To be presented at the Winter Annual Meeting of the Electrical and Electronic Packaging Division of the American Society of Mechanical Engineers in Dallas, Texas, November 25-30. 1990.

CONF-901109--16

Received by OSTI

AUG 1 4 1990

SAND90-0650C

DEVELOPMENT OF HERMETIC MICROMINIATURE CONNECTORS

M.K. Neilsen, L.A. Andrews, S.L. Monroe, H.L. McCollister
Sandia National Laboratories
Albuquerque, New Mexico 87185

SAND--90-0650C

DE90 015562

Abstract

Miniaturization of hermetic packages has provided the incentive to develop a new family of hermetic microminiature connectors. Microminiature connectors, with a pin spacing of 1.27 mm, have previously been available only in the non-hermetic form. New microminiature connectors with compression seal materials, 304 Stainless Steel housings, Alloy 52 pins, and TM-9 Glass* insulators, were examined because compression seals are currently used in larger hermetic connectors and are typically designed to create a residual compressive stress state in the insulator during manufacture. The new microminiature connectors with compression seals were evaluated analytically with two- and three-dimensional finite element models and experimentally by fabrication of prototype connectors. The finite element analyses predicted the development of undesirable tensile stress in the insulator during manufacture and identified the mechanism responsible for the generation of tensile stress in the glass. The experimental investigation confirmed the existence of undesirable tensile stress in the glass with the observation of crack development during manufacture. Since the design requirements would not allow the geometric modifications needed to manufacture crack-free connectors with compression seals, insulator materials that generate a matched seal with 304 Stainless Steel housings were developed. Connectors with these matched seals were sucessfully manufactured.

Introduction

Sensitive electronic components are protected from the outside environment for extended periods of time by hermetically sealing them in metal containers. Connectors with glass-to-metal seals are often used to provide electrical contact to the isolated components. The manufacture of glass-to-metal seals is discussed in a number of references (Kohl, 1967 and Rulon, 1972). Fabrication of connectors with glass-to-metal seals includes several steps. First, a solid glass preform is placed inside a metal housing and metal conductor pins are inserted through holes in the preform. Then, the assembly is heated in a controlled atmosphere furnace until the glass flows and fuses to both the metal pins and the metal housing. The assembly is then cooled to room temperature.

Stresses are generated in the glass, pins and housing during the glassing operation due to differential thermal contraction of the glass and metal. Two different design approaches are used to control the tensile stresses generated in the glass (Rulon, 1972). One approach is to use glass and metal materials that have nearly the same thermal expansion properties. When this approach is taken the seal is referred to as a matched seal. Matched seals usually produce a stress free state in the glass after manufacture. The second approach is to use a glass that has a thermal expansion coefficient that is less than the thermal expansion coefficient of the housing. This is referred to as a compression seal because glass near the housing is compressed during cooling. Design guidelines for coaxial compression pin seals have been developed (Miller and Burchett, 1982). A properly designed connector with either a stress free or compressive stress state in the glass at room temperature is essential if the connector is to survive subsequent assembly and operational environments.

New connectors were developed to provide electrical contact to small components that are isolated from the environment. Connectors in this family have two parallel rows of conductor pins and a total of between 7 and 51 pins. A 15-pin connector is shown in Figure 1. All connectors have a uniform pin spacing of 1.27 mm; thus, the overall length of the connector increases as the number of pins is increased. Parallel rows of pins were used to provide pin access which facilitated the soldering of cables to the pins. Also, the connector geometry was chosen to meet space requirements and allow for assembly to standard design non-hermetic mating connectors. The baseline design used materials that have been shown to generate good compression seals: a 304 Stainless Steel housing, a TM-9 glass insulator, and Alloy 52 conductor pins.

* Kimble Glass, Toledo, Ohio.

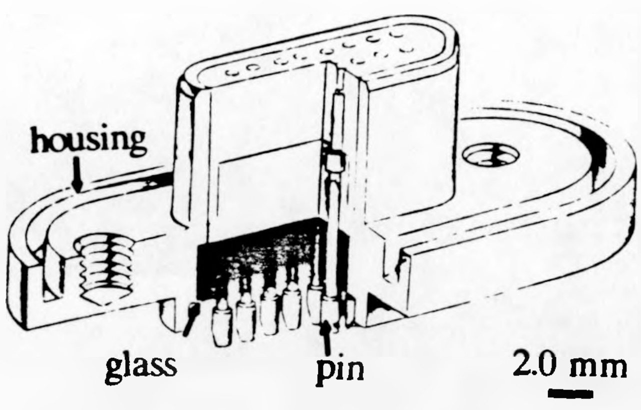


Fig. 1 Hermetic Microminiature Connector

This paper describes analytic and experimental evaluations of the new microminiature connector designs. A series of two and three-dimensional finite element analyses characterized the stress state generated during manufacture and identified the deformation mechanism responsible for the generation of tensile stress in the glass insulator. Results from the manufacture of prototype connectors is also presented and compared with the finite element results.

Finite Element Analyses

Residual stress states generated in the connector during manufacture were computed using a series of finite element models and the structural computer codes JAC (Biffle,1984) and JAC-3D (Biffle,1989). In these analyses, the materials were assumed to be stress free at the set point temperature for the glass, specifically, 445 C for TM-9 glass. The finite element models were subsequently cooled to room temperature, and the resulting residual stresses were computed. The effects of residual tensile stress in the glass were evaluated using design guidelines from Miller and Burchett (1982). Tensile stress in excess of 35 MPa was expected to generate cracks in TM-9 glass and tensile stress in excess of 7 MPa was undesirable.

Material properties used in these analyses are given in Table 1. The glass was assumed to remain linear elastic below its set point temperature. The metals were modelled as strain hardening elastic-plastic materials. Two connector geometries were analyzed. The first geometry used a single glass preform to isolate the conductor pins from the housing, and the second geometry used an individual glass bead to isolate each pin from the housing.

Table 1 Material Properties

Material	Young's Modulus GPa	Poisson's Ratio	Yield Strength MPa	Thermal Expansion 1/°C
TM-9 Glass	67.6	0.21	—	10.2E-06
Alloy 52	206.9	0.30	344.8	10.2E-06
304 SS	193.1	0.30	241.4	18.4E-06

Connectors with Single Glass Preforms

Two-dimensional Finite Element Analyses. Initial generalized plane strain analyses used the two-dimensional finite element model shown in Figure 2. This model was generated from cross section A-A of an actual connector and represents the symmetry plane of a long connector. The conductor pins were not included in the model. Nevertheless, this initial model is appropriate for estimating stress levels in the glass and housing near cross section A-A.

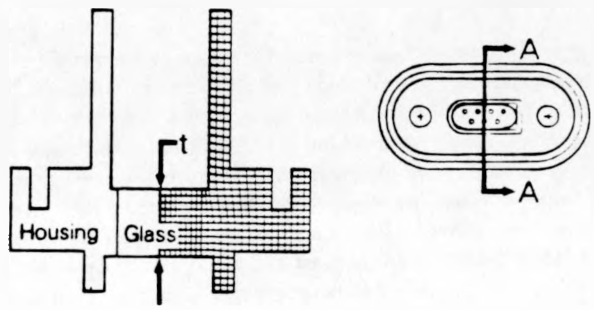


Fig. 2 Two-dimensional Generalized Plane Strain Finite Element Model of the Connector Symmetry Plane

The first analysis was completed using a 2.54 mm thick (dimension t in Figure 2) glass insulator. Results from this analysis indicated that a very small section of the 304SS housing is plastically deformed as the connector is cooled to room temperature. However, a large portion of the glass insulator is in tension. A contour plot of maximum principal stress in the glass (Figure 3) indicates that the maximum tensile stress is 71.8 MPa located near the bottom surface of the glass and oriented in a direction parallel to the bottom surface of the glass. This tensile stress is caused by the mismatch in thermal expansion between the 304SS housing and the TM-9 glass. The 304SS contracts more than the TM-9 glass in the vertical direction and tends to stretch the top and bottom surfaces of the glass which generates tensile stress near the surfaces of the glass. The next analysis was completed using a 1.27 mm thick glass insulator. Results from this analysis indicate that the maximum tensile stress in the glass will decrease to 47.6 MPa as the thickness of the glass is decreased.

Stresses that are generated near the ends of an actual connector were then estimated with an axisymmetric finite element analysis that used the same model as the initial analysis (Figure 2). In this analysis, the model represents a connector that has a 2.54 mm thick circular disk of glass surrounded by a ring of housing material and should provide reasonable estimates of stress levels generated near the ends of an actual connector. This analysis indicated that a maximum tensile stress of 17.5 MPa was generated near the center of the glass (Figure 4) and that the top and bottom surfaces of the glass were in compression. A similar axisymmetric analysis was completed for a 1.27 mm thick glass insulator. This analysis indicated that a maximum tensile stress of 17.6 MPa was generated near the center of the glass.

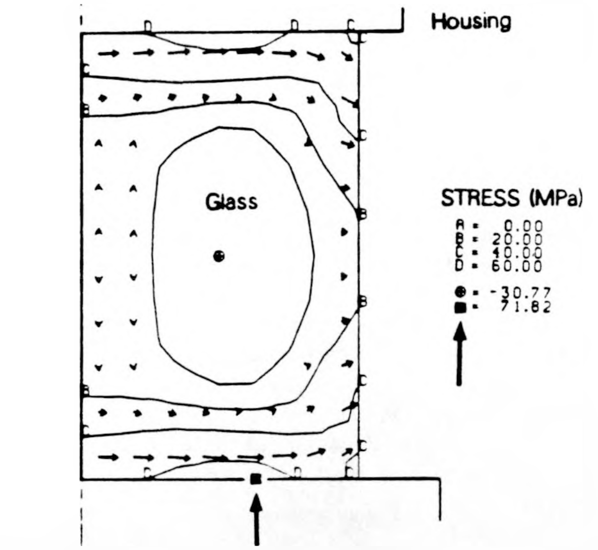


Fig. 3 Maximum Principal Stresses (MPa) in the Glass Resulting from the Two-dimensional Generalized Plane Strain Analysis

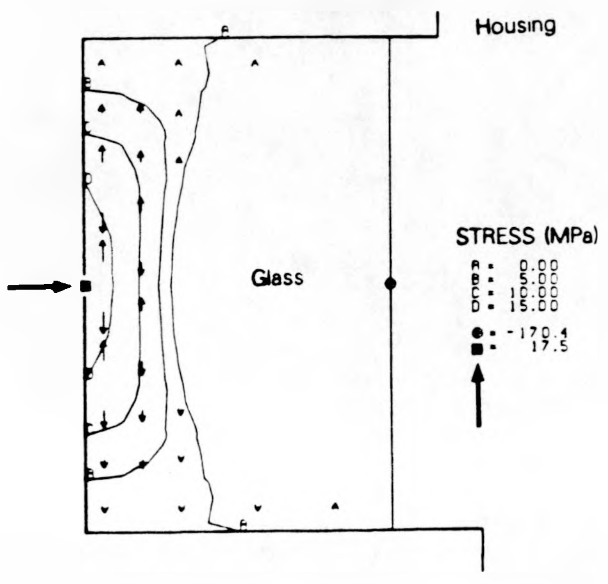


Fig. 4 Maximum Principal Stresses (MPa) in the Glass Resulting from the Axisymmetric Analysis

The two-dimensional generalized plane strain and axisymmetric analyses indicated that the largest tensile stress in the glass is generated near the surface of the connector's symmetry plane. The magnitude of this tensile stress can be significantly reduced by reducing the thickness of the glass insulator.

Three-Dimensional Finite Element Analysis. The effect of pins on the residual stress state in the glass was investigated using a three-dimensional finite element model of a 15-pin connector (Figure 5). Due to symmetry, only one half of the connector was modeled and appropriate symmetry boundary conditions were applied to the left face in Figure 5.

A maximum tensile stress of 70.9 MPa is generated in the glass when the connector is cooled to room temperature after the glassing operation. This maximum stress is located on the symmetry plane and near a conductor pin as shown in Figure 6.

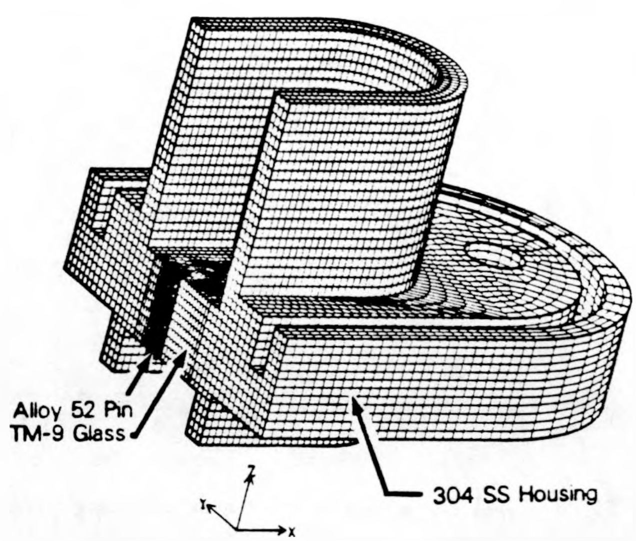


Fig. 5 Finite Element Model of a 15-Pin Connector with Single Preform

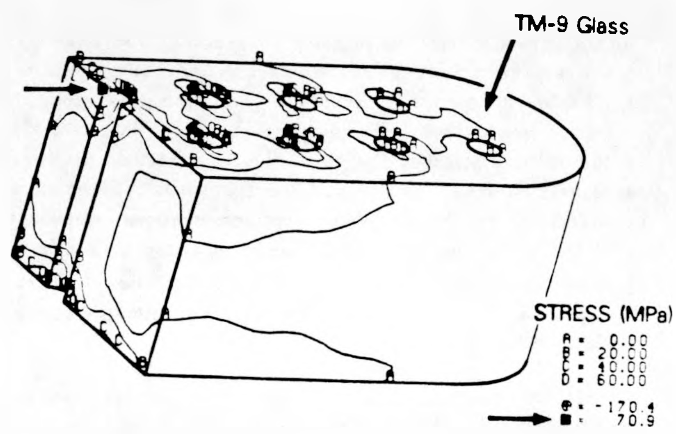


Fig. 6 Maximum Principal Stresses (MPa) in the Glass Resulting from the Three-dimensional Analysis of a 15-Pin Connector with Single Glass Preform

This result and the stress distribution generated on the symmetry plane compare reasonably well with the results from the two-dimensional generalized plane strain analysis. The large tensile stress predicted by these analyses indicates that the generation of cracks in the glass during manufacture is likely.

Experimental Investigation. To evaluate the analytic results, a few prototype 15-pin connectors each using a single, 2.54 mm thick, TM-9 glass preform were tested. As predicted by the three-dimensional model, glass in the 15-pin connector cracked near the pins during manufacture as shown in Figure 7. The observed crack was oriented in a direction perpendicular to the maximum tensile stress and ran the length of the connector.

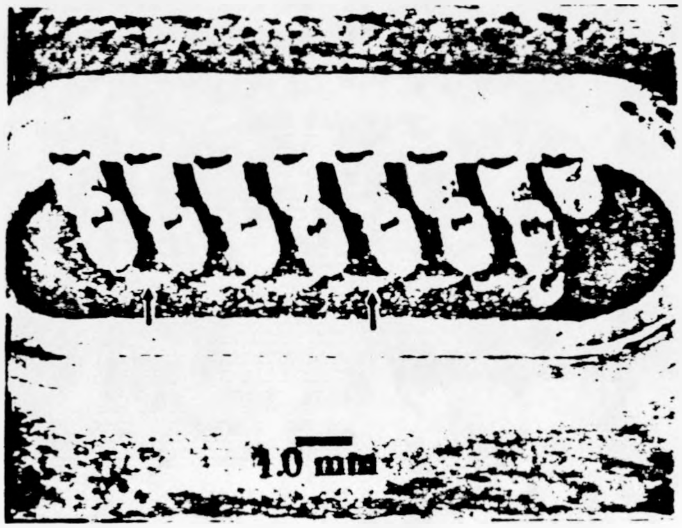


Fig. 7 Crack Generated in Connector with Single Glass Preform

Deformation Mechanisms. There are two mechanisms that affect the stress state generated in the glass during the glassing operation. Both mechanisms are driven by the mismatch in thermal expansion between the housing and the glass. The first mechanism is differential in-plane contraction where the connector plane is defined as the plane whose normal is the z-axis in Figure 5. As the connector is cooled to room temperature, the housing tries to contract more in-plane than the glass and generates a compressive stress in the glass. This mechanism produces good compression seals. The second mechanism is differential vertical contraction. As the connector is cooled to room temperature the housing tries to contract more than the glass in a direction normal to the connector plane. This mechanism stretches the surfaces of the glass and generates tensile stress near the top and bottom surfaces of the glass.

If the compressive stress generated by differential in-plane contraction is larger than the tensile stress generated by differential vertical contraction then a net compressive stress is generated. However, when the housing is designed such that the compressive stress generated by differential in-plane contraction is smaller than the tensile stress generated by differential vertical contraction a net tensile stress on the surfaces of the glass is generated. The new microminiature connector housing does provides an adequate amount of in-plane compression in a direction parallel to the connector axis (x-direction in Figure 5) but does not provide enough in-plane compression in a direction perpendicular to the connector axis (y-direction in Figure 5).

Connectors with Individual Glass Insulators

Results from the previous section indicated that unacceptable stress levels are generated in the 15-pin connector when a solid glass preform is used. In this section, the effects of using 1.27 mm thick individual glass insulators in place of the solid glass preform were investigated.

Review of Design Guidelines for Compression Pin Seals. Design guidelines for compression pin seals constructed from Alloy 52 pins, TM-9 glass and 304 Stainless Steel housings were developed by Miller and Burchett in 1982. These guidelines indicate that the ratio of glass bead wall thickness-to-height ratio should be greater than 0.25 and less than 0.33 (Figure 8). The individual glass beads used in the microminiature connector design have a wall thickness-to-height ratio of 0.24. Also, the design guidelines recommend that a minimum spacing equal to 0.75 times the glass bead diameter should be used between any two glass beads. The minimum glass bead spacing in the microminiature connector design is equal to 0.254 mm which is only 0.25 times the glass bead diameter. Thus, the original microminiature connector design seriously violates the minimum insulator spacing guideline.

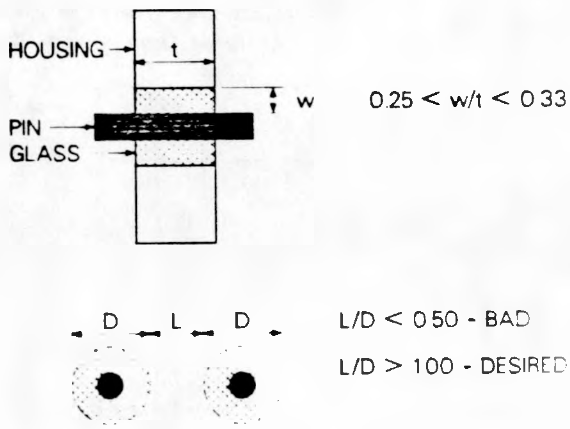
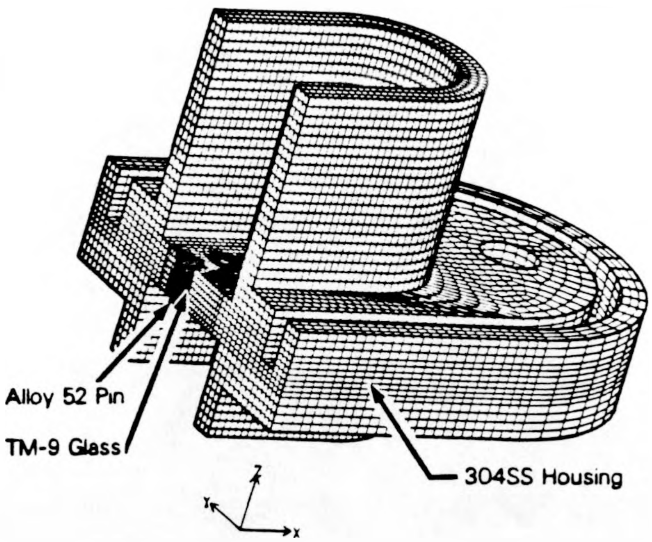


Fig. 8 Design Guidelines for Coaxial Compression Pin Seals (Miller and Burchett, 1982)

Finite Element Analysis. A three-dimensional finite element analysis characterized stress levels that are generated during the glassing operation using the model shown in Figure 9. Due to symmetry, only one half of the connector was modelled and appropriate boundary conditions were applied to the cut surface.

Results from this analysis indicated that the housing material near the glass insulators yields and plastically deforms as the assembly is cooled to room temperature. Also, a maximum tensile stress of 64 MPa is generated in one glass seal near the symmetry plane when the connector is cooled to room temperature (Figure 10). This tensile stress is oriented in a direction perpendicular to the connector axis (y-direction in Figure 10). The tensile stress is much higher in seals near the symmetry plane than in seals near the ends of the connector. This occurs because the housing is not able to provide the same amount of in-plane compression in all directions. Additional finite element analyses indicated that tensile stress in the glass can be significantly reduced by increasing the conductor pin spacing.



Fi[illegible] 9 Finite Element Model of a 15-Pin Connector with [illegible] Glass [illegible]sulators

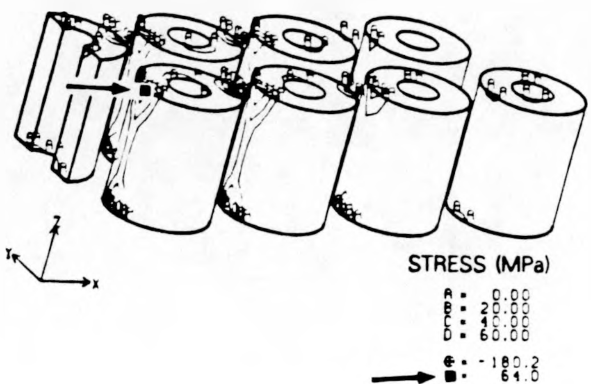


Fig. 10 Maximum Principal Stresses (MPa) in the Glass Resulting from the Three-dimensional Analysis of 15-Pin Connector with Individual Glass Insulators

Experimental Investigation. To validate the analytic results a few prototype 15-pin connectors were manufactured using individual TM-9 glass insulators. Results from this experimental investigation indicated that, as predicted by the finite element analyses, glass beads near the connector's symmetry plane cracked during manufacture (Figure 11). As expected, the observed cracks were oriented in a direction perpendicular to the maximum tensile stress and ran across each insulator.

Fig. 11 Crack Generated in Connector with Individual Glass Insulators

Connector with Matched Seals

Analytical and experimental results presented in the previous sections indicated that the housing geometry would have to be modified to generate more in-plane compression in a direction perpendicular to the connector axis. This could be accomplished by either increasing the width of the connector with the single glass preform or increasing the pin spacing in the connector with individual glass insulators. Both of these modifications would reduce the conductor pin density. Since the original conductor pin density was an essential design feature, future development was directed towards developing a connector with matched seals. Since, the 304 Stainless Steel housing material could be easily welded to the various containers in which these connectors are used, a new insulator material that had expansion properties similar to 304 Stainless Steel was needed. A new glass ceramic material that has thermal expansion properties similar to 304 Stainless Steel was recently developed at Sandia National Laboratories. Crack free microminiature connectors with 304 Stainless Steel housings, the new glass ceramic insulators and RA 330 pins have been sucessfully manufactured. The new connectors with matched seals have also survived a series of thermal tests in which the environment varied from -55 C to 75 C.

Concluding Remarks

There are two mechansims that affect the stress state generated in the glass during the manufacture of a compression seal. Differential in-plane contraction generates compressive stress in the glass and differential vertical contraction generates tensile stress near the top and bottom surfaces of the glass. Connectors with compression pin seals must be designed such that the compressive stress in the glass generated by differential in-plane contraction exceeds the surface tensile stress generated by differential vertical contraction.

The mechanical design guidelines for coaxial compression pin seals proposed by Miller and Burchett, 1982, accurately indicated that the original individual glass insulator design was not adequate and that the insulator spacing should be increased to improve the design. Because the original conductor pin density was an essential feature of the new connectors, the insulator spacing could not be changed. Consequently, a matched seal design was pursued in place of the compression seal design. Insulator materials that generate a matched seal with 304 Stainless Steel were recently developed. Prototype microminiature connectors with matched seals have been sucessfully manufactured.

Acknowledgment

This work was supported by the United States Department of Energy under Contract DE-AC04-76DP00789.

References

Biffle, J.H., *JAC - A Two-dimensional Finite Element Computer Program for the Nonlinear, Quasistatic Response of Solids with the Conjugate Gradient Method*, SAND81-0998, Sandia National Laboratories, Albuquerque, New Mexico, April 1984.

Biffle, J.H., *JAC3D - A Three-dimensional Finite Element Computer Program for the Nonlinear, Quasistatic Response of Solids with the Conjugate Gradient Method*, SAND87-1305, Sandia National Laboratories, Albuquerque, New Mexico, March 1989.

Kohl, W.H., *Handbook of Materials and Techniques for Vacuum Devices*, Reinhold Publishing Corporation, 1967.

Miller, J.D. and Burchett, S.N., *Some Guidelines for the Mechanical Design of Coaxial Compression Pin Seals*, SAND82-0057, Sandia National Laboratories, Albuquerque, New Mexico, April 1982.

Rulon, R.M., *Glass To Metal Seals*, in *Introduction to Glass Science*, edited by L.D. Pye, H.J. Stevens, and W.C. LaCourse, Plenum Press, 1972.