Diagnosing Common Causes of Sealing Failures

Knowing what to look for can prevent failures from reoccurring

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Sealing failures are always events that are met with dismay and frustration on the part of process engineers and maintenance engineers alike. These failures can be costly and time consuming to fix. Eventually, design engineers get pulled into these unfortunate situations and are called upon determine exactly what caused the seal failure to begin with.

There are a multitude of reasons why seals fail. While it is impossible to determine all possible causes of sealing system failures, there exists a large body of “lessons learned” knowledge that can be applied to help minimize the dreaded leaking seal.

The long-range goal of the engineering community should be to strive for a robust seal reliability program that includes features such as preventative and predictive maintenance programs using reliable seal manufacturers’ products. However, before any seal reliability program can be established, the engineering team needs to be able to accurately diagnose the causes of the seal failures that they are experiencing to begin with. Some of the more common, well-diagnosed causes of sealing failures are presented here, along with some methodologies for improving the reliability of the sealing applications at production facilities.

Definitions

The first step in a seal-failure analysis is to determine what, exactly, constitutes a “failure.” This point cannot be emphasized enough. Experience has shown that there are diverse definitions of seal failure, which are typically application-specific. Although seals can generally be defined as any elements, or assemblies of elements, that are used to prevent the passage of a solid, liquid, gas, or vapor from one point in a system to another, seals are in fact designed to allow for a wide range of leakages: some seals are described as zero-leakage seals, while others are designed to allow for a small, controlled amount of weeping of the solid, liquid, gas, or vapor.

In light of this wide range of intended sealing uses, diagnosing a failure of any given seal can be very difficult. It is the responsibility of the design community to provide guidance with respect to the intended use of the seals that they specify in various pieces of equipment.

Before we investigate the specific types of seal failures that have been identified, let us summarize the wide variety of types of seals that exist today. The potential failure modes of seals are as far-reaching as the number of sealing solutions that are available.

Seal types

Broadly speaking, seals are categorized as functioning either in a static or a dynamic fashion. The reality is that there is a large chasm between a truly static seal and a truly dynamic one. The vast majority of seals used in industry today function along an imaginary continuum between static and dynamic functionality; pseudostatic and pseudodyamic are the order of the day in the sealing industry. With this fact in mind, the diagnosing of seal failures becomes even more difficult.

A short list of the more common types of seals in use today is shown in Table 1. As the table indicates, these configurations are used in both static and dynamic environments. Table 2 presents a listing of more sophisticated sealing solutions that are used in a variety of ways, statically and dynamically and in-between.

Even though there are a multitude of seal types available for use, there are some common types of seal failure modes that can be discussed that apply to wide array of sealing solutions, independent of shape or material of construction.

Common failures

All seals can fail due to a variety of environmental influences, including temperature, pressure, fluid incompatibilities, time, and human factors. The failure diagnosis can be complex, in many cases encompassing a number of these influences in the same failure scenario. Another reason for failure is many seals are damaged in some way during installation, resulting in premature seal leakage. Some of the visual indicators of installation damage include short cuts, V-shaped notches in the seal, skinned surface in localized areas, or thin, peeled-away area on the seal. However, the real key to diagnosing installation damage is typically, time; seals that fail very quickly, or never seal at all upon start-up, are typically victims of seal-installation damage or simply improper installation of the seal. Now, let's look at some other common types of seal failures that are relatively straightforward to diagnose.

Compression set: Probably the most well-known seal failure mode for elastomers is their loss of resiliency, commonly called compression set. When seals fail to rebound after they have been deformed for some period of time, the seal will exhibit a flattened surface that corresponds to the contours of the mating hardware, such as the seal shown in Figure 1. There are a number of contributing factors for this type of failure, including exposure to excessive temperature or incompatible fluids, excessive deformation of the elastomer at installation, or an incompletely vulcanized seal.

The solution to this type of failure typically involves analyzing the gland design to ensure that the proper deflection for the seal was present, along with investigating whether the elastomer material chosen for the application was appropriate in terms of thermal stability and compression set resistance. Information about the appropriate temperature range and chemical and physical resistance of commonly used elastomers is provided in Figure 2 and Table 3.

Nibbing and extrusion: The next most common type of failure with elastomeric or polymeric seals is that of nibbling and extrusion. In this case, the seal starts to appear to be torn away in little pieces, typically referred to as nibbling of the sealing surface. As the nibbling continues, the amount that is torn away increases to the point that a large portion of the seal degrades. Ultimately, the seal loses its overall shape and “flows” into whatever void area is available. The result of such behavior is shown in Figures 3 and 4.

Typical causes of nibbling and extrusion are related to the pressure differentials that the seal is exposed to versus the clearances of the mating hardware. The volume-to-void ratio of the seal to the gland can be a contributor as well. Excessive clearance gaps, improper seal material (for example, too low a hardness, modulus), excessive volume-to-void ratio, and inconsistent clearance gaps are all contributors to this type of failure. There are a number of suggestions for correcting nibbling/extrusion failures, such as increasing the bulk hardness of the sealing element, decreasing the clearance gaps between the mating hardware, redesigning the volume-to-void ratio for the sealing element, or simply adding anti-extrusion devices, typically called back-up rings, to the sealing-element package.

Spiral failure: Another failure mode, usually associated with O-ring type seals, is called spiral failure, as shown in Figure 5. In this case, the seal literally rolls within its gland, which results in cuts or marks that spiral around the seal's circumference.

There are many reasons for this, but the most prevalent is when the seal is used in a slow, reciprocating fashion, which causes the seal to roll itself up inside the groove. Another contributor to spiral failure can be an irregular surface finish over the mating parts. This can cause the seal to “grip” at certain contact points, thus creating the starting point for the spiraling.

There are a number of solutions to this problem. First, choose an elastomer that has a higher bulk hardness (modulus). Second, increase the installed stretch on the seal, if it is a male-type installation. Third, specify a smoother, more uniform surface finish on the mating hardware. Fourth, change the seal configuration completely, considering a T-seal or some other lip-type configuration.

Explosive decompression is another, interesting type of seal failure for elastomeric seals. The seal exhibits blisters, fissures, pock marks or pits, both externally and internally, as shown in Figure 6. The primary reason for this is gas entrapment within the elastomer during high-pressure cycling, followed by a rapid depressurization (or decompression). This failure can be violent and, in some instances, can cause a catastrophic situation.

The primary solution for this type of seal failure is to specify another elastomer material that is more resistant to explosive decompression or to radically change the seal design. If possible, polymeric or metal seals should be used.

Wear: Normal wear is another type of seal failure that is common and, indeed, is to be expected. As shown in Figure 7, this type of failure looks like a smooth burnishing of a sealing surface that is caused by the relative motion of the seal against the mating surface. In dynamic or pseudodynamic dynamic instances, the seals can be expected to wear, but this should take place in a gradual, predictable manner. The possible solution to excessive wear is, again, to consider a higher hardness (modulus) material or possibly redesign the seal, considering a polymeric solution.

Unique seal-failure modes

Mechanical seals also have a number of unique failure modes that can be difficult to determine due to the relative complexity of the seal assembly itself. Typical of these are: flaking or peeling of the seal face; corrosion, flaking or pitting of the carbon faces; degradation of the elastomer energizer seals; and spring or bellows breakage. The main reason why mechanical seals fail prematurely in these ways is rapid degradation due to contamination being introduced directly to the seal faces, thus causing severe wear quite rapidly.

The usual failure modes described above for homogenous elastomer seals also apply to bonded seals to a great extent. For instance, compression set, excessive wear, chemical attack, thermal degradation, nibbling, extrusion and explosive decompression are all possibilities for bonded seals. However, there are three distinct areas of seal failure that are unique to bonded seal elements.

They stem from the specific nature of bonded seals. There are usually four “layers” with bonded seals: the rubber sealing element, the seal adhesive, the retainer primer, and the retainer itself, which can be metal, composite, polymeric or the like. These layers are potential sources for seal failures. For example, there can be a rubber-to-adhesive failure, an adhesive-to-primer failure, or a primer-to-retainer failure. In all instances, the specific failure point(s) can be very difficult to detect. Typically, extensive microscopic analysis of failed sealing elements is required rather than a simple visual examination. Once the true root-cause of the failure is determined, corrective actions can be taken by focusing on the specific interface problem (rubber-to-adhesive, adhesive-to-primer, or primer-to-retainer).

Electrically and or thermally conductive seals have a unique set of failure criteria as well. In these cases, the seal element has material properties that either conduct electrical currents or dissipate thermal energy. A failure of these types of seals results in a loss of electrical conductivity or loss of thermal dissipation. These types of “seal failures” are difficult, if not impossible, to observe visually. Whereas a failed O-ring seal is readily diagnosed, both visually and via the gross leakage of the solid, liquid, gas or vapor, the electrical or thermally conductive material may not be visually degraded. Diagnosis in this kind of situation requires system-level measurements.

Final thoughts

The ability to diagnose seal failures rests with experience and a strong power of visual observation. With this repository of information, the goal of seal reliability programs can potentially be realized.

The world of seal engineering has come a long way in addressing the difficult question, “When will this seal wear out and leak?” However, when seals do leak, (and they will), it is important that the engineering community be able to diagnose the root-cause failure of the seal.

The science of seal life prediction has come into its own in the last few years. Seal-life-prediction models have been used with some success as a result of extensive testing, research and empirical confirmation. The sealing industry continues to strive to improve the modeling techniques available and innovate new design configurations with the goal of preventing the unwanted passage of solid, liquid, gas or vapor from one point to another. In the meantime, successful diagnosis of sealing system failures remains a central need of the engineering community.

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