

POLYMERS AS A HYDRAULIC SEAL MATERIAL

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ABSTRACT

Current trends concerning hydraulic cylinder sealing systems are aimed at decreasing energy consumption which can be materialized by minimizing leaks and reducing friction. The latest developments in the field of materials and sealing system geometries as well as modern simulation possibilities allow maximum performance levels of hydraulic cylinders. Reducing friction is possible by hydro-dynamic separation of the sliding and sealing points already at very low velocities and by using materials, such as plastomers, from polytetrafluoroethylene (PTFE) (virgin PTFE and filled PTFE). It is within this context that this paper discusses a theoretical and experimental study focused on the tribological behavior of coaxial sealing systems mounted on the pistons of hydraulic cylinders.

For the analyzed working conditions related to pressure, speed, and temperature, the paper concludes with a set of criteria for the selection of the optimum seal material so as to maximize energy efficiency.

Keywords: *Dynamic seals, Static seals, Elastomeric, Thermoplastics, Elastomers — Polyurethane (TPU), Elastomers, Engineered Resins, Nitrile rubber (NBR), Carboxylated Nitrile rubber (XNBR), Hydrogenated Nitrile rubber (HNBR), Ethylene Propylene rubber (EPR), Fluorocarbon Elastomers (FKM), PTFE.*

INTRODUCTION

There are mainly two types of hydraulic reciprocating seals: rod and piston seals (Fig. 1). They are typically made of polymeric or plastic materials and most commonly by elastomers. Hydraulic seals are met in industrial, automotive and aviation applications involving linear and rotational motion, as for example in linear hydraulic actuators (Fig. 1) and rotary vane actuators. These seals operate under dynamic conditions of variable sealed pressure, stroking velocity and operating temperature. Several seal shapes have evolved over the years based on practical experience and engineering research to suit particular applications.

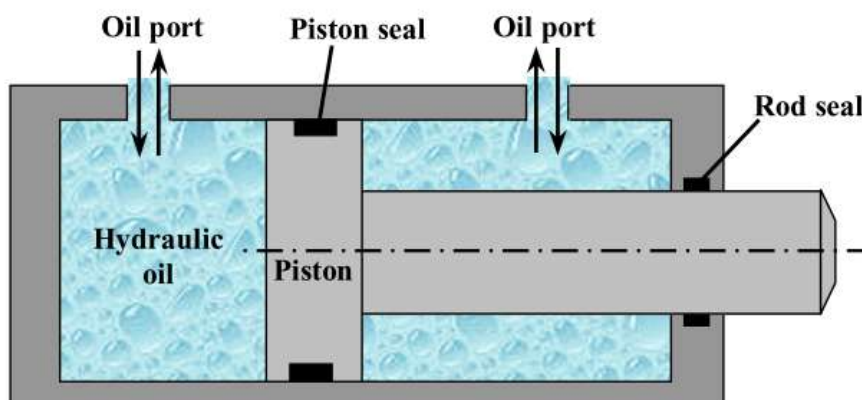


Fig. 1 Hydraulic seals in a linear hydraulic actuator.

HYDRAULIC SEALS AND GUIDES

Hydraulic cylinder seals are used to seal the opening between various components in the hydraulic cylinder. Figure 2 shows an example of the seal and guide components of a heavy duty cylinder. There are two main types of hydraulic seals in the system:

- **Dynamic seals**

They seal between components in relative motion. In a hydraulic cylinder the rod sealing system seals dynamic reciprocating motion between the piston rod and head, while the piston sealing system seals dynamic reciprocating motion between the piston and cylinder bore.

- **Static seals**

They seal between components fixed together without relative motion. Hydraulic cylinders use static seals in various locations depending on the design and construction. The most common are static seals between the piston and piston rod and between the head and cylinder bore tube. Each dynamic seal in a hydraulic cylinder has a special function to contribute to the performance of the system:

Piston seal functions

- Act as pressure barrier and prevent fluid passing the piston – important for controlling the cylinder motion or maintaining the position when at rest

Rod seal functions

- Act as pressure barrier and keep the operating fluid inside the cylinder.
- Regulate the fluid film which extends with the surface of the piston rod – important to inhibit rod corrosion and to lubricate the wiper seal and the rod seal itself
- Accept the lubrication film back into the cylinder when the rod retracts

Buffer seal functions

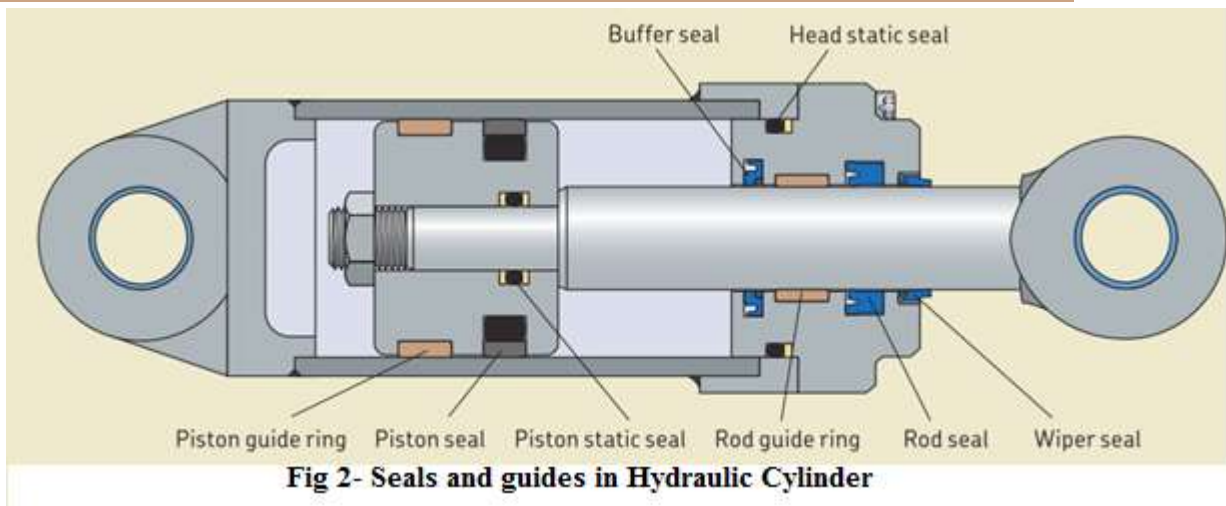
- Protect the rod seal from fluid pressure peaks in excess of system pressure • attenuate the fluctuations in system pressure, thereby improving rod seal performance by allowing the rod seal to deal with more constant or gradually changing pressure
- Act as an internal excluder to keep system contaminants, such as metal particles, from damaging the rod seal

Wiper seal functions

- Exclude external contaminants from entering the cylinder assembly and the hydraulic system
- Accept the lubrication film back into the cylinder when the rod retracts

Guide rings (rod and piston) functions

- Prevent metal-to-metal contact between components
- React the radial load caused by side loads on the cylinder assembly
- Keep the piston rod and piston accurately centred in the cylinder assembly – important for performance of the rod sealing system and piston sealing system



SEAL SELECTION CRITERIA

Selecting the right sealing system for new cylinder designs. Before seals can be selected certain application parameters and information should be collected. Depending on application, some of the most important requirements in selecting the best available hydraulic seal are as follows.

- (a) Low leakage rate.
- (b) Low friction (low power loss and high efficiency).
- (c) Fluid pressure range, the range of operating fluid system pressure, as well as frequency and severity of pressure peaks
- (d) Resistance to wear and long service life with consistent performance.
- (e) Resistance to gap extrusion (usually in high-pressure applications).
- (f) Resistance to extreme temperatures (for example, in the aerospace industry).
- (g) Temperature range, the range of the fluid and cylinder assembly, both when operating and at rest.
- (h) Speed, the stroking speed of the reciprocating piston rod
- (i) Fluid media, the type and viscosity of fluid used in the system
- (j) Hardware dimensions, the rod and bore diameters, seal groove dimensions and gaps, cylinder overall length and stroke length as well as surface finish specifications.
- (k) Application of the cylinder, the type of equipment the cylinder will be used on and how the cylinder will operate in the equipment as well as installation, duty cycles and environmental factors (external temperature, contaminants)
- (l) Chemical compatibility with sealed fluids.
- (m) Ease of installation.
- (n) Low cost.

Some of the listed requirements may be conflicting, as for example (a) and (b) (low leakage and low friction), in which case a compromise must be accepted. For a given application, the main parameters used for seal selection in conjunction with the listed requirements include the size, maximum sealed pressure, maximum stroking velocity (speed) and acceleration, the range of operating temperature, and the chemical properties of the sealed fluid.

SEAL MATERIALS

Hydraulic seals are made of polymeric materials, thermoplastics and composite materials. The choice is mainly based on the lowest and highest operating temperature, maximum stroking velocity, desirable resistance to abrasive wear and extrusion, as well as on the requirement to have low friction and to avoid stick-slip phenomena.

4.1 Elastomeric materials

Polymeric seals such as rectangular, toroidal and U-caps are usually made of elastomers, including rubber. Elastomers are suitable for hydraulic seals because of their flexibility. They have relatively low elastic and shear moduli, accommodating large deformations, both in tension and compression, as well as shear deformations, without permanent deflection or fracture. They are nearly incompressible with Poisson's ratio very close to 0.5 (typically 0.499 or higher), resembling liquids or metals in perfectly plastic state. Thus, they are suitable for reciprocating seals because they give them flexibility and the ability to adapt to temperature and sealed-pressure changes whilst maintaining sealing ability. Moreover, as nearly incompressible materials, they offer seals the ability to transfer the pressure exerted by a hydraulic fluid onto the sealing surface with negligible change in their volume and, thus, perform dynamic sealing, which is proportional to the sealed pressure.

However, elastomers have several performance limitations. The main problem is their mechanical properties greatly depending on temperature, strain and strain rate, as well as time. The elastic modulus of elastomers generally decreases with temperature and the change is very large at subzero temperatures where elastomeric seals stiffen. The response to strain is nonlinear near the glass transition temperature, which, for most elastomers varies between zero and + 70 °C. Operation below the glass transition temperature can cause irreversible structural changes and permanently reduce sealing performance. Moreover, owing to large thermal expansion coefficients of elastomers, elastomeric-seal dimensions change significantly with temperature, which impairs sealing performance at low temperatures and can even cause loss of sealing when the sealed pressure is very low. Other important deficiencies of elastomers include the following.

- Sensitivity to oxidation, which is accelerated at higher temperature and limits their storage life. Thus, the recommended storage life of elastomeric seals is under five years.
- Chemical attack from incompatible hydraulic fluids.
- Swelling from fluid uptake, which affects sealing performance owing to change of the sealing dimensions and, consequently, contact pressure.
- Ageing, which makes obvious the hardening, embrittlement and eventual loss of seal material.
- Relaxation and adhesion as for example in seals remaining stationary for long periods of time, which then exhibit high friction during start-up of motion and stick-slip phenomena, manifesting as vibration.

Because of their deficiencies, elastomers are often replaced by other materials in hydraulic seals, mainly plastics and composite materials.

4.2 Thermoplastics and composite materials

The use of plastics and composites in seals originated several decades ago. Among the main benefits of such materials are the increased resistance to wear, lower friction, avoidance of stick-slip and relaxation phenomena, wider operating temperature range with more consistent performance, and higher resistance to extrusion during reciprocating motion.

The best known material in this category is polytetrafluoroethylene (PTFE). Other materials have also found applications. For example, ultra-high-molecular-weight polyethylene (UHMWPE), polyurethanes and other low-stiffness materials. Composites are also used, for example, bronze-filled PTFE as in coaxial seals, PTFE with glass fibres and bonded with elastomers as in (reciprocating) rotary vane seals, and PTFE with other fillers such as stainless steel and graphite. The selection of these materials depends on the particular application requirements and should match the operating conditions. For example, UHMWPE cannot be used at temperatures higher than about 176 deg. F (80 deg. C). Some PTFE compounds on the other hand can be used at much higher temperatures because of their filler, which provide added strength.

4.2.1 Thermoplastics

All thermoplastics are resins designed to soften and melt when exposed to heat. Utilizing an injection molding process, thermoplastics are melted at high temperature and injected into the mold. It is then cooled causing the plastic to solidify. If high heat is introduced again, the molded part will melt. The molecules of thermoplastics are held together by physical bonds rather than chemical bonding.

4.3. Elastomers — Polyurethane (TPU)

Polyurethanes exhibits outstanding mechanical and physical properties in comparison with other elastomers. Specifically, its wear and extrusion resistance make it a popular choice for hydraulic applications. Its temperature range is generally -65°F to +200°F (-54°C to +93°C), with some compounds, such as Resilon® 4300 having higher temperature ratings up to +275°F (+135°C). Polyurethanes are highly resistant to petroleum oils, hydrocarbon fuels, oxygen, ozone and weathering. On the other hand, they will deteriorate quickly when exposed to acids, ketones and chlorinated hydrocarbons. Unless specifically formulated to resist hydrolysis (Resilon® 4301), many types of polyurethanes are sensitive to humidity and hot water. Other acronyms polyurethane may be known by are AU, EU, PU, and TPU or may simply be known as urethanes.

4.4. Elastomers — Polymyte (TPCE)

Polymyte is a Parker proprietary polyester elastomer. It has exceptionally high tear strength, abrasion resistance, modulus, and a wide temperature range of -65°F to +275°F (-54°C to +135°C). Polymyte is resistant to petroleum fluids, some phosphate ester and chlorinated fluids, common solvents and water below +180°F. It is not compatible with cresols, phenols, and highly concentrated acids. Due to its higher hardness and modulus, seals made from this material can be difficult to install. Also, care must be taken not to damage the seal lips during assembly into the gland..

4.5. Engineered Resins

Engineered resins such as Nylons and PEEK, sometimes called hard plastics, are generally categorized as compounds with hardness measured on the Rockwell M or R scale. These compounds exhibit high tensile and compressive strength and are typically used in wear rings for bearing support and in auxiliary devices for extrusion resistance.

4.5.1 Engineered Resins — UltraCOMP (PEEK)

UltraCOMP engineered thermoplastics are semi crystalline materials manufactured for extreme temperatures, chemicals and pressures. Their excellent fatigue resistance and stability in high temperature environments make them the material of choice where other materials fail. With a melt temperature of over +600°F, UltraCOMP can be used at continuous operating temperatures of -65°F up to +500°F (18 deg. C to 260 deg. C).. Superior strength and wear resistance properties make it an ideal alternative to metal or metal alloys in applications where weight, metal to-metal wear or corrosion issues exist. Such capabilities translate into reduced equipment down time and increased productivity. For example,

UltraCOMP back-up rings exhibit optimum strength flexibility for ease of installation and high tensile strength properties for premiere extrusion resistance. UltraCOMP is available in molded geometries and machined geometries. UltraCOMP engineered thermoplastics are semi crystalline materials manufactured for extreme temperatures, chemicals and pressures. Their excellent fatigue resistance and stability in high temperature environments make them the material of choice where other materials fail. With a melt temperature of over +600°F (316 deg. C). UltraCOMP can be used at continuous operating temperatures of -65°F up to +500°F (18 deg. C to 260 deg. C). Superior strength and wear resistance properties make it an ideal alternative to metal or metal alloys in applications where weight, metal to-metal wear or corrosion issues exist. Such capabilities translate into reduced equipment down time and increased productivity. For example, UltraCOMP back-up rings exhibit optimum strength flexibility for ease of installation and high tensile strength properties for premiere extrusion resistance. UltraCOMP is available in molded geometries and machined geometries.

4.6 Nitrile (NBR)

Nitrile rubber (NBR) is the general term for acrylonitrile butadiene copolymer. Nitrile compounds offer good resistance to abrasion, extrusion, and compression set. The acrylonitrile (ACN) content influences the physical properties of the compound. As the ACN content increases, oil and solvent resistance improve, tensile strength, hardness and abrasion resistance increase, while permeability, low temperature flexibility, and resilience decrease. Parker offers a variety of nitrile compounds, formulated with varying ACN content, to provide the best physical properties for a wide range of applications. Typical temperature ratings are -40°F to +250°F (-4° to 121°C)

4.6.1 Nitroxile (Carboxylated Nitrile) (XNBR)

Carboxylated nitriles are formed by exposing nitrile polymer to carboxylic acid groups during polymerization. This forms an improvement over nitrile by producing a more wear resistant seal compound with enhanced modulus and tensile strength. Nitroxile offers exceptionally low friction characteristics and has

excellent resistance to petroleum oils, hydrocarbon fuels and water. The typical temperature for Nitroxile is about 250°F (+121°C).

4.6.2 Hydrogenated Nitrile (HNBR)

Hydrogenated nitrile offers improved chemical compatibility and heat resistance over standard nitrile by using hydrogen in the formulation to saturate the backbone of the nitrile molecule. However, the compound usually becomes less flexible at low temperatures. This can be offset to some degree by adjusting the ACN content as is done with NBR. Typical temperature ratings are -25°F to +320°F (-4° to +160°C).

4.7 Ethylene Propylene (EPR)

Ethylene propylene has excellent dimensional stability in water-based fluids and steam; however, it should never be exposed to petroleum lubricants, water / oil emulsions, solvents or other petroleum based fluids (CAUTION! Do not lubricate the seals with petroleum oils or greases during installation). Ethylene propylene rubber is compatible with phosphate ester fluids used in aircraft hydraulic systems. EPR is also the recommended seal material for automotive brake fluids (DOT 3, 4 and 5) as well as many commercial refrigerants. Ethylene propylene rubber is also useful in sealing weak alkalis, acids, and methyl ethyl ketone (MEK). The typical temperature range is -65°F to +300°F (-18° to +149°C). Maximum temperature in water or steam is +400°F (+240°C).

4.8 Fluorocarbon Elastomers (FKM)

Fluorocarbon elastomers are highly specialized polymers that show the best resistance of all rubbers to chemical attack, heat and solvents. FKM is of critical importance in solving problems in aerospace, automotive, chemical and petroleum industries. FKM is suitable for use in most hydraulic fluids except Skydrol® types and ester-ether fluids. Standard temperatures range from -20°F to +400°F (-7°C to +204°C).

4.9 PTFE

PTFE (Polytetrafluoroethylene) offers the following characteristics over thermoplastic and thermoset compounds, making it a unique problem solving solution for sealing applications:

- Low coefficient of friction The low coefficient of friction (.06) of PTFE material results from low interfacial forces between its surface and other materials that come in contact. This behavior of PTFE material eliminates any possibility of stick-slip effects in dynamic sealing applications.
- Wide temperature range PTFE's high melting point and morphological characteristics allow components made from the resin to be used continuously at service temperatures to +600°F (+316°C). For sealing cryogenic fluids below -450°F (-213°C), special designs using PTFE and other fluoropolymers are available, which are with the properties like,--
- Chemically inert
- Dry running capability
- Resist temperature cycling

- High surface speeds
- Low water absorption
- Low dielectric constant and dissipation factor

CONCLUSION

The article presents a literature review which allowed systematizing the currently available knowledge on materials used in power hydraulics. The issue is quite important, as currently the industry is strongly interested in new materials and technologies for the production of hydraulic system seals and components. When choosing the appropriate material, it is necessary to take into account the working conditions of the component. Hydraulic actuator elements often operate under high loads and are exposed to an aggressive environment. This must be noted as early as at the design stage, because possible failures endangering human health and life and can cause adverse environmental or economic effects. This is due to the increasing climate requirements, but also to the greater awareness of manufacturers about environmental protection. The use of modern materials often increases the efficiency of the system and extends the durability of components occurring in it. So it is important to look for more environmentally friendly solutions to reduce costs and increase productivity.

Industrial seals are exposed to a wide range of challenging operating conditions such as high temperature, speed, pressure, and aggressive chemicals. To handle these and other harsh conditions, it is essential to select the most suitable sealing materials. Several factors impact material selection, including exposure to media, pressure, temperature, and potentially stringent regulatory requirements common in food and beverage or oil and gas applications.

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