Determination of Spring Modulus for Several Types of Elastometric Materials (O-Rings) and Establishment of an Open Data Base for Seals*

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INTRODUCTION

Seals that provide the containment system interface between the packaging body and closure must function in high- and low-temperature environments, under dynamic and static loading conditions, and with different types of contained media. It is one of the most critical elements in the container since the container fails to meet regulations if the seal does not function properly. A research and testing program for seal materials was initiated at Sandia in 1988 with the goal of characterizing the behavior of seal materials commonly used in packages conditions as specified in the regulations (NRC 10CFR Part 71) and American National Standards Institute (ANSI) 14.5. The performance of Elastometric seals in undeformed closures at both high and low temperatures has been investigated (Bronowski 1995). Work has begun with this program to determine the response of elastomeric seals to fast-acting, dynamic deformations in the closure.

The response of elastomeric o-ring seals during closure movements due to long-term deformations has already been characterized. What has not been well characterized are short-term closure movements with duration's of only a few milliseconds that result in the so called "burp" release. Methods for generating this type of response in a repeatable manner had not been developed, and standard leak detection equipment does not have a fast enough response time to measure these transient events. One factor which affects the length of the burp is the ability of the o-ring to quickly close the gap to prevent a significant leak. The dynamic characteristics of the elastomeric o-ring material including the dynamic spring modulus and internal damping are directly related to its ability to quickly close the gap. A set of tests designed to determine the dynamic properties for various material types and durometers (hardness) of elastomers that were both lubricated and dry at ambient temperature were conducted.

A data base available to any cask designer to aid in the choice of seals will be made available on the Internet inside the Sandia National Laboratories home page. Since most people have access to the Internet this data can be available to designers at little or no cost.

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Managing and updating this data-base within the home page is very easy, thus reducing the cost of maintaining such a data-base. This home page is in the design stage and should be ready in early 1996.

APPROACH

The test fixture designed for this series of tests consisted of two flanges mounted on a support structure. A schematic of the fixture is shown in Figure 1, and a photograph of the partially assembled fixture is shown in Figure 2. The fixture was designed to be placed in an MTS 50 Kip Servo-Hydraulic test frame where the compressive load to the o-ring is applied. The bottom flange which retained the o-ring was fixed while the compressive force was applied to the upper flange through a bolt with a built-in load cell. This flange was free to move after the force was quickly released. The only force acting on the upper flange after release was gravity and the force of the o-ring expanding. By measuring the response of the flange the dynamic properties of the o-rings could be determined.

Two different upper flanges were used, with one weighing 7.5 pounds and the other 18.42 pounds The release of the load, movement of the upper flange, and the stroke of column were measured and recorded. The results of the tests will be used to determine the dynamic performance of each of the o-rings.

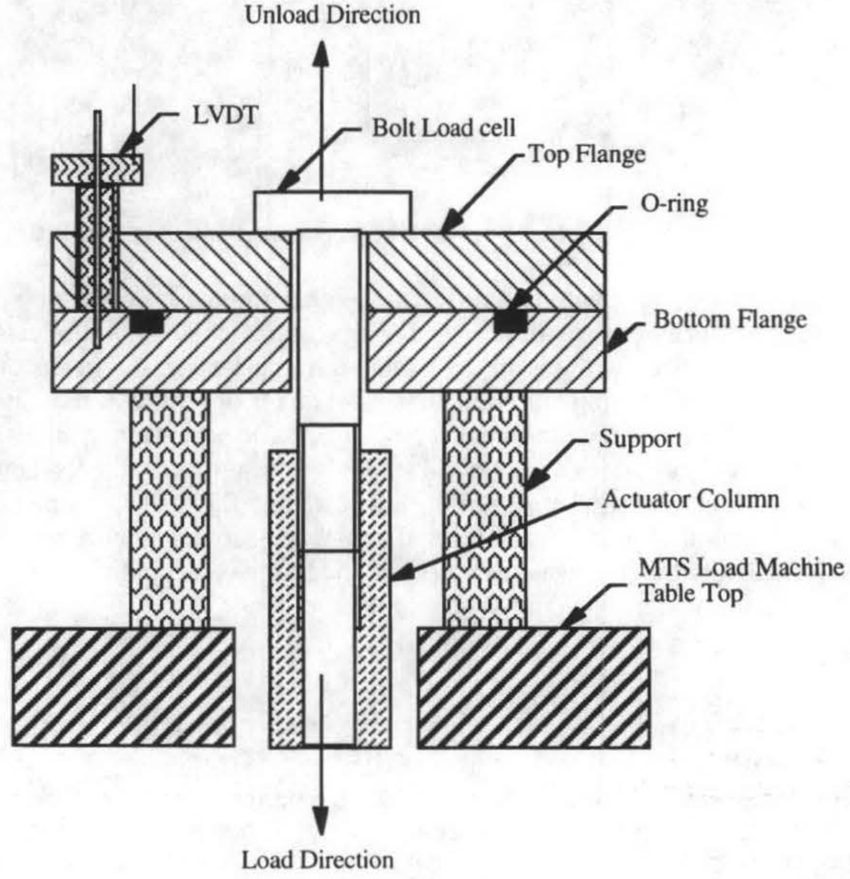


Figure 1. Schematic of the Test

TESTING PROCEDURE

To test the o-rings they were placed between the flanges and loaded to a fully compressed condition. The initial distance between flanges was set at 0.051 inches, and the increase in load to completely compress the o-rings was recorded. The load was released very quickly (78 inches per second) so that the only remaining load on the o-ring was the weight of the top flange.

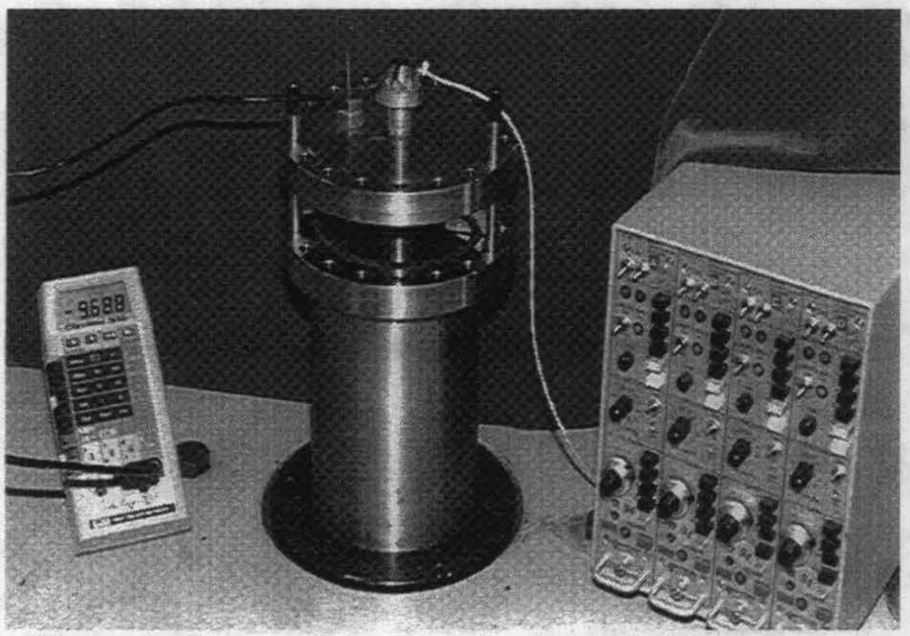


Figure 2 Figure of the Partially Assembled Test Fixture.

Tests were run using flanges with two different weights, three different o-ring materials of different hardness (durometer), and with the o-rings lubricated and not lubricated. The o-ring materials were Nitrile, with 6 samples having durometers measurements of 40 to 90; Silicone, with 5 samples having durometers measurements of 40 to 80; and Viton with 6 samples having durometers measurements of 50 to 90. The seventeen samples were tested with and without lubrication for a total of 34 tests. The test measurements included force from the load cell, stroke displacement of the load cell, and flange displacement, all measured as a function of time. The force and stroke measurements were performed to determine how rapidly the load was released, and the linear velocity displacement transducer (LVDT) measured the movement of the top flange caused by the rebound force of the o-ring.

DISCUSSION OF THE RESULTS

The behavior of the o-rings in all the tests was similar. The differences between lubricated and nonlubricated sample was not significant. As the hardness of the o-rings increased, the load to compress them increased, but the general dynamic behavior remained similar. The Silicon was the most responsive of the three materials with Nitrile next and Viton the least responsive. The differences between all three materials was not large as all three exhibited the same type of response.

For the results of the tests to be meaningful, the load on the upper flange must be released faster than the o-ring response. The release rate of the load for one of the tests is shown in Figure 3. As shown in the figure the total duration of the release was less than 20 milliseconds, which is much faster than the response of the flange from the o-ring rebound force. Thus the release mechanism was fast enough so that it would not influence the dynamics of the tests. A displacement versus time curve for the rebound of the upper flange position is shown in Figure 4. The release of the load is much quicker than the 50-millisecond initial response time of the flange movement.

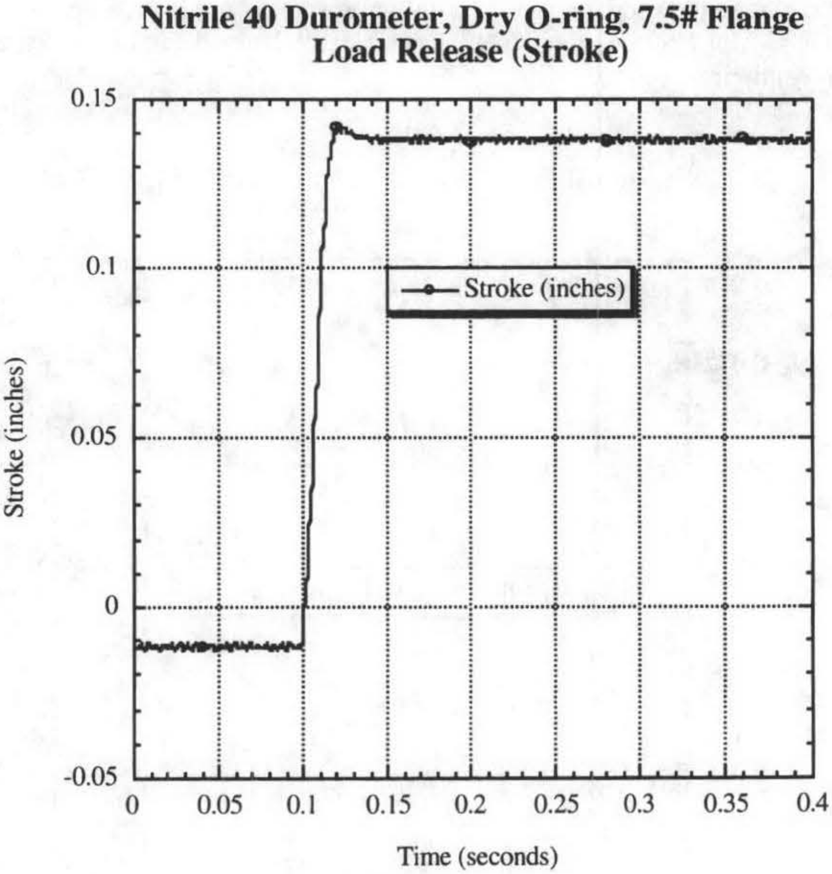

Nitrile 40 Durometer, Dry O-ring, 7.5# Flange
Load Release (Stroke)

Figure 3. Load Release Response of the Top Flange.

Readily apparent in Figure 4 is the high amount of damping in the response of the upper flange. The o-ring was deformed such that it did not return immediately to its initial undeformed position. Instead it vibrated around a position halfway between its initial position and its compressed position. Most of the tests had responses that resembled the above figure. Some of the tests did rebound to the initial position immediately. All of the tests exhibited very high damping in their response.

This test can be modeled as a simple, damped, single degree of freedom system. The damped frequency can be determined from the response. The critical damping ratio can be estimated by the decay in the amplitudes of the response. Together this information can be used to calculate the dynamic spring constant for the o-ring.

The damped natural frequency from Figure 4 can be determined by measuring the period of each oscillation. The period from the figure is about .14 seconds, which corresponds to a natural frequency of 7.14 Hz or a natural circular frequency of 44.9 radians / second. The damping can be estimated by the amount of decay in amplitude for each cycle. From the figure the amplitude decreases in magnitude by about 50% each cycle. This corresponds to a critical damping ratio of .1 or 10% (Clough and Penzien 1975). This means that amount of internal damping is 10% of the critical damping where critical damping refers to a system where the response does not oscillate but gradually returns to its original state. This 10% damping is a fairly high damping value compared to many structural systems. It should be noted that the example used here exhibited more response and less damping than most of the other tests. Many of the other tests were critically damped and did not exhibit any oscillations in their response.

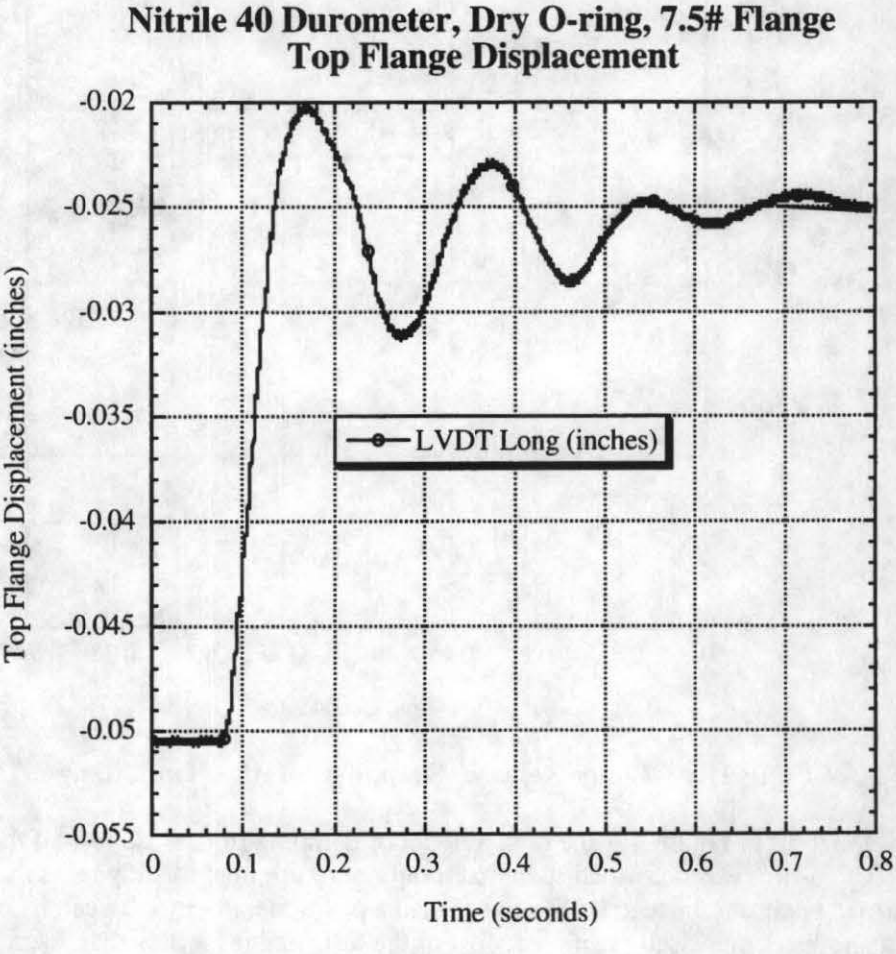


Figure 4. Response of the Top Flange Displacement vs. Time.

The undamped natural frequency of this example can be determined by Equation 1 (Clough and Penzien 1975).

$$\omega = \frac{\omega_d}{\sqrt{1-\xi^2}} \quad (1)$$

where:

ω = undamped natural circular frequency

ω_d = damped natural circular frequency = 44.9 radians/second

ξ = ratio of critical damping = 0.1

The undamped natural circular frequency is 45.4 radians/seconds or a natural frequency of 7.22 Hz. The dynamic spring modulus can be determined by solving for the stiffness in Equation 2 (Clough and Penzien 1975).

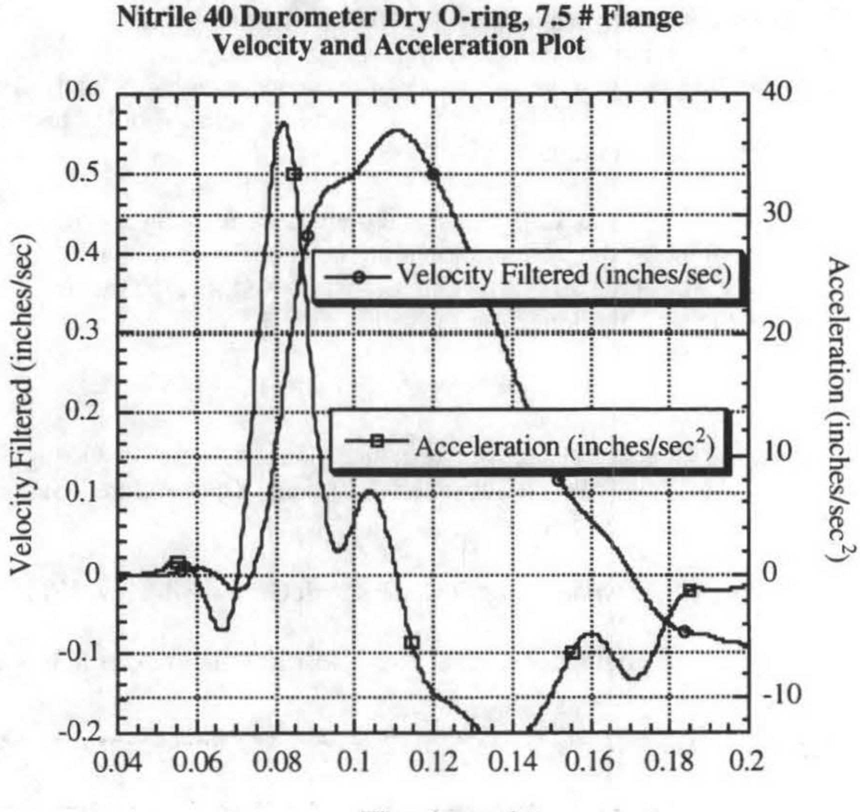
$$\omega = \sqrt{\frac{k}{m}} \quad (2)$$

where:

k = dynamic spring stiffness of the o-ring seal

m = mass of the upper flange weight = 0.0194 pounds-second^2/in

ω = undamped natural circular frequency = 45.4 radians/second



Nitrile 40 Durometer Dry O-ring, 7.5 # Flange
Velocity and Acceleration Plot

Figure 5. Typical Calculated Velocity and Acceleration Response.

The dynamic spring stiffness k is calculated to be 40 pounds/inch. The static spring coefficient can be determine from the initial load to compress the o-ring. The static coefficient is 280 pounds/.051 inches = 5490 pounds/inch. The static spring coefficient is over two magnitudes greater than the dynamic spring coefficient.

Because of the low spring coefficient and high damping, the velocities and accelerations of the top flange are low. Figure 5 shows these parameters as a function of time. The values for the velocity and acceleration were calculated by taking the derivatives of the displacements with respect to time. The low velocities of less than 1 inch/second and the low accelerations of less than 30 inches/second^2 make the top flange susceptible to leaks through "burp" action. The o-rings will resort back to their initial condition after several seconds or more to eventually stop any leaks.

CONCLUSIONS

Test were conducted on three different types of o-rings with six different durometers, in both lubricated and nonlubricated conditions with two different reaction masses. These tests were conducted at ambient temperature.

From the data and the displacement curve it can be seen that the o-ring does not respond very quickly and does not immediately return to its precompressed size. After the initial expansion it takes seconds or even minutes to return to its initial condition. The displacement curves also indicate that the damping factor is large at 10% for the example shown in this paper and much higher for many of the other samples. The dynamic spring modulus is also quite low compared to the static spring modulus. For the test shown this difference was over two magnitudes.

If an o-ring is used in a container or package and there is an accident in which there is a gap opened between the flanges, the o-rings should not be counted on to quickly fill the gap and stop the leak. Also, if the gap is changing quickly with time, the o-rings will not respond to any but the slowest flange motions.

REFERENCES

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