PRECISION INDUSTRIES CORPORATION

DIAPHRAGM ENGINEERING & DESIGN MANUAL

Since 1986 Precision Industries has been creating solutions to complex engineering questions.

Precision has designed and manufactured millions of diaphragms. Our diaphragms are used in sophisticated technologies as well as basic applications.

As the diaphragm design specialists, Precision Industries has prepared this manual to help you develop a greater understanding of the unique aspects of diaphragm design and their uses. It does not replace our creative engineering staff.

With the combined experience of more than 60 years of diaphragm engineering, our staff is dedicated to helping solve design problems, one diaphragm at a time. We thrive on challenge, call us.

PRECISION INDUSTRIES
CORPORATION

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PERRY JOHNSON REGISTRARS, INC.
ISO 9002 REGISTERED

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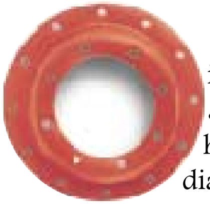
The design, construction and application of each and every Precision Industries' diaphragm is engineering driven. We are particularly adept at working alongside the design team at the prototype stage.

Precision Industries Quality and Manufacturing systems are certified to ISO 9002 and are QS 9000 compliant. As a Tier I supplier to General Motors, we understand the need for consistent and reliable product delivered on-time, every time.

We have constructed diaphragms for highly exacting industries such as the medical equipment field. For example, one of our customers, Quest Medical, Inc., of Allen, Texas, produces Myocardial Protection Systems used during open heart surgery. Custom fit to meet Quest's application, the complex tooling for the Precision diaphragm required four convolutions on a single flange. Precision met those standards.

Consider the actuator mounted on Ford Cosworth XB engines used at Indy. When a race car is hitting qualifying speeds of more than 200 miles an hour, every single piece of equipment on that car must be functioning at maximum efficiency. Precision diaphragms are used in the Ford-Cosworth XB engine turbocharger waste-gate actuator.

Precision Industries diaphragms are used by successful manufacturers of a variety of equipment and products. Walbro Engine Management Corp. of Cass City, MI controls nearly 70% of the world's small engine carburetor market. Precision supplies millions of diaphragms to Walbro each year while maintaining the highest quality standards. We have continued to improved our processes thus contributing significantly to Walbro's competitive edge.



Precision Industries is out of this world, and our engineers have designed diaphragms to prove it. The NASA Ames Research Center commissioned Precision to produce diaphragms for their prototype flexible space suits, the suits have gone on to be used in the1998 space program.

Precision Industries Corporation, Inc. the Diaphragm Design Specialists. Whether you need one prototype diaphragm, or a run of a million, Precision Industries delivers exact, accurate, and on-time.

The Precision 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. No warranty is expressed or implied. All efforts have been made to provide comprehensive and accurate data. Any other use of the Diaphragm Engineering and Design Manual is strictly prohibited without written permission from Precision Industries Corporation.

Introduction

A Bit Of History

Diaphragms, gaskets and seals have been with us for centuries. Before the advent of the polymers (rubbers), animal skins (leather), and fabrics treated with pitch were often used to form the pump seals and valves we take for granted today.

When Columbus returned from the New World with articles made of dried natural rubber, a whole new industry was born. Though it took centuries and thousands of more discoveries and process improvements to get here, we are now in an age of superior polymer design.

One of the first industries to take advantage of the availability of rubber was the textile industry. With the ability to rubberize fabrics, textile manufacturers were able to offer a vast improvement over the water repellent cloth of the day. As rubber technology grew, this water resistance was improved to cover many more chemicals and environmental conditions to meet the demanding needs of growing industrial economies.

One of the many out-growths of this coated fabrics' industry is the diaphragm industry. What started as an additional customer service by the coated fabrics manufacturers, diaphragms have now become a highly technical, engineered element with critical applications in many diverse environments.

Through the years, customer needs for longer strokes pushed the diaphragm industry to making molded diaphragms from materials not originating as coated fabrics. These styles certainly have their place, but with the improvements in the draw (molding) capabilities of today's fabrics, coated fabrics can once again be an option for applications requiring longer stroke diaphragms. Precision Industries is dedicated to this direction. Precision Industries produces many styles of diaphragms, however, we encourage the use of coated fabrics whenever possible because of the dramatically improved performance characteristics. As you use this manual we believe you'll understand why.

There are basic questions to answer whenever a diaphragm is being designed. Before you begin, ask the following:

1. What is the device's basic function (i.e. regulator, pump, etc)?
2. What are the environmental conditions (i.e., temperature, moisture, etc)?
3. What fluid will contact the diaphragm?
4. What are the minimum and maximum pressure requirements?
5. Will there be pressure spikes or reversals?
6. How much stroke, and at what rate, will the device require?
7. How will the diaphragm device be assembled?
8. What style of flange will be needed (flat or beaded)?

Initial Considerations

Diaphragms come in many forms and are made from a wide variety of materials. This manual covers only those diaphragms made from elastomers, polymers with rubber-like properties, and/or a natural or synthetic reinforcing material. Selecting the right material for the need is only part of the equation. The diaphragm's shape and manufacturing process are equally important.

This manual has been organized into three main sections — Materials, Styles & Constructions, and finally a miscellany of Design Criteria. For your convenience, the manual includes a supply of Engineering & Applications Data Forms and a Glossary of Terms.

The Materials Section covers what's available and when to use specific materials. Environmental conditions, especially chemical contact (for the elastomer) and temperature range (for both the fabric and elastomer), are some of the most important factors you will need to consider when making material selections for your diaphragm.

Styles & Constructions provides you with step-by-step instruction on how to select a particular shape or construction for your application. There are two basic constructions for diaphragms: flat and formed. Both flat and formed diaphragms can be made with or without a fabric reinforcement in a variety of thicknesses and styles.

The Design Criteria is a compendium of information to consider when engineering a diaphragm. For example, What happens to a diaphragm during stroking? How to determine diaphragm strength requirements?

As mentioned earlier, a supply of Engineering & Application Data Sheets are included in this manual. Complete it for your own records, or use it to fax information to our engineering group.

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MATERIALS

Environmental conditions, especially chemical contact (for the elastomer) and temperature range (for both the fabric and the elastomer), are some of the most important factors you will need to consider when making material selections for your diaphragm.

This section outlines materials used in diaphragm construction and the advantages of each.

THE ENVIRONMENT

The environmental conditions, especially chemical contact (for the elastomer) and temperature range (for both the fabric and the elastomer), are some of the most important factors you will need to consider when making material selections for your diaphragm.

General chemical resistance and temperature ranges can be gleaned from the following data and the accompanying materials' chart. If necessary, more specific data will be supplied by Precision Industries Engineering Department.

THE EFFECTS OF THERMAL CONDITIONING

For the most part rubber compounds react in a predictable manner. As the temperature rises, the chemical activity increases. In terms of oil and fuel resistance this means the materials swell at a greater rate. The flexibility of the material also increases at elevated temperatures, which can be advantageous if the membrane is still capable of sealing.

On the other hand, low temperature 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 rubber compounds 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 examples of plasticized rubbers.

An important point for consideration is the effect of high temperature operations on the low temperature functioning of the diaphragm. High temperatures will volatilize the plasticizers out of the rubber, leaving the material with a higher modulus (stiffness) requiring more energy to activate the diaphragm. The loss of the plasticizers can also cause the part to shrink and will affect its fit, function and life.

To evaluate the material realistically all low temperature testing should be done after high temperature exposure.

THE EFFECTS OF CHEMICAL CONDITIONING

The chemicals diaphragms come in contact with can also have the same general effect on the rubber compounds as high temperatures — they can extract the plasticizers.

Studies show that during use fuels, oils and chemicals often act as a plasticizer, giving greater flexibility to the elastomer at lower temperatures. However, when the chemical or fuel evaporates, causing a dry-out condition, it is often very difficult, if not impossible, to replasticize the compound just by bringing it into contact with the 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.

GENERAL PURPOSE COMPOUNDS - 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)

ECO has an outstanding temperature range surpassing both neoprene and nitrile. It is 300°F material with a 50° advantage at the upper end. This is significant as it is established in the automotive market for under-the-hood applications. The oil and fuel resistance equals that of nitrile.

The low temperature properties -40°F are unique in that the addition of plasticizers are not required to achieve a low temperature flexibility. Therefore, thermal conditioning of ECO has little effect on its flexibility.

COMMON RUBBER COMPOUNDS

NAME	ADVANTAGES	ASTM 1418 DESIGNATION	ASTM D2000 DESIGNATION
Butyl	Low permeation to many gases. OK in vegetable oil and oxidating chemicals.	IR	BA
Ethylene-propylene	Very good hot water, low pressure steam and heat resistant.	EP or EPDM	CA
Neoprene	Good oil, ozone and weather resistance. Good general purpose materials.	CR	BC or EB
Nitrile	Good general purpose oil and fuel resistant material.	NBR	BF, BG, BK or CH
Epichlorohydrin	Similar to NBR with good aging and wider temperature range. Ozone resistant.	ECO	CH or DH
Polyacrylate	Oil and heat resistant to 350°F. Good in transmission fluids.	ACM	DH, DF
Ethylene-acrylic	Oil and heat resistant to 350°F. Good in transmission fluids. Better low temperature than ACM.	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 and fuel resistant. High temperature resistance.	FKM	HK

The Ozone and weathering properties 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 ECO is exposed to elevated temperatures (over 300°F) for long periods of time.

NEOPRENE

This material is similar to nitrile rubber, it can be compounded for the same service temperatures. It has inherent Ozone and weathering properties without antioxidants.

NITRILE (A/K/A NBR OR BUNA-N)

This material is perhaps one of the most widely used diaphragm elastomers. It is made

KEY PROPERTIES OF COMMON COMPOUNDS

NAME	TYPICAL TEMPERATURE SERVICE RANGE	OIL(1) RESISTANCE	AIR (2) PERMEABILITY	OZONE RESISTANCE	WEATHER RESISTANCE
Butyl	-20°F to +212°F	Poor	0.37	Excellent	Excellent
Ethylene-propylene	-40°F to +350°F	Poor	9	Excellent	Very
Neoprene	-40°F to +250°F	Good 60% swell	14	Good	Good
Nitrile	-65°F to +250°F	Very Good 10 to 40% swell	.46 to 1.1	Fair	Very Good
Epichlorohydrin	-40°F to +300°F	Very Good 30% swell	0.7	Good	Poor (3)
Poly-acrylate	0°F to +350°F	Very Good 30% swell	1.5	Excellent	Good
Ethylene-acrylic	-20°F to +350°F	Very Good 30% Swell	No Data	Very	Very
Silicone	-80°F to +425°F	Fair 80% swell	17	Good	Good
Fluorosilicone	-65°F to +375°F	Excellent 10% swell	50	Excellent	Very
Fluorocarbon	-10°F to +400°F	Excellent 10% swell	0.32	Excellent	Good

NOTES: (1) Oil Test: ASTM #3 oil, 70 hours @ 70C
(2) Air Permeation X 10 8 cm 3+CM 2/CM/SEC/Atmos@ 77F
(3) This result is for straight nitrile.

of two polymers: butadiene and acrylonitrile. The oil resistance and low temperature flexibility can be modified by adjusting the ratio of the two polymers. For example, increasing the percentage of butadiene will improve the low temperature flexing, but will lessen the oil resistance. The reverse can also be true! Increase the acrylonitrile and the oil resistance improves, but the low temperature resistance decreases.

Ozone and weathering resistance are weak attributes of the material. Certain antioxidants can be added to aid in this situation. This is not necessarily a panacea as the addition of antioxidants can then adversely affect other properties.

GENERAL PURPOSE COMPOUNDS - NON-OIL RESISTANT

BUTYL

An outstanding characteristic of this material is its low permeation rate of gasses. This feature, however, can create problems in the molding process as it becomes difficult to eliminate any trapped air or gas. This problem can be overcome with the proper venting in the mold and various other manufacturing approaches.

ETHYLENE PROPYLENE (EP OR EPDM)

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

SPECIALTY ELASTOMERS

ETHYLENE-ACRYLIC

Ethylene/acrylic compound are used in automotive applications such as boots, grommets, seals, etc. where their very good flex, ozone resistance and high-temperature properties combines 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

This material has many desirable properties with the exception of economy. It excels in high temperature resistance to fuels and oils. Because of fluorosilicone's inherent low temperature properties, after being soaked in fuel it does not shrink during "dry-out."

Ozone and weathering are also outstanding features. Like silicone, fluorosilicone is available in various colors.

FLUOROCARBON

Fluorocarbons have the highest chemical resistance of today's elastomers. In fuels and oils they also have the lowest volume swell. Because of its chemical resistance, fluorocarbons are rapidly becoming the elastomer of choice in the fuel application field.

Its stability at elevated temperatures is excellent. Unfortunately, its low temperature flexibility is poor which can cause problems in overall diaphragm function, especially in applications where extreme temperature fluctuations are expected, such as automotive under-the-hood applications during northern winter months. The addition of plasticizers to increase the low temperature flexibility does little good. In an effort to cure this problem, fluorocarbon manufacturers have produced a line of compounds with improved low temperature flexibility. They have recommended service lows from -10 to 20°F. These elastomers should not be considered a cure-all for low temperature applications. The performance of these elastomers depends greatly on the conditions of the application.

POLYACRYLATE

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

Silicone is often used when a broad temperature range is expected. It has natural low temperature flexibility and does not require the addition of plasticizers. Silicone is not fuel or oil resistant, however, it does exhibit moderate chemical resistance. It can be compounded for low hysteresis (low rolling resistance) where exceptionally flexible diaphragms are required. Silicone is usually furnished colored as it does not require carbon black for reinforcement.

FABRICS

Fabric is the strength member in a fabric reinforced diaphragm. The covering elastomer brings little additional strength to the diaphragm. Its primary function is to seal. Therefore, use the same care when choosing a fabric as you do when choosing an elastomer.

The first consideration is the environmental conditions your diaphragm will be exposed to, including: temperature range, chemical exposure, cycle rate and pressure, etc. This information is important for Precision Industries' Engineers to determine the best type and style of fabric for your application.

COTTON

Cotton is used to some extent when more give is required and/or bulk is needed to make thicker cross-sections.

FIBERGLASS

Glass fabrics are available and used, but generally not 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 turns to powder, which then renders the glass fabric non-productive.

NOMEX AND KEVLAR

Nomex and Kevlar (registered trademarks of DuPont) are of the aramid family and related to nylon. Both can be used in extremely high tem-

GENERAL CHEMICAL RESISTANCE TO SOME COMMON CHEMICALS

ELASTOMER CHEMICAL	NITRILE	ETHYLENE-PROPYLENE	FLUORO-CARBON	NEOPRENE	POLY-ACRYLATE	BUTYL	FLUORO-SILICONE	SILICONE	EPICHLORO-HYDRIN	ETHYLENE ACRYLIC
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	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		

A blank space means Not Rated or insufficient data is available.

perature applications. Kevlar is unique because of its extremely high tensile strength, but this strength also makes it difficult to process and hard to cut. Nomex and Kevlar are premium materials commanding premium prices.

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 and because of their lower strength capabilities, for diaphragms with low to moderate pressure requirements.

COATED FABRICS

We have been discussing the elastomers and supporting fabrics as separate components. Many of these components are brought together in a coated fabric form. The main advantage of a coated fabric is the fabric is pre-coated on both sides before being cut, or formed into a diaphragm. This two-sided coating gives excellent protection to the reinforcing fabric.

Coated fabric materials have an edge when used in very thin materials such as .005" to .012" thicknesses. They are used in applications requiring very sensitive materials such as gas appliance controls, regulators, pressure reducers and valves, etc. Diaphragms for these purposes have to respond to differentials in the

FABRICS - GENERAL CHARACTERISTICS				
MATERIAL	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*	B	B	A	375/400°F
Kevlar*	A	B	A	375/400°F
Fiberglass	A+	A	A	500°F+

NOTES: A is the highest possible ranking within a category.
**=Registered DuPont trademark*
***=Hot water and steam hydrolyzes nylon*

neighborhood of 2” to 3” of water pressure. Many pneumatic controls fall into this category.

When low volume parts are needed, coated fabrics may be too expensive. Since the coating process requires minimum yardage to make running the equipment worthwhile, diaphragm users will often have to order more material than they could possibly use. And compounding this situation, sometimes the fabric/elastomer combination desired is not always readily available.

Precision Industries is always researching ways to make coated fabrics more available to the average user. We will steer applications towards existing material combinations or find multiple users for a material we develop.

When considering coated fabric be mindful of their limited forming depths. A limited amount of rubber coating on each side is the problem. Keeping the fabric in the center of the diaphragm cross section may require special forming techniques. With the limited coating the size of sealing beads is often very limited, pages 21-22 covers design solutions.

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Styles & Constructions

Advantages

Coated Fabrics

Thin sensitive cross-sections

Two-side coating protects fabric from attack and wear

Two-side coating can withstand pressure reversals

Balance coating

Lower tooling costs

Excellent laminating capability

Flat cuts

Higher Adhesion Between Rubber & Fabric

Lay-Up

Deep draw capabilities

Material available in small lots

Excellent bead & feature formation

Typically lower piece pricing

Disadvantages

Coated Fabrics

Costs of parts can be higher for low volume parts.

Availability of materials

Minimum material runs

Limited coating thickness can reduce bead and feature size

Lay-Up

Unbalanced coated

Can not handle pressure reversals

Generally higher tooling costs

DIAPHRAGM CONSTRUCTIONS

There are two basic constructions for diaphragms: flat and formed. Both flat diaphragms and formed diaphragms can be made with or without a fabric reinforcement, in a variety of thicknesses, and in a variety of styles. It is the Precision Industries goal to develop the parts as stress-free as possible by managing the stresses through careful design.

FABRIC REINFORCED DIAPHRAGMS

Why is fabric used as a reinforcing agent? What purpose does fabric serve when incorporated in a diaphragm?

Fabrics are soft and pliable and can be helpful in the forming and shaping of diaphragms. In addition to being capable of high degrees of flexing, fabrics also serve as a carrier for the rubber coating.

ADVANTAGES OF FABRIC REINFORCED DIAPHRAGMS

The fabric can be considered the backbone of the diaphragm. It is the load carrying member. In that capacity it assumes the tension in the sidewalls. In case of the non-supported diaphragm, the rubber is constantly under tension as the pressure is applied. The physical properties of rubber deteriorates at a more rapid rate when under tension. This would be particularly so at elevated temperatures. The rubber coating is under stress just being involved with the rolling and flexing action.

Failures of reinforced diaphragms usually start with a small hole in the rubber coating and eventually a fracture in the fabric develops. Leakage would start out slow but would not be catastrophic. On the other hand, homogeneous parts have a tendency to rip once a small hole or defect is present in the material. This type of failure sends no warning.

Another advantage of reinforced diaphragms is they can be made thinner in the flexing area and handle higher pressures than homogeneous parts.

The decision to use or not use a fabric reinforcement rests largely on the expected system pressures (minimum, nominal and maximum). If very low pressures are expected, 10 psi or less, then the use of nonreinforced diaphragms may be possible. However, just because it may be possible to leave out the fabric, doesn't mean you should in every case.

Under pressure non-reinforced diaphragms can stretch quite a bit before they transfer movement to the system. If this presents a problem fabric should be added to improve response time as well as diaphragm strength. Certain diaphragm shapes can also be difficult to reinforce. (More information on this subject is covered in the Molded Diaphragm Styles portion of this manual pages 12-13).

THICKER ISN'T ALWAYS BETTER

"If a little is good, a lot must be better!" Well not always, and especially not when it comes to diaphragm thickness. Many engineers have tried to overcome high pressure by adding more thickness. This is especially true with non-reinforced diaphragms and diaphragms used in some pumps.

While it may be advisable to use a thicker product in some applications, the design rule is, "as thin as safely possible." Thinner diaphragms roll easier as less energy is absorbed resulting in a lower hysteresis. The more rolling resistance your diaphragm sees, the greater the likelihood for early failure. Thinner is also more responsive.

FLAT DIAPHRAGMS

In general, flat diaphragms are the most unencumbered and simplest to use. From a manufacturing standpoint it is merely punching out a part from a flat sheet of material. There is no further fabricating work involved. Because of the minimal amount of labor and tooling, there are often economical advantages to using this style of diaphragm.

WHEN TO USE A FLAT DIAPHRAGM

Many factors determine if a flat diaphragm is practical. First is the stroke requirements of the application. Flat diaphragms do not have long stroke capability. Depending on size, reinforced flat diaphragm stroke capabilities may range from a few thousandths of an inch to not much more than an inch. Non-reinforced versions may be somewhat greater due to their ability to stretch. In fact, for a flat diaphragm to function properly it should be bloused, or bagged, during assembly to make material available for stroking. If this is not done properly, catastrophic problems can occur, please refer to The Trampoline Syndrome on page 11. Whether or not a flat diaphragm can be bloused without forming severe wrinkles is another important factor in deciding if this style of diaphragm is right for your application. The magnitude and concentration of the wrinkles will have an effect on the performance and life of the part as well as the ability to seal the flange area.

What has been described above relates to the suppleness of the material and its ability to conform to a shape. In the actual installation, diaphragms are often assembled against a spring loaded plate which blouses the material in the center. In some cases the material does not pull-in uniformly, leaving an uneven amount of material around the circumference between the bore and the piston. This variation can cause erratic movement of the piston as well as excessive material wear. The unsupported section of the diaphragm is referred to as the web or working area. (A web area as wide as possible can allow a flat diaphragm more stroke capability. The material is able to accommodate the assembly blousing with little or no wrinkles).

Wider web widths are less able to handle higher pressures. Some of the pressure handling limitation can be minimized with stronger fabrics. However, stronger fabrics often mean

DIAPHRAGM STYLES

A Quick Guide to Determining Which Style of Diaphragm Is Right For Your Application

The style of diaphragm will depend upon the required stroke and available working width within the device. The convolution width and stroke are directly related to each other in function. The working area of the diaphragm is defined by the bore diameter, minus the piston diameter, divided by two.

FLAT DIAPHRAGMS

Flat diaphragms work best when the working area is limited to a 12° angle of deflection as measured from the clamping flange (bore) to the piston at full stroke.

CONVOLUTED DIAPHRAGMS

For best results, the overall height of a convoluted diaphragm should not exceed one-half of the width of the working area. In other words, the radius of curvature would be equal to, or greater than, one-half of the working area. The clamping flange would normally be in the same plane as the piston. The maximum stroke works out to be 2.13 times the working area.

DROP CENTER DIAPHRAGM

This design covers the maximum stroke recommended for a diaphragm and still satisfy the parameters for maximum service life. The stroke limit would be 3.7 times the width of the working area.

SHALLOW (DISHED) AND DEEP DRAW (TOP HAT) DIAPHRAGMS

These styles are versatile and can be manufactured for long stroke requirements. A rule of thumb for maximum recommended stroke length is to keep the height of the diaphragm less than, or equal to, the diameter of the bore. While these styles offer longer strokes, there are inherent service problems and are covered in the Molded Diaphragms portion of the manual, pages 12-13.

DESIGNING FOR STROKE EXAMPLE

An applications' engineer has determined the need for a flat diaphragm with an OD of 5", a bore of 4", and a piston of 3" (from Fig. #D1). This configuration yields a web width (bore-piston)/2) of .500." Assembly will be via a crimped flange.

To determine how much material to be added to the OD for blousing during assembly, the engineer uses the following formula:

M (Material Required) = 2x (S-[web width]), where S^2 = (half stroke)^2 + (web width)^2

$M = 2x(2-.500), S^2 = (.106)^2+(.500)^2$
$M = 2x\ (S - .500), S = .511$
$M = 2x\ (.511 - .500) = .022''$

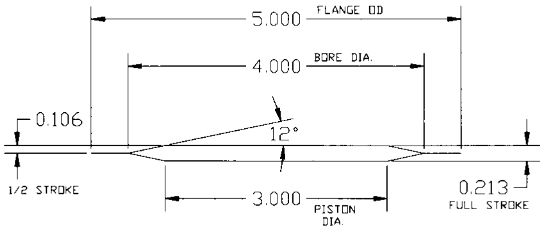
The minimum tolerance for the diaphragm OD would be 5.022". Additional dimensional tolerance should be added to determine the nominal and maximum dimensions.

thicker material cross sections, and remember, thicker is not always better.

Designing For Stroke

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° (Fig. #D1). The minimum web 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 applications this is not a hard and fast rule, but merely a starting point. (When designing any diaphragm, one half of the stroke should be above the flange plane, and one-half before the flange plane, this will allow judicious use of the material).

Fig #D1



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. The example to the left explains how.

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.

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. More energy is required to start the stroke. During the return stroke energy is returned to the system. 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 accompanied by some 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 resulting in set point changes. If there is concern that these kind of changes are going to present problems on instruments or control devices, it may be best to start with a formed diaphragm. These will be discussed in our next section, Design Criteria pages 14-23.

Please note: Some relaxation or sagging of the fabric diaphragm may occur during flex conditioning or cycling. This is very important to manufacturers of regulators and other devices with critical set points. The set points could drift until the fabric is broken in. Precision Industries Engineers suggest diaphragms for these types of applications be exercised before set points are established.

To circumvent the pre-bag/trampoline syndrome, some inventive engineers have taken extreme approaches to diaphragm design. In one instance an automotive fuel systems company designed an elliptical diaphragm so that when it was pushed into the hardware, the flange would be smooth, round and ready for assembly.

MANY FACTORS INFLUENCE THE SUCCESS OF A FLAT DIAPHRAGM APPLICATION. TO EXTEND DIAPHRAGM LIFE KEEP THE FOLLOWING FOUR CRITERIA IN MIND AS YOU DESIGN YOUR DIAPHRAGM EXPECTANCY:

- **A.** Keep the web area as wide as possible.
- **B.** Provide enough material slack in the diaphragm.
- **C.** Whenever possible use a thinner and/or a more flexible material.
- **D.** Keep the stroke requirements as small as possible.

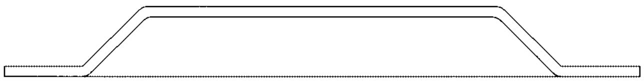
MOLDED OR FORMED DIAPHRAGMS

Many of the problems associated with flat diaphragms can be overcome by using a molded or formed diaphragm. The primary advantage of formed diaphragms are their marked performance versatility over the flat diaphragms. They command a premium price and usually tooling is required. However, the additional cost is often offset by the ease of assembly and minimal rework to bring the device into working specification.

The several types of molded diaphragms are listed below in general order of stroke capability (minimum to maximum):

A. SHALLOW DRAW, DISH OR (PIE PAN) STYLE:

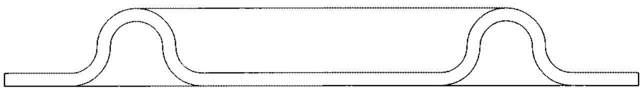
Fig. #D2



As the name implies, this style looks very much like a pie pan. Shallow draw diaphragms are used for strokes just beyond the range of flat diaphragms. The advantage here is easier assembly and non-prebagging.

B. CONVOLUTED STYLE:

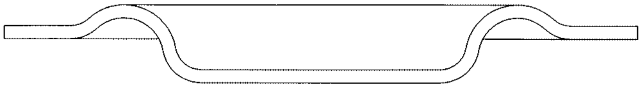
Fig. #D3



This style also has stroke capabilities just beyond flat diaphragms. 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.

C. DROP CENTER:

Fig. #D4

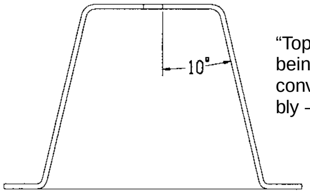


Drop center diaphragms are convoluted diaphragms with a deeper center draw. This style has all the advantages of the convoluted style with longer stroke capability. Drop center styles can also be easier to assemble than convoluted styles particularly if a return spring or some other hardware limitation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

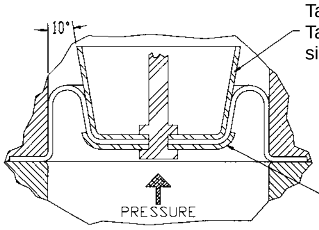
D. Deep Draw or “Top Hat” Style:

Deep draw diaphragms have the longest strokes available. Their stroke capabilities are only limited by their height to bore ratio (which for best results should not exceed 1:1) and the chosen reinforcing fabric’s ability to be conformed to the necessary shape. Before assembly, deep draw diaphragms must be convoluted so they will roll properly. Deep draws can occasionally invert in the convolution area. This problem can be controlled by tapered pistons and curved lip retainer plates that match the diaphragm sidewall angle that locks the piston and radii of the diaphragm to the hardware.

Fig. #D5



“Top Hat” Diaphragm before being positioned into its convoluted state for assembly – see below



Tapered Piston. Taper to match sidewall angle.

Curved Lip Retainer Plate

Each style can be made with or without:

A. Fabric
B. Sealing Beads, ID and OD
C. Gasketing

Each of these options will be discussed in the Design Criteria Chapter of this manual.

Most of the molded styles with some exceptions, notably the deep draw, can be made from many of the coated fabric styles available. For deep draw styles it is often necessary to produce these parts from the lay-up method.

Lay-up is a construction where the chosen fabric and elastomer are brought together at the mold to form the finished part. The down side to this type of construction is the fabric has 90 to 95% of the elastomer on one side and only 5% to 10% on the other. By their very construction, lay-up diaphragms are designed to be used with pressure on the rubber side only. Pressure reversals, or pressure on the fabric side, tend to blow the rubber off the fabric causing a failure due to the limited adhesion of the rubber to fabric mechanical bond. Occasional momentary pressure spikes may not be a problem, but consistently repeated ones will. Coated fabric negates this issue, but draw depths can result in limited stroke lengths.

Precision Industries Engineering Department can help you with a solution to this challenge.

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. No warranty is expressed or implied. All efforts have been made to provide comprehensive and accurate data. Any other use of The Diaphragm Engineering and Design Manual is strictly prohibited without written permission from Precision Industries Corporation.

DESIGN CRITERIA

This section covers a variety of diaphragm engineering design criteria.

What happens to a diaphragm during stroking?

How to determine diaphragm strength requirements?

What are appropriate diaphragm dimensional tolerances and stresses?

How to maximize diaphragm performance with its mating parts.

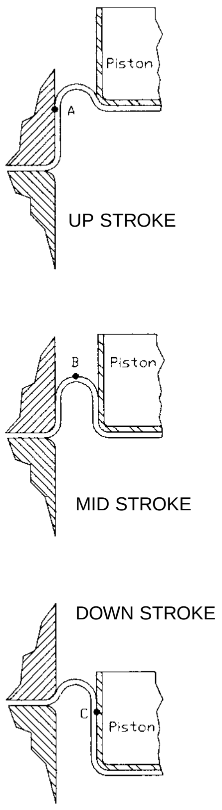
A review of how to design a diaphragm for maximum performance.

THE DYNAMICS OF A DIAPHRAGM

It is a good idea to review the dynamics of a diaphragm and what happens during stroking. These comments will be confined to a diaphragm with fabric reinforcement activated by means of a pressure differential and operates without a 180° convolution throughout its stroke.

SIDEWALL ACTION

Fig. #D6



Drawing #D6 shows the cross section of the web area in three positions. Please note that point A is an arbitrary position on the web sidewall, selected for illustration. The B and C positions are in the same place in the web, but they have changed position within the convolution. The 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. Pressure shapes the web moving within the confines of the piston and bore. The configuration of the curve closely resembles a curve generated by a catenary, regardless of its previous molded shape.

During the positive stroke the material, rolling away from the piston, is in an expansion mode. 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 the constricting forces which cause radial creases on the sidewall. Known as the molded position, the effect of these stresses can be negated if, when molded, the initial shape of the diaphragm is at the bottom of the stroke. With the diaphragm molded in this position, the material on the inner wall will be returning to its original shape on the return stroke.

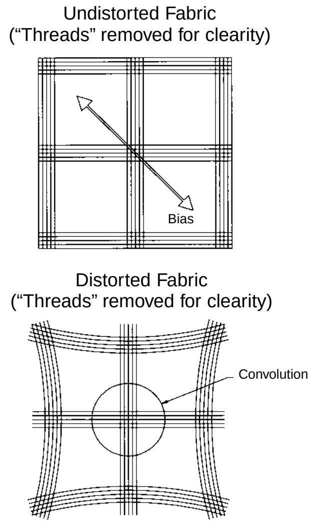
On the up stroke the full pressure is across the web stretching the material. However, on the return stroke, the pressure drops off and the energy in the spring becomes the dominating force returning the piston. Often, there may not be sufficient pressure across the diaphragm to prevent wrinkles. In cases like this, the wrinkles can become creases and creases can become failure points. This is especially important in very light pressure applications. This phenomenon is referred to as cornering because of the fold or seam that forms at the failure point.

THE PISTON ACTION & MATERIAL DYNAMICS

A piston does not usually travel at right angles to the axis unless it is well guided. Sometimes, at slow strokes, the pistons 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.

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

Fig. #D14



Stresses on the bias of the fabric during the formation of the convolution narrows it along the warp and fill directions of the yarns.

CAUSES FOR NON-LINEAR STROKING

A. Yarn geometry within the fabric.
B. Return spring not seated or not flat ground.
C. Insufficient bearing support of the piston rod.
D. Spring coil diameter too small for piston.
E. Piston height too low. Does not support the diaphragm sidewall.
F. Too wide a web width.

Diaphragms have a circular working area. Four positions within the working area will have yarns running in a radial direction from the center. Fabric being stressed in the direction of these yarns will exhibit little or no stretch. In sections half way between the four quadrants, the yarns are on the diagonal or bias of the fabric. With stress on the bias, (Refer to Fig. #D14), yarns want to divert in the direction of the stress. They become skewed to each other and the fabric elongates in the direction of the bias. Conversely, the straight threads within the fabric will appear to shrink. In an application the diaphragm OD is held secure. The shortening in the straight threads is, therefore, not evident with the diaphragm in place, but the distortion in the bias direction is evident as the material becomes bunched. The amount of elongation in the diaphragm sidewall will be directly related to the angular change between the yarns.

A flat cut reinforced diaphragm will react as indicated above with 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 case of a molded diaphragm, the yarns become more distorted as the material is drawn into shape and the condition described above will become more pronounced. Little can be done about this condition. However, diaphragms with generous radii will support an easy rolling action and the wobble should not create any harmful effects on the diaphragm.

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

EFFECTIVE AREA - DIAPHRAGM TYPE CYLINDERS

For the purpose of this discussion, consider any diaphragm operating device a cylinder. This would include transducers, relief valves, reducing valves, pressure switches and the like.

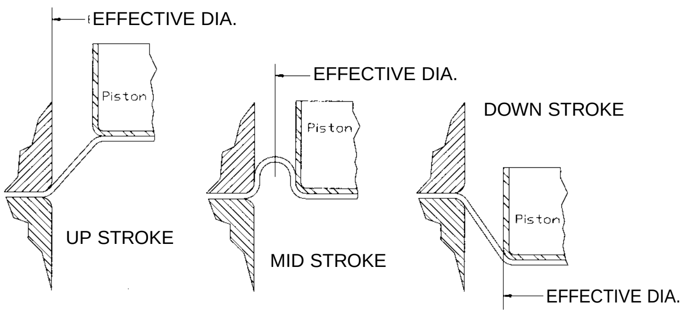
For all practical purposes the effective area of a conventional cylinder is the area of the piston. The clearance between the bore and piston is usually small to contain a compression type seal, i.e. o-ring, packing, etc.

By comparison, a much larger clearance is required for a diaphragm type cylinder as this clearance provides space for the active portion of the diaphragm, the convolution. The diaphragm bridges the gap between the housing and the piston and functions as a seal.

When a 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.

In the absence of the 180° convolution, the effective area would vary from a maximum defined by the bore diameter, to a minimum bounded by the piston diameter. In this case the size of the piston, therefore, determines the minimum effective area of the diaphragm. The area change occurs as the material is drawn tight against the piston plate and housing. At this point there is no distinctive curve within the web material.

Fig #D7



Once, there was considerable emphasis on using diaphragms to produce a constant effective area throughout the useful stroke. With the addition of more convolution height and a narrower piston and bore gap, 180° convolutions could be accomplished. This approach did not produce the most durable parts as 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 a 180° convolution, under light pressure, featured measurable changes in effective diameters. However, these same parts, showed no measurable change when higher pressures were introduced as long as there was some semblance of a curve in the web during travel, the higher pressures overcame the internal resistance of the material and formed a concentric convolution. Once the web comes under tension, as it comes to the top or bottom of its stroke, the effective area changes rapidly.

The change in effective area, in terms of changing energy requirements is minimal. The diaphragm is but one link in the chain that involves energy usage.

EFFECTS OF THE RETURN SPRING

In most applications a return spring is used in conjunction with a diaphragm assembly. A typical assembly consists of a piston plate attached to the diaphragm. Initially, the spring is compressed to effect a preload. The compression of the spring creates a negative force requiring a higher pressure to move the diaphragm. The influence of the spring greatly reduces the net effective area of the diaphragm. This change far exceeds anything achievable by a diaphragm. The energy stored within the spring is responsible for the major share of the hysteresis in the system. This is especially true on some very light pressure sensing devices where hysteresis can become a major concern.

Mechanical friction in the system also contributes to the energy requirements. The rolling friction and spring rate changes can effect the system's energy requirements. With these variables factored in, the actual effective area is significantly different from any changes that could be contributed to the diaphragm alone.

The contention is it is best to design diaphragms to maintain a 180° convolution throughout their useful stroke. Conversely, practical applications often shows it is advantageous to utilize diaphragms with wider web sections and gentle radii to reduce stresses by removing radial compression and easing the rolling action.

DIAPHRAGM STRENGTH REQUIREMENTS

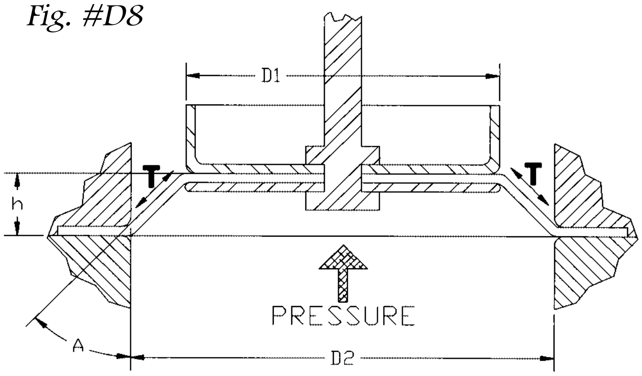
Determining diaphragm sidewall tension is a complicated procedure. Knowing the tension in the flex area while the piston is in the transition mode can get complicated and is beyond the scope of this manual. The tension will modulate while the diaphragm is moving from point A to point B and to point C (Fig. #D6).

We have concentrated on the worst case scenario which is when the diaphragm has reached the end of its stroke and the material stops the motion of the piston.(See Fig. #D8)

Considering the worst condition, the total 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 web area.

Fig. #D8



In both cases the forces are translated to the peripheral pounds per inch for each area and then added together.

Formula:

Total Tension

$= T = .25P/COS\ A+(D_1+(D_2{}^2-D_1{}^2)/D_2)$

= Lb/in (of Bore Circumference)

Where:

D_1 *= The piston diameter in inches*

D_2 *= The bore diameter in inches*

P = The pressure in PSI

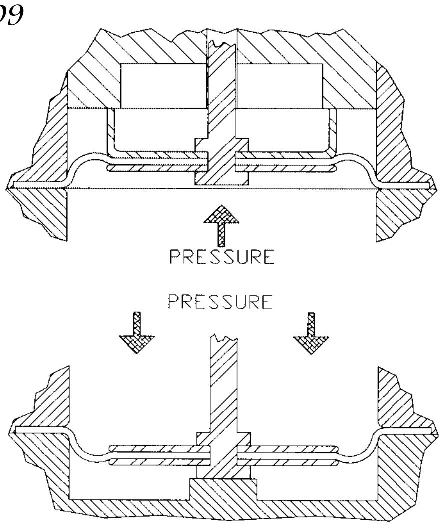
A = The angle of the sidewall from the vertical

Note: $A=Tan^{-1}((D_2-D_1)/2)/h$ *(the Height of the convolution at max stroke)*

A positive stop (see Fig. #D9) should be incorporated in the system design to prevent the diaphragm from acting as a brake for the piston.

EXAMPLES OF POSITIVES STOP

Fig. #D9



RESIDUAL STRESSES

There are additional problems that come under the mantle of stresses that are not design problems. Such problems are encountered by the fabricator of the diaphragms and can be classified as residual stresses.

These stresses often manifest themselves as distorted parts. Some common causes are:

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. Undercure of the rubber.

It is up to the manufacturer to deal with these issues, they need to be considered by all parties as they are often a result of diaphragm shape and the elastomer/fabric combination.

TOLERANCES

(A chart on page 19 provides a comprehensive look at typical tolerances.)

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

The first rule of thumb should be form, fit and function, or: 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 should be a clear understanding between all involved as to acceptable dimensions and how they are to be verified.

Diaphragms made via the lay-up process and coated fabric diaphragms have differing tolerance requirements. Both have their greatest need in 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 in dimensional tolerancing of diaphragms. The Precision Industries Engineering and Quality Departments will be happy to discuss all options available for your intended application.

THE CARE AND HOUSING OF DIAPHRAGMS

Up to this point we have only been concerned with the diaphragms themselves. Our discussion will now turn to the diaphragm's mating parts. These surrounding parts must be compatible with the diaphragm, otherwise the performance will suffer. Allow the diaphragm to operate in a place that is wide enough to offer free movement.

All hardware that contacts the diaphragm must be smooth, burr free, having matching radii and supporting sidewalls.

FLANGE MOUNTING

There are two elements that should be considered as key conditions greatly influencing the function and reliability of a diaphragm. These elements are aside from the material selection. They are the geometry of the web section and the housing design and assembly method.

The most common cause for diaphragm failure and poor performance can be attributed to problems in the flange area. The most important consideration is not only the design of the housing, but also the method of assembling the diaphragm to the unit. The basic problem stems from the difficulty controlling the compression on the material. The rubber portion of the material can only support a limited amount of squeeze. A seal cannot be maintained when the loading exceeds the compression capabilities of the material.

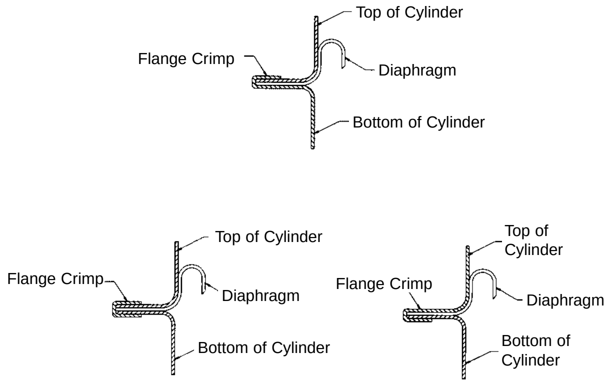
The problem, as with any gasket material, is the difficulty in determining what the flange loading should be. The rubber portion of the diaphragm is the most sensitive to compression loading. The temperature and the resistance to the fluid affect the set properties of the material. To maintain a set, the loading capacity of the material must not deteriorate. Often a cut and try method is required to arrive at the amount of compression on the flange.

TYPICAL TOLERANCES

	RANGE	TOLERANCE
ID/OD Trim Diameters and Hole Sizes	.50” and below	+/-.005”
	.50 to 1.00”	+/-.010”
	1.01 to 3.00”	+/-.015”
	over 3.01”	+/-.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
	over 4.01”	.020” True Position
Convolution Height		+/-.015” per inch of height (not to be less than +/-.015”)
Angular Relationship of Holes		+/-1/2°
Thickness	.005 to .011”	+/-.002”
	.012 to .018”	+/-.003”
	.019 to .025”	+/-.004”
	.026 to .032”	+/-.005”
	.033 to .039”	+/-.006”
	over .039”	+/-.007”
Piston and Bore Diameters		+/-.010” per inch of diameter (not to be less than +/-.010” or greater than +/-.060”)
Bead Width	.062 to 187”	+/-.003”
	.188 to .250”	+/-.004”
	over .250”	+/-.006”
Bead Height	.062 to .187”	+/-.005”
	.188 to .25”	+/-.006”
	over .250”	+/-.008”
Trim Flash (Where Applicable)		.025” x .025” max

If your requirements are not covered by this information, please contact the Precision Engineering Department for more information.

VARIOUS CRIMPED FLANGE STYLES
Fig. #D10



Problem solving is often attempted by asking for a heavier material. The thinking is that more is better. While there will always be exceptions, it is strongly suggested to use thinner material.

If the flanges are held together by screws or bolts, the torque will have to be determined in order to produce the optimum flange loading. With crimped sheet metal parts (See Fig. #D10), the closing dies can be adjusted. In either case it is strongly suggested that exposure tests, at temperatures and with the fluid involved, be conducted to establish optimum loading.

Also of concern is the amount of material that extrudes into the web area. The extrusion forms a thicker "bead-like" cross-section just inside the bore diameter which is a major flex area. With the addition of the "bead," or thicker cross section, the material will be vulnerable to flex failure. Soft materials tend to extrude more easily. On the other hand, firm materials exhibit a higher modulus of elasticity which, while not easily extruded, can affect the flex resistance of the material. A trade-off or compromise would be in order. Testing will increase your confidence level.

FLANGE MOUNTING - LARGE DIAMETERS

In this section the discussion will cover flange mounting of diaphragms with large diameters.

Often, these devices are made from cast metal housings that require machining. Bolts are the usual fastening method. The bolt diameters have to be considered as they will add to the flange width.

The unit loading requirements do not change with the width or size of the flange. However, the total loading increases dramatically as the area under the flange increases. The bolt size and the spacing can be determined by testing the sealing requirements of the material.

It is not our intention to detail the method of calculating the bolt requirements, only to point out what is involved. This method can get complicated and several factors have to be taken into consideration. A gasket design manual details the methods of obtaining flange loadings. To avoid duplicating material found in a gasket design manual, we will highlight some of the problems that can occur with bolt type installations.

ITEMS ARE LISTED IN ORDER OF FREQUENCY OF PROBLEM OCCURRENCES.

1) Bending of the material in the flange between the bolts. Correction can usually be made by adding more bolts thus reducing the distance between them. Increasing the thickness in the flange material will reduce the amount of distortion.

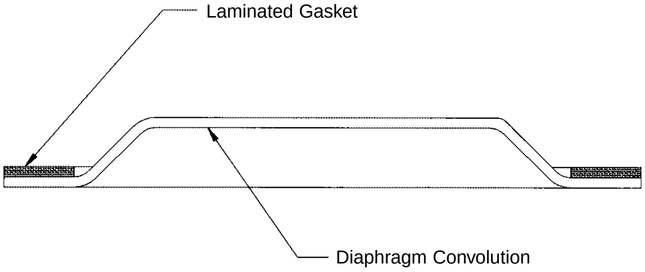
2) Distortion of the flange material around the bolt holes. Lightweight sheet-metal designs lend themselves to this type of distortion. This is usually caused by excessive force applied to the bolts. Lightening up on the torque on the bolts and/or increasing the thickness in the flange material will 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. Warped flanges can also become a major problem and often can be overcome by uniform bolt loading. On the other hand, the surfaces

might have to be machined to bring them into parallel. Plastic housings and covers are very apt to exhibit warpage as the molding operations tends to create depressions in certain areas due to varying wall thicknesses.

4) Surface Roughness. In most cases the commercial finishes should not present sealing problems. However, an exceptionally hard material might not conform to the rough surface. Another option would involve heating the material enough to soften it so as to conform to the flange surfaces. Other considerations would include a slightly thicker or softer material.

Fig. #D11



The physical properties of the material cannot be ignored as it not only serves as a gasket, but also as flexible barrier. Careful attention to design features and methods of installations can often avoid material compromises.

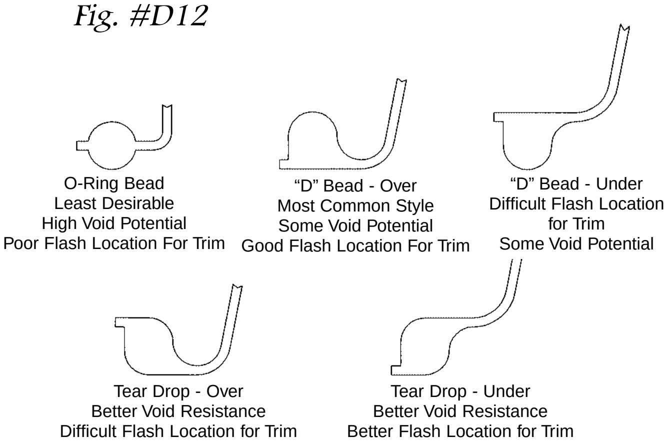
There are types of diaphragms, which are made from thin coated fabric, that incorporate a fibrous gasket material bonded to the flange. Precision Industries specializes in this bonded gasket construction. A typical construction is shown in Fig. #D11.

Gasket materials are available in Rubber, Cork/Rubber, Cork Composition, Cellulose/Rubber and High Performance Fiber/Rubber. Not only can this style of construction improve the sealability of the diaphragm, it can help reduce assembly costs by eliminating multiple suppliers and components.

Flange Sealing With Beads

Beaded diaphragms have been available to the designer for some time and are widely used.

Fig. #D12



Our discussion here will center mainly on the beads used to seal the flange. Beads offer many advantages over flat flanges.

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. Upon cooling, the plastic material shrinks. The shrinkage is not always uniform. Under these conditions, flat flanged diaphragms often do not have enough material thickness to compensate for the irregularities of the housing material. Machining the plastic parts to remove irregularities is not practical and defeats the purpose of using plastic.

The second challenge to flange sealing with plastic hardware involves the high coefficient of

THE ADVANTAGES OF TEAR DROP BEADS ARE AS FOLLOWS:

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 back pressure in the mold to allow positive flow of the rubber and flushes out trapped gasses in the bead.

expansion and contraction of the plastic materials. At temperature extremes, the materials change dimensionally and possibly even in shape. All these factors become part of the sealing equation. 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 would function as an O-ring. The bead, having a small contact surface, can affect a seal with high unit loading and low strain on the unit itself.

The primary function of the beads is to seal the diaphragm to the housing. Some feel that the bead renders a degree of confidence in preventing diaphragm pull-out. Pull-outs are generally the result of over clamping, crushing and adhesion failure.

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

BEAD PROFILE

While the most common bead forms are circular or D shaped, we recommend bead design known as The Tear Drop. This design provides for the flange 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. Fig. #D12 shows some of the typical styles. Other styles can be made depending on overall diaphragm style and construction. Please consult with the Precision Industries Engineering Department for further details.

BEAD & GROOVE DESIGN:

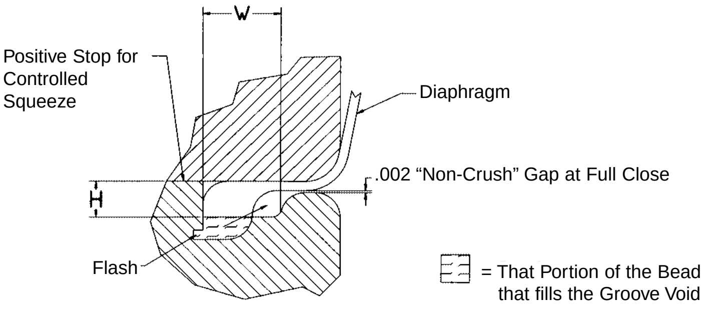
Beads can vary in size and shape to provide for special conditions. Adjustments to the bead shop or the groove design may be required to compensate for the stock flow due to compression and environment swell.

We recommend a 30% compression on the bead as a starting point. Higher compression would be required for higher modulus compounds. Beads should fit snugly against the outer wall of the bead groove.

Rubber does not change in volume but flows when compressed and it will assume the shape of the bead groove. Rubber swell would be a factor when determining the bead groove ID. 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.

A TYPICAL BEAD GROOVE CONFIGURATION
Fig #D13



DETERMINING THE SIZE OF THE PISTON

We have assumed that the effective diameter is the piston diameter rather than midpoint between the bore and the piston (as others may do). This approach will partially 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. (Refer to pages 14-15).

In determining the amount of force the diaphragm will have to tolerate, consider return springs and other pressures that have to be overcome. These forces must be added to the primary requirements. Spring loading can be worked out knowing the rate and calculating the load at full stroke. Other pressures may have to be measured or estimated. If there are severe size restrictions on the diaphragm, the working pressure may have to be increased or the spring force requirement reduced.

DETERMINING THE WIDTH OF THE WORKING ZONE

Width of Work Zone = Total Stroke x 26%

The relationship of the width of the working zone and the stroke is of prime importance. The ratio has been worked out to minimize stresses in fabrication and diaphragm function.

It is preferred that when working out the stroke that one half of the stroke be above the flange plane, and the other half below the flange, which will optimize the material usage.

TRANSITION RADII

The transition radii are the radii that define the shape of the web area of the diaphragm by connecting it to the flange and the piston. For all practical purposes both the exit and entrance radii should be the same. In any case, these radii should be 1/4 of the width of the web width and should never be less than .015”.

The corresponding radii on the hardware must also be the same as those on the diaphragm. These radii must be as smooth as possible with no tool marks or burrs.

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. No warranty is expressed or implied. All efforts have been made to provide comprehensive and accurate data. Any other use of The Diaphragm Engineering and Design Manual is strictly prohibited without written permission from Precision Industries Corporation.

PRECISION INDUSTRIES ENGINEERING STAFF

This Design Manual has been a goal of the Precision Industries engineering staff for quite some time.

We have kept notes, refined techniques, developed innovative designs and solutions to diaphragm challenges, and generally brain-stormed about the need and creation of a useful, working manual for Precision Industries customers.

This manual is the culmination of efforts of the entire staff of Precision Industries, Inc. However, three Precision engineers are responsible for the majority of this document and the creativity, engineering skill and dogged pursuit of solutions to customer challenges.

Glenn Thomas, Engineering Director

Glenn is a native Bostonian who earned a BSMET degree with honors from the University of Massachusetts at Lowell.

More than 15 years of his professional engineering experience has been concentrated in the manufacture of diaphragms, diaphragm controls, coated fabric and gaskets.

Glenn has been with Precision Industries since 1990 and is a member of The Society of Automotive Engineering (SAE), The Wisconsin Rubber Group and has had special training in SPC and Basic Rubber Technology.

Those of you who have worked with Glenn know he thrives on challenge and won't give up until a solution is found. Easy to work with and highly skilled, Glenn Thomas is a valuable asset to your design team.

Robert A. Witte, Consultant

Perhaps the most experienced diaphragm engineer in the country, Bob Witte, has worked with the Precision Industries team to create this manual.

Bob has nearly 40 years of application engineering of diaphragms, seals, packings and highly-technical rubber products experience. There simply hasn't been a diaphragm engineering challenge he hasn't seen, nor met.

Bob earned his BS Degree in Mechanical Engineering from Syracuse University in 1948 and possesses a Certificate in Rubber Technology from the American Chemical Society and is a Life Member of SAE.

Gerald Miller, Vice President-Technical Services

Jerry has been working with diaphragms since 1965.

He has designed diaphragm production equipment along with the complex tooling necessary for diaphragm manufacture. He is considered a leading expert in coated-fabric diaphragm design and engineering.

In 1986, he started Precision Industries Corporation. Since its beginning, Jerry has helped guide the company's exceptional growth, including a major expansion of the company's production facilities and staffing.

Jerry, along with Glenn and Bob represent decades of diaphragm design and engineering experience. Their experience, expertise, dedication and skills are included in this manual. We offer this manual as a service and encourage you to contact the Precision Industries Engineering Department for consultation on all of your diaphragm needs.

Thank you.
PRECISION INDUSTRIES CORPORATION TEAM

Engineering & Application Data Forms

This as the name implies is several pages of fill-in-the-blank forms. These forms, hopefully, will be used to give Precision the opportunity for business.

The form asks several questions to provide our Engineering Department with information to assist in the analysis of the customer's application. Where possible, Precision would like prints, layouts or sketches of the proposed installation.

PRECISION INDUSTRIES CORPORATION
6115 Executive Drive 105N
Mequon, Wisconsin 53092
(414) 238-5000 FAX (414) 238-5010

ENGINEERING and APPLICATION DATA FORM

Your Name____ Date________________

Company____

Address____

____

Phone #__________________________ FAX#____________________________

E-mail Address____

Answers to the following questions will provide our Engineering Department with information to assist in the analysis of your specific application. Where possible, please provide prints, layouts or sketches of the proposed installation.

☐ Existing Application ☐ New Application

Type of Flange Mounting_______________ Minimum Pressure (psi)__________

Pistion Diameter (in)_________________ Maximum Pressure (psi)__________

Up Stroke*(in)______________________ Reverse Pressure______yes______no

Down Stroke*(in)____________________ Minimum Operating Temp._______°F

Cylinder Bore Diameter (in)______________ Maximum Operating Temp._______°F

Cycle Rate: Test_________ Use__________ Interval at High Temp.____________

Fluid or Gas in contact with diaphragm_____________________________________

Special Quality Considerations____

____

Annual Quantity Requirements____

____

Other Information____

____

____

*As measured from the flange.

GLOSSARY OF TERMS

GLOSSARY OF TERMS

ABRASION -- The wearing away of a material surface through friction. Particles become detached through a combined cutting, shearing and tearing action.

ADHESION -- The clinging or sticking of two material surfaces to one another. In rubber parlance, the strength of bond or union between two rubber surfaces or plies, cured or uncured. The bond between a cured rubber surface and a 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. Some antioxidants cause staining or discoloration of the rubber compound on exposure to light.

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.

BLEEDTHROUGH -- Refers to the movement of fabric toward the pressure side of the diaphragm, during the molding operation.

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.

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.

COMPOUND -- (1)In chemistry, it is the material resulting from the chemical union of two or more elements in definite proportions and in which the properties of the individual elements have disappeared. (2) 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 -- The residual decrease in thickness of a test specimen measured 30 minutes after removal from a suitable loading device in which the specimen has been subjected for a definite time to compressive deformation under specified conditions of load application and temperature. Method A measures compression set of vulcanized rubber under constant load. American Testing and Safety Materials (ASTM) Method B employs constant deflection.

CONVOLUTION WIDTH -- 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. This can be caused by the fabric weave, hardware, or diaphragm shape or slack material. Cornering normally results in failures that look like cuts that are perpendicular to the flange.

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.

DRY OUT – The condition of the rubber after a chemical soak.

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

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

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

ELASTICITY – A property of an 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.

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 Bleedthrough.

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

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

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 – Same as the "convolution Width."

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

GLASS TEMPERATURE – The temperature when a rubber becomes glass-like. A more recent name for Second Order Transition Point.

HARDNESS – See Durometer.

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

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.

Lay-Up -- The process of producing a 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.

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

Mill -- A machine consisting of two adjacent, heavy, chilled iron rolls set horizontally, and which count 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.

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 an 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 to obtain the combination of properties most desirable for the article under consideration.

Overcure -- A state of excessive vulcanization resulting from overstepping the optimum cure, i.e. vulcanizing longer than necessary to attain full development of physical strength. Manifested by softness or brittleness, and impaired age resisting quality of the vulcanizate.

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

Ozone -- An allotropic form of oxygen, (0_3), 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 cracked condition.

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

Permanent Set -- The amount by which an elastic material fails to return to its original form after a deformation. In the case of elongation, the difference between the length after retraction and the original length, expressed as a percentage of the original length is called the permanent set. Permanent set is dependent on quality and type of rubber, degree and type of filler loading, state of vulcanization, and amount of deformation.

Plasticizer -- A substance that softens or plasticizes 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.

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 lay-up 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.

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.

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.

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 to produce a given elongation. Extreme reversion may result in 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.

ROLLING ACTION – Refers to the way a convolution moves during its cycling.

SCORCHING – A term frequently used to denote premature vulcanization of a rubber compound occurring on a mill or calendar, or in an extruder. Same as burning or setting up.

SEALING BEADS – See Bead & Groove.

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

STRIKETHROUGH – Refers to the amount of rubber on the non-pressure side of the diaphragm. Refers to the lay-up process to achieve best possible mechanical adhesion of fabric to rubber.

STROKE – The total travelor movement the diaphragm will be required to make.

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.

TRANSITION RADII – The radii that connect the flange to the sidewall and the sidewall to the piston portions of the diaphragm.

UNDERCURE - 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.

WEB AREA, WORKING AREAS, WORKING ZONE - See Convolution Width.