Tables Key					
Meaning	Excellent	Very Good	Good	Fair	Poor
Letter	A	B	C	D	E

Elastomers

The elastomer brings little strength to the diaphragm. Its primary function is to seal. Compound should be chosen based on the environmental conditions, the cycle rates of the diaphragm, and the contact fluids. While making your decisions, please reference **Tables 1**, **2**, and **4** in the **Materials Section** of the manual as well as the information provided on **Thermal and Chemical Conditioning of Elastomers**.

General Purpose - Oil Resistant

Three rubber compounds are considered general-purpose diaphragm materials -- Epichlorohydrin, Nitrile, and Neoprene. All are oil resistant and widely used in the automotive industry.

Epicholorohydrin (ECO)

Epicholorohydrin has an outstanding application temperature range. Its typical maximum constant-use ceiling of 300°F is a 50° advantage over Neoprene and Nitrile. This is significant, especially when considering automotive under-the-hood applications. The fuel resistance of Epicholorohydrin equals that of Nitrile.

The low temperature properties of Epicholorohydrin allow it to have a minimum constant-use temperature of -40°F. This is unique in that the addition of plasticizers is not required to achieve this kind of low temperature flexibility. Therefore, thermal conditioning of Epicholorohydrin has little effect on its flexibility.

The ozone and weathering properties of Epicholorohydrin are equal to Neoprene. The basic mode of failure for ECO is reversion. Reversion is a softening of the material to the extent that rubber-like properties no longer exist; the material reverts back to what it was prior to vulcanization. This happens when Epicholorohydrin is exposed to elevated temperatures (over 300°F) for very long periods of time.

Neoprene (CR)

Neoprene is similar to Nitrile in basic properties, but is not recommended for fuel related automotive under hood applications. While it can be compounded for the same service temperatures as Nitrile, its main advantage is its natural resistance to ozone and weather attack.

Nitrile (NBR or Buna-N)

Nitrile is perhaps one of the most widely used diaphragm elastomers due to its low cost and its nearly universal properties. It is made of two polymers: butadiene and acrylonitrile. Adjusting the ratio of the two polymers can modify the oil resistance and low temperature flexibility.

For example, increasing the percentage of butadiene will improve the low temperature flexing, but will lessen the oil resistance. The converse of this is true as well. Ozone and weathering resistance are weak attributes of this elastomer, but antioxidants can be added to aid in this situation.

COMMON ELASTOMER COMPOUNDS

Name	Advantages	ASTM 1418 Designation	ASTM D2000 Designation
Butyl	Low permiation to many gases. OK in vegetable oil and oxidating chemicals.	IR	BA
Ethylene-propylene	Very good hot water, low pressure steam, and heat resistance.	EP or EPDM	CA
Neoprene	Good oil, ozone, and weather resistance. Good general purpose material.	CR	BC or EB
Nitrile	Good general purpose oil and fuel resistant material.	NBR	BF, BG, BK or CH
Epichlorohydrin	Similar to nitrile with better resistance heat aging and a wider temperture range. Also has excellent ozone resistance.	ECO	CH or DH
Polyacrylate	Oil and heat resistant to 350°F. Good in transmission fluids.	ACM	DH or DF
Ethylene-acrylic	Oil and heat resistant to 350°F. Good in transmission fluids. Better low temperature capability than polyacrylate.	EA or EAM	CH
Silicone	Good dry heat resistance and low temperature. Good ozone and weather resistance.	VMQ	GE
Fluorosilicone	Oil and fuel resistant. Wide temperature range.	FVMQ	FK
Fluorocarbon	Oil, fuel, solvent resistant. Excellent high temperature range.	FKM	HK

Table 1 – Common Elastomer Compounds

General Purpose - Non-oil Resistant

Butyl (IIR)

An outstanding characteristic of Butyl is its natural low permeation rate to gasses. This feature, however, can create problems in the molding process as it becomes difficult to eliminate any trapped air or gas.

Ethylene Propylene (EP or EPDM)

Ethylene propylene has good heat resistance up to 300°F. It is often used in cold water, hot water, and low-pressure steam applications. Ethylene Propylene is also widely used with synthetic lubricants, automotive brake fluids and engine coolants.

Specialty Elastomers

Ethylene-acrylic (EA)

Ethylene-acrylic elastomer is used in automotive applications where their combined properties provide very good flex, ozone resistance, and high-temperature resistance along with fairly good low-temperature characteristics and oil resistance. The good dampening characteristics of Ethylene-acrylic elastomers make it well suited for vibration mounts, pads, isolators, and so forth.

Fluorosilicone (FVQM or FSI)

Fluorosilicones excel in high temperature resistance and to attack from fuels and oils. Also, due to fluorosilicone's inherent low temperature properties, it will not shrink during "dry-out" after being soaked in automotive fuels. Ozone resistance and weathering are also outstanding features of Fluorosilicone elastomers.

One shortcoming of Fluorosilicones is their permeability to fuel vapor. Under the current government evaporative emissions regulations, fluorosilicone may not be a viable solution for all automotive under-hood fuel system sealing applications.

Fluorocarbon (FKM)

Fluorocarbons have the highest chemical resistance of today's elastomers. In fuels and oils they also have the lowest volume swell. Because of their chemical resistance, Fluorocarbons are rapidly becoming the elastomer of choice in the fuel application field. Their stability at elevated temperatures is also excellent.

The major drawback to Fluorocarbon elastomers is that their low temperature flexibility is generally poor, which can cause problems in overall diaphragm function. This is especially true in applications where extreme temperature fluctuations are expected, such as automotive under-hood applications during the winter months.

In an effort to correct this problem, Fluorocarbon manufacturers have introduced a line of compounds with improved low temperature flexibility. They have typical recommended service temperature lows from -10ºF to 20ºF. Some of the newest variations will dry flex (no fluid contact) to -40ºF.

Polyacrylate (ACM)

Historically, conventional acrylic elastomers have been successfully utilized in a wide variety of critical automotive seal applications. These include automatic-transmission seals, valve-stem seals, crankshaft seals, pinion seals and oil-pan seals. The newer, more versatile types are also gaining rapid acceptance in other mechanical-goods applications such as hose, tubing, electrical-cable jacketing, rolls and belting.

Silicone (VQM or SI)

Silicone elastomers are often used when a broad temperature range is expected as it has natural low temperature flexibility. Silicone is **not** fuel or oil resistant. It does, however, exhibit some moderate chemical resistance. It can be compounded for low hysteresis (low rolling resistance) where exceptionally flexible and sensitive diaphragms are required.

KEY PROPERTIES of COMMON ELASTOMER COMPOUNDS

Name	Typical Service Temperature Ranges	Resistance To:											
		Abrasion	Acids - Dilute	Alkalies - Dilute	Gas Permeability	Compression Set	Heat @ 212°F	Oil (1)	Ozone	Tear	Water / Steam	Weather	Hysteresis
Butyl	-20°F to +212°F	D	C	C	C	E	B	E	A	C	B / B	A	
Ethylene-propylene	-40°F to +350°F	C	A	A	D	E	A	E	A	D	B / A	B	C
Neoprene	-40°F to +250°F	B	A	C	D	E	B	C	C	D	D / C	B	B
Nitrile	-40°F to +250°F	C	C	C	D	C	C	B	D	C	D / D	E (2)	
Epichlorohydrin	-30°F to +300°F	D	C	D	A	C	B	B	C	D	C / E	C	C
Polyacrylate	0°F to +350°F	D	D	D	C	E	A	B	A	E	E / E	B	
Ethylene-acrylic	-20°F to +350°F	C	C	C	A	E	A	B	B	C	B / E	B	C
Silicone	-80°F to +450°F	E	D	E	E	C	A	D	C	E	A / D	A	D
Fluorosilicone	-65°F to +375°F	E	A	A	E	D	A	A	A	E	A / D	A	C
Fluorocarbon	-10°F to +400°F	C	C	C	C	C	A	A	A	D	A / E	A	C

Notes: **(1)** Oil Test - ASTM Oil #3, 70 hours @ 70°C, **(2)** This result is for straight nitrile and can be improved through additives.

Table 2 – Key Properties of Common Elastomer Compounds – Reference Key on page 10

Fabrics

General Purpose Fabrics

Cotton

Cotton is used to some extent when special shape compliance is required and/or bulk is needed to make thicker cross-sections.

Nylon and Polyester

Nylon and polyester fabrics are used for the majority of diaphragm applications. These fabrics are available in a variety of woven and knitted styles. Woven styles are normally used for shallow draw and/or high-pressure diaphragms. Knits, because of their high stretch capabilities, are used primarily for deep drawn diaphragms. Their lower strength capabilities are best suited for diaphragms with low to moderate pressure requirements.

Specialty Fabrics

Fiberglass

Fiberglass fabrics are available and used, but are not generally recommended for diaphragms because they can be extremely brittle. As the diaphragm functions, the glass fabric in the flexing area of the diaphragm abrades on itself and can turn to powder, rendering the glass fabric non-productive.

Nomex™ and Kevlar™

Nomex™ and Kevlar™ are of the aramid family and are related to nylon. Both can be used in extremely high temperature applications. Kevlar™ is unique because of its extremely high tensile strength, but this strength also makes it difficult to process and hard to cut.

Both Nomex^{TM} and Kevlar^{TM} are high performance materials. Price considerations in regard to the overall application's cost constraints should be considered before using them.

GENERAL CHARACTERISTICS of FABRICS

Fabric	Tensile Strength	Moisture Resistance	Heat Resistance	Maximum Operating Temperature
Cotton	D	C	D	350°F
Nylon	B	B**	C	300°F
Polyester	C	A	B	350°F
Nomex^{TM}	B	B	A	375/400°F
Kevlar^{TM}	A	B	A	375/400°F
Fiberglass	A	A	A	500°F+

Notes: "A" is the highest possible rating wihtin a category., Nomex and Kevlar are registered tradmarks of DuPont., ** Caution - hot water and steam hydrolyzes nylon.

Table 3 – General Characteristics of Fabrics – Reference Key on page 10

Other Fabric Types

In addition to the fabrics listed above, several other fabric types are available for diaphragm reinforcement. They include silk for ultra thin, ultra sensitive diaphragms and non-woven or chopped fabric for reducing pressure or fluid wicking.

Formula 1 – The Diaphragm's Designed Fabric Tensile Strength

$$Fabric\,Tensile\,(Design) = \left(\frac{Convolution\,Width\,x\,Burst\,\Pr essure}{2} \right)$$

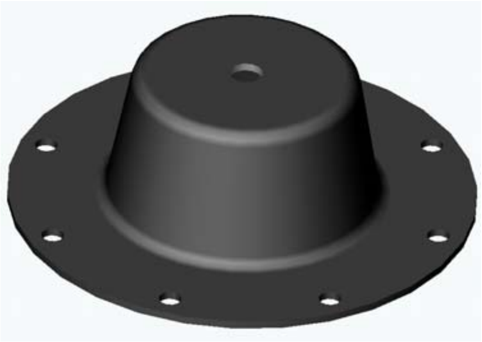
GENERAL CHEMICAL RESISTANCE to SOME COMMON CHEMICALS

Elastomer	Nitrile	Ethylene-propylene	Fluoro-carbon	Neoprene	Poly-acrylate	Butyl	Fluoro-silicone	Silicone	Epichloro-hydrin	Ethylene-acrylic
Chemical										
Air	A	A	A	A	A	B	A	A		A
Alcohols (General)	B	C	B	B		B				
Antifreeze	A	A	A	B				C		
Brake fluid		A		B						
Butane	A		A	C			B		A	B
Citric acid	A	C	B	B		C	C	C	C	C
Diesel oil	A		A	C	B		A		A	
Fruit juice	A	A	A	A		C	B	B		
Gasoline, automotive	A		A				B		B	C
Hydraulic oil (petro)	A		B	B			B	C	B	B
Natural gas	A		A	A	B	C	B	B	B	B
Salt water	A	A	A	A	C	C	B	B		

Note: A blank space means Not Rated or insufficient data available.

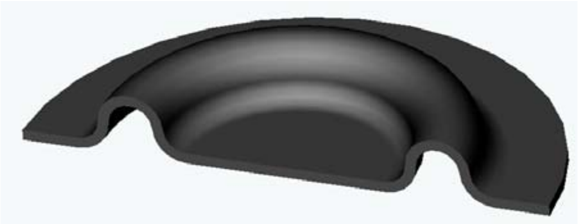
Table 4 – Elastomer Resistance to Some Common Chemicals – Reference Key on page 10

Diaphragm Styles

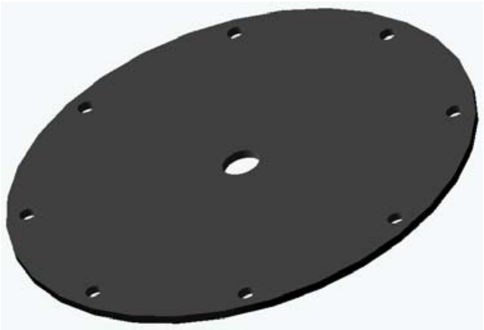


Deep Draw with ID and Flange Holes – See page 23

Shallow Draw with Beaded Flange – See page 20



Convoluted with Flat Flange – See page 21



Flat Cut with ID and OD Holes – See page 18

Double Taper with Flat Flange – See page 24

Drop Center with Piston Hole – See page 22

Diaphragm Construction Styles

Before the topic changes to the geometric diaphragm styles available, a word or two about diaphragm construction styles is necessary. Up to this point we have been discussing the elastomers and supporting fabrics as separate components. To construct a diaphragm, elastomer and fabric components must be brought together in one of the following forms:

One Side Coated Construction

The main advantage to the one side coated construction is the ability to mix and match various fabrics and elastomers in small runs for specialty applications. Due to this material flexibility, one side coated parts can use fabrics and elastomers not normally available for two side coated construction.

In addition to this, one side coated parts can be formed with taller, narrower, convolutions and can be easily made with various sealing features (e.g.: beads, v-ribs, etc.). One side coated construction is also commonly referred to as lay-up or single coat construction.

Two Side Coated Construction

The main reason for considering two side coated construction is that it gives excellent protection to the reinforcing fabric, provides a seal on both sides of the diaphragm in reverse pressure applications and reduces abrasion wear.

Two side coated construction comes in two distinct styles: as a coated fabric and as a molded double coat. Diaphragms made via a two side coated construction are sometimes referred to as double coated.

The advantages and disadvantages of these two construction styles are compared in **Table 5** below.

Two Side Coated Construction Styles Comparison		
Construction	**Advantages**	**Disadvantages**
Coated Fabric	**1** Thin sensitive cross-section **2** Lower tooling cost **3** Lower manufacturing cost	**1** Limited availability of material combinations **2** Large minimum material runs **3** Limited geometric features (e. g.: height, beads)
Molded Double Coat	**1** More robust geometric features - similar to single coat **2** Limitless elastomer and fabric combinations **3** Small order minimums	**1** Higher tooling cost **2** Higher manufacturing cost **3** Less sensitivity **4** Limited production volumes

Table 5 – Two Side Coated Construction Styles Comparison

Flat Diaphragms

Flat diaphragms are an economical way to incorporate a diaphragm into an application. Simply put, flat diaphragms are shapes, typically round, cut from a roll of diaphragm material.

A flat diaphragm's main limitation is stroke length. This limitation can be overcome, to some degree, by blousing (also see **Design Guideline – Flat Diaphragm Stroke Limits**), but a flat diaphragm should not be considered as an inexpensive substitute for a properly engineered formed diaphragm.

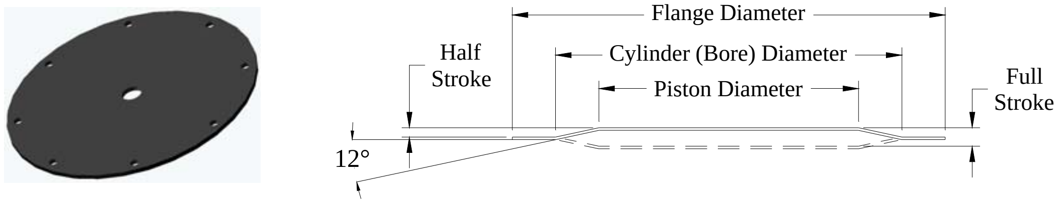


Figure 1 – Flat Diaphragm – Shown in an Up Stoke Position

Typical applications for flat diaphragms are high-pressure regulators; gage protectors and some diaphragm pump styles.

Design Guideline – Flat Diaphragm Stroke Limits

The expected half stroke, the part of the stroke that's above or below the neutral plane of the flange of a flat diaphragm, can be determined by limiting the angle of deflection between the flange plane and the piston assembly to 12° (see **Figure 1**).

The minimum convolution width should not be less than 1/8". The maximum stroke capability of the diaphragm would then be twice the deflection from the flange plane. Due to the wide variety of diaphragm applications, this information should be considered a starting point only.

Blousing

Blousing is a way to provide a flat diaphragm with enough slack for stroking. Creating slack or "blouse" material in a flat diaphragm can be handled in a couple of ways. In the case of bolted flange mountings, the bolt circle can be slightly larger in the diaphragm than on the housing. If the part is round and crimped at the OD, the diaphragm should be made larger than the OD (see **Formula 2** below).

This same approach would be followed to find the minimum bolt circle diameter needed if you plan to use a bolted flange to capture your diaphragm OD.

Formula 2 - Blousing Flat Diaphragms for Stroke (reference **Figure 1**)

$$OD = Bore\ Diameter + 2\ x\left(S - \left(\frac{Bore\ Diameter - Piston\ Diameter}{2}\right)\right)$$

$$where \quad S = \sqrt{\left(Half\ \ Stroke\right)^2 + \left(\frac{Bore\ Diameter - Piston\ Diameter}{2}\right)^2}$$

The Trampoline Syndrome

This phenomenon is typical of a diaphragm stretched during assembly instead of being bloused. What results is a bouncing or spring type of action requiring more energy from the system to start the stroke. In all but a few cases, this type of diaphragm interference is unwanted and should be avoided.

Flat Diaphragms - Closing Comments

Rubber under stress most often reacts by taking a set, which is almost always a result of stretching. Often when removing a diaphragm after use, the diaphragm will have formed a convolution. This change results in a lessening of the energy required to activate the diaphragm and can change the effective area, which can result in set point changes. If there is concern that these kinds of changes are going to present problems in your application, it may be best to design your application around a formed diaphragm.

Formed Diaphragms

Many of the problems associated with flat diaphragms can be overcome by using a formed diaphragm. The primary advantages of formed diaphragms are their application versatility (see **Technical Flyer Page 55** for additional insight on this topic). There are several basic types of formed diaphragms and they are detailed in the following sections in the order of their stroke capability – minimum to maximum:

Many of the formed styles, with the notable exception of the deep draw, can be made as two side coated. For deep draw styles it is often necessary to produce these parts in a one side coated construction.

One side coated construction is where the chosen fabric and elastomer are brought together at the mold to form the finished part. The main difference between one side coated construction and two side coated construction is that in one side coated construction the fabric has 90 to 95% of the elastomer on one side and only 5% to 10% on the other. A one side coated diaphragm is designed for use with the system’s highest pressure on its elastomer side only.

Pressure reversals, or pressure on the fabric side of a one side coated diaphragm, can blow the elastomer off the fabric causing a failure. Occasional or momentary pressure spikes may not be a problem, but consistently repeating ones will be.

Simrit’s team of diaphragm engineers is ready to guide you to the best diaphragm solution for your application needs, regardless of construction.

Design Guideline – Minimum Convolution Width for One Side Coated Parts

The minimum convolution width for one side coated parts is generally accepted to be four times the thickness of the diaphragm's convolution.

Shallow Draw, Dish or Pie Pan Style - Figure 2:

As the name implies, this formed style looks very much like a pie pan. Shallow draw diaphragms are used for strokes just beyond the range of flat diaphragms.

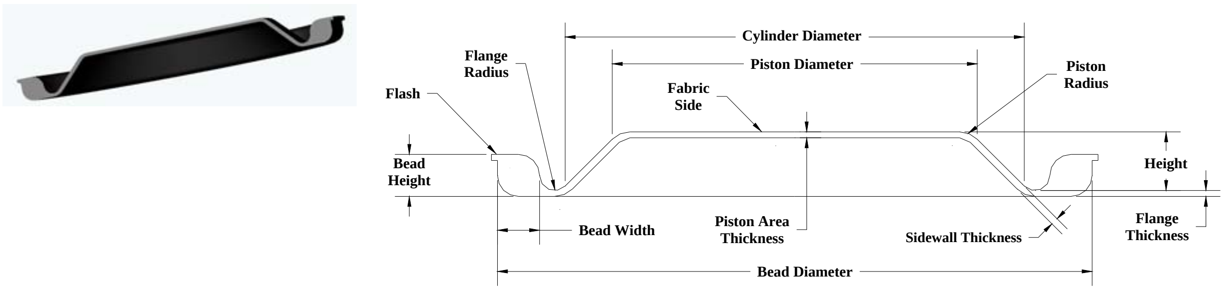


Figure 2 – Beaded Shallow Draw Diaphragm – See Section on **Beads** for additional Information

The advantage here is easier assembly and no blousing. For longer stroke requirements refer to deep draw styles.

Cylinder Diameter (CD)	.25" / .99"	1.00" / 2.50"	2.51" / 4.00"	4.01" / 8.00"	8.01" & Up
Piston Area Thickness	.015"	.017"	.024"	.035"	.045"
Flange Area Thickness	.015"	.017"	.024"	.035"	.045"
Convolution Thickness	.015"	.017"	.024"	.035"	.045"
Piston Radius	.094"	.125"	.156"	.250"	.250"
Flange Radius	.031"	.063"	.094"	.125"	.125"
Flange Diameter (Typ)	CD + .75"	CD + 1"	CD + 1.5"	CD + 2"	CD + 2"

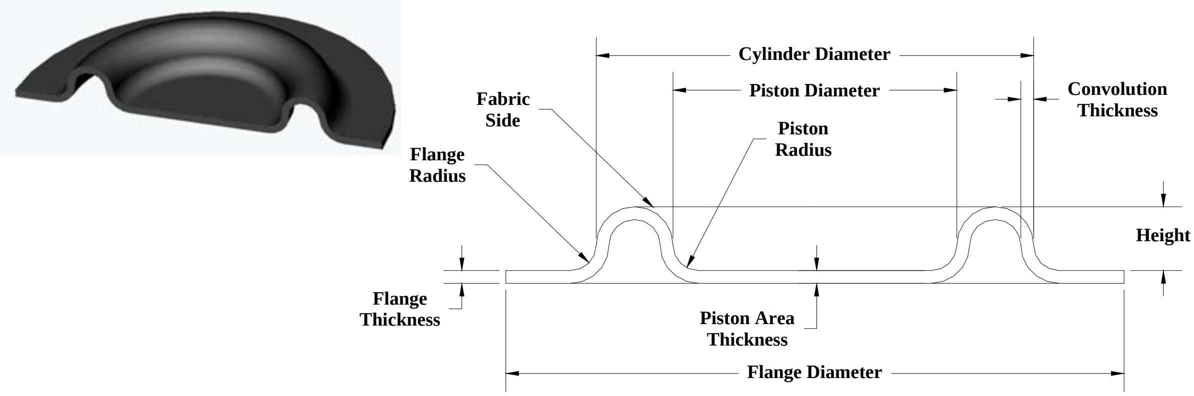
Table 6 – Dimensional Guidelines for Shallow Draw Diaphragms

Convoluted Style - Figure 3:

This formed style also has stroke capabilities slightly greater than flat diaphragms. A convoluted style diaphragm is one that has the clamping flange and the piston area on the same plane.

Convoluted diaphragms are best known for their responsiveness and are well suited to applications requiring stable set points such as regulators. Convoluted styles exhibit very low hysteresis.

Figure 3 – Convoluted Diaphragm



Design Guideline – Convoluted Stroke Limit for Two Side Coated Parts

For two side coated, convoluted parts the suggested total stroke length is 2.13 times the convolution width.

This limitation ***does not*** apply to one side coated formed parts.

Cylinder Diameter (CD)	.25" / .99"	1.00" / 2.50"	2.51" / 4.00"	4.01" / 8.00"	8.01" & Up
Piston Area Thickness	.015"	.017"	.024"	.035"	.045"
Flange Area Thickness	.015"	.017"	.024"	.035"	.045"
Convolution Thickness	.015"	.017"	.024"	.035"	.045"
Piston Radius	.031"	.063"	.094"	.125"	.125"
Flange Radius	.031"	.063"	.094"	.125"	.125"
Flange Diameter (Typ)	CD + .75"	CD + 1"	CD + 1.5"	CD + 2"	CD + 2"

Table 7 – Dimensional Guidelines for Convoluted and Drop Center Diaphragms

Formula 3 – Half Stroke for Convoluted Diaphragms

$$Convoluted\ Half\ Stroke = 2\ x\ Height - \left(Convolution\ Width + 2\ x\left(Flange\ Radius\right)\right)$$

Formula 4 – Height Calculation for Convoluted Diaphragms

$$Convoluted\ Height = \frac{1}{2}\left(Convolution\ Width + 2\ x\ \left(Flange\ Radius\right) + Flange\ Thickness + Half\ \ Stroke\right)$$

Drop Center or Offset Convolution Style - Figure 4:

Drop center formed diaphragms are convoluted diaphragms with a deeper center draw. This style has all the advantages of the convoluted style with longer stroke capability. Drop center styles can also be easier to assemble than convoluted styles, particularly if a return spring or some other hardware limitation doesn't allow the piston surface and the flange to be on the same plane during assembly. Please reference **Table 7** for dimensional guidelines.

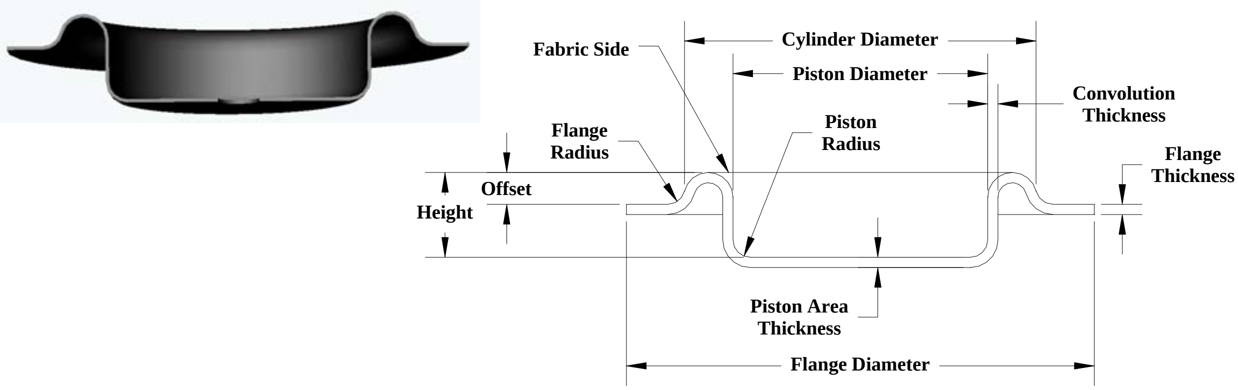


Figure 4 – Drop Center Diaphragm

Design Guideline – Drop Center Stroke Limit for Two Side Coated Parts

For two side coated, drop center parts the suggested total stroke length is 3.7 times the convolution width.

This limitation *does not* apply to one side coated formed parts.

Deep Draw or "Top Hat" Style - Figure 6:

Deep draw formed diaphragms have the longest available stroke lengths among diaphragm geometries. Their stroke capabilities are only limited by the chosen reinforcing fabric's ability to be conformed to the necessary shape. Before assembly, deep draw diaphragms must be manually formed into the shape of a tall, convoluted diaphragm so they will roll properly (reference **Figure 5**).

One issue with deep draw diaphragms is that they can occasionally invert in the convolution area as they cycle. Using an appropriately designed piston along with a curved lip retainer plate to lock the piston and radii of the diaphragm to the hardware can control this issue.

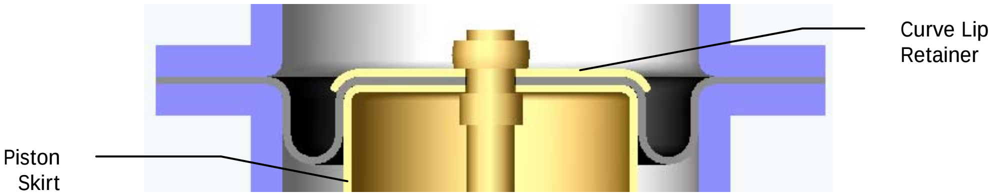


Figure 5 – Diaphragm Assembly With a Curved Lip Retainer

Design Guideline – Deep Draw Maximum Convolution Height

The maximum recommended stroke length for deep draw diaphragms is determined by keeping the height of the diaphragm less than, or equal to, the diameter of the bore. For best functional results, these styles must be used with well-guided pistons and supported by sufficiently long piston skirts.

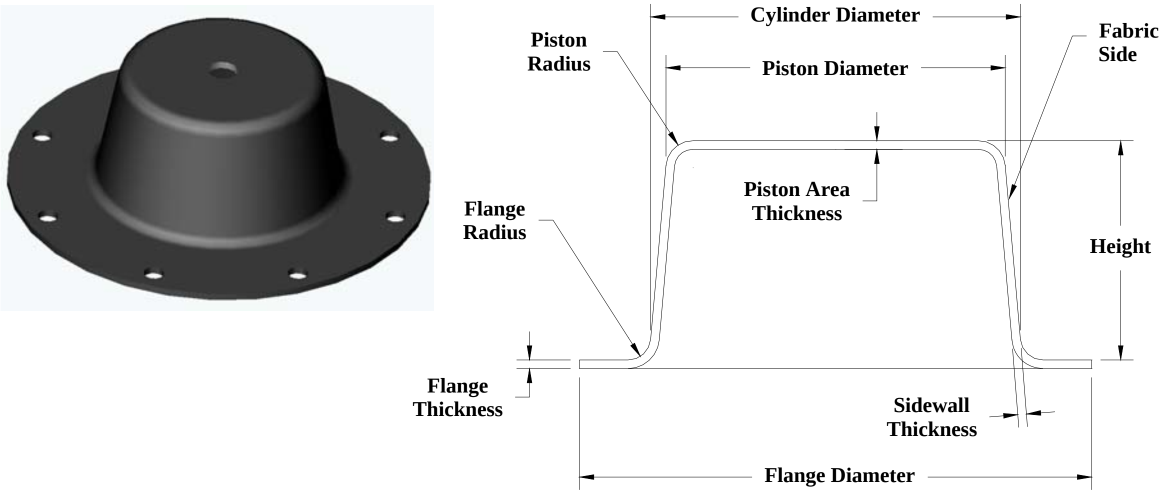


Figure 6 – Deep Draw Diaphragm

Cylinder Diameter (CD)	.25" / .99"	1.00" / 2.50"	2.51" / 4.00"	4.01" / 8.00"	8.01" & Up
Piston Area Thickness	.015"	.017"	.024"	.035"	.045"
Flange Area Thickness	.015"	.017"	.024"	.035"	.045"
Convolution Thickness	.015"	.017"	.024"	.035"	.045"
Piston Radius	.094"	.125"	.156"	.250"	.250"
Flange Radius	.031"	.063"	.094"	.125"	.125"
Flange Diameter (Typ)	CD + .75"	CD + 1"	CD + 1.5"	CD + 2"	CD + 2"

Table 8 – Dimensional Guidelines for Deep Draw Diaphragms

Formula 5 – Height Calculation for Deep Draw Diaphragms

$$Deep\ Draw\ Height\ = Half\ \ Stroke\ + \left(Flange\ Thickness\ \ + 2\left(Flange\ \ Radius\ \right) + 1.56\left(Conv.\ Width\ \right) + SF\ \right)$$

Formula 6 – Half Stroke for Deep Draw Diaphragms

$$Deep\ \ Draw\ Half\ \ Stroke\ \ = Height\ \ - \left(Flange\ Thickness\ \ \ + 2\left(Flange\ \ Radius\ \right) + 1.56\left(Conv.\ Width\ \right) + SF\ \right)$$

Table 9 – Calculation Safety Factors

Cylinder Diameter	.25 / .99	1.00 / 2.50	2.51 / 4.00	4.01 and Up
Safety Factor (SF)	0.06	0.10	0.12	0.14

Double Tapered Deep Draw Style - Figure 7:

As a way of reducing the **Circumferential Compression** a rolling convolution normally goes through during its stroke cycle, a standard deep draw diaphragm can be augmented with a second taper. By adding this second taper, the main sidewall angle is greatly reduced thereby reducing the circumferential compression increasing the life of the diaphragm.

Please also review the discussions on **Circumferential Compression** and **The Effective Area of Diaphragms** in the **Selected Design Topics** section for additional information.

Due to the wide variety of options, please contact Simrit for dimensional details on double taper diaphragms

Figure 7 – A Typical Double Taper Diaphragm

Alternate Diaphragm Constructions

All formed diaphragm styles can be made with or without:

- Fabric
- Added Sealing Features
- Gasketing
- Inserts, and Cladding

Each of these options are further detailed in the next section, **Selected Design Topics**.

Selected Design Topics

Common Causes for Non-Linear Stroking

1. Yarn geometry within the fabric.

2. Return spring not seated or not flat ground.

3. Insufficient bearing support of the piston rod.

4. Spring coil diameter too small for piston.

5. Piston height too low. Does not support the diaphragm sidewall.

6. Convolution width too wide.

See page 27

Common Causes for Residual Stresses

1. Hot creased parts.

2. Uneven draw of fabric in preforming or molding.

3. Old or nervy compound

4. Excessive precure time on coated fabric or compound.

5. Excessive post-curing of parts.

6. Molded at too high a pressure, or mold overloaded with compound.

7. Bad packaging.

8. Under cure of the rubber.

See page 32

The Three Most Common Types of Bead Failures:

1. Not enough compression, which can result in flange leakage.

2. Over compression which can cause a cut in the bead or the diaphragm.

3. Over compression can cause the bead material to flow back into the diaphragm convolution causing increased stress and potential premature failure.

See page 39

Advantages of Tear Drop Beads:

1. Provides for a more even draw of the fabric onto the diaphragm. While smoothing out possible wrinkles, it also aids in keeping the fabric in place within the part.

2. Provides for a positive location of the part in the trim die, which controls the concentricity.

3. Provides for backpressure in the mold to allow positive flow of the rubber and flushes out trapped gasses in the bead.

See page 40

Ideal Diaphragm Thickness

Design Guideline – The Ideal Diaphragm Thickness

As the saying often goes, "If a little is good, a lot must be better!" In fact, the opposite is typically true when it applies to diaphragm thickness.

Historically, engineers have tried to overcome higher pressures by adding more thickness to the diaphragm, especially non-reinforced diaphragms.

The guideline is, "design your diaphragm as thin as safely possible." Thinner diaphragms roll easier and are more responsive to small pressure changes.

Another concern surrounding excessively thick part cross-sections is what happens to the "excess" elastomer when the part is compressed during assembly (reference section on **Flange Sealing – Material Compression** for additional details). The excess elastomer extrudes into the convolution area forming a thicker "bead-like" cross-section just inside the bore diameter or just outside the piston diameter. The addition of this "bead," or thicker cross-section will make the diaphragm more vulnerable to flex failure.

Soft elastomers tend to extrude more easily while firm elastomers exhibit a higher modulus of elasticity and are not so easily extruded. One caution is that diaphragms made from higher modulus elastomers can have reduced flexibility.

Diaphragm Convolution (Sidewall) Action

Figure 8 shows the cross section of the convolution in three positions. Please note that point A is an arbitrary position on the convolution, selected only for illustration purposes.

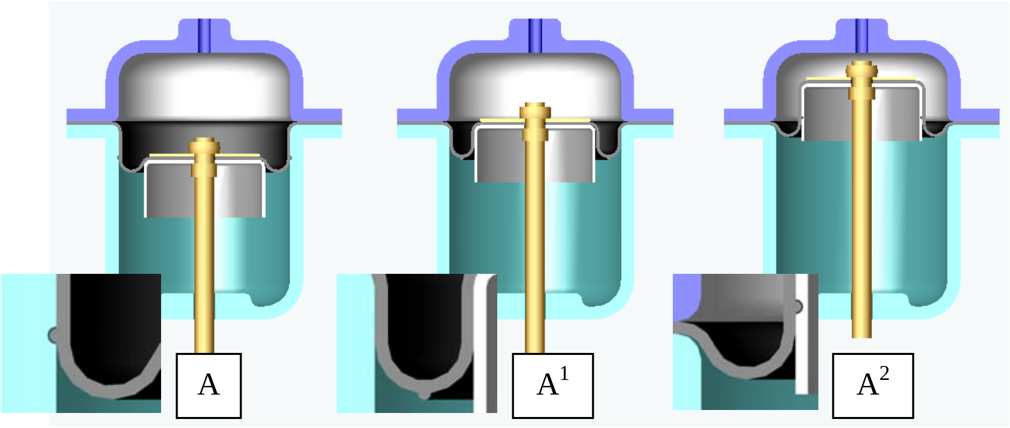


Figure 8 – Convolution / Sidewall Action - Showing the Movement of a Point on a Diaphragm's Convolution

The points A^1 and A^2 are at the same location as point A on the convolution. Their position change is due to the rolling action of the convolution. The diameter of the convolution moves inward on the upstroke, and outward on the return stroke. Activation pressure applied to the system shapes the rolling convolution within the confines of the piston and bore.

The configuration of the convolution curve closely resembles a catenary curve, regardless of its previous molded shape. During the positive or working part of the stroke, the convolution material is rolling away from the piston in an expansion mode. During this movement, the fabric reinforcement controls any radial stretching.

On the return stroke, the material is rolling toward the piston. In this mode the material will compress, as it is moving into a smaller diameter. The differences in circumference of both positions will be an indication of how much material will either have to be squeezed or folded over to conform to the space between the piston and sidewall. The concern is that the constricting forces will cause radial creases on the sidewall.

On the up stroke the full pressure is across the convolution stretching the material. However, on the return stroke, the pressure drops off and the energy in the return system (typically a spring) becomes the dominating force in returning the piston to its original position. Often there may not be sufficient pressure across the diaphragm to prevent wrinkles.

In cases like this, the wrinkles can become creases and the creases can become failure points. This phenomenon is referred to as cornering because of the fold or seam that forms at the failure point.

Guiding the Piston

A diaphragm piston assembly does not normally travel at right angles to its movement axis unless it is well guided. Sometimes during very slow stroke rates the piston may actually appear to wobble. During rapid stroking, the wobble can become disruptive or even a destructive oscillation as one side of the piston tips during its travel. Positive linear stroking of the piston will lead to better system function and longer diaphragm life.

Diaphragms with generous flange, piston, and convolution radii will support an easy rolling action and the wobble should not create any harmful effects on the diaphragm.

Common Causes for Non-Linear Stroking
1. Yarn geometry within the fabric.
2. Return spring not seated or not flat ground.
3. Insufficient bearing support of the piston rod.
4. Spring coil diameter too small for piston.
5. Piston height too low. Does not support the diaphragm sidewall.
6. Convolution width too wide.

Table 10 – Common Causes for Non-Linear Stroking

The Effects of Fabric Geometry

Fabric geometry refers to the type of weave, yarn count, and construction style of the yarns. These characteristics are inherent to any woven fabric. Most fabrics used for diaphragm reinforcement are square woven. Square woven fabrics have the same number of threads in the warp direction (the length of the fabric) as is in the fill direction (the width of the fabric). The yarns also have the same construction and weight.

Formed diaphragms typically have a circular working area. Four directions within the working area will have yarns running straight from the center of the diaphragm to the OD. Fabric being stressed in the direction of these yarns will exhibit little or no stretch (Refer to **Figure 9**).

In the locations 45^o to these straight runs, the yarns are on the diagonal or bias of the fabric. With stress on the bias (Refer again to **Figure 9**), yarns want to divert in the direction of the stress. They become skewed to each other and the fabric elongates. This elongation can be seen as the yarns gather together.

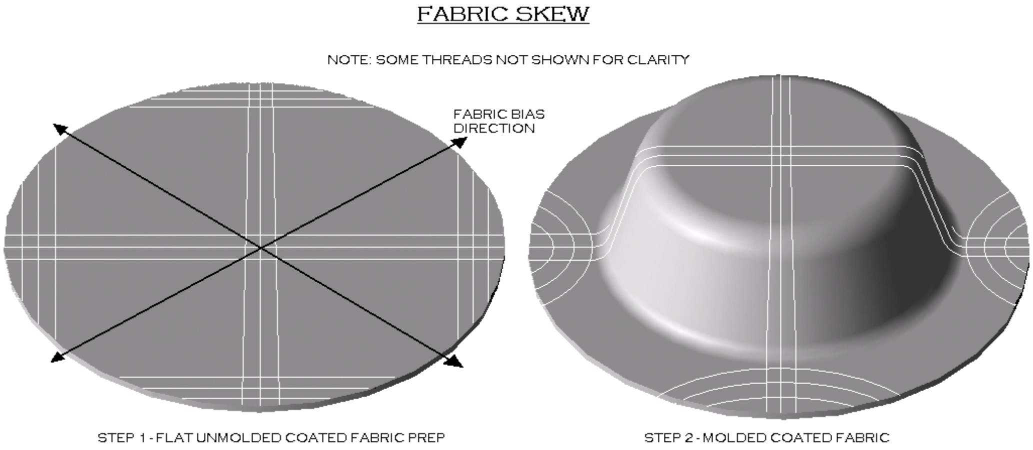


Figure 9 – Fabric Skew Due to Forming

The amount of variable elongation in the diaphragm convolution or sidewall will be directly related to the angular change between the straight yarns and the bias yarns.

A flat reinforced diaphragm will react like a formed diaphragm to the application of stress. Sections of the working area will react and respond differently to the pressure differential. The section with the yarns skewed will appear to bulge, producing a slack, delaying the response to the piston. On the other hand the section with the yarns still at right angles will act immediately upon the piston.

In summary, the material composition within the convolution varies due to the directional nature of the yarns and skewing or distortion of the yarns during molding. Therefore, each individual section reacts differently to pressure when being stroked. This is much more pronounced in large diaphragms and slow acting devices.

The Effective Area of Diaphragms

For all practical purposes, the effective area of a conventional piston device is the area of the piston itself. The clearance between the bore and piston is usually only large enough to contain a compression type seal, i.e. o-ring, packing, etc.

By comparison, a diaphragm device requires a much larger clearance to provide space for the active portion of the diaphragm, the convolution. The convolution bridges the gap between the housing and the piston and functions as a flexible seal.

When an 180° convolution is formed, or if the flange and piston are in the same plane, the effective area is calculated by using the midpoint diameter bounded by the piston and bore (see **Figure 10**). In the absence of the 180° convolution, the effective area would vary from a maximum as defined by the bore diameter, to a minimum as defined by the piston diameter.

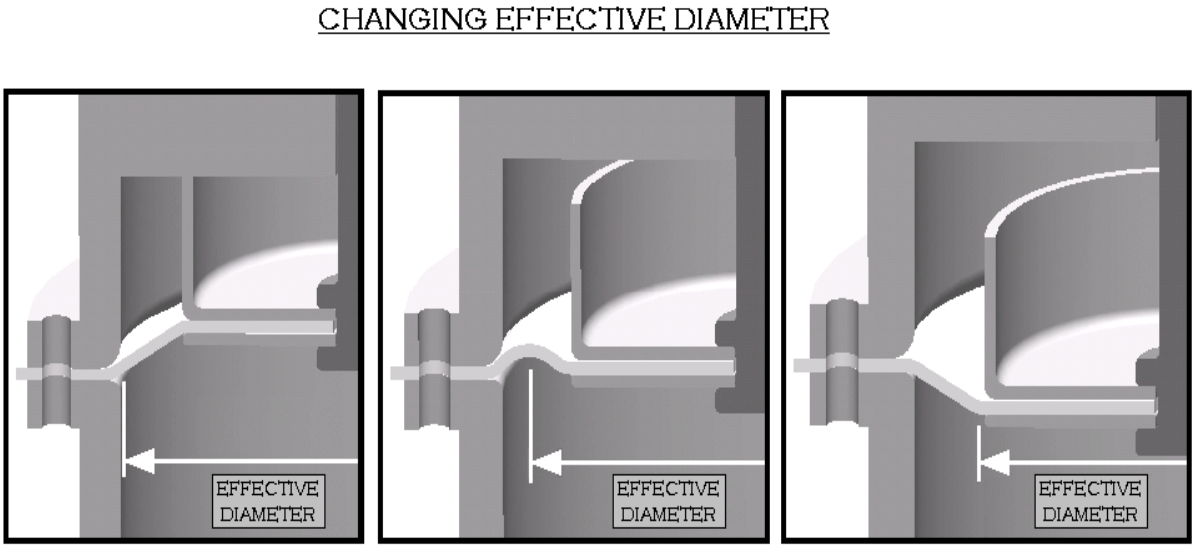


Figure 10 – The Changing Effective Diameter

In the past, considerable emphasis was placed on using diaphragms to produce a constant effective area throughout the useful stroke. With the addition of more convolution height and a narrower piston-bore gap, 180º convolutions could be accomplished. This approach did not produce the most durable diaphragms. The rolling of the material through tight radii at the top of the convolution increases internal friction and raises the potential for compression cracks.

In the final analysis, the maximum area change that could be realized would be the difference in the area of the piston and the area of the bore. Tests on diaphragms with less than an 180º convolution, under light pressure, featured some measurable changes in effective area.

Conversely, these same parts showed no measurable changes when higher pressures were introduced as long as there was some semblance of a curve in the convolution during the stroke.

While a changing effective area can have some negative affect on diaphragms required to be functional at extremely low pressures (inches of water), practical applications have shown that it is often more advantageous to utilize diaphragms with lower, wider convolutions and gentle blending radii to reduce stresses, than to worry about its potential change in effective area.

Devices requiring return springs are one limitation to this approach and this circumstance is further developed in the next section.

Formula 7 – The Diaphragm’s Designed Effective Area

$$Effective\ Area\ (Design) = \left(\frac{Piston\ Diameter + Cylinder\ Diameter}{4} \right)^2 \ x \ \pi$$

The Effects of The Return Spring

In most diaphragm applications a return spring is used in the assembly to ensure that the diaphragm resets itself to its home position. During a typical assembly the spring is compressed slightly against the piston adding a preload. This compression creates a slight negative force on the diaphragm requiring a pressure greater than the preload to move it. The influence of this preload on the diaphragm is a reduction in the net effective area.

This change in effective area caused by the return spring far exceeds anything achievable by the diaphragm alone. Additionally, the potential energy within the spring is responsible for a major share of the hysteresis in the diaphragm device. This issue can be especially troublesome on diaphragm devices required to function at very light pressures (inches of water).

Diaphragm Strength Requirements

In determining the amount of force the diaphragm will have to tolerate, keep in mind any springs or additional forces that have to be overcome. These forces may have to be estimated but they must be added to the primary requirements.

Along with any additional forces, the designer must keep in mind the space available for the application hardware and its effect on the size of the diaphragm. If space is severely restricted, the system pressure may have to be increased to allow for the diaphragm to properly actuate in the application. Increasing the pressure will impact the tension and burst requirements of the convolution and its fabric reinforcement.

The tension of the convolution sidewall is dynamic during the diaphragm's stroke phase, as was demonstrated in **Figure 8** as point A moved to point A^2. For calculating the sidewall strength requirements we will concentrate on the worst-case scenario, which is when the diaphragm has reached the end of its stroke capability and the diaphragm material stops the motion of the piston – which is ***not*** recommended (**see Figure 11**).

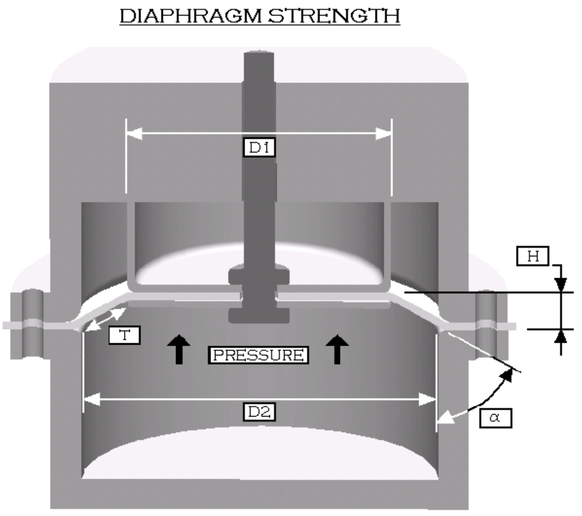


Figure 11 - Diaphragm Strength - Assembly Illustration for ***Formula 8***

In this worst-case scenario, the total sidewall tension is made up of two components:

1) The tension prompted by the pressure acting upon the piston portion to the system.
2) The tension generated by the pressure acting on the convolution area.

The forces are converted to the peripheral $\left(\frac{lbs.}{in}\right)$ for each area and added.

Formula 8 – Calculating Sidewall Tension

$$Total\ Tension(T) = \frac{.25\,P}{COS\ \alpha} + \left(D_1 + \frac{\left(D_2^{\ 2} - D_1^{\ 2}\right)}{D_2}\right) = \frac{Lbs.}{in}\left(of\ \ Bore\,Circumference\right)$$

*Where: D_1 = the piston diameter in inches, D_2 = the bore diameter in inches, P = the pressure in PSI, and a = the angle of the sidewall **from the vertical***

Note:

$$\alpha = Tan^{-1}\left(\frac{\left(\frac{(D_2 - D_1)}{2}\right)}{h}\right) where\ h\ is\ the\ height\ of\ \ the\ convolution\ at\ \max\ stroke$$

Formula 9 – The Diaphragm's Designed Burst Pressure

$$Burst\ \Pr essure\ (Design) = \left(\frac{Fabric\,Tensile\ x\,2}{Convolution\,Width}\right)$$

For most applications the designed burst pressure should be at least 4 times the expected working pressure of the application.

Positive Stops

To ensure that the diaphragm never sees the kind of destructive tension noted in the previous section, a positive stop (see **Figure 12**) should be incorporated into the system. Positive stops are design to prevent the diaphragm material from acting as a brake for the piston's movement and thereby helping to increase the diaphragm's cycle life.

Stops can also be added to a portion of the assembly outside of the diaphragm chamber, such as on the piston rod.

Positive stops should be added to both sides of the piston for double acting diaphragm systems.

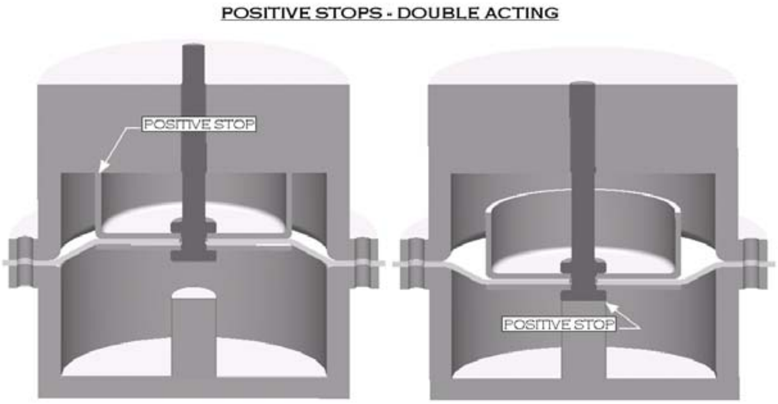


Figure 12 – Two Types of Positive Stops

Residual Stresses

There are additional issues that come under the mantle of stresses that are not part of design problems. Such issues are encountered by the fabricator of the diaphragms and can be classified as residual stresses. These stresses often manifest themselves as distorted parts. **Table 11** shows some of the common causes for residual stresses.

While it is the responsibility of the manufacturer to deal with these issues, they need to be considered by all parties, as they can be a result of diaphragm shape, the manufacturing process required or the application's required elastomer and fabric combination.

Common Causes for Residual Stresses
1. Hot creased parts.
2. Uneven draw of fabric in preforming or molding.
3. Old or nervy compound
4. Excessive precure time on coated fabric or compound.
5. Excessive post-curing of parts.
6. Molded at too high a pressure, or mold overloaded with compound.
7. Bad packaging.
8. Under cure of the rubber.

Table 11 – Common Causes for Residual Stresses

Enhancements for Improving Stroke Life

Attention to design detail can greatly enhance the stroke life of a diaphragm. Keeping the mating parts as smooth as possible will offer some of the greatest gains. All mating hardware surfaces should be no rougher than 32 micro inches and in high-cycle applications a 16 micro inch surface is recommended. Lubricating the moving surfaces of the diaphragm with molybdenum disulfide or the piston with Teflon^{TM}

prior to assembly can also help reduce abrasion and increase stroke life.

Three additional keys to stroke life longevity are:

1) Making sure that the piston assembly is well guided (as previously noted) to minimize cocking or wobble (see **Figure 13**).
2) Ensuring that the system is properly vented or that the change in pressure direction across the diaphragm is such that it eliminates the possibility of backpressure and the resulting reversal of the convolution (see **Figure 14**).
3) Eliminating circumferential compression of the convolution.

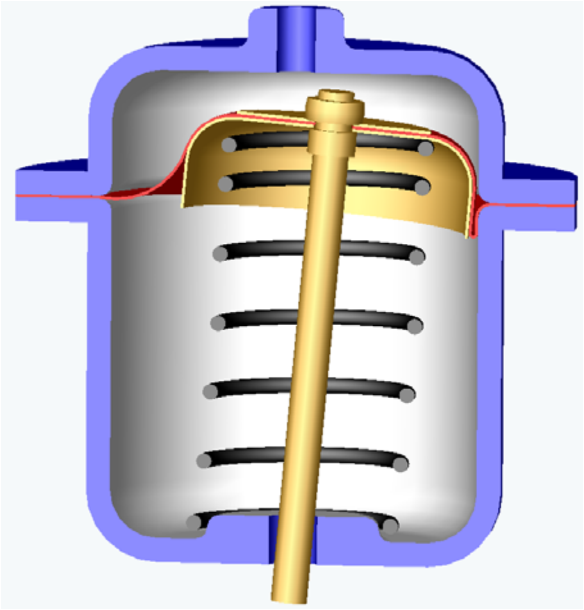


Figure 13 – Effects of a Cocked Piston

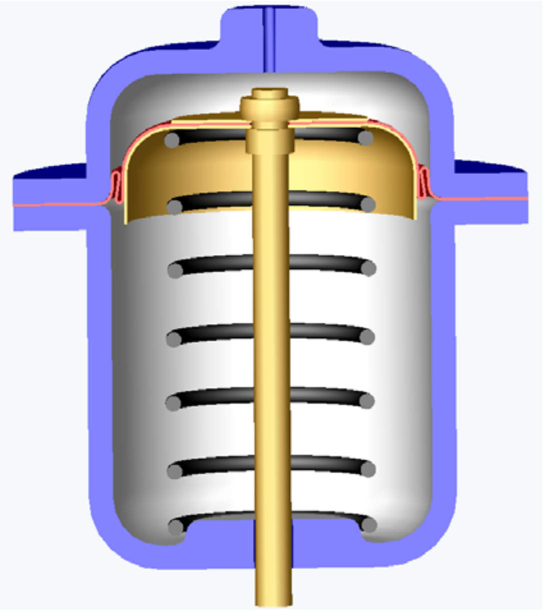


Figure 14 – Effects of Reversed Pressure

Circumferential Compression

Circumferential compression results from the larger convolution diameters being compressed around the smaller diameters of the piston. This compression causes folds in the convolution and this continual action of forming and un-forming these folds will eventually cause the fabric, and ultimately the diaphragm, to rupture.

The tell tale sign of this problem is often referred to as cornering or “four cornering,” as diaphragms that are experiencing circumferential compression in their convolution or sidewall will often exhibit four equally spaced folds.

Circumferential compression typically occurs in the longer stroke, top hat style diaphragms. Two ways to lessen the circumferential compression effect are:

1) Lower the stroke requirements so that a convoluted diaphragm can be used (in the down-stroke direction only).
2) Use a double tapered diaphragm (see **Figure 7** in the **Diaphragm Styles** section).

Please also review the **Diaphragm Convolution (Sidewall) Action** section of this manual for additional insight into this phenomenon.

Piston Design Criteria

Size

In sizing the piston for your application the initial assumption should always be that the required effective system diameter is the piston outside diameter. This approach will help compensate for the energy loss due to internal friction within the system itself. It also eliminates some of the messy issues associated with a fluctuating effective area (see the section on **Effective Area**).

Length (Piston "Skirt")

When considering the length of the piston, often referred to as the piston skirt, the designer must keep in mind the movement of the convolution during the stroke cycle. While almost any skirt length may work in principle, best design practices call for the skirt to be long enough to support the convolution during all phases of the stroke cycle (reference **Figure 15**). At no time should the convolution be able to expand or move beyond to top edge of the skirt.

Extending the length of the skirt can also offer the designer one option for a positive stop, which will help protect the diaphragm from over stroke (reference **Figure 16**).

Formula 10 – The Piston Skirt Length for Best Diaphragm Support

$$Piston\ Skirt\ Length = \left(\frac{Convolution\ Height + Half\ \ Stroke}{2} \right)$$

Shape

Most applications will call for a round piston with a piston skirt, designed to support the diaphragm's sidewall throughout its stroke length (reference **Figure 15**). To ensure a proper fit, the radius on the base of the piston must match the piston radius of the diaphragm.

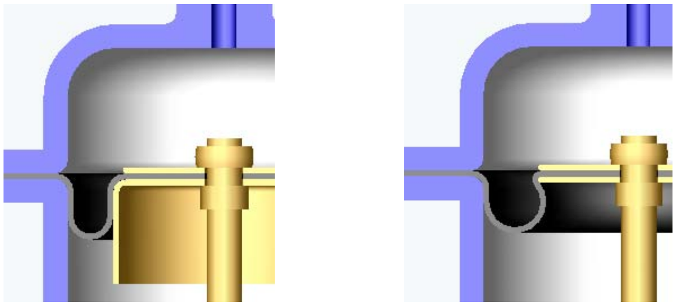


Figure 15 – Proper Piston to Convolution Support vs. Poor Support

Please refer to the part figures in the **Diaphragm Styles** section of this design guide for the location of the diaphragm's piston radius.

In cases where a special piston shape may be required, please consult with our team of diaphragm design engineers for the optimum shape and attachment method.

The Care and Housing of Diaphragms

As noted in the manual's introduction, the hardware that captures and surrounds the diaphragm is as important to the success of the application as the elastomer, fabric, and geometry. These surrounding or mating parts must be compatible with the diaphragm in every way; otherwise performance and cycle life will suffer.

First and foremost all hardware that contacts the diaphragm must be as smooth as possible and burr free (see the section on **Enhancements for Improving Stroke Life**).

The second most important requirement is that all mating hardware match the diaphragm's geometry and capture it in such a way as not to distort it while allowing for free movement of the convolution. Any induced distortion in the diaphragm can affect the rolling action of the convolution, add additional stresses or create wrinkles.

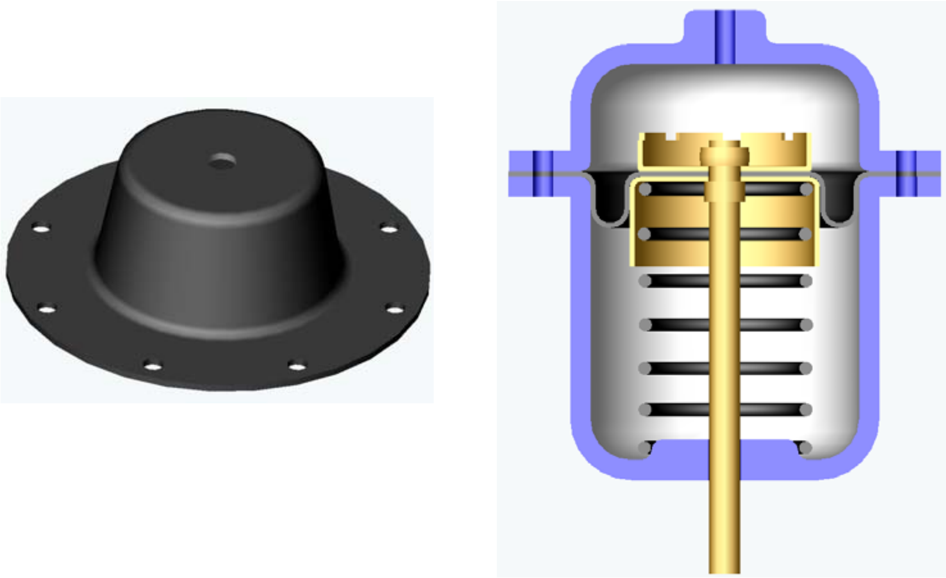


Figure 16 – A Typical Deep-Draw Diaphragm Assembly with a Return Spring and Positive Stop

To minimize distortion during assembly, some consideration should be given to using jigs and fixtures to compress return and / or balance springs, align housing halves and support the diaphragm. One method of rendering support to the diaphragm during assembly would be to inflate it with a steady stream of low-pressure air.

If the method of housing assembly includes screwing one piece of hardware into another with the diaphragm captured between them, some form of thrust washer should be considered to eliminate any twist or wrinkling.

This hardware and assembly discussion is further expanded on in the section titled **Flange Sealing**.

Transition Radii

The transition radii are the features on the diaphragm that help define the shape of the convolution by connecting it to the flange and the piston surfaces. For all practical purposes these radii should never be less than .015".

As with all hardware surfaces, the corresponding radii on the hardware must also be the same as those on the diaphragm and must be as smooth as possible.

Please reference **Figures 2**, **3**, **4**, and **6** along with **Tables 6**, **7**, and **9** for illustrations and recommended sizes of transition radii.

Assembly Issues

Material Compression

One of the more reoccurring causes for diaphragm failure and poor performance can be attributed to the compression of the diaphragm during assembly. Proper compression is required to affect a long lasting seal in both the piston and flange areas.

The typical failure modes are over-compression, leading to flex failure, or under-compression, leading to leakage. The root cause of the problem stems from the difficulty in controlling the compression on the diaphragm's sealing surfaces during assembly.

The elastomer portion of the diaphragm can only support a limited amount of compression. In an over-compression situation the assembly load exceeds the compression resistance of the elastomer and extrudes elastomer out to unclamped areas of the diaphragm.

In an under-compression situation, the assembly load is too light and does not approach the normal compression limit of the elastomer for an effective seal.

The challenge facing the designer is the difficulty in determining what the proper loading should be for their particular application. Further exacerbating the loading issue is the effect of temperature and / or fluid on the compression set properties of the elastomer (see the section on the **Effects of the Application Environment** for more details).

To maintain a stable compression set and therefore a proper seal the loading capacity of the elastomer must not deteriorate.

Due to the wide variety of applications and available elastomers, it is often necessary to do a cut-and-try method. In order to arrive at an appropriate amount of flange compression via this method:

1) The material must be tested while under compression
2) Various temperatures must be tried
3) Several suitable contact test fluids must be used

In the past designers attempted to solve compression related sealing issues by designing thicker parts (see **Design Guideline – The Ideal Diaphragm Thickness** at the beginning of this section for more on this point).

Assembly Specific Issues

Screwed and Bolted

If screws or bolts are planned for holding the assembly together, a torque requirement will have to be determined in order to produce the optimum loading. Here again, the cut-and-try method may be the best development alternative.

Any perforations through the diaphragm used for attaching hardware (flange or piston) should be located such that there is at least .100 to .125 inches of material between the edge of the perforation and the next hole or trim edge.

It is equally important to keep the mounting perforations away from the flange or piston corner radii to improve clamping seal and reduce the opportunity for potential leaks. As a starting point the minimum distance should be .100 to .125 inches at pressures less than 50 psi and increase as pressures increase.

Please refer to **Figure 17** and **Table 11** for additional information on minimum sealing area for bolted piston and flange hardware.

Max System Pressure (psi)	0 - 50	51 - 150	151 - 300	301 - 500
Minimum Sealing Area **(length from radius to perforation in inches)**	.100	.150	.200	.250

Table 12 – Minimum Clamp Area for Bolted Pistons and Flanges

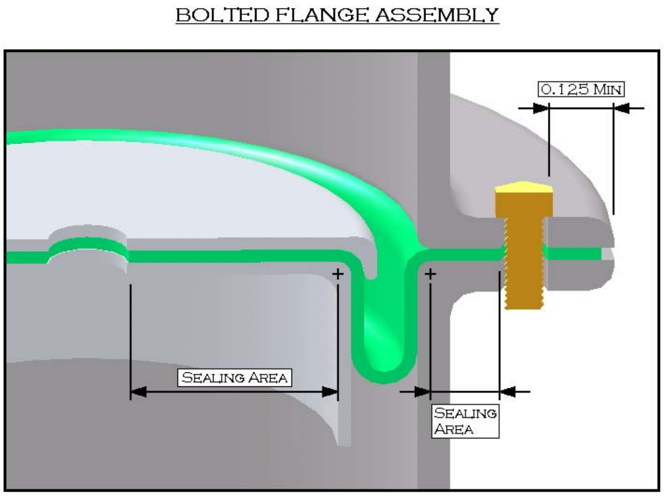


Figure 17 – Clamp Area for Bolted Pistons and Flanges

Additional Styles

These same compression issues and solution approaches apply to all other forms of hardware assembly such as crimped, swaged and spun metal parts as well as sonic welded, glued or snap fit plastic parts.

Please feel free to contact Simrit's Engineering Group to discuss these and other methods for proper diaphragm capture in your assembly

Typical Assembly Challenges and Suggested Solutions

1) **Bending of the material in the flange between the bolts**. Adding more bolts, thus reducing the distance between them, can usually make a correction. Increasing the thickness in the hardware flange material will also reduce the amount of distortion.

2) **Distortion of the flange material around the boltholes**. Lightweight sheet-metal designs lend themselves to this type of distortion. This is usually caused by excessive force applied to the bolts. Lightening up on the bolt torque and / or increasing the thickness in the hardware flange material will help.

3) **Non-parallel Flanges (Cocking or Warpage)**. Often caused by uneven bolt loads. Bolt tightening should be done sequentially, uniformly loading the flange prior to final tightening.

   Flange surfaces might require machining to bring them into parallel.

   Plastic housings and covers are very apt to exhibit warpage as a result of varying wall thicknesses.

4) **Surface Roughness**. In most cases the commercial finishes should not present a sealing problem. However, an exceptionally hard elastomer material might not conform to the rough surface. One option to overcome this issue would be to heat the diaphragm under a heat lamp before assembly; enough to soften it so it will better conform to the flange surfaces.

   Another option would be to use a gasket material in conjunction with the diaphragm.

Sealing Issues

Gaskets and Gasket Lamination

There are types of diaphragms made from very thin coated fabric that incorporate a fibrous gasket material bonded to the flange for improved sealing.

Simrit specializes in bonding or laminating gasket materials to diaphragms. Three advantages of this approach are:

1) Improved sealing
2) Improved assembly
3) Inventory reduction for the customer

A typical construction is shown in **Figure 18**. Gasket materials are available in Rubber, Cork/Rubber, Cork Composition, Cellulose/Rubber, and High Performance Fiber/Rubber.

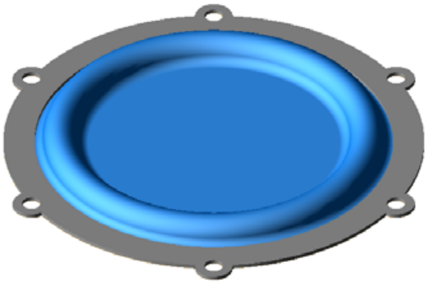


Figure 18 – Gasketed Diaphragm

Beads

Beaded diaphragms have been available to the designer for some time and are widely used. This discussion will center on the beads used to seal the flange.

Beaded diaphragms became popular with the advent of molded plastic hardware. In fact, beaded diaphragms became almost a necessity. Plastic parts present unique challenges in realizing effective seals. Surfaces are apt to be wavy with depressions due to non-uniform thickness and distortion upon cooling as the plastic material typically shrinks in a non-uniform manner.

Under these conditions flat-flanged diaphragms often do not have enough elastomer thickness to compensate for the irregularities of the housing. Machining the plastic parts to remove the irregularities is not practical and defeats the purpose of using plastic in the first place.

The Three Most Common Types of Bead Failures:
1. Not enough compression, which can result in flange leakage.
2. Over compression which can cause a cut in the bead or the diaphragm.
3. Over compression can cause the bead material to flow back into the diaphragm convolution causing increased stress and potential premature failure.

Table 13 – The Three Most Common Types of Bead Failures

The second challenge to flange sealing with plastic hardware involves the high coefficient of expansion and contraction of the plastic materials. At temperature extremes the materials change in dimension and possibly even in shape. Add in the thermal and fluid effects on the rubber compound and sealing issues become very involved.

The obvious solution is to add a bead to the flange area of the diaphragm. The bead functions as an O-ring seal where having a small contact surface can affect a seal with high unit loading while imparting a low strain on the assembly hardware.

While the primary function of the bead is to seal the diaphragm to the housing, some feel that it offers a degree of confidence in preventing diaphragm pull out. This is true to some extent, but pullouts are generally the result of over clamping, crushing and / or fabric-to-rubber adhesion failure.

For optimum sealing the beads should be placed on the pressure side of the diaphragm thus enabling the system pressure to assist in sealing the bead.

Advantages of Tear Drop Beads:
1. Provides for a more even draw of the fabric onto the diaphragm. While smoothing out possible wrinkles, it also aids in keeping the fabric in place within the part.
2. Provides for a positive location of the part in the trim die, which controls the concentricity.
3. Provides for backpressure in the mold to allow positive flow of the rubber and flushes out trapped gasses in the bead.

Table 14 – Advantage of Tear Drop Beads

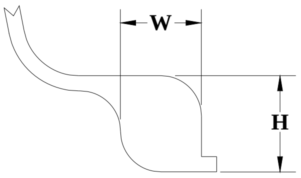
Bead Profile

While the most common bead shapes are circular or shaped like a "D", Simrit recommends a bead design known as the Tear Drop (see **Figure 19** and **Table 15**). This design allows for the flash point to be above or below the flange plane, unlike the circular, which flashes in the middle or the "D" bead which flashes at the bottom.

This flash point difference is critical in improving the quality of the bead fill and reducing bead flash. Improved fill means less trapped air in the bead making a more homogeneous compression feature. Less flash means fewer assembly issues due to excessive flash extension.

Cylinder Diameter (CD)	.25" / .99"	1.00" / 2.50"	2.51" / 4.00"	4.01" / 8.00"	8.01" & Up
Bead Width	.094"	.125"	.187"	.250"	.250"
Bead Height	.095"	.135"	.200"	.270"	.270"

Table 15 – Suggested Bead Dimensions



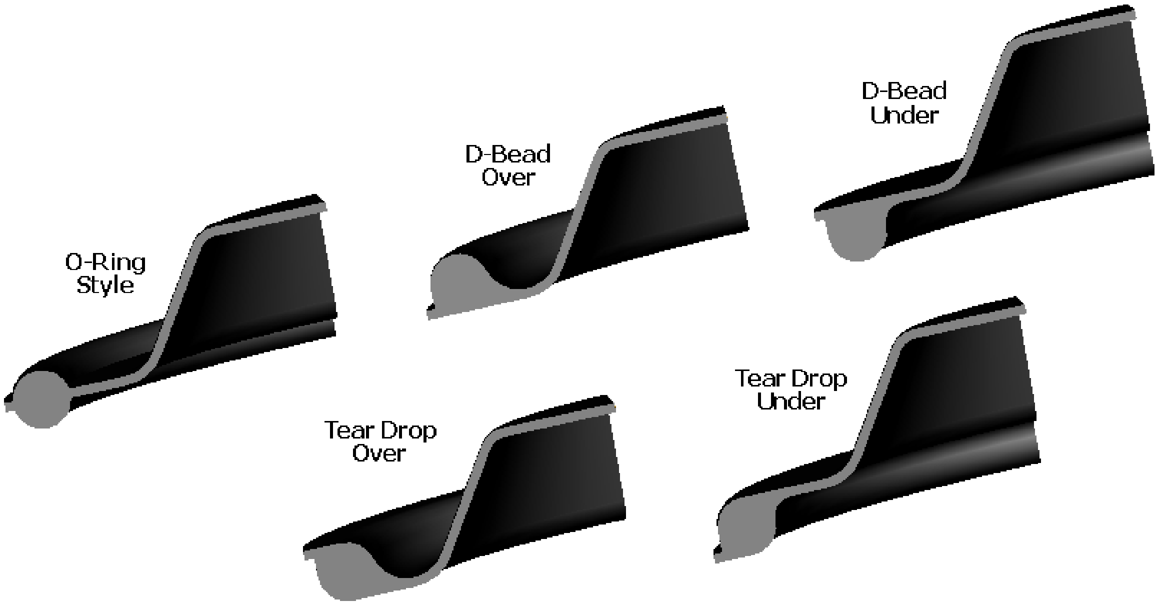


Figure 19 – Typical Sealing Bead Styles

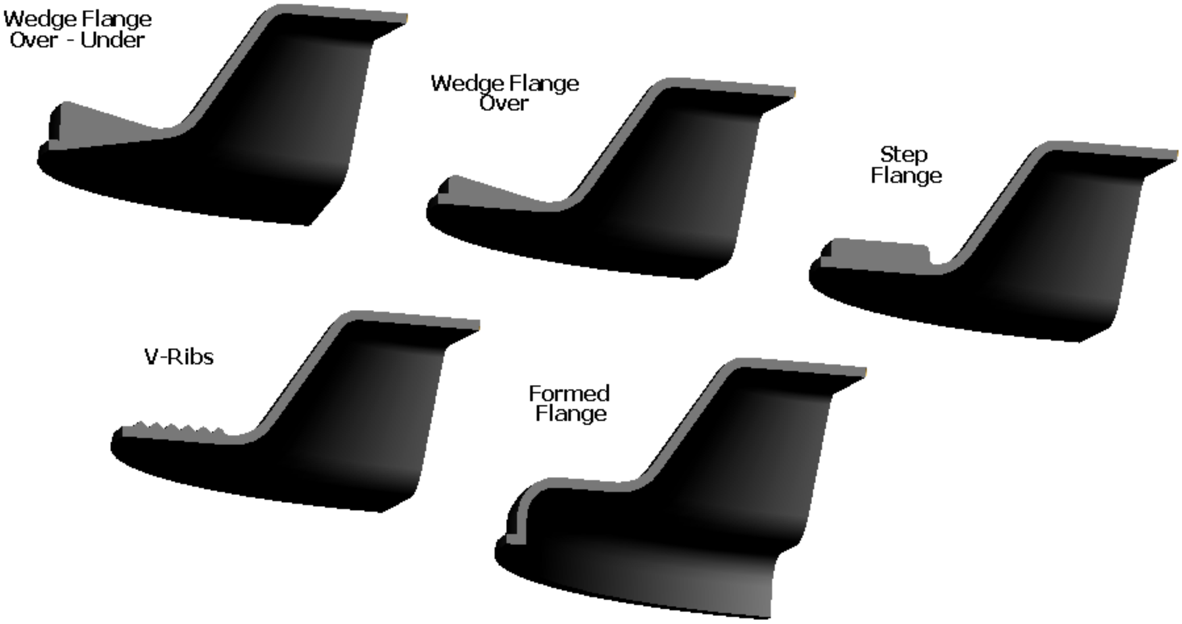


Figure 20 – Alternate (Non-bead) - Flange Sealing Styles

Figure 20 offers some additional flange sealing options if a bead is not desired or required. Still other "bead" or flange sealing styles can be made depending on overall design, construction and application of the diaphragm. Please consult with the Simrit Engineering Department for further details.

Bead Groove Design:

Regardless of shape, to affect a proper seal the bead requires a correctly sized corresponding receiver, often referred to as a bead groove, in the assembly hardware. The bead groove must not only be positioned properly it must also make provision for the displacement of the elastomer during assembly compression.

Beads should fit snugly against the inner wall of the bead groove. Rubber does not change in volume and flows when compressed assuming the shape of the bead groove.

Designing the diaphragm’s bead to fit against the inner bead groove wall will help in centering the diaphragm during assembly and remove the possibility of interference from any OD flash.

The rubber must be contained within the groove and not allowed to extrude into the working area. There might be a concern that the diaphragm will pull out under these conditions; it is highly unlikely if the diaphragm is not pulled taut. A clearance must be maintained between the groove lip and the diaphragm allowing the pressure to assist in sealing around the bead.

Figure 21 and **Table 16** offer some guidelines for sizing a proper bead groove for typical applications. Please note the use of the positive stop to control the bead compression. For custom applications, contact the Simrit’ Engineering Group for guidance.

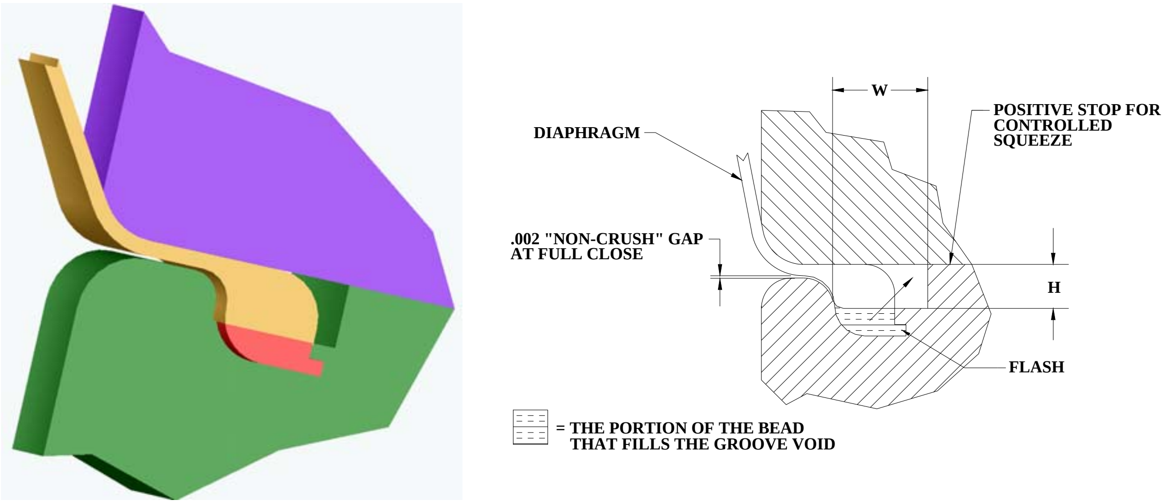


Figure 21 – Bead Groove Sealing Issues

Design Guideline – Bead Compression

25% +/- 5% compression on the bead is the recommended starting point. Higher compression may be required for higher modulus compounds or higher system pressures and visa versa for lower modulus and lower system pressures.

Cylinder Diameter (CD)	.25" / .99"	1.00" / 2.50"	2.51" / 4.00"	4.01" / 8.00"	8.01" & Up
Bead Groove Width	.109"	.141"	.219"	.281"	.281"
Bead Groove Height	.076"	.105"	.160"	.224"	.224"
Flange Corner Radius	.031"	.063"	.094"	.125"	.125"
Piston Corner Radius	.031"	.063"	.094"	.125"	.125"
Groove Lip Width	.062"	.125"	.187"	.250"	.250"
Groove Lip Clearance	Flange Area Thickness + .005"	Flange Area Thickness + .005"	Flange Area Thickness + .005"	Flange Area Thickness + .005"	Flange Area Thickness + .005"

Table 16 – Dimensional Guidelines for Bead Grooves

Solutions for Special Sealing Problems

Sometimes putting holes in what is supposed to be a non-permeable seal for piston hardware attachment will conflict with application requirements for zero potential leak paths. In situations like these, Simrit offers several sealing solution constructions that can give your diaphragm enhanced protection against these potential leak paths.

One sealing solution option is to bond an insert to the diaphragm to act as a piston or as an attachment platform while still maintaining a non-permeable surface. Inserts such as these are typically made of plastic or metal and can range from simple flat disks to complex machined components. In general, these types of bonded inserts are limited only by the temperatures and pressures of the molding process.

Insert bonding can be accomplished in multiple ways depending on the specific need for the application. One option is to chemically attach the insert during the vulcanizing process using an adhesive. Another option would be to develop a cohesive bond between elastomer and insert through molecular attraction such as can be seen between sulphur cured Nitrile elastomers and brass inserts. A third option is to mechanically attach an insert to the piston area of the diaphragm by allowing the elastomer to flow around and through it during the molding process and encapsulating it.

Bonded inserts offer some additional benefits as they can aid in the assembly process by reducing or eliminating costly assembly steps as well as eliminate the need to purchase and inventory multiple components.

A second sealing solution option Simrit offers are diaphragms clad with a barrier material which can reduce vapor permeation through the diaphragm, enhance the diaphragm's temperature handling capabilities and offer an "FDA approved" surface on an otherwise "non-FDA" seal. An example of a barrier clad diaphragm is a PTFE foil or facing on the fluid side of a chemical pump diaphragm. This will enable the diaphragm to withstand harsh chemicals while still maintaining its flexibility and low hysteresis.

There are some occasions where the diaphragm's geometry coupled with the mating hardware geometry makes joining the two during the molding process very difficult if not impossible. In situations like these, Simrit has field proven, leak resistant sealing solutions comprised of mechanically or chemically attaching hardware to the diaphragm in a post molding operation. As in the case of the bonded inserts, the need to purchase, inventory, and assemble additional components is eliminated.

As there are a wide variety of combinations relative to the sealing solutions outlined in this section, you are encouraged to contact the Simrit diaphragm engineering group to see what is available for your particular application.

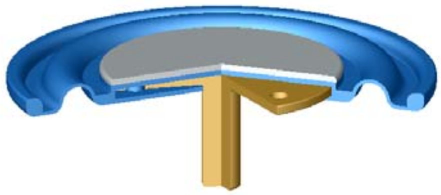
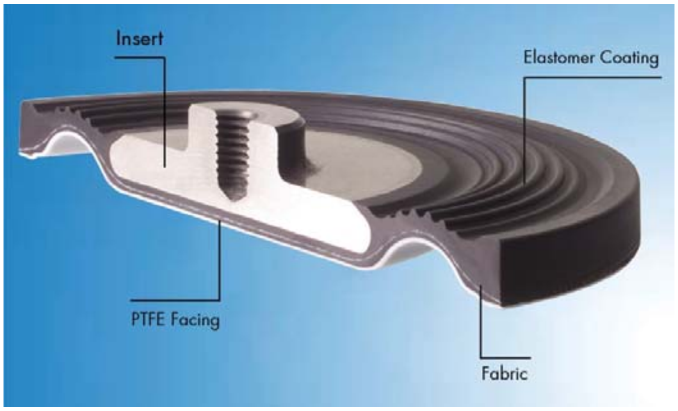


Figure 22 – Example of a Diaphragm with a Bonded Piston



Effects of the Application Environment

Thermal Conditioning of Elastomers

For the most part, rubber compounds react in a predictable manner. As the temperature rises, the molecular activity within the elastomer increases. In terms of chemical resistance, this means that the elastomer will swell at a greater rate (see **Chemical Conditioning of Elastomers**). The flexibility of the elastomer also increases at elevated temperatures, which can be advantageous if the diaphragm is still capable of sealing.

On the other hand, low temperatures will not necessarily reduce swelling, but will greatly affect flexibility and response. Therefore, allowable changes in the response rate of the device from room temperature to the lower temperature limit must be considered. Many elastomers achieve their flexibility, especially low temperature flexibility, from the addition of plasticizers. Plasticizers are substances that soften other substances through solvent action. Neoprenes and nitriles are typical examples of plasticized rubbers.

Another important point for consideration is the effect of high temperature operations on the low temperature functioning of the diaphragm. High temperatures will volatilize many plasticizers out of the elastomer, leaving the diaphragm with a higher modulus (greater stiffness) thus requiring more energy to activate it. The loss of the plasticizers may also cause the diaphragm to shrink, which may affect its fit, function and life. To evaluate the diaphragm realistically all low temperature testing should be done only after the diaphragm has had some high temperature exposure.

Chemical Conditioning of Elastomers

The chemicals diaphragms come in contact with can also have the same general effect on the elastomers at high temperatures — they too can extract plasticizers.

Studies have shown that during use, fuels, oils and other chemicals often replace the elastomer's plasticizers, giving greater flexibility to the elastomer at lower temperatures.

However, when the chemicals or fuels evaporate, causing a dry-out condition, it is often very difficult, if not impossible, to replasticize the elastomer just by bringing it back into contact with the same chemical or fuel.

Relying on the absorbed chemicals or fuels to solve the low temperature problem is not a recommended practice and is discussed here for informational purposes only.

Tolerances

Due to the interplay between dimensional tolerances and stresses (residual and otherwise), our discussion on diaphragm design criteria would not be complete without an overview of diaphragm tolerancing.

Design Guideline - Form, Fit, and Function

In today's quality environment, the designer is often forced to choose tolerances that convey the critical nature of their application. While Simrit is always striving to develop new ways to make consistently better products, the nature of rubber with fabric reinforcement precludes the use of machining style tolerances.

In an effort to keep the cost of quality in line with the diaphragm's application, we offer the following questions for the designer to consider as they develop their diaphragm geometry:

1) Is the final product the right shape to do the job?
2) Does it fit properly in the hardware without distortion?
3) Does it function within the desired design parameters of the assembly?

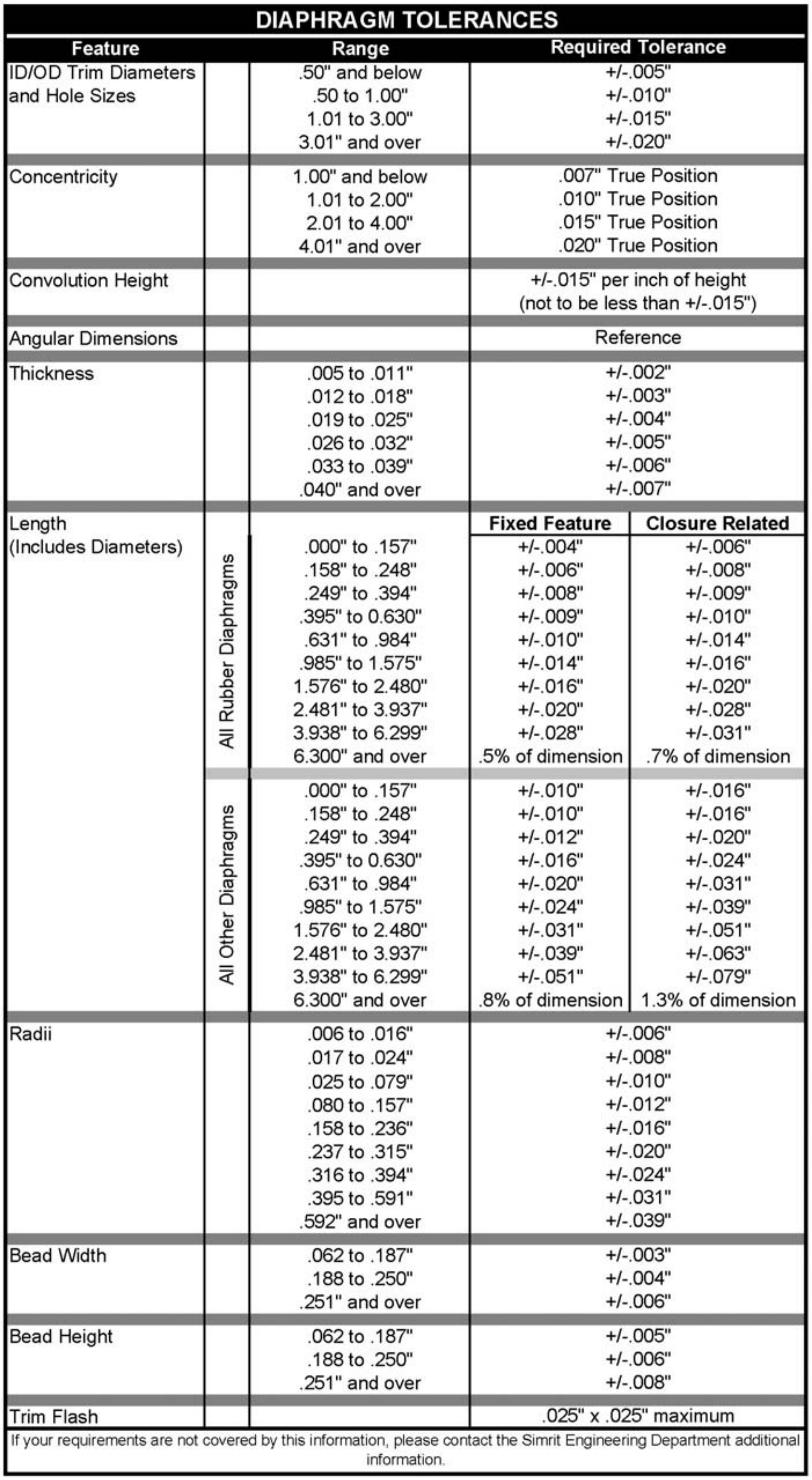
There **must** be a clear understanding between all involved as to acceptable dimensions and how they are to be verified.

Diaphragms made via a one side coated process and coated fabric diaphragms have differing tolerance requirements. Both have their greatest tolerance needs in relation to the height of the convolution, especially those made from cured coated fabric. When it comes to cross-sectional thickness, coated fabrics can generally hold tighter tolerances on this and other closure related dimensions.

The wide variety of situations and applications precludes a detailed discussion on the dimensional tolerancing of diaphragms, but please review **Table 17**, which list tolerance standards for all of the typical diaphragm requirements.

Please also see **Technical Flyer Page 60– Tolerances of Fabric Reinforced Diaphragms** for additional insight into this topic.

Should you feel that your situation is not covered by the information contained herein, the Simrit Engineering and Quality Groups will be happy to discuss all options available for your intended application.



DIAPHRAGM TOLERANCES

Feature		Range	Required Tolerance	
ID/OD Trim Diameters and Hole Sizes		.50" and below	+/-.005"	
		.50 to 1.00"	+/-.010"	
		1.01 to 3.00"	+/-.015"	
		3.01" and over	+/-.020"	
Concentricity		1.00" and below	.007" True Position	
		1.01 to 2.00"	.010" True Position	
		2.01 to 4.00"	.015" True Position	
		4.01" and over	.020" True Position	
Convolution Height			+/-.015" per inch of height (not to be less than +/-.015")	
Angular Dimensions			Reference	
Thickness		.005 to .011"	+/-.002"	
		.012 to .018"	+/-.003"	
		.019 to .025"	+/-.004"	
		.026 to .032"	+/-.005"	
		.033 to .039"	+/-.006"	
		.040" and over	+/-.007"	
Length (Includes Diameters)			**Fixed Feature**	**Closure Related**
	All Rubber Diaphragms	.000" to .157"	+/-.004"	+/-.006"
		.158" to .248"	+/-.006"	+/-.008"
		.249" to .394"	+/-.008"	+/-.009"
		.395" to 0.630"	+/-.009"	+/-.010"
		.631" to .984"	+/-.010"	+/-.014"
		.985" to 1.575"	+/-.014"	+/-.016"
		1.576" to 2.480"	+/-.016"	+/-.020"
		2.481" to 3.937"	+/-.020"	+/-.028"
		3.938" to 6.299"	+/-.028"	+/-.031"
		6.300" and over	.5% of dimension	.7% of dimension
	All Other Diaphragms	.000" to .157"	+/-.010"	+/-.016"
		.158" to .248"	+/-.010"	+/-.016"
		.249" to .394"	+/-.012"	+/-.020"
		.395" to 0.630"	+/-.016"	+/-.024"
		.631" to .984"	+/-.020"	+/-.031"
		.985" to 1.575"	+/-.024"	+/-.039"
		1.576" to 2.480"	+/-.031"	+/-.051"
		2.481" to 3.937"	+/-.039"	+/-.063"
		3.938" to 6.299"	+/-.051"	+/-.079"
		6.300" and over	.8% of dimension	1.3% of dimension
Radii		.006 to .016"	+/-.006"	
		.017 to .024"	+/-.008"	
		.025 to .079"	+/-.010"	
		.080 to .157"	+/-.012"	
		.158 to .236"	+/-.016"	
		.237 to .315"	+/-.020"	
		.316 to .394"	+/-.024"	
		.395 to .591"	+/-.031"	
		.592" and over	+/-.039"	
Bead Width		.062 to .187"	+/-.003"	
		.188 to .250"	+/-.004"	
		.251" and over	+/-.006"	
Bead Height		.062 to .187"	+/-.005"	
		.188 to .250"	+/-.006"	
		.251" and over	+/-.008"	
Trim Flash			.025" x .025" maximum	

If your requirements are not covered by this information, please contact the Simrit Engineering Department additional information.

Table 17 – Dimensional Tolerance Guidelines for Diaphragms

Glossary of Terms

Diaphragm Related

As-Molded Position – Refers to the molded shape of a diaphragm. This shape is typically determined by the system assembly requirements and or the diaphragm stroke requirements.

Bead & Groove – The bead is a raised rubber ridge around a portion of the diaphragm (usually and ID hole or the OD trim) for the purposes of enhancing the seal. The groove is that portion of the hardware that accepts the bead and compresses it for the seal.

Bias of the Fabric – The direction 45° to the weave of the fabric.

Bleed through – Refers to the movement of fabric – shown in red in **Figure 23** below - toward the pressure side of the diaphragm during the molding operation. This type of fabric movement can expose the fabric to pressure, potentially causing a leak path from one side of the diaphragm to the other.

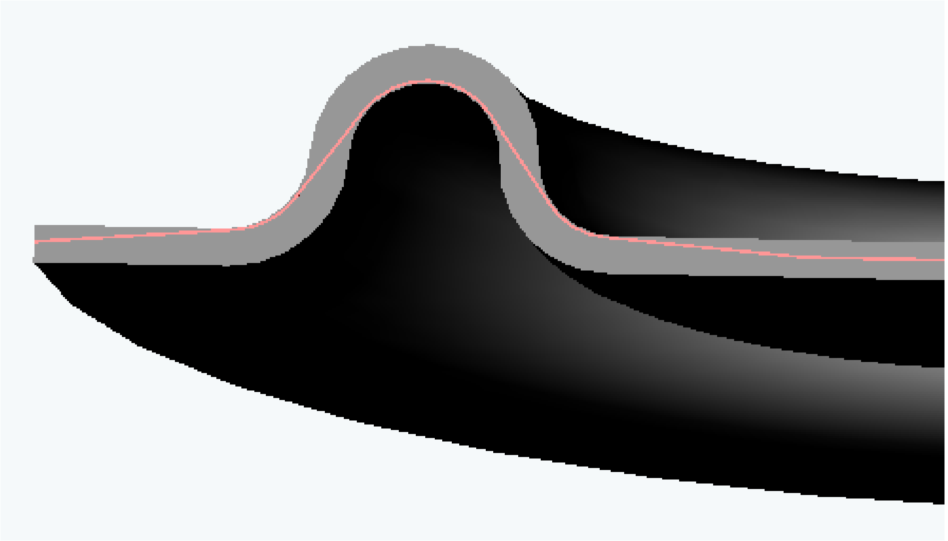


Figure 23 – Fabric Bleed Through

Bore – See **Cylinder Diameter**.

Convolution – The portion of the diaphragm that is available to flex or move.

Convoluted Diaphragm – Conversely to a Top Hat Diaphragm, a convoluted diaphragm has a molded in convolution and requires no hand shaping of the convolution before installation.

Convolution Width – This is the distance between the inside diameter of the bore and the outside diameter of the piston.

Cornering – A fold or gathering of material within the convolution. The fabric weave, hardware, diaphragm shape or slack material can cause this phenomenon. Cornering normally results in failures that look like cuts perpendicular to the flange.

Figure 24 – Cornering

Curl – A lifting at the OD of the diaphragm due to unbalanced coating in the coated fabric.

Curved Lip Retainer – See **Piston Cap**.

Cylinder Diameter (Bore) – The inside diameter of the cylinder used to define the maximum, or outside, diameter of the convolution.

Cylinder Radius – The transition radius between the flange and the cylinder wall.

Dish Diaphragm – This diaphragm shape refers to a shallow Top Hat Diaphragm. A dish diaphragm is often used in applications where a stroke requirement cannot be satisfied by a flat cut diaphragm.

Drop Center Diaphragm – This diaphragm shape is similar to a Convoluted Diaphragm but its piston area surface is located above or below the flange plane to assist assembly, stroke or both. This style of part typically has a slightly greater stroke length than the convoluted style.

Effective Area – The area of the diaphragm the pressure acts on. This area normally comprises the piston diameter + one convolution width.

Exercised -- Broken-In - Example: A regulator diaphragm that is exercised prior to final set point adjustment will likely not drift or have to be reset prior to shipment.

Fabric Drift – See **Bleed through**.

Fabric Side – On a one side coated diaphragm the fabric side of the diaphragm is the side where the underlying fabric reinforcement is visible. The fabric side must ***always*** be located on the low-pressure side of the system.

Flange – The outside portion of the diaphragm beyond the convolution.

Flange Diameter – The outside diameter of the flange.

Flange Radius – See **Transition Radii**.

Flash – The excess material left behind as a result of the molding or trimming operations.

Flat Cut – A diaphragm cut from flat sheet material, with or without fabric reinforcement, for use with low stroke applications.

Flex Failure – Any failure due to improper flexing of the diaphragm. This can result from improper diaphragm or hardware design, assembly problems or incorrect material choices.

Flexing Area – See **Convolution and Convolution Width**.

Four Cornering – See **Cornering.**

Gasketing – Cellulose, fiber, cork and rubber combinations added to the diaphragm for the purpose of enhancing its sealing properties.

Height – This measurement often refers to the distance from the underside of the flange to the highest point of the convolution and is instrumental in determining the diaphragm's stroke capability.

Hysteresis – As used in physics, the lagging of the effect in a body when the force acting on it is changed.

Lay-Up – This is a process for producing a one side coated diaphragm in which the rubber is laminated to the reinforcing fabric in the molding operation. Rubber coverage is typically greater on one side than the other (See **Fabric Side**).

Loading – Refers to the amount of pressure exerted on the diaphragm surface to achieve a seal.

Offset Convolution – See **Drop Center Diaphragm**

Permeation – The ability of a fluid to pass from one side of the diaphragm to the other.

Pie-Pan Diaphragm – See **Dish Diaphragm.**

Piston Area – This refers to the portion of the diaphragm that will cover the working surface of the diaphragm.

Piston Cap – A piston cap, sometimes referred to as a Curved Lip Retainer, is a piece of hardware that attaches to the diaphragm, opposite the piston, to help retain the diaphragm and aid in its convolution movement.

Piston Diameter – This refers to the portion of the diaphragm that will fit over the outside diameter of the piston hardware. This diameter defines the inside diameter of the diaphragm's convolution.

Piston Radius – See **Transition Radii**.

Piston Skirt – The piston skirt is the extension of the piston that extends 90^o away from its top surface and aids in forming and supporting the diaphragm sidewall during its stroke.

Preforming – Refers to the forming of the fabric or the rubber to a specific shape before molding.

Pressure Differential – Many times referred to as a “delta-P” this is the difference in pressures from one side of the diaphragm to the other.

Pressure Side of the Diaphragm – On one side coated diaphragms this is typically on the rubber side. On coated fabric diaphragms this is less of an issue, but is normally on the concave side of the convolution.

Pull Out(s) – The act of a portion of the diaphragm pulling out from the hardware due to a lack of clamping pressure or improper design.

Radial Creases – See **Cornering**.

Reverse Pressure – This is a situation where the higher system pressure is acting on the low-pressure side of the diaphragm causing the convolution to collapse and or the rubber to be blown off of the fabric reinforcement.

Rolling Action – Refers to the way a convolution moves during its cycling.

Rolling Diaphragm – See **Top Hat**.

Sealing Beads – See **Bead & Groove**.

Shallow-Draw Diaphragm – See **Dish Diaphragm**.

Sidewall – The flexing portion of the diaphragm that connects the flange and the piston together.

Single Coat – Another term for a one side coated diaphragm.

Spring Rate – The inherent force of a molded diaphragm as it tries to return to its as-molded position.

Strikethrough – Refers to the amount of rubber on the non-pressure side of the diaphragm used to achieve the best possible mechanical adhesion of fabric to rubber.

Stroke – The total travel or movement the diaphragm will be required to make. Sometimes referred to as the stroke length. The stroke is made up of two half strokes, the down stroke and the up stroke. Both are measured relative to the flange location

Thrust Washer – A piece of slippery material (e.g.: plastic) that is used in conjunction with a diaphragm, which is sealed between two threaded pieces of hardware, to keep the diaphragm from twisting and wrinkling during assembly.

Top Hat – This type of diaphragm has the greatest available stroke and often looks like a top hat, as its name implies. The user must convolute top hat diaphragms, before assembly and use. For best results, top hat diaphragms should not be taller than their flange diameter.

Transition Radii – The radii that connect the flange and piston surfaces to the convolution portion of the diaphragm.

Web Area, Working Areas, Working Zone – See **Convolution Width**.

Materials Related

Abrasion – Is the wearing away of a material surface through friction. Particles become detached through a combined cutting, shearing and tearing action.

Adhesion – In rubber parlance, it refers to the strength of the bond between a cured rubber surface and a corresponding non-rubber surface, i.e. metal, or fabric.

Aging – A progressive change in the chemical and physical properties of rubber, especially vulcanized rubber, usually marked by deterioration. Aging may be retarded by the use of antioxidants.

Antioxidant – A substance, which inhibits or retards oxidation and certain other kinds of aging. Antioxidants can cause staining or discoloration of the rubber compound when the rubber is exposed to light.

Bloom – The coating or efflorescence of sulfur, wax or other ingredients of vulcanized rubber, which may gradually appear on the surface of some rubber articles. Bloom depends on the solubility of the substance in the rubber.

Bonding Agents – Substances or mixtures of substances that are used for attaching rubber to metal, fabrics or other substrates.

Checking – The development of minute surface fissures as a result of exposing rubber articles to sunlight, generally accelerated by bending or stretching.

Chemical Resistance – The resistance offered by elastomer products to physical or chemical reactions as a result of contact with or immersion in, various solvents, acids, alkalies, salts, etc.

Coated Fabric – A diaphragm construction that uses previously rubberized fabric. The fabric is typically coated on both sides. These coatings can be of differing thicknesses and made up of different rubbers or compounds.

Compound – In rubber manufacturing, it is the composition or formula of stock, the ingredients of which, however, may not all be chemically combined and is therefore more of a physical mixture.

Compression Set – see **Permanent Set**.

Coefficient of Expansion – The coefficient of linear expansion is the ratio of the change in length per degree to the length at 0°Celsius. The coefficient of surface expansion is two times the linear coefficient. The coefficient of volume expansion (for solids) is three times the linear coefficient.

Disperse – To cause particles or molecules of matter to separate and become uniformly scattered throughout a medium. In a rubber compound, the particles of compounding ingredients are dispersed in the rubber. In latex, rubber globules are dispersed in an aqueous medium.

Double Coat – Refers to a diaphragm that has a rubber coating on both sides of the reinforcing fabric. Can be a molded double coat or a coated fabric.

Dry Out – The condition of the rubber after a chemical or similar type soak.

Durometer – Hardness of the cured rubber. Normally shown in Shore A numbers with a +/-5 point tolerance.

Elastomer – For the purposes of this manual elastomer is used interchangeably with compound.

Elasticity – A property of a material, which makes it, tend to recover its original dimensions after removal of the force, which deforms it.

Elastic Modulus – The value of the load (in pounds per square inch of original cross-section), required to give an intermediate elongation is usually called the modulus at that elongation. The expression used is modulus at 300% elongation. Tensile-stress observations of this sort are exceedingly useful in characterizing a particular compound, since by indicating the position and shape of the stress curve; they show the relative toughness of the rubber.

Elongation – In the physical testing of rubber, the increase in length of a test-piece when stretched, usually expressed as a percentage of the original length. For example, a 1” piece stretched to 6” has an elongation of 500%. Elongation at break - the elongation of a test-piece at the moment of rupture, usually expressed as percentage of the original length.

Embrittlement – A rubber compound becoming brittle during low or high temperature exposure or in the process of aging.

Fill – The fabric strands that run from edge to edge across the width of a woven fabric 90^o to the Warp. Sometimes referred to as the Fill Direction.

Filler – Any compounding material, usually in powder form, added to rubber in a substantial volume to improve quality or lower cost.

Glass Transition Temperature – The temperature when a rubber becomes glass-like. A more recent name is the Second Order Transition Point.

Hardness – See **Durometer**.

Interstices – Are the spaces between the yarn or thread bundles in a knit or woven fabric. The interstices allow the elastomer to flow through and adhere to the fabric.

Knit – A fabric style that allows for higher bore-to-height convolution ratios. This type of fabric is typically not as strong as equally thick woven fabrics.

Mill – A machine consisting of two adjacent, heavy, chilled iron rolls set horizontally, and which counter rotate at dissimilar speeds (i.e. upper surfaces rotate), used for the mechanical working of rubber.

Mixing – The process of incorporating the ingredients of a rubber compound into the rubber, usually done on a mixing mill or in an internal mixer.

Modulus – See **Elastic Modulus**

Mooney Viscometer – The plasticity of raw rubber or unvulcanized rubber compounds.

Nervy – This refers to the excess stress imparted to the diaphragm by rubber that has been scorched, begun to cure, or is too old to use even though it may still be moldable.

Oil Resistance – Ability to withstand swelling by a specified oily liquid for specified time and temperature, expressed as percentage swelling or volume increase of specimen. Oil Resistance **–** as applies to vulcanized elastomer compositions: resistance to change in size and shape and resistance to loss in physical (mechanical) properties due to contacts with or immersion in oil.

Optimum Cure – The physical properties of a rubber compound vulcanized at a given temperature for increasing periods of time undergo continuous change. For example, tensile strength may rise to a maximum, continue on a plateau, and then decline, whereas breaking elongation may continuously decrease.

Therefore, it is impossible to choose any one time of cure at whichever property will be at its optimum. Hence, optimum cure is a compromise and may be considered as that time required in obtaining the combination of properties that are most desirable for the article under consideration.

Over cure – A state of excessive vulcanization resulting from overstepping the optimum cure. Manifested by softness, brittleness, or impairment in the age resisting quality of the cured elastomer.

Oxidation – Active oxygen degrades organic materials. This is called oxidation.
Rate of degradation will increase with rising temperatures.

Ozone – Is an allotropic form of oxygen, (03), produced by the action of electrical discharges in air. It is a gas with a characteristic odor, and is a powerful oxidizing agent. Rubber compounds in a stretched condition are susceptible to the deteriorating action of ozone in the atmosphere, which results in a cracking.

Permanent Set – Sometimes referred to, as compression set, it is the amount by which an elastic material fails to return to its original form after a deformation.

Plasticizer – A substance that softens another substance through its solvent action.

Polymer – A polymer is a very long chain of units of monomers prepared by means of an addition and/or a condensation polymerization. The units may be the same or different. There are copolymers, dipolymers, tri- or terpolymers, quadripolymers, high polymers, etc.

Post Curing – An extended curing cycle after molding usually done to enhance the physical properties of the rubber.

Precure – Typically done to coated fabrics. This process leaves some molding properties in the material but allows the fabric to remain better centered in the rubber coating especially in “aggressive” convolution shapes.

Processing Aids – Waxes, low molecular weight polyethylene, metal soaps, petroleum oils and other agents, which dissolve or lubricate rubbers, soften them and act as processing aids.

Reinforcing Agent – In rubber compounding, a finely-divided substance or filler which when properly dispersed in rubber produces improved physical properties in the vulcanized product, i.e. greater energy of resilience, greater resistance to abrasion, higher modulus of elasticity and tensile strength.

Replasticize – The act of making a “dry” rubber part soft again. Normally refers to diaphragms that contact gasoline intermittently. Without fuel contact they can become dry and stiff due to loss of oils but become soft and pliable again with fuel contact.

Resilience – The energy returned by vulcanized rubber when it is suddenly released from a state of strain or deformation.

Reversion – The softening of some vulcanized rubbers when they are heated too long, usually accompanied by an increase in extensibility, a decreasing in tensile strength and a lowering of the stress required producing a given elongation. Extreme reversion may result n tackiness; the rubbers “revert” to unvulcanized, then to a non-polymeric condition.

Rheology – The science of deformation and flow of matter. Deals with the laws of plasticity, elasticity and viscosity and their connections with paints, plastics, rubber, oils, glass, cement, etc.

Scorching – A term frequently used to denote premature vulcanization of a rubber compound occurring on a mill or calendar, or in an extruder.

Tensile Strength – The capacity of a material to resist a force tending to stretch it. Ordinarily the term is used to denote the force required to stretch a material to rupture, and is known as breaking load, breaking stress, ultimate tensile strength.

Under cure – Degrees of cure less than optimum. May be evidenced by tackiness, loginess (lack of snap or resilience), or inferior physical properties.

Vulcanizing Agent – Any material, which can produce in rubber the change in physical properties known as vulcanization, such as sulfur, polysulfides, organic polynitro derivatives, peroxides and quinone dioximes.

Warp – The fabric strands that run along the length of a roll of woven fabric 90° to the Fill. Sometimes referred to as the Warp Direction.

Rolling vs. Flat Diaphragms

A diaphragm is a seal that is usually affixed to a moving piston, and is actuated by differential pressure. The diaphragm converts a pneumatic or hydraulic force to a mechanical force by containing this force to one side of the piston. As the diaphragm expands, it pushes on the piston creating the mechanical force.

The diaphragm functions as a barrier, preventing a mixture of fluid and/or gas, or protecting pressure barriers. If the application requires only a separating membrane and a short stroke, a flat cut diaphragm is usually sufficient. Should the application require a long stroke, or a constant effective area, then a rolling diaphragm is the best choice.

Flat Diaphragm Overview

A flat cut diaphragm is simply a piece of material cut into the desired shape. Rolling diaphragms are molded diaphragms typically configured in a "top hat" style, or with a molded convolution. The molded diaphragm will allow easier movement of the piston, resulting in low friction, exceptional sensitivity, and provide zero leakage.

If appropriate, flat diaphragms can be economical due to the low manufacturing costs. However, while effective at separating chambers, their application is limited. The maximum stroke for a flat diaphragm ranges from a few thousandths of an inch to just over one inch, depending on the diameter of the part. The best way to increase the stroke for a flat cut is to increase the diameter of the diaphragm, which is not always an option!

Another factor to consider when using a flat diaphragm is the "blousing" that is required. Because the diaphragm will move, some space must be provided across the part to allow for motion. The most common solution to this problem is to cut a larger diaphragm than necessary, and let the diaphragm sit slack in the application. Think of the alternative - a diaphragm stretched tight across the chamber will not allow for any movement.

In fact, the energy used to start the stroke will be returned to the system, an effect called the "trampoline syndrome". This inefficient handling of the system's energy is avoidable with the use of a rolling diaphragm.

Finally, flat diaphragms tend to take a shape when repeatedly cycled. As the cycling increases, the life span of the diaphragm decreases since it has to adjust to the stroke. If the material gathers unevenly when installed, the chances for material wear increases, decreasing the life of the diaphragm as well. Set points could also change through the life of the diaphragm. In control devices, regulators, or other applications with critical set points, a set point change could lessen the energy required to start the stroke, possibly leading to changes throughout the entire application.

Rolling Diaphragm Overview

Rolling diaphragms avoid this problem by factoring in the required stroke of the diaphragm in the hardware. A convolution molded into the diaphragm, designed to move in conjunction with the piston, uses less energy to start the stroke, and provides a constant effective pressure area. This guarantees a repeatable displacement each and every time.

Molded diaphragms provide stable set points, low hysteresis, and longer life. Since the molded diaphragm is designed to meet the specific stroke requirements, the resistance to movement is significantly less than the flat diaphragm, resulting in a more efficient system. Additionally, because the diaphragm has already taken the shape of the stroke, the material suffers less wear.

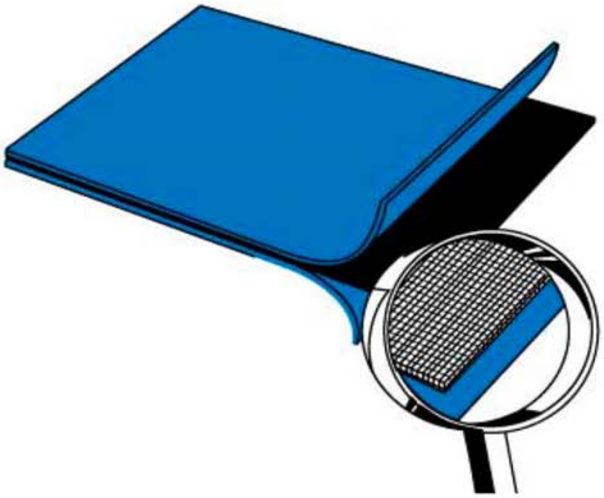
Besides technical advantages, molded diaphragms can also offer assembly advantages too. Since flat diaphragms almost always require some blousing, time must be taken at assembly to incorporate the diaphragm into the application. A molded convoluted diaphragm can be placed into the assembly without any additional work. In most cases, a molded diaphragm offers lower total cost when considering assembly, and life.

Summary

Flat diaphragms can be an effective seal in limited applications. However, based on the application requirements, a molded diaphragm is a cost effective sealing solution that will provide significant advantages over a flat diaphragm. The result will be longer life, a constant effective pressure area, low friction, repeatability and sensitivity in a broad pressure range.

Fabric Reinforcement in 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 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 a mechanical force to perform a task or, conversely, take a mechanical force and convert it into either a pneumatic or a 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 streching with fabric

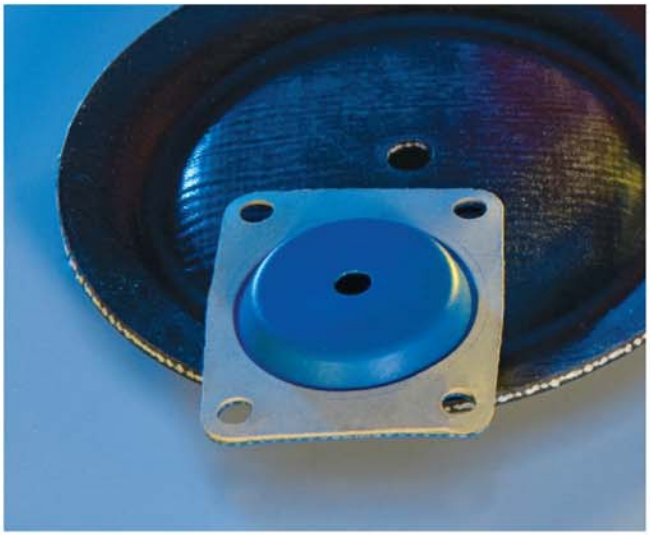
The elastomer's ability to resist stretching varies from compound to compound. It will also vary in the same formula from batch to batch due to mixing variations as well as thickness variations. A homogeneous diaphragm will also become stretched out over time due to pressure being applied repeatedly 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 the high pressure. When pressure is applied to the diaphragm, the elastomer pushes against the fabric, which resists 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 a 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 stretching and transferring the energy to the piston.

Fabric reinforced diaphragms come in two types: single coat and double coat. The single coat diaphragm has the elastomer on the high-pressure side of the diaphragm and the fabric on the low-pressure side. The double coat has elastomer coating on both sides of the fabric. The reasons to select one type of construction over the other merit their own paper later.

Fabric, like elastomer, has to be in the correct environment with regard 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.

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 elastomer's 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 that you involve a Simrit engineer for optimized materials design, for both elastomer and fabric. For additional information or questions please contact your local Simrit sales person or call our toll-free number below.

When To Design a Single Coat or Double Coat Elastomeric Seal

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.

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

First, in double acting systems the pressure differential flips back and forth in a system resulting in the need to seal the fabric from both sides in order to convert the 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 or gas into the 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 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.

Simrit's technology specialists will evaluate each design for the optimal construction to extend the life of the diaphragm and provide for overall system reliability. Please feel free to contact Simrit at 866-274-6748 with your design questions.

Tolerances of Fabric Reinforced Diaphragms

One of the most misunderstood areas in development of a fabric-reinforced diaphragm is dimensional tolerance. In regard to rigid objects or assemblies, such as metals or plastics, the dimensional tolerances may be relatively straightforward. Since these materials are homogeneous, it is a matter of applying a certain value for shrinkage when designing the 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 the manufacture 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 convolutions 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 insets, and soon there is an even greater amount of interplay between the stresses. Additionally, reinforced diaphragms tend to relax over time. The convolution height may decrease and hole sizes may also change. This phenomenon is directly related to the type of elastomer and fabric used, molded-in inserts (if any), the geometry of the part, and the style of manufacture (coated fabric versus single coat, see Simrit's Design Manual for more information on these styles). Although Simrit's team of engineers is uniquely qualified to design processes matched to each customer's product to minimize the effects of these stresses and shrinkages, it is impossible to completely eliminate them.

Measuring Diaphragms

Elastomer often comprises the majority of the raw material in many diaphragm designs. This presents a challenge when measuring dimensions on a diaphragm. For this reason, one of the most important things to consider when measuring a diaphragm's dimensions is the measurement technique. Generally, it is a good idea to agree upon a measurement technique prior to the introduction of a part for regular production. This way a correlation can be made between the customer and Simrit for part inspections. Simrit recommends documenting inspection procedures for all parts, including methods, as well as the equipment used for conducting the measurements. Will digital or analog gages be used? Are the gages contact or non-contact? Are there specific instructions for measuring the part? There is a lot of potential variation and subjectivity that should be addressed when developing an incoming inspection plan. One type of gauge that Simrit recommends is a Go/No-Go gauge as it takes a significant portion of subjectivity and variation out of the measurement.

Recognizing that there is a significant amount of interaction between the design of a reinforced diaphragm and the subjectivity in measurement, it is easy to see that standard tolerance techniques are not suited to dimensioning reinforced diaphragms. There are certain areas of a diaphragm that can be produced to tighter tolerances, such as mold closure related dimensions like thickness, while other areas require larger tolerances. Simrit's team of engineers has developed tolerance guidelines specific to fabric-reinforced diaphragms. These tolerance guidelines are illustrated on page 46.

For more information on tolerances, please contact Simrit at 866-274-6748. We would be glad to provide guidance on tolerances, dimensioning or any other technical aspect during your product's development.

Diaphragms: Design for Manufacturing

When developing original component designs 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 for manufacturability. This achieves the most competitive part price for several reasons: improved scrap rates, lower capital tooling costs 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 (for this refer to the Simrit Engineering & DesignManual). Here, 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 two basic design options. With a flat/gasketed flange it is more difficult to control the compression of the material when compared to a 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's manufacturability and eliminates many of the quality issues related to beaded diaphragms.

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 designed 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. Refer to the follwing graphic for several bead geometries and their stregths and weaknesses.

Tear Drop - Under
Better resistance to trapping air
Better flow for less knit lines
Better flash location for trimming

Tear Drop - Over
Better resistance to trapping air
Better flow for less knit lines
Worse flash location for trimming

"D" Bead - Over
Worse resistance to trapping air
Worse flow for less knit lines
Better flash location for trimming

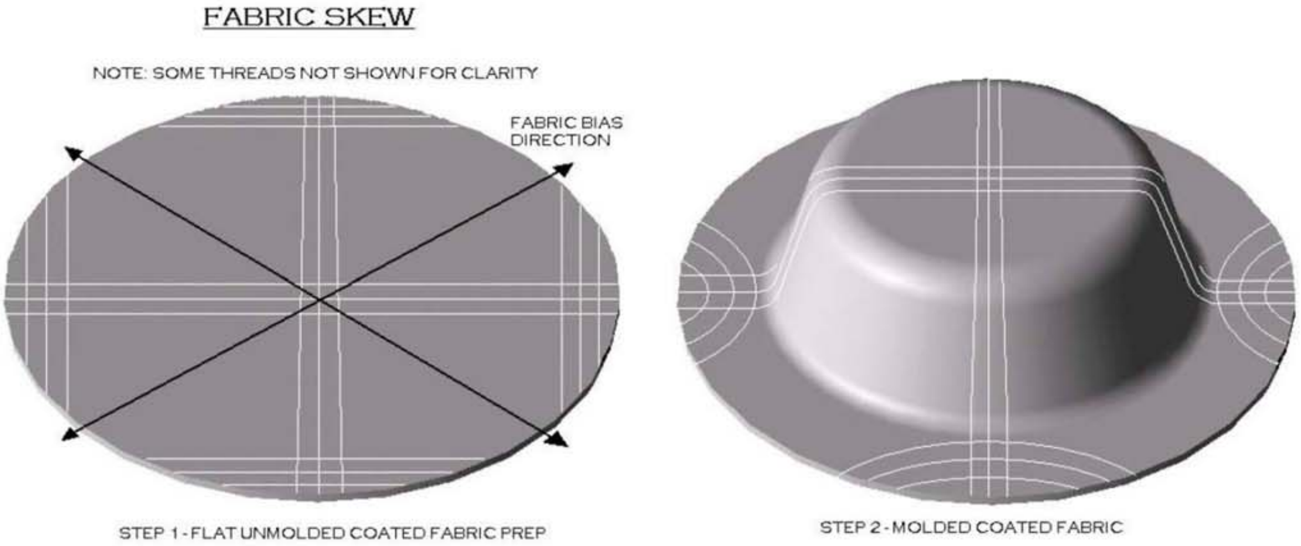
"D" Bead - Under
Worse resistance to trapping air
Worse flow for less knit lines
Worse flash location for trimming

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 diaphragm, but often unnecessary costs can be avoided by not over-designing 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 (see the picture below). 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. Additional design background is explained in the Simrit Design Manual or for direct feedback contact Simrit at 866-274-6748.

Diaphragm Engineering and Application

Whether you need a single or double coated, rolling or flat, fabric reinforced or custom engineered diaphragms, Simrit can help match a design to your specific application. The following information will help Simrit know your needs to create a superior product.

- Name ______________________ Date ____/____/____
- Company ______________________
- Address ______________________
- Phone # ______________ Fax # ______________
- Email ______________________

Included drawings, prints, layouts or sketches of the proposed application and installation: #______________

____

Specific function of the diaphragm:______________________

☐ Existing Application ☐ New Application

- Type of Flange Mounting ______________
- Piston Diameter (in/cm) ______________
- Up Stroke (in/cm) ______________
- Down Stroke (in/cm) ______________
- Cylinder Bore Diameter ______________
- Cycle Rate: Test ________ Use ______________
- Pumping Volume ______________
- Minimum Pressure (psi) ______________
- Maximum Pressure (psi) ______________
- Reverse Pressure: Yes _______ No _______
- Minimum Operating Temp ________° F / C
- Maximum Operating Temp ________° F / C
- Duration at Max Temp ______________
- Contact Fluid or Gas (please be specific to the exact fluid/gas) ______________

____

DV Testing: ☐ Customer responsible ☐ Simrit responsible and should consider in quotation

- Required Dates

  Prototypes ____/____/____
  ISIR ____/____/____
  SOP ____/____/____

Special Considerations ______________________

____

	Year 1	Year 2	Year 3
Annual Quantity Requirements	______________	______________	______________

Target Price ______________

Other Information ______________________

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Publication No.3507 © 2009 Simrit