SAE International™ SURFACE VEHICLE INFORMATION REPORT

SAE J1002 CAN-CELLED OCT2002

Issued 1973-01
Cancelled 2002-10

Superseding J1002 OCT2000

Seals—Evaluation of Elastohydrodynamic

1. *Scope*—This SAE Information Report is a review of test methods that have been used to evaluate elastomeric hydrodynamic seals. The advantages and disadvantages of each method are discussed. There are ten methods total which include three suggested methods. For those interested in more detailed information on hydrodynamic sealing systems, see 2.2.

1.1 Background for Establishing Evaluation Techniques—Two items must be kept in mind when evaluating hydrodynamic seals.

1.1.1 PATTERN—The presence of ribs, triangles, or other configurations on the outside lip surface of a seal does not automatically make a seal hydrodynamic. These configurations in conjunction with the contact line of the seal can make a specific contact pattern (Figure 1) on the transparent shaft (Figure 2) in order for the sealing system to be more effective than a standard sharp lip seal (Reference 3.9). The specific contact pattern of the hydrodynamic configuration should be agreed upon between user and supplier.

1.1.2 CONDITION—If there is no shaft or seal damage, improper installation, or abnormal operating conditions, a hydrodynamic seal functions the same as a plain sharp lip seal in that the dynamic sealing devices are not required to make the seal function. This characteristic makes hydrodynamic seals difficult to evaluate. A condition in which a plain sharp lip seal would leak must be artificially created in order to evaluate the sealing capacity and efficiency or improved sealing performance created by a hydrodynamic seal. Sealing capacity is defined as the difference in the leakage rates of a hydrodynamic seal (Lh) and a sharp lip seal (Ls), when operated on a shaft designed to pump fluid through the seal. Sealing efficiency is then defined as:

$$\frac{Ls - Lh}{Ls}(100) \qquad \text{(Eq. 1)}$$

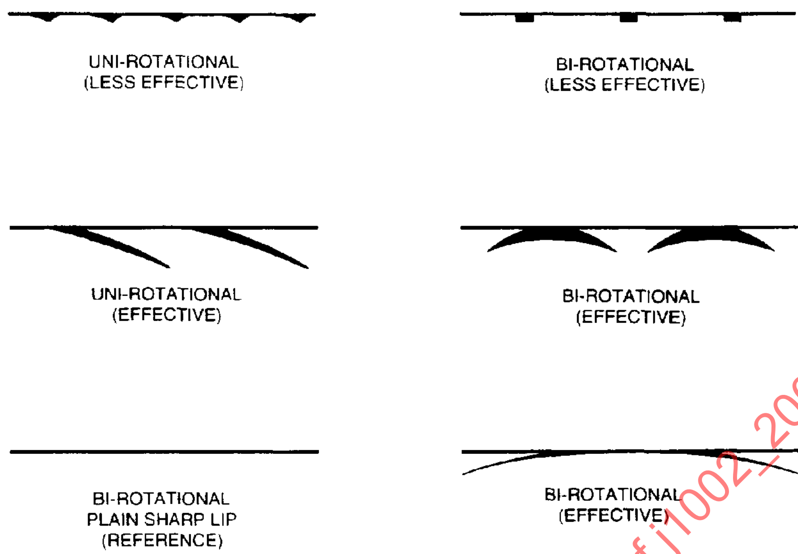
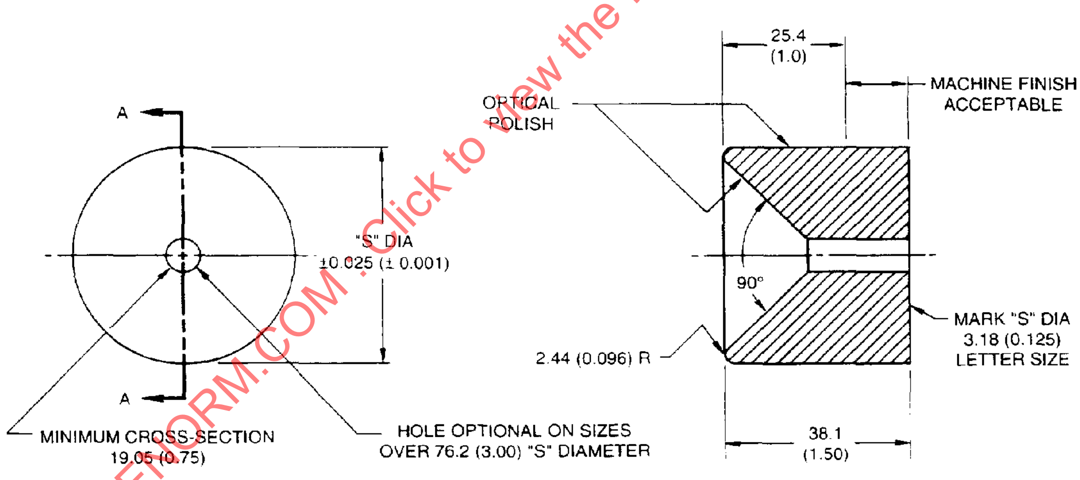


FIGURE 1—"ON-SHAFT" CONTACT PATTERNS OF SOME ELASTOHYDRODYNAMIC AIDS



MATERIAL: TRANSPARENT ACRYLIC PLASTIC

NOTE: DIMENSIONS ARE mm (in)

FIGURE 2—PLASTIC SHAFT CONFIGURATION

2. References

2.1 Applicable Publication—The following publication forms a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J110—Seals—Listing of Radial Lip

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

1. T. R. Balmer, “Duodirectional Seal’s Floating Triangles Oppose Swirling Lubricant,“ *Design News*, Feb. 2, 1968, pp. 44-45.
2. A. S. Berens, “Testing Hydrodynamic Seals,“ *Automotive Industries*, March 1, 1968, pp. 60–63.
3. R. A. Burton, “An Experimental Study of Turbulent Flow in a Spiral-Groove Configuration,“ ASME Paper 67-WA/Lub-3.
4. R. L. Dega, “Zero Leakage: Results of an Advanced Lip Seal Technology,“ BHRA Paper D-3, April 1967.
5. R. L. Dega, “Zero Leakage: Results of an Advanced Lip Seal Technology,“ ASME Paper 67-WA/Lub-11.
6. J. N. Hodgson, “Designing a Molecular Pump as a Seal-to-Space,“ ASME Paper 65-GTP-15.
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11. A. E. King, “Engineering Information Report on Tests Made with a Hydrodynamic Screw Seal (Viscoseal) in Oil, Water, and Potassium,” Report No. WAED 63.3E, Rev. A, Westinghouse Aerospace Electrical Division, Lima, Ohio, September 1964.
12. A. E. King, “Developing Screw Type Shaft Seals for Potassium Environment,” *Research/Development*, May 1966, pp. 48–51.
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14. E. T. Jagger, “Positive Action Seals in Europe,” ASME Paper 67-WA/Lub-2.
15. L. P. Ludwig, T. N. Strom, and G. P. Allen, “Experimental Study of End Effect and Pressure Patterns in Helical Groove Fluid Film Seal (Viscoseal),” NASA Technical Note D-3096.
16. L. P. Ludwig, T. N. Strom, and G. P. Allen, “Gas Ingestion and Sealing Capacity of Helical Groove Fluid Film Seal (Viscoseal) Using Sodium and Water as Sealed Fluids,” NASA Technical Note D-3348.
17. R. L. Lessley and J. N. Hodgson, “Low-Leakage Dynamic Seal to Space,” ASME Paper 65-GTP-14.
18. A. I. Golubiev, “Studies on Seals for Rotating Shafts of High Pressure Pumps,” *Wear*, Vol. 8 (1965), pp. 270–288.
19. J. D. McHugh, “Limits of Effectiveness of the Screw Seal in Laminar Flow,” *Bearing and Seal Design in Nuclear Power Machinery*, ASME, 1967, pp. 187–202.
20. J. M. McGrew and J. D. McHugh, “Analysis and Test of the Screw Seal in Laminar and Turbulent Operation,” *ASME Jrl. of Basic Engrg. Trans.*, Series D. Vol. 87 (1965), pp. 153–162.
21. D. C. Kuzma, “Analysis of the Screw Seal,” Report MD-61, Research Labs., General Motors Corp., May 1965.
22. D. C. Kuzma, “Theory of the Mechanism of Sealing with Application to Face Seals,” Report GMR-776, Research Labs., General Motors Corp., June 5, 1968.

23. J. M. McGrew and A. J. Orsino, "Non-Contacting Dynamic Seals for Space Power Alternators," *Bearing and Seal Design in Nuclear Power Machinery*, ASME, 1967, pp. 398–420.
24. W. K. Stair, "Analysis of the Viscoseal Part I—The Concentric Laminar Case," NASA Report CR-285, August 1965.
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26. W. K. Stair, "Effect of Groove Geometry on Viscoseal Performance," *Jrl. Engrg. for Power*, Vol. 89 (1967), pp. 605–614.
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29. L. H. Weinand, "Helixseal—A Practical Hydrodynamic Radial Lip Seal," ASME Paper 67-WA/Lub-8.
30. J. Zuk, L. P. Ludwig, and R. L. Johnson, "Flow and Pressure Analysis of Parallel Groove Geometry for an Incompressible Fluid with Convective Inertia Effects," NASA Technical Note D-3635.
31. J. Zuk, L. P. Ludwig, and R. L. Johnson, "Experimental and Theoretical Study of the Viscoseal," NASA Technical Memo X-52245.
32. J. Zuk, T. N. Strom, L. P. Ludwig, and R. L. Johnson, "Convective Inertia and Gas Ingestion Effects on Flow Regimes of the Viscoseal Theory and Experiment," ASLE Trans., Vol. 10 (1967), pp. 273–293.
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3. Evaluation Methods—There are ten methods of evaluation which are being or have been used. Three of the ten methods are suggested and discussed in detail in 3.1, 3.2, and 3.3. They are not listed in order of preference and are intended to be short type screening tests to determine the effectiveness of designs as new seals only. They are not intended to reproduce actual service conditions. These methods are designed to test seals with only the primary sealing lip. Method used should be agreed upon between user and supplier.

3.1 Visual Examination of Seal on Plastic Shaft

3.1.1 METHOD—This test consists of placing a clean dry seal airside first, squarely on a dry plastic shaft (Figure 2) and observing the contact pattern. General seal effectiveness can be judged by its contact pattern (Figure 1) under static conditions and often can be associated with its contact pattern.

3.1.2 LIMITATIONS—Limitations of this evaluation technique are:

a. A pseudo-contact pattern can be produced by fluid at the interface or misalignment of the seal.
b. Visual examination will allow judgment of performance of the seal only at the time of observation.
c. Shaft runout and/or STBM (shaft to bore misalignment) in the application can affect the contact pattern.

3.2 Roll-Coined Spiral Grooved Mandrel Testing

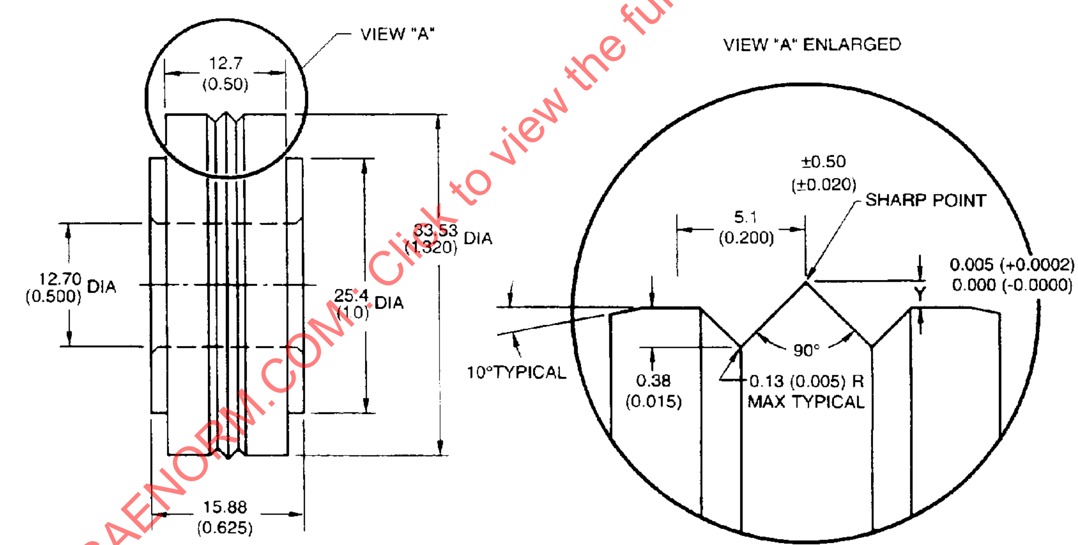
3.2.1 METHOD—This method is an economical means of evaluating the effectiveness of hydrodynamic seals which closely simulates shaft damage or conditions that could occur. A 0.02 to 0.08 mm (0.0008 to 0.0031 in) groove is rolled into a standard test mandrel or application shaft with a helix angle of 4 to 5 degrees by using a form ground roller (see Figure 3). The groove depth is very closely controlled within a shaft and is also reproducible from one shaft to another (see Figure 4). Test techniques are similar to those used in 3.1 and 3.9.

3.2.2 LIMITATIONS—Limitations of this evaluation technique are:

a. Some application shaft materials are too hard to be roll-coined.
b. Higher than normal seal wear will occur.
c. Typically is not used for application testing with reciprocating shafts.
d. Depending on length of test and sealing lip material (such as PTFE) wear particles can plug the grooves at lip contact surface thus distorting results. Use of method(s) for these type seals should be agreed upon between user and supplier.

3.2.3 MANUFACTURING ROLL-COINED SPIRAL GROOVED MANDRELS—Hydrodynamic spiral grooves are added to a standard plunge ground seal test mandrel or, in some cases, an application shaft by a process known as roll-coining. The mandrel or application shaft is rotated in a lathe and the spiral groove is rolled into the surface with a form ground, hardened steel roller.

The form ground roller is mounted on the tool post of the lathe by utilizing a special adapter. The roller is mounted at a specific helix angle. The lathe is then set up to produce a spiral groove in the mandrel with a helix angle of 4 to 5 degrees. (See Figure 5.) Shoulders which are part of the roller configuration regulated the groove depth (Figure 3). The action of the roller will produce a raised ridge of displaced metal on either side of the groove. These should not be removed as they simulate application shaft damage. (See Figure 4.) Groove depth variation in one shaft is approximately ±0.005 mm (±0.0002 in); from shaft to shaft the variation could be ±0.0010 mm (±0.0004 in).

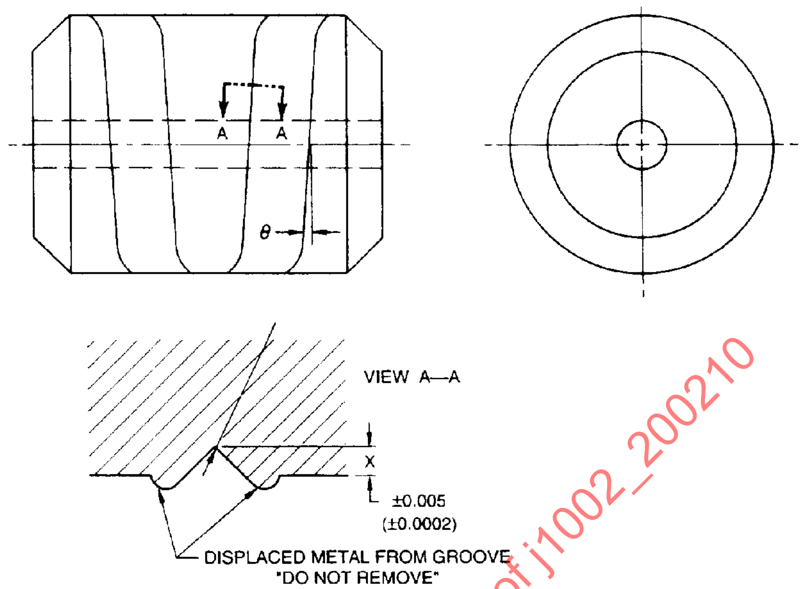


MATERIAL: CARBIDE OR HIGH-SPEED STEEL

NOTE: DIMENSIONS ARE mm (in)

MANDREL TYPE	I	II	III
ROLL GROOVE DEPTH DIMENSION "Y"	0.02 (0.0010) 0.030 (0.0012)	0.05 (0.002) 0.056 (0.0022)	0.08 (0.003) 0.081 (0.0032)

FIGURE 3—ROLL-COINING ROLLER DETAILS



MANDREL TYPE	I	II	III
X=	0.025 (0.001)	0.05 (0.002)	0.08 (0.003)
HELIX ANGLE:	4-5°	4-5°	4-5°

NOTE. DIMENSIONS ARE mm (in)

FIGURE 4—ROLL-COINED MANDREL DETAILS

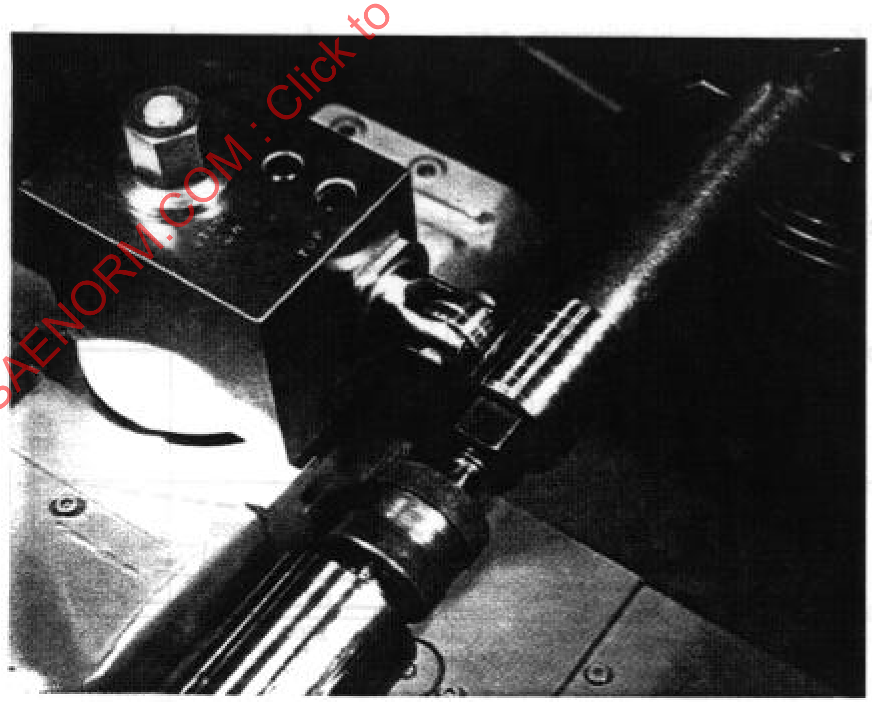


FIGURE 5—ROLL-COINING APPARATUS

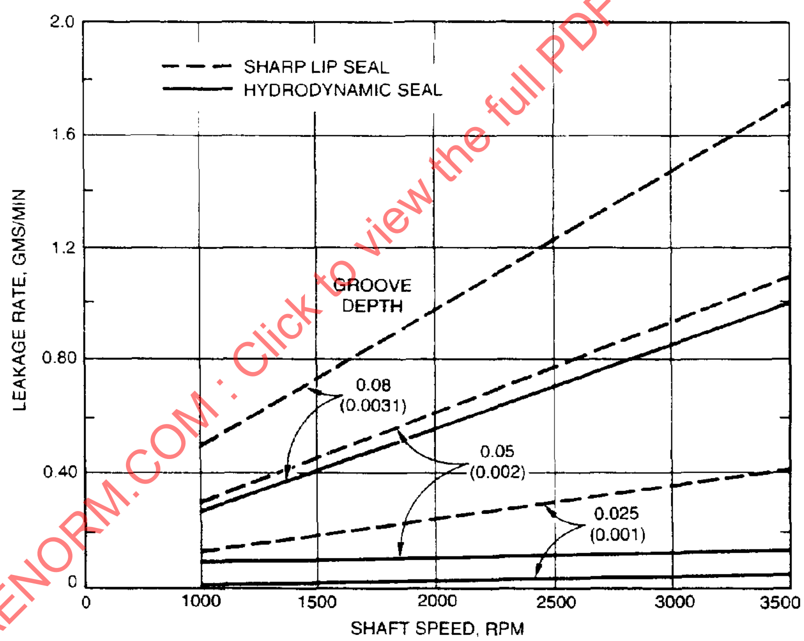
3.2.4 HYDRODYNAMIC SEAL EVALUATION USING ROLL-COINED SPIRAL-GROOVED MANDRELS—The following techniques are used in evaluation of hydrodynamic seals

3.2.4.1 *Leak Rate Determination*—This technique is used for comparing various hydrodynamic seal designs with each other or against the leak rate of plain sharp lip seals. Figure 6 for typical seal leakage curves. Seals of various designs are run on a roll-coined hydrodynamic spiral shaft of a given groove depth at normal application speed for a specified length of time, and the leakage is measured and compared to determine the relative sealing efficiency. Sealing efficiency is determined by dividing the sealing capacity by the leakage rate of a sharp lip seal (Reference 1.1.2).

3.2.4.2 *Application Testing*—This technique is used for evaluating a hydrodynamic seal's ability to seal a damaged shaft under actual application conditions.

Application shafts are roll-coined to a depth which compares with the damage that could occur during manufacturing, handling, and installation.

Hydrodynamic seals and the roll-coined shafts are installed in the application. If there is no leakage, it can be assumed the sealing efficiency is great enough to overcome a given amount of shaft damage.



NOTE: DIMENSIONS ARE mm (in)

FIGURE 6—TYPICAL SEAL LEAKAGE CURVES ON ROLL-COINED SPIRAL-GROOVED MANDRELS HYDRODYNAMIC VERSUS SHARP LIP SEAL LEAKAGE RATES

3.3 Oil Drop Testing

3.3.1 METHOD—This is a method of evaluating the ability of a properly functioning seal to pump oil from the air side of the lip contact surface to the oil side. The test consists of running a seal under application conditions either on a horizontally or vertically mounted shaft.

a. Horizontal shaft—With seal mounted vertically, a small metered quantity of oil is placed as close as possible to the lip contact surface at the 12 o'clock position by means of a hypodermic needle.
b. Vertical shaft—With seal mounted horizontally (face up), a small metered quantity of oil is placed uniformly around seal lip circumference at shaft interface.

The meniscus formed for each type setup is observed by means of an ultraviolet light and the time for its disappearance is recorded.

The vertical shaft method yields very consistent results.

3.3.2 LIMITATIONS—Limitations of this evaluation technique are:

a. Plain sharp lip seals can transfer oil.
b. Difficulty of uniform application of oil to the interface (with horizontal shaft only).
c. Minute variations in shaft, presence of shaft lead and seal geometry can affect oil transfer rate.

3.4 Accelerated Test Parameters

3.4.1 METHOD—One of the first methods used to evaluate hydrodynamic seals was to increase the shaft speed, shaft runout, offset, or the temperature of the medium being sealed to a point that a plain sharp lip seal could not tolerate.

3.4.2 LIMITATIONS—This test method evaluates the sealing material rather than the sealing concept. This method typically does not correlate with application conditions and, therefore, evaluates a design not necessarily representative of that required for actual service conditions.

3.5 Life Testing

3.5.1 METHOD—This method consists of testing plain sharp lip seals under application conditions (SAE J110) and establishing a mean life or time to failure. If hydrodynamic seals of the same design tested under the same conditions had an increased mean life, it could be attributed to the increased sealing efficiency of the hydrodynamic design.

3.5.2 LIMITATIONS—The limitations of this evaluation technique are: (a) the length of time; (b) the amount of equipment required to conduct a test program; and (c) the difficulty of obtaining plain sharp lip seals and hydrodynamic seals of exactly the same design except for the hydrodynamic aid. If the designs are not equivalent, the difference in sealing efficiency could be attributed to factors other than hydrodynamic capability.

3.6 Pumping Capacity Testing

3.6.1 METHOD—This is a variation of method 3.3 (oil drop testing). The seal is mounted backwards in the test head (so that the outside lip surface is exposed to the oil in the head). The test may be run with the oil at midshaft or a full head. The shaft is then run at a given speed for a specified length of time and the amount of oil transferred to the air side is measured.

3.6.2 LIMITATIONS—The limitations of this evaluation technique are:

a. It does not accurately simulate oil transfer that may occur in the application because it is not pumping against a head of oil on the normal oil side of the lip.
b. A seal with a damaged lip can appear to be more efficient than an undamaged seal.
c. Minute variations in shaft, presence of shaft lead, and seal geometry can affect oil transfer rate.

3.7 Etched Spiral Grooves Shaft Testing

3.7.1 METHOD—This method is a means of comparing plain sharp lip seal leakage rates with hydrodynamic seal leakage rates when run on a hydrodynamic shaft. The spiral grooved shafts are produced by a photoetching process. They are approximately 0.8 mm (0.031 in) wide and 0.02 to 0.08 mm (0.0008 to 0.0031 in) deep. The helix angle is 45 degrees.

A plain sharp lip seal is run on the spiral grooved shaft at a given speed for a specified length of time. The leakage is measured. A hydrodynamic seal is run at the same position on the shaft for the same length of time. The difference between the leakage rates is called the sealing capacity (Reference 1.1.2).

3.7.2 LIMITATIONS—The limitations of this evaluation technique are:

a. The grooves in the shafts used to date have been much more severe than the actual damage the seal would see in an application and could also alter sealing capacity by lip distortion.
b. The process for etching the shaft produces variable geometry. Some application shaft materials cannot be etched at all. It is also a costly procedure.

The previous limitations could be reduced subsequently or eliminated with improved etching techniques.

3.8 Damaged Seal Testing

3.8.1 METHOD—Another method of evaluating the sealing capacity of a hydrodynamic seal is to damage the seal by removing a section of lip at the contact line. The seal is then run on a plain shaft with damage at the 6o'clock position to determine if hydrodynamic aids will prevent leakage.

Many methods have been tried to produce reproducible nicks in seal lips:

a. Triangular jeweler's file embedded in a shaft size mandrel.
b. Heated nichrome wire embedded in a shaft size mandrel.
c. Notching the seals with a razor blade under a microscope.

3.8.2 LIMITATIONS—This method of evaluation has been quite widely used, but there are limitations:

a. It is difficult to notch a group of seals uniformly.
b. In some cases, the test results are erratic due to vibration of the lip at the notch.

3.9 Damaged Application Shaft Testing

3.9.1 METHOD—This method of evaluation has been used for seals in the actual application. Application shafts are damaged by etching, filing, scratching, or grinding grooves in them. These are installed in the application with the hydrodynamic seals. If the seals do not leak, it is assumed that they have enough sealing capacity to counteract the damaged shafts.

3.9.2 LIMITATIONS—The limitations of an evaluation technique such as this are the same as for damaged seals, lack of uniformity, and reproducibility of the damage.

3.10 Flatted Shaft Testing

3.10.1 METHOD—This method is another form of damaged shaft testing. A series of evenly spaced flats 0.04 to 0.08mm (0.0016 to 0.0031 in) deep are ground on a test mandrel. The number of flats is increased in a geometric progression along the shaft. A set of leak rate curves for the various numbers of flats at various speeds is established with a plain sharp lip seal. Then a hydrodynamic seal is run on the same shaft. The difference in leak rate curves establishes the sealing efficiency of the hydrodynamic seal.

3.10.2 LIMITATIONS—The limitations of this evaluation technique are:

a. The flats on the shaft are more severe and of a different configuration than the seal would normally experience in the application.
b. The leak rate curves are not linear and tend to indicate that the seal lip is unstable at a particular speed.
c. Distortion of the seal lip caused by the flats may impair or assist the hydrodynamic sealing device being evaluated.

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