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VISCOELASTIC ANALYSIS OF SEALS FOR EXTENDED SERVICE LIFE

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Introduction

The space station is being developed for a service live of up to thirty years. As a consequence, the design requirements for the seals to be used are unprecedented. Full scale testing to assure the selected seals can satisfy the design requirements are not feasible. As an alternative, a sub-scale test program (2) has been developed by MSFC to calibrate the analysis tools to be used to certify the proposed design. This research has been conducted in support of the MSFC Integrated Seal Test Program. The ultimate objective of this research is to correlate analysis and test results to qualify the analytical tools which in turn, are to be used to qualify the flight hardware.

Seals are simple devices, in wide spread use. The most common type of seal is the O-ring. O-ring seals are typically rings of rubber with a circular cross section. The rings are placed between the surfaces to be sealed, usually in a groove of some design. The particular design may differ based on a number of different factors. This research is focused on O-rings that are staticly compressed by perpendicular clamping forces, commonly referred to as face seals. In this type of seal the O-ring is clamped between the sealing surfaces by loads perpendicular to the circular cross section.

Specific Problem Addressed

The Integrated Seal Test Program is currently performing load decay tests to be used in the qualification of the analysis tools. For these tests to provide an accurate benchmark for analyses the tests must produce accurate repeatable results. This study was undertaken to assure the quality of test results produced. To that end, test results from three different tests are evaluated for repeatability, in both load magnitudes and time dependent behavior. Further, in an initial attempt to qualify the analysis tool, the results are compared to finite element analysis results.

Method of Approach

The load decay tests being conducted under the Integrated Seal Test Program use a sub-scale test article to load an O-ring to a specified level of squeeze. The test article is closed with a single bolt at the center of the fixture. A load cell is attached to the bolt to measure the clamping force on the O-ring. The load cell output is converted to digital information by an analog to digital converter and stored with the time of measurement in data files using a dedicated 286 computer. Data files generated by the load test are transferred to other computers by floppy disc. After initial testing, the computer has been setup to automatically resume load measurements in the event of power loss. The test article is sub-scale in major diameter only. The cross section diameter of the O-ring (6.86 mm, 0.270 inches) and the squeezes (15%, 25%, and 40%) are of the same order as the full-scale design. The desired level of squeeze is obtained by clamping the test fixture down to a fixed shim height and the shims removed.

Due to the nature of the load decay tests, a single test will generate multiple data files with a very large number of data records. These files are combined into a single file and reduced in size using Microsoft Excel (version 4.0) command and function macros developed for the research. These programs are documented in an associated report (1).

Two issues associated with repeatability of the load decay tests must be addressed to ensure test quality. They are: load magnitudes and time dependent behavior. Load magnitudes are be compared by plotting the loads from different tests on a single graph. The time dependent behaviors are compared by plotting the normalized loads from different tests on a single graph.

The effects of aging are studied in the same manner as the repeatability issues. In addition, results from testing of an aged specimen are compared with a virgin specimen by plotting the two sets of data on the same graph with the time axis for the aged specimen shifted horizontally. Time shifting of relaxation curves is a commonly accepted procedure in the analysis of viscoelastic materials. These results are not shown here due to space limitations.

Results

Results from three preliminary load decay tests performed on O-rings with no side wall contact are shown in Figure 1. The results are plotted on linear scales. Preliminary tests 1 and 2 were performed on virgin O-rings. Results from preliminary test 1 are indicated with filled squares, results from test 2 are indicated with filled circles, and results from tests on an aged O-ring are indicated with unfilled triangles. Note from the figure that the initial, i.e., maximum, load for test 1 is 3.76 kN (846 lbs.) while the initial load for test 2 is 4.92 kN (1105 lbs.). This is a percentage difference of 23.4% relative to the test 2 initial load. This difference may be explained by several factors: variation in O-ring cross section diameter from one specimen to another; lack of a reference point on the test article, resulting in angular displacement of the top relative to the bottom; and different shimming procedures. Each of these causes could result in a different squeeze level between tests, and hence different load magnitudes. However, shim height is the most significant factor. Review indicated that a shim height of 1.78 mm (0.070 inches) was used for test 1 and 1.75 mm (0.069 inches) for test 2 and the aged O-ring test. The gaps in the data plotted are due to suspension of data acquisition due to power losses.

Note in Figure 1 for test 1 minor fluctuations in the load value, approximately ± 44 N (± 10 lbs.), for times between approximately 1.5 million seconds and 2 million seconds. Preliminary analysis indicates that these fluctuations are due to thermal cycling. These fluctuations have a basic period of one day, with a secondary period found on seven days. The test article is located in a temperature controlled space. However, due to a number of factors, the temperature control system can not maintain a close control on the temperature.

The aged O-ring was thermally aged to accelerate the aging process. The load decay curve shown in Figure 1 was obtained for a specimen that was not loaded during the aging process. Note from the plot that the load values are significantly below those observed in either for tests of either virgin O-ring. A theoretical explanation for this result is not available at this time.

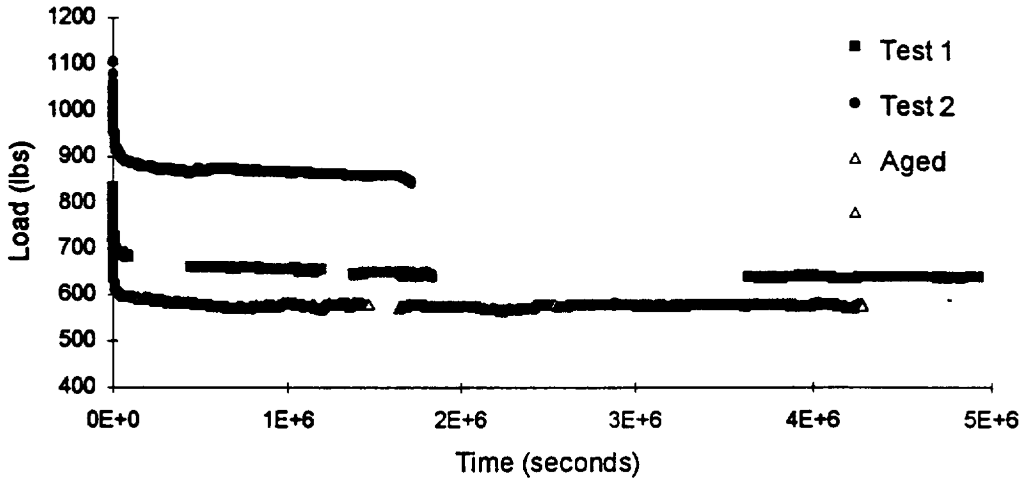

Figure 1. A Plot Of Load Versus Time
For Three Preliminary Load Decay Tests On Linear Scales.

Figure 2 shows a plot of the normalized load versus time for the preliminary tests performed on virgin O-rings shown in Figure 1, normalized stress relaxation data (2), and finite element analysis using the stress relaxation data (5). For these plots, the loads measured at each time are normalized with respect to the maximum load. Both the ordinate and abscissa for the plot are logarithmic scales. This figure shows that the results from the two preliminary tests are virtually indistinguishable from one another. Review of the numerical values shows less than one percent difference in the normalized values. These results show that the two load decay tests display the same time dependent behavior in spite of the 23.4% difference in initial load values. Further, one can conclude that what ever the cause of the differences in initial load, it does not affect the time dependent behavior of the seal in this load decay test (at least for the time observed by the test).

Note in Figure 2 that the normalized stress relaxation data curve is consistently below the load decay curves. The stress relaxation data was obtained from uniaxial testing O-ring material (V747) at a strain level roughly comparable to that used in the load decay tests. From other testing of O-ring material it is known qualitatively that the stress relaxation behavior changes with strain level; the rate of decay is faster at lower strain levels and slower at higher strain levels. On the basis of this and load decay test results shown, the operative strain level in the O-ring tested is expected to be above that used to obtain the stress relaxation data. Further, observe in the figure that the curve for the finite element analysis passes through the stress relaxation data. This is as expected from theory as implemented by the ABAQUS finite element code for a constant load analysis (3). On the basis of this conclusion and the foregoing discussion, the finite element analysis does not accurately describe the seal behavior because a proper stress relaxation curve was not available.

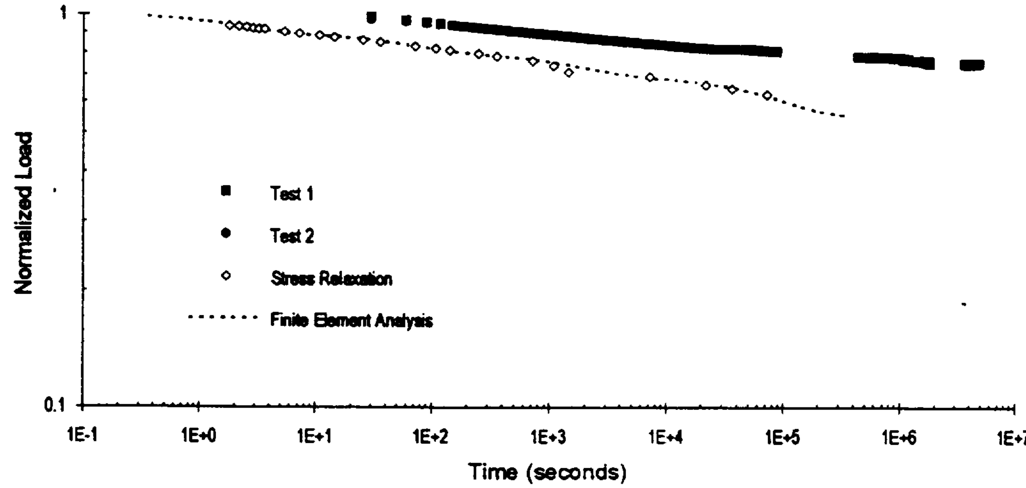

Figure 2. A Plot Of Normalized Load Versus Time
For Two Preliminary Load Decay Tests Of Virgin O-rings, Normalized Stress Relaxation Data (2), and Finite Element Analysis Results (5) On Logarithmic Scales.

Conclusions

The conclusions from this review of the load decay tests and comparison of experimental results with finite element analysis results are:

1. The load decay tests are repeatable.
2. Minor changes in the test procedure are recommended, i.e., create a reference datum on the test article to ensure alignment is the same from test to test; use a consistent shimming method; and re-evaluate time intervals used between measurements to reduce data file size.
3. Temperature fluctuations should be controlled as much as possible to minimize impact on load decay testing.
4. Another mechanism other than simple stress relaxation is present, causing the load decay response to deviate from results predicted by finite element analysis.
5. Additional data processing capability is needed within EP43 to analyze the test results.

References

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