SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

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Lip Force Measurement—Radial Lip Seals

1. ***Scope***—This SAE Recommended Practice defines radial lip force for shaft seals. The principle of lip force measurement is described and the types of radial force measuring devices are discussed. A type of radial force measuring device and procedure for use is recommended.

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.

SAEJ111—Seals—Terminology of Radial Lip

3. Definitions

3.1 Lip Force Definition—Lip force, radial lip force, radial force, or radial load are all terms used to describe the characteristic of a radial lip seal, that is, the force it exerts upon the mating shaft. SAE J111 defines this as "lip force." However, regardless of terminology, it is important to understand how it is measured and the units in which it is expressed.

4. Principle of Lip Force Measurement

4.1 Method—The majority of devices used for obtaining lip force measurement utilize the split shaft design. One-half is rigidly mounted and the other half is attached to a measuring system so that forces on it perpendicular to the split may be determined. One-half of the split shaft should have a gap of 0.75 to 1.50 mm to prevent the two halves from exerting a force on each other. This gap is considered small enough so as not to affect the measurement. The various measuring devices differ in the methods with which the force exerted on the split shaft is determined.

4.2 Principle—Figure 1 illustrates the split shaft principle. A radial lip seal exerts an incremental lip force F, expressed in appropriate force units per unit of shaft circumference. The force components perpendicular to the split are balanced for force P, which the instrument actually measures.

$$P = 2\int_{0}^{\pi/2} Fr \cdot r d\alpha \cdot \sin\alpha = 2Fr = FD \qquad \text{(Eq. 1)}$$

$$F = \frac{P}{D} \qquad T = F\pi D \qquad \text{(Eq. 2)}$$

where:

r = shaft radius
D = 2r = shaft diameter
α = the angle from the center of the shaft split to any point on the shaft surface
$d\alpha$ = the incremental angle over which the incremental force (F) acts

Therefore, the lip force per unit of circumference (F) is obtained by dividing the force sensed by the instrument (P) by the shaft diameter (D). The total radial force of the seal (T) is the lip force per unit of circumference (F) multiplied by the shaft circumference (πD).

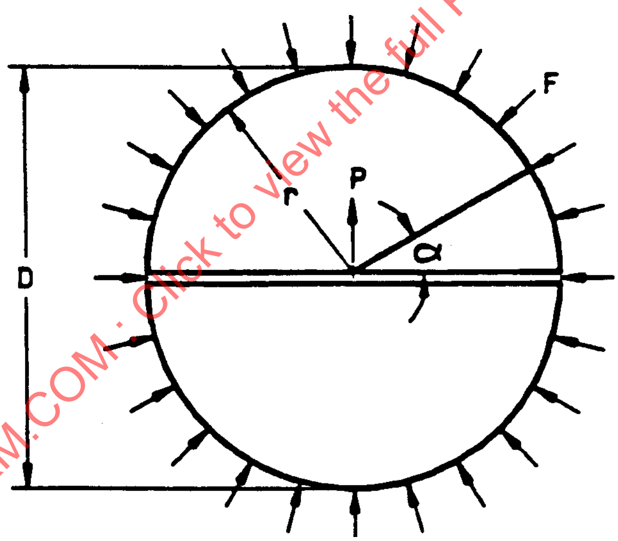

FIGURE 1—SPLIT SHAFT PRINCIPLE

4.3 Conversion of Units—The conversion units for the values determined previously are as follows:

a. F — lip force per unit of circumference
b. oz-in x 0.109 = N/cm
c. N/cm x 9.137 = oz-in
d. T — Total radial force of P-measured force
e. oz x 0.278 = N
f. N x 3.597 = oz

5. Types of Radial Load Measuring Devices

5.1 Mechanical—The moveable half of the split shaft is supported by a calibrated leaf spring and its movement is shown on a dial indicator. The spring is calibrated to show force versus deflection. The dial indicator reading, the result of force P against the spring, is converted to F or T by the equations.

Units can be English or SI depending on the calibration of the spring and the particular dial indicator used. This type of measuring device is subject to several factors that could affect measuring accuracies:

5.1.1 SYSTEM STIFFNESS—In order to measure the deflection of the leaf spring mechanically, the system is designed to deflect significantly. This can introduce measurement errors due to effective shaft size change as the moveable half deflects.

5.1.2 SIZE EFFECT—Large shaft sizes tend to deflect the leaf spring due to excessive weight and cause measurement errors.

5.1.3 DISTANCE FROM FULCRUM POINT—Large variations in tooling or positions of the lip on the shaft can introduce measuring errors.

5.2 Pneumatic—Force P is balanced by air pressure through a pneumatic cylinder attached to the moveable half of the split shaft. The air pressure gauge may be calibrated to read directly in force P rather than in pressure units and may be in either English or SI units. There are two significant factors related to this type of device:

5.2.1 SYSTEM STIFFNESS—Since a pneumatic cylinder is used to counteract the radial force, there is, in effect, no shaft deflection. The system stiffness is effectively perfect.

5.2.2 SUSPENSION—In some devices, the method of suspending the moveable half can require some force and, therefore, introduce some measuring errors.

5.3 Electronic—An electronic transducer (strain gauge) senses the force P against the moveable half of the shaft. A variable “diameter divider” in the electronic circuit is set to the proper shaft size, D, and the readout is directly in F, N/cm. With the diameter divider switched out of the circuit, the readout is P in ounce or Newton. The significant factors here are as follows:

5.3.1 SYSTEM STIFFNESS—Due to the sensitivity of electronic transducers, very small shaft deflections can produce accurate measurements.

5.3.2 MOVEABLE HALF SUSPENSION—Many of the electronic devices are designed with the moveable half of the shaft suspended on a system of stiff leaf springs to produce a friction-free movement insensitive to variations in the vertical position of the seal lip. This allows the use of multiple step split shafts.

6. Factors Affecting Design—The following factors are important in the design of a radial load device:

6.1 System Stiffness—Stiff measuring systems will have low measuring errors due to shaft size effect. A typical electronic device has a stiffer system and lower measurement errors, due to the shaft size change effect, than a typical mechanical device (see Figure 2). Therefore, electronic devices are preferred.

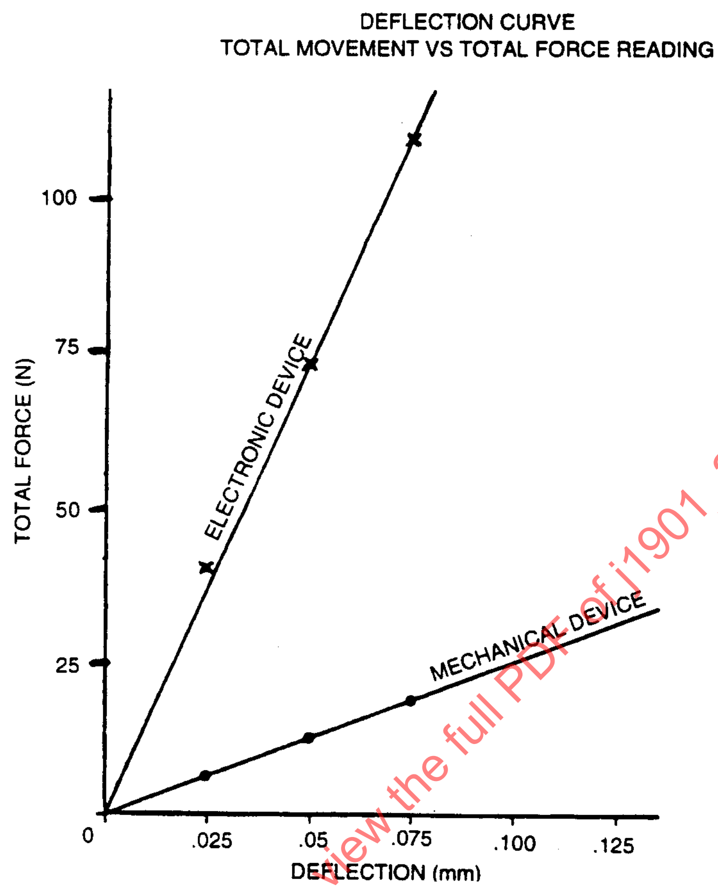

FIGURE 2—DEFLECTION CURVE—TOTAL MOVEMENT VERSUS TOTAL FORCE READING

6.2 **Shaft Suspension—**The majority of the devices evaluated used a multiple leaf spring suspension. For the moveable half of the shaft, this is a friction-free configuration, which appears to be durable and insensitive to variations in the vertical position of the seal lip.

6.3 A digital readout that locks the reading after a set time delay is essential for accurate readings. This is due to stress relaxation of the sealing lip(s) on the shaft which results in a constantly changing reading.

6.4 **Calibration—**The unit must be capable of dead weight calibration. Most units evaluated were easily calibrated. This calibration should be done monthly.

7. ***Factors Affecting Measurements—***The following factors can affect the measurement of radial load:

7.1 **Stress Relaxation—**When a seal is placed on a shaft, the radial force the lip exerts decreases exponentially as a function of time (see Figure 3).

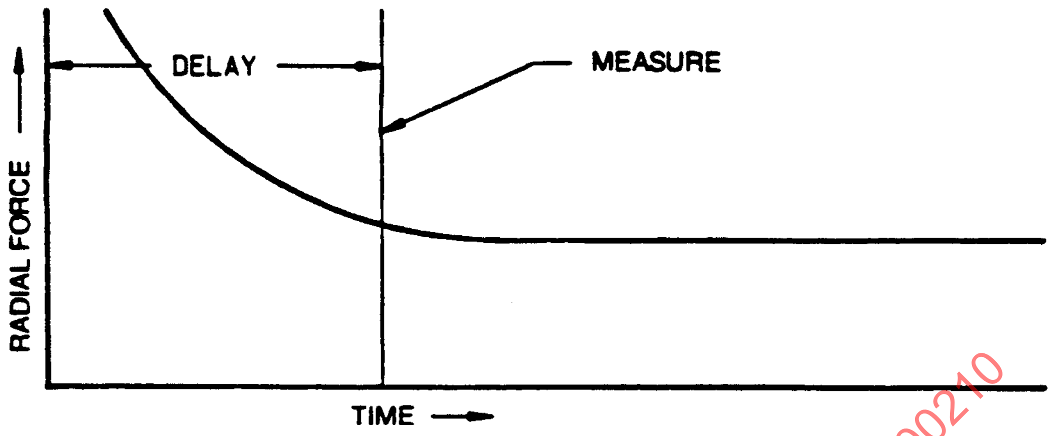

FIGURE 3—STRESS RELAXATION CURVE

Tests were run by the Rubber Manufacturers Association (RMA) with seals produced in four basic polymer types. The approximate time to reach a constant decay rate (0.0055 N/cm/s) at a constant temperature is as follows:

a. Nitrile—25 s
b. Polyacrylate—10 s
c. Silicone—3 s
d. Fluoroelastomer—30 s

It is recommended that a standard time delay be established at 30 s for all materials.

7.2 Seal Temperature—Seals are sometimes stored in areas that may get very hot or cold. Measuring these seals before they reach a standard temperature can have a significant effect on the results. Measurements are made with seals produced in four basic polymer types. The approximate difference based upon ±11 °C temperature differential from 21 °C were:

a. Nitrile—±6%
b. Polyacrylate—±8%
c. Silicone—±3%
d. Fluoroelastomer—±12%

It is suggested that the seals be stored at 21 °C ± 3 °C for 24 h prior to measurement. Room temperature has been chosen for convenience of handling, inspection, and measurement. To determine the effects of application conditions upon radial load, the seals may be tested after a hot oil soak at a temperature and time mutually agreeable to both user and manufacturer.

7.3 Time Interval Between Readings—It is known that certain types of seal materials, such as preswelled silicone, experience a significant change in radial force with time (days) due to the effects of the preswell lubricant. An offset in the specification between seal supplier measurement and seal user measurement may be required in these cases. Also, when making multiple readings on the same seals to establish a mean, the seals must be allowed to relax for 8 h between readings.