

SPRING ENERGIZED SEALS IN SPACE APPLICATIONS

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ABSTRACT

Spring energized seals are critical to the handling of cryogenic, hypergolic fluids and propellants for space applications where O-rings and other elastomeric seals cannot perform. Sealing these fluids in pressurized conditions is very challenging. In cryogenic propulsion systems, some fuels and oxidizers (e.g., liquid hydrogen and liquid oxygen) are stored in storage tanks well below cryogenic temperatures (-238°F/-150°C) all the way down to -424°F (-253°C). In the case of sealing room temperature hypergolic fluids, the safe handling of these extremely corrosive and toxic chemicals such as monomethyl hydrazine (MMH) and nitrogen tetroxide (NTO) are important. Spring energized seals with PTFE or other polymers and stainless steel springs are compatible and approved for the handling of hypergolic fluids. A basic spring energized seal consists of two components, a polymer seal jacket and a metallic spring. Usually the polymer jacket is made of PTFE or PTFE with fillers. Typical spring materials are stainless steels, Elgiloy®, Hastelloy®, and Inconel®. Unlike elastomeric seals where gland design and seal installation is relatively simple, the successful implementation of spring energized seals requires careful planning with gland design, seal installation method and selecting right type of seal style and spring load. Because sealing in space applications are often challenging, rather than users picking seals out of the catalogs, they should work with spring energized seal design engineers to select the optimal gland type and seal design.

SPRING ENERGIZED SEALS – OVERVIEW

Spring energized seals are critical to the handling of cryogenic, hypergolic fluids and propellants for space applications. O-rings or other elastomeric seals work very well if the service conditions permit. However, elastomeric seals run into problems when the operating temperature drops below -60°F (-51°C) or above 300°F (149°C), or when media pressure exceeds 5000 psi and/or when sealing corrosive hypergolic fuels such as MMH and NTO. Spring energized seals also excel in dynamic applications where low friction and/or long seal life is required. A basic spring energized seal consists of two components, a polymer seal jacket and a metallic spring (Figure 1). Usually the polymer jacket is made of PTFE or PTFE with fillers. Other polymers such as TFM, PCTFE or UHMW are also used. The typical spring materials are Stainless Steels, Elgiloy, Hastelloy, and Inconel. Different seal types are suited for different service modes such as static, reciprocating, or rotary (Figures 2 to 5). Unlike elastomeric seals where gland design and seal installation is relatively simple, the successful implementation of spring energized seals requires careful planning with gland design, seal installation method and selecting right type of seal style and spring load. Because sealing in space applications are often challenging, rather than users picking seals out of the catalogs, they should work with spring energized seal design engineers to select the optimal gland type and seal design.

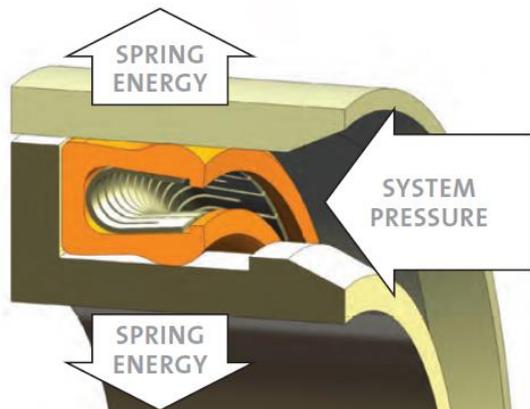


Figure 1 – A basic spring energized seal consists of a polymer seal jacket and a metal spring. It has three force components: jacket interference, spring force, and media pressure acting on seal cavity. Since PTFE's elasticity is only 3% to 5% and PTFE cold flows, jacket interference force will be near zero after installation into the gland and the seal is subjected to some cycling.

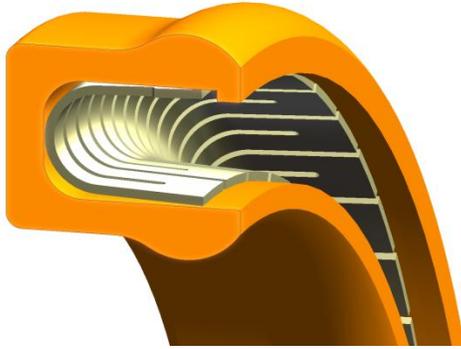


Figure 2 - 400A Seal Type (Cantilever or U-spring) - recommended in general purpose sealing in dynamic (reciprocating and rotary) service.

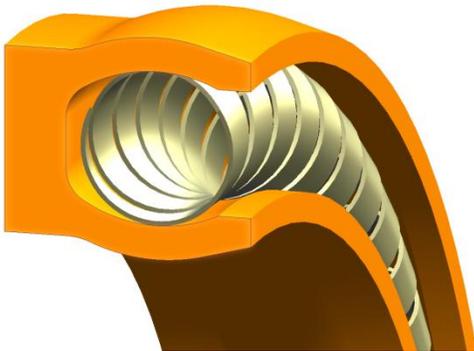


Figure 3 - 103A Seal Type (Helical Coil) - used in static and slow dynamic service.



Figure 4 - APS Seal Type (Advanced Pitch Spring) - produces almost constant spring load over a wide range of deflection. Good for high speed service.



Figure 5 - RACO Face Seal Type - Ideal for cryogenic service with extremely low leakage requirement. Continuous edge spring provides uninterrupted edge sealing and minimizes seal jacket shrinkage.

SEALING AT CRYOGENIC TEMPERATURES AND SEALING HYPERGOLIC FLUIDS

There are many challenges in sealing at cryogenic temperatures. At cryogenic temperatures, the media are usually gases or gases in liquid forms so sealing is difficult. Any application where operating temperature is under -60F, excludes the use of elastomeric seals. Exposure to low temperature causes elastomeric materials to contract and harden resulting in smaller compression, cracking and leakage. Spring energized seals' polymer jackets also contract when subjected to low temperatures. However, since a large percentage the cross-sectional height of spring energized seals is the metal spring, the total contraction of spring energized seals is much less when compared with elastomeric seals. For spring energized seals, the polymer jacket is usually made of PTFE or PTFE with various fillers. Other jacket materials such as UHMW, PCTFE or TFM are also used. In addition, if designed properly, polymer seal jackets do not crack when exposed to cryogenic temperatures. Polymers have a thermal coefficient of expansion roughly 10 times greater than that of metallic hardware and PTFE's modulus of elasticity increases as the temperature decreases and that presents two problems. First, as the seals contract more than the hardware, some built-in interference is lost and the outer lip of the seal shrinks away from the bore; the stiffening up of the seal jacket material also reduces the ability of the seal to seal because hard materials are also poor sealing materials since they are less able to flow into the surface crevices and imperfections to reduce media flow paths and leakage. These are the reasons spring energized seals for cryogenic applications have heavy springs to resist the shrinkage of the outer seal lip (Figure 6). The extra spring force is also needed to provide a net sealing force against the bore. In the case of sealing room temperature hypergolic fluids, the safe handling of these extremely corrosive and

toxic chemicals are important. Spring energized seals with PTFE or other polymers and stainless steel springs are compatible and approved for the handling of hypergolic fluids.

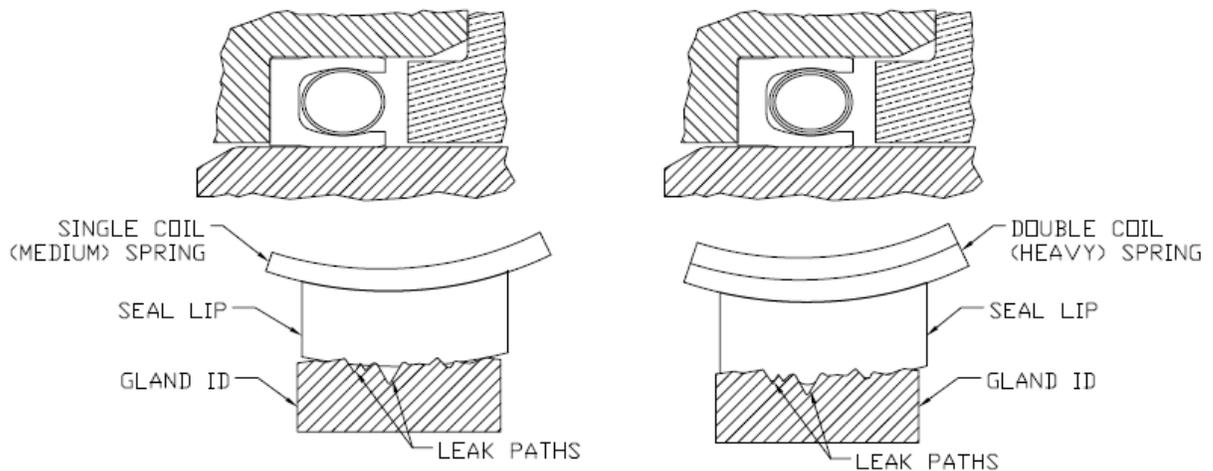


Figure 6 – 103A seal type with heavy double coil spring reduces the size of media leak paths. The heavy spring also prevent the OD lip from shrinking and provides net sealing force against the bore.

GLAND DESIGN AND SEAL INSTALLATION

Split (open) glands are preferred for spring energized seals because polymer jacket materials like PTFE are much stiffer than elastomers and difficult to stretch or twist into a solid gland. If a split gland is not feasible, step glands, and snap-ring glands can also be used. In cases where the customer must have solid glands, installation tools are needed in most cases and there are diameter restrictions. These restrictions apply for both piston seals and rod seals. For piston seals, a ratio of gland ID to gland cross-section of 8 to 1 means a seal can be installed into a solid piston gland. On the other hand, a ratio of 12 to 1 is required for rod seals going into a solid rod seal gland (Figure 8). These are very general guidelines and the type of seal, the spring load, jacket material, and access to the gland will determine the practicality of seal installation into a solid gland.

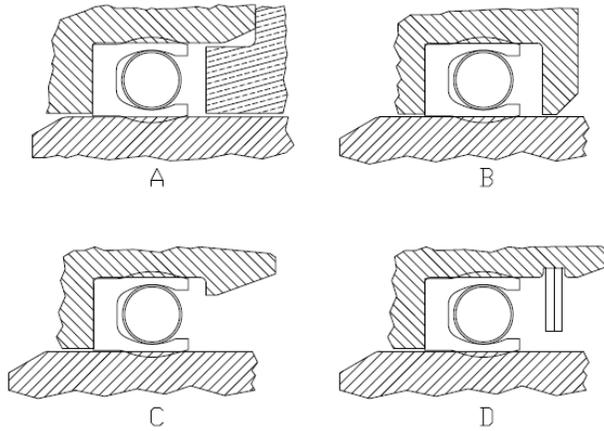


Figure 7 - A) Split Gland, B) Solid Gland, C) Step Gland, D) Snap-ring Gland – Split gland type is preferred for spring energized seals but other gland type can also be used.

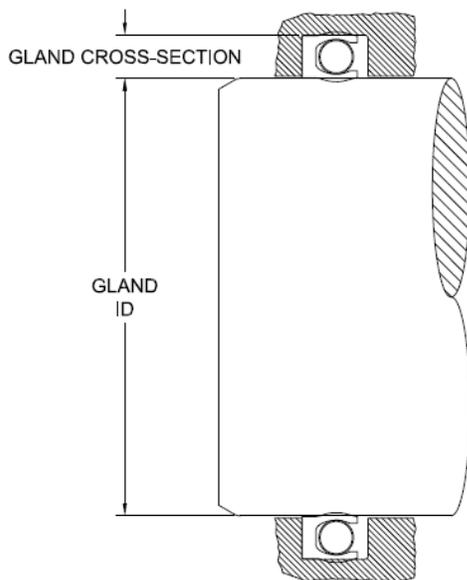


Figure 8 - Gland ID to Gland Cross-Section Ratio determines seal installability into solid glands. 8 to 1 for piston seals and 12 to 1 for rod seals.

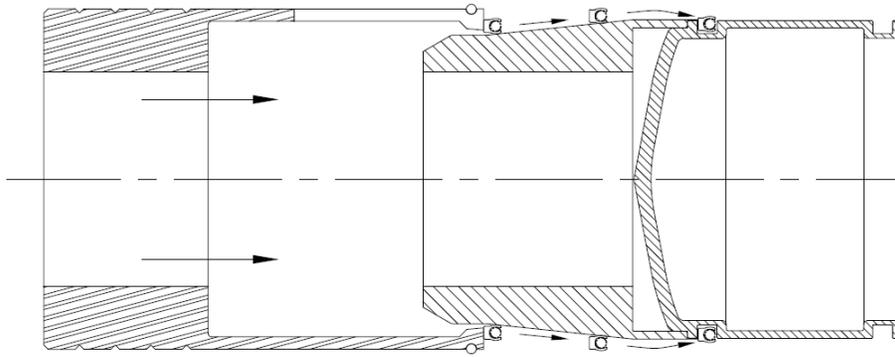


Figure 9 - Installing a piston seal into a solid gland

Good gland surface finish both on the gland ID and gland OD are much more critical to good sealing for spring energized seals compared to elastomeric seals. Spring energized seals with their harder polymer jackets, do not flow into gland surface imperfections as readily as elastomers. At cryogenic temperatures, these polymers become much harder thus, a good surface finish to 8 Ra microinches or sometimes 4 Ra microinches is required when sealing gases at cryogenic temperatures. Chamfer length, chamfer angle and chamfer radius are needed to prevent damage to the seal surfaces when the shaft is inserted through the ID of a rod seal or when a piston seal and piston is forced into a cylinder bore. Usually minimum chamfer length should be 70 percent of the cross-section height of the seal. Chamfer angle should be 15 to 20 degrees and the chamfer radius should be .060" minimum.

The best way to get the optimal performance from spring energized seals is to work with a spring energized seal Design Engineer during the design phase of your products. The initial design discussion should include application data such as service mode (static, reciprocating or rotary), pressure and temperature ranges, media and seal life required, friction and allowable leakage limits. Next in line is discussion about hardware design that includes gland type, gland material and hardness, gland surface finish and installation method. And then lastly, the spring energized seal Design Engineer will recommend the seal design type, and appropriate seal jacket and spring materials. The combination of complete knowledge of the service conditions, optimal gland type and seal design will increase the chance of achieving a successful sealing solution.

1. Elgiloy® is a trademark of Elgiloy Specialty Metals
2. Inconel® is a trademark of Specialty Metals Corporation
3. Hastelloy is a trademark of Haynes International, Inc.