ADVANCED METALLIC SEAL FOR HIGH TEMPERATURE APPLICATIONS

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Abstract

The U-Plex® was designed to allow greater elastic deflection capability in a given gland volume than the now conventional E-seal®. Greater deflection capability with the associated lower bending stresses provides several benefits. For pneumatic duct joints, the axial free height is increased to allow sealing of flanges with weld distortions significantly in excess of what could be tolerated with E-seals®. This performance is achieved while maintaining the re-usability and ease of assembly typical of E-seal® rigid duct joints. For turbine engine air seal applications, which are quite often at temperatures where stress relaxation of metallic seals needs to be considered and significant axial cavity excursions exist, the lower stresses inherent in the U-Plex® design can provide extended seal performance, life and applicability with current, suitable materials. The development of a better "duct joint seal" led to defining seal characteristics which needed to be improved. These characteristics include increased elastic deflection, conformity to local deformations, improved pressure energization characteristics, lower force to compress (while maintaining the same level of sealing capability) and better geometric stability. These features associated with the U-Plex® design, result in both performance benefits for the seal and manufacturing benefits associated with producing the cavity for the seal to operate in.

Description

The geometry of the U-Plex® seal differs from the E-seal® in that the "legs" of the seal are incorporated in the convolution of the seal where an E-seal® has a distinct convolution and "legs". This permits the convolution radius to be significantly larger. The basic U-Plex® consists of two plies of material. The plies of material are not circumferentially welded. The end of the U-Plex® legs are tightly curled backward to provide a good sealing land area and to shield the interstitial gap between the plies from the higher pressure medium to be sealed, by facing the gaps towards the lower pressure side.

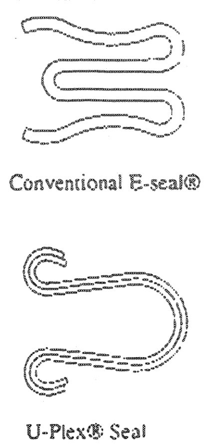
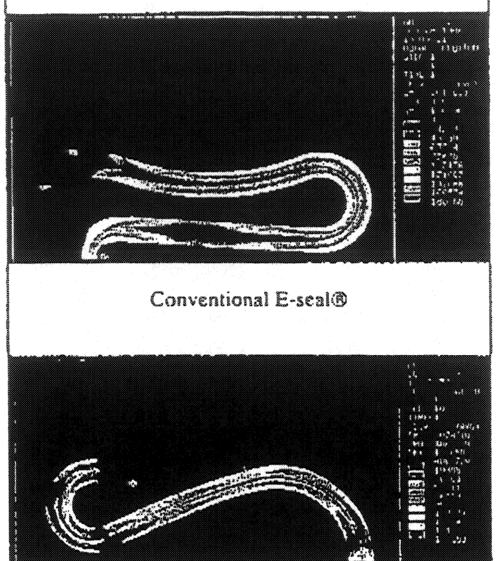


Figure 1

The U-Plex® design can be adjusted to accommodate different applications by varying the number of plies, ply thickness, ply material, number of convolutions, seal dimensions, and adding wear resistant coatings. Note that the individual plies could be made from different type or thickness material.

A multiple ply seal, provided all plies experience the pressure loading, allows pressure induced stresses to be evenly split between the plies. In a two ply seal, at a given pressure, the bending stresses created by deflection would be one half that of a single ply seal of the same total thickness, thus increasing the elastic deflection capability, which is key to maintaining sealing contact with the cavity surfaces.

Another aspect of the U-Plex® seal design that reduces operating stresses is the large convolution radius. The seal is designed so that compression of the seal only takes place on the seal "legs", maximizing the deflectable length of the seal. The large radius can then provide a broad area over which the bending strain is distributed and allows pressurization to induce forces that oppose this strain, resulting in a much lower combined stress situation. This effect serves to minimize stress relaxation, which could compromise seal performance, as during the majority of time the seal is at operating temperature, it is also pressurized. E-seals® also benefit from pressurization, however, the effect is much less pronounced due to the tighter bend radii. Figure 2 is a comparison of the stress contours of the two cross sections.



Conventional E-seal®

U-Plex® Seal

Temperature - Room Temperature
Pressure - 918 psig

Figure 2

In some applications, buckling of flexible metallic seals can be a concern due to the relatively low thermal inertia of the seal or transient differential movements. The geometry of the U-Plex® seal resists buckling better than the conventional E-seals since the large radius and reversed curled legs result in a higher moment of inertia in the critical plane. The reverse curl on the seal legs provides an additional benefit in segmented cavity applications; flow induced resonance has been suspected of causing occasional high cycle fatigue failures of seals, the curled legs greatly increase the resonant frequency of the seal, thus preventing a "reed" effect. Recent testing has confirmed that the U-Plex® design minimizes seal resonance.

Pneumatic Duct Joint Applications

The U-Plex® Seal improves the integrity and robustness of Rigid Ducting Joints. Figure 3 illustrates a typical rigid ducting joint with a U-Plex® installed. All EG&G Pressure Science rigid duct joint seals, both E-seals® and U-Plex® seals, are heat treated Inconel 718.

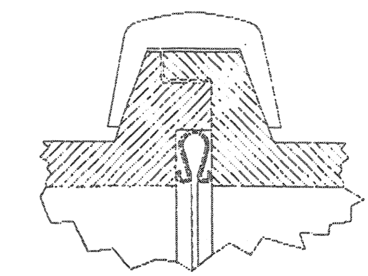


Figure 3

Testing has been performed to compare the leakage control capability between the U-Plex® seal and the conventional E-seal® in both ideal and out-of-flat conditions. The increased elastic deflection capability of the U-Plex® Seal will allow it to seal when assembled in weld distorted flanges which are as much as 2.5 to 5 times worse than those in which the convention E-seal® can accommodate. This allows relaxed flange flatness tolerance requirements and reduces rework of the ducting joint flanges. Figure 4 is a comparison of the conventional E-seal® to the U-Plex® as they relate to axial flange cavity height as specified by Aerospace Standard, SAE Document, AS 1895.

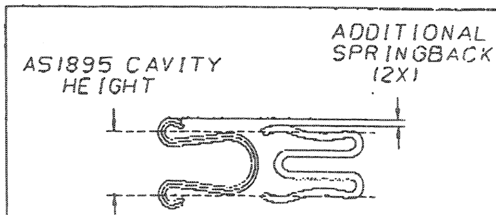
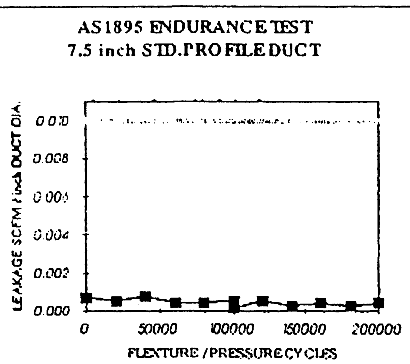


Figure 4

It is important to note that the U-Plex® seal, by design, stores significantly more strain energy to accommodate flange distortions and deflections. Therefore, the highly compliant U-Plex® seal can accommodate relatively large local deformations. For example, duct joints from Ø1.50" to Ø3.50" assembled with the U-Plex® seal will adequately seal flanges that are up to .011" per linear inch circumference out-of-flat. This value increases to .018" per linear inch circumference out-of-flat for diameters greater than 3.5".

The U-Plex® Seal is qualified to the Aerospace Specification for Rigid Pneumatic Joints AS1895, under section AS1895/23. A Ø7.5" U-Plex® Seal was endurance tested in a Standard Profile Rigid Duct Joint for 200,000 cycles. Each cycle consisted of pressurizing the duct and applying a bending moment to the duct while at 1200 °F. The leakage from the joint remained consistently low throughout the test.



Max. Leakage Limit - .010 SCFM
Max. Leakage Actual - .0008 SCFM

Operating Temperature - 1200 °F
Operating Pressure - 250 psig
Applied Bending Moment - 6344 lbs-in

Figure 5

Additionally, the U-Plex® Seal was able to pass the difficult AS1895 Safety Latch Test. This test historically has been a test that the rigid joint utilizing a conventional-E-seal®, or similar sealing method, has not been able to meet in all sizes with regard to the specified leakage limit. The test involves taking a pressure loaded rigid joint and intentionally causing a bolt failure. The intent of the test is to insure that the joint does not separate as a result of an unlikely bolt failure. The safety latch is required to keep the joint intact while a finite excessive leakage requirement is met. The conventional E-seal®, or similar sealing method, can not meet the specified leakage and is not functional subsequent to the test. The U-Plex® Seal meets the required leakage of the AS1895 Safety Latch Test and is still functional subsequent to a successful test. The ability of the U-Plex® Seal to meet this demanding requirement is due to it's improved pressure energization characteristics, and lower resistance to bending. Figure 6 is a graph of leakage vs. axial cavity height. The E-seal® is not capable of sealing at cavity heights greater than the seal's axial free height. The U-Plex® seal is capable of sealing at cavity heights greater than it's axial free height.

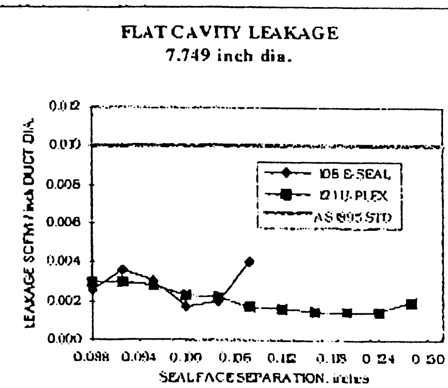


Figure 6

The U-Plex® Seal can achieve the leakage control capabilities of the conventional E-seal® at significantly lower contact loads. The E-seal®, qualified to AS1895, has a force-to-compress of approximately 60 lbs per circumferential inch, while the U-Plex® Seal, qualified to AS1895, has a force-to-compress of approximately 20 lbs per circumferential inch. This feature will allow the same level of sealing with less wear of the sealing surfaces. This was evident by examination of the flange sealing surfaces after the 200,000 cycle endurance test. This benefit is more applicable to the turbine engine applications where wear is a more significant issue.

Turbine Engine Air Seal Applications

Many of the features and benefits of the U-Plex® Seal identified for pneumatic rigid joint applications can be applied to turbine engine air seal applications. These features are:

- Increased elastic deflection
- Conformity to local deformations
- Improved pressure energization characteristics
- Lower force to compress
- Lower wear

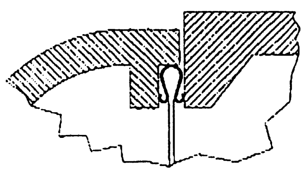


Figure 7 - Typical Turbine Engine Air Seal Application

Increased elastic deflection and a lower spring rate allows a larger deflection range over which the internal stresses within the cross section of the seal can remain below the elastic limit of the seal material. Since the cyclic stresses in the seals are primarily a function of axial deflection, not axially applied loads, the lower spring rate will provide a better stress profile for low cycle fatigue.

Improved pressure energization characteristics will allow better conformity in applications where the axial cavity increases during operation and in applications where stress relaxation is a concern. With any "spring loaded" face seal, the contact load will decrease as the axial cavity height increases. Since the U-Plex® Seal has better pressure energization characteristics, as demonstrated in the AS1895 Safety Latch Test, the contact load will be higher for the U-Plex®, compared to a conventional E-seal® as the axial cavity increases, and all other parameters are equal. The better pressure energization characteristics will reduce the effects of stress relaxation at high temperatures. In typical E-seal® applications where stress relaxation is an issue, the seal axial free height will approach the axial cavity height dimension during operation, thus reducing the contact load and level of sealing. This phenomena will also occur with U-plex® Seal design, but the effects will be minimized by the pressure opposing the deflection induced strain and the fact that the better pressure energization of the seal will result in sufficient contact load as long as the seal system is designed such that line-to-line contact is maintain. For example, in the AS1895 Safety Latch Test, the axial cavity height after bolt failure is greater than the axial free height of the seal and a certain level of sealing ability is maintained.

The lower force to compress inherent to the U-Plex® design will provide better wear characteristics, while maintaining the same level of sealing. Additionally and more importantly, the U-Plex® design can accommodate more than one material type. Hence, a hybrid U-Plex® could be made from two materials, the material making up the seal contact surface would be chosen based on optimizing the tribological pairing between seal and cavity; and the other material would be chosen on material strength properties. The U-Plex® can be manufactured in any of the high temperature alloys that E-seals® are currently produced in. These materials are as follows:

- Inconel 718
- Waspaloy
- Haynes 214, 188, 242
- Rene 41
- Incoloy 909
- and new alloys as they become available

Additionally, these seals can be coated with a Tribaloy coating to provide wear resistance for the seal. The operating temperature and pressure limits for both the E-seal® and the U-Plex® are dependent on the material selection and application parameters.

To date limited testing has been done on large diameter (>∅20") U-Plex® Seals. The U-Plex® seal will be tested in a test rig which can simulate operating temperature, pressure and differential radial movements between the seal and cavity wall. This test will also provide insight as to if the curled leg improves resistance to high cycle fatigue. One large diameter U-Plex® has been tested in this rig. This seal was split radially in one location. Large diameter E-seals® are radially split in some high pressure turbine applications to minimize the effects of mismatched thermal and/or radial restraints of the seal cavity. The split in the seal allows circumferential growth, instead of radial growth, of the seal and therefore removes the detrimental hoop loads that could induce buckling of the seal. During previous testing of convention E-seals® in this test rig, audible high pitched noise was observed. It was hypothesized that the noise was being created by high pressure air escaping through the cavity segments over an unsupported section of the seal acting to produce a "reed" effect. In the same test set-up, the U-plex® Seal did not exhibit the same noise behavior. It is theorized that the curled legs greatly increase the resonant frequency of the seal, preventing a "reed" effect.

Further Testing and Development

For small diameter U-Plex® Seals, less than ∅7.5" and primarily for pneumatic duct joint applications, all testing is complete for qualification to AS1895/23 and tests to verify performance improvement over the conventional E-seal® is complete. Additionally, all manufacturing process development is complete.

Testing and development of the larger diameter U-Plex® seals, for turbine engine applications, will continue. A large diameter, ≈∅30", U-Plex® seal will be tested in a test rig which can simulate operating temperature, pressure and differential radial movements between the seal and cavity wall. The testing is intended to compare/evaluate the performance benefits of the U-Plex® Seal identified above to the current performance of the E-seal®.

Conclusion

During the design process of a typical E-seal® application, where a new seal section is required, the seal cross section is usually optimized for maximum elastic deflection, lower compression loads and sufficient geometric stability. The U-Plex® Seal is, in fact, a truly optimized metallic seal cross section with additional features, such as, improved conformity to local deformation and improved pressure energization characteristics. Although first developed to "raise the bar" on performance for pneumatic duct joint seals, it is quite evident that the benefits associated with this new metallic seal cross section can be extended to improve large metallic seal technology. The U-Plex® design is a next generation product, reflecting 30 years of experience in resilient metallic seals.