FRANGIBLE GLASS CANISTERS

By Richard Seifert*

ABSTRACT

The need for a canister that can release its contents without disturbing the contents dynamically is discussed. The solution of this problem by the use of a frangible glass canister is presented. The basic theory applicable to frangible glass and the method of initiating a command flaw are discussed. A brief description of the test program and the results of a flight test are presented.

INTRODUCTION

In one program, there was a requirement that a payload be deployed in space in a manner which would impart only negligible dynamic disturbances upon release. The payload should be ejected from a standardized launch tube that would be flown for test purposes on a Nike-Hydac sounding rocket. The internal and external dimensions of the launch tube were fixed and governed the external dimensions for the payload-carrying device (that is, a canister that houses the payload). The obvious solution was to carry the payload inside the previously developed canister, for which the launch tube had been designed (fig. 1). This approach was tried during a test program.

The assistance provided by Morris Creel, Tracor, Inc., and Gary Goodman, Owens-Illinois, and their associates is gratefully acknowledged, as well as their ideas on the detailed development aspects of this design concept, test, and implementation of the device.

ALTERNATE CONCEPT

In addition to a propelling device, the existing canister consists of two metallic cylindrical half shells that are held together by several fasteners, locking two tongue-and-groove joints that are separated by 180° and that extend the full length of the cylinder. Separation of these half shells is accomplished by redundant pyrotechnic means. The tongue-and-groove joint is constructed so that it accommodates a small column insulated delay (SCID) line. The gas pressure resulting from the burning of the SCID is used to shear the fasteners, rupturing the cylindrical canister. The gases propel the separated halves away from the payload.

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Although the existing metallic canister could easily accommodate the payload, in the test program mentioned earlier it was demonstrated that the canister would not meet the most important requirement: excessive dynamic disturbances were not to be imparted to the payload. It was evident from the beginning that the propagating SCID separates the canister halves near the point of entry into the tongue-and-groove joint before it arrives at the opposite end. Tests showed that each canister-half end deflects outward from the longitudinal centerline because of the thin-wall construction, and becomes banana shaped. This action causes the escaping gases to impinge on the payload, imparting motion to it. Although the duration of this event is very short, it is sufficient to impart dynamic motion beyond tolerable limits to the released payload.

FRANGIBLE GLASS CANISTERS

The foregoing tests resulted in an investigation to find a new canister design that would not subject the internal payload to a detrimental dynamic environment. A solution was found: use a specially treated glass tube that has a uniform wall thickness. A fuzed lithium-alumina-silicate glass exists that, when subjected to an ion-exchange process, results in a rearranged molecular structure. The process consists of immersing the so-called "green" glass tube in a heated bath for a certain length of time. Near the surfaces, the small lithium ions are exchanged for larger sodium ions, in effect producing three layers in the glass-tube wall. Both outer layers are in compression; the middle layer is in tension (fig. 2).

Two principles are used to develop the strengthened frangible glass canister. First, glass is much stronger in compression than in tension. Second, almost all failures in glass result from a surface defect that acts as a tensile-stress riser. Chemically strengthened glass is processed to incorporate a residual compressive stress in the surface layers of the glass; this stress is balanced by tensile stresses in the interior of the glass wall. The forces in the thin layers of highly compressed glass can be balanced by relatively low tensile stresses in the thicker middle layer. Because the tensile stress is relatively low and is contained in the interior of the glass thickness, spontaneous failure resulting from the presence of tensile forces is inhibited. The residual stress distribution in this glass is shown in figure 3.

Command failure results when the outer layer, containing the high residual compressive stress, is penetrated; an imbalance of forces in the glass wall results. The stored tensile stress is relieved, resulting in rapid fracture of the glass. The stored energy is sufficient to result in multiple forked fractures that dice the glass into very small fragments. In a tube configuration, the fragments are forced outward radially as the highly compressed surface layers attempt to expand to relieve the residual internal-stress condition.

CONFIGURATION

For the intended application, the glass was produced in open-ended-tube configurations. The cylinders were produced with a carefully controlled wall thickness (0.127 ± 0.005 centimeter (0.050 ± 0.002 inch)), without excessive outer or inner waviness, and in the lengths required (fig. 4). The existing specification is for glass fragments to have an area of less than 0.65 square centimeter (0.10 square inch), with the stipulation that no fragment exceed 0.95 centimeter (3/8 inch) in the largest dimension. The unrestricted radial dispersal rate of the glass fragments has been defined as follows.

1. No more than 10 percent of the fragments may have a velocity of 0 to 1.22 m/sec (0 to 4 ft/sec).

2. Ninety percent of the fragments must have velocities in excess of 1.22 m/sec (4 ft/sec). Although not in the specification, the cracking propagation rate for the glass-tube length and wall thickness applicable in this case was approximately 134.15 m/sec (440 ft/sec).

GLASS FRANGING

Having established that a suitable glass tube could be produced, a suitable means of initiating the glass-franging process had to be found. As usual, conventional methods were tried at first. These consisted of building pins (or "pingers") of various hard materials, varying front cone angles, varying shank diameters, and driving the pins from various distances toward flat frangible-glass specimens. These tests were unsuccessful. Pins either broke or deflected when contacting the glass surface. Because of a very tight schedule, it was decided not to pursue an investigation into possible unusual alloys that would maintain structural integrity and act as successful pingers for the glass. It was decided to use a diamond-tipped pin to shatter the glass. Both the diamond and its mounting had to be controlled carefully. The diamonds that were used were unicrystals and, therefore, were susceptible to shattering if the cleavage planes were not oriented properly with respect to the tip radius. The result of this development is shown in figure 5.

The installation of this franging pin in the housing is shown in figure 6. The SCID is routed around the circumference of the franging-pin shank, which is held in position by mean of a shear pin. The SCID is initiated by the rocket motor through the use of a timer and redundant delays. When the motor burns, the resulting gases act on the franging-pin shoulder, creating a force adequate to shear the small pin. Now, the gas is permitted to act together with an expanding coil spring. Working together, these forces propel the franging pin forward into the glass with sufficient force to penetrate the thin compression layer. In turn, this initiates the cracking process. Two franging pins, 180° apart, were incorporated in the final design. These pins strike the glass simultaneously from the inside. To obtain a high-reliability franging process, it was decided to position the diamond-tipped pins near the tube end where a metal backing existed on the outside of the glass wall. It was shown that the propelling forces on each pin not only caused complete penetration of the glass but, in fact, impacted this metal backup. An empty glass cylinder before initiation of the franging process is shown in figure 7. The glass particles are shown moving away radially in figure 8. The second picture was taken a few milliseconds after the franging pin impacted the glass.

Other tests, involving the same franging system, were performed to determine correct standoff distances between the retained pin and the glass surface, with and without a metal backup behind the point of diamond impact, and using various thicknesses of treated glass. The force required to initiate the franging process was determined experimentally to be approximately 27.58×10^7 N/m^2 (40 000 psi) which, in this case, is achieved by controlling the gas force, the spring force, and the diamond-tip radius. The velocity distribution of the glass particles also was obtained experimentally by placing 8.89-centimeter-diameter (3.5 inch diameter) containers side by side (in a pie shape) on the floor of a chamber, starting at the point in line with the glass canister centerline. Inspection of these containers after a franging test demonstrated a concentration of particles in a circular band, as had been predicted.

It should be noted that, during one of the tests in this series, a frangible-glass canister inadvertently was permitted to fall free from a height of approximately 35 feet before it impacted into 15.24 centimeters (6 inches) of polyurethane. The glass canister did not break as a result of the fall, and X-rays revealed no damage to it or to the franging device that had been installed.

CONCLUDING REMARKS

When all tests were completed, flight articles were assembled and installed in the sounding rocket. The canister and the franging system were successful during a flight test. This was demonstrated conclusively by tracking of the payload, which could operate only when it was released from the canister.

DISCUSSION

T. G. Harrington:

Do you have any test data to verify that no glass particles moved inboard? How were data obtained?

Seifert:

Glass-particle motion was, in fact, as stated: 10 percent had velocities 0 to 4 ft/sec; 90 percent moved away at rates in excess of 4 ft/sec. The data were obtained by collecting of particles at the bottom of the chamber in the containers that were visible in the movie. No particles were found in the containers on the chamber floor located in line with or near the canister centerline.

W. E. Oakey:

In your movie, some of the glass fragments appeared to be approximately 2 inches long. Were they in fact this long, or were you able to meet the 3/8-inch maximum-dimension requirement?

Seifert:

The fragments were all of the specified dimension. The first camera was quite close to the test specimen and fragments appear larger than they are in reality.

W. A. Stewart:

Please comment on the appearance of "shock" waves at the outer edges of expanding glass.

Seifert:

If the film is viewed at a slower speed, the cracking propagation is visible in an orderly manner. The franging over the entire cylinder length is visible in 3 frames, whereas the movie was taken at 10 000 frames/second. What is visible in the movie does not represent a shock wave. It is visible indication of already created particles moving away from the portion of the canister which is still undisturbed.

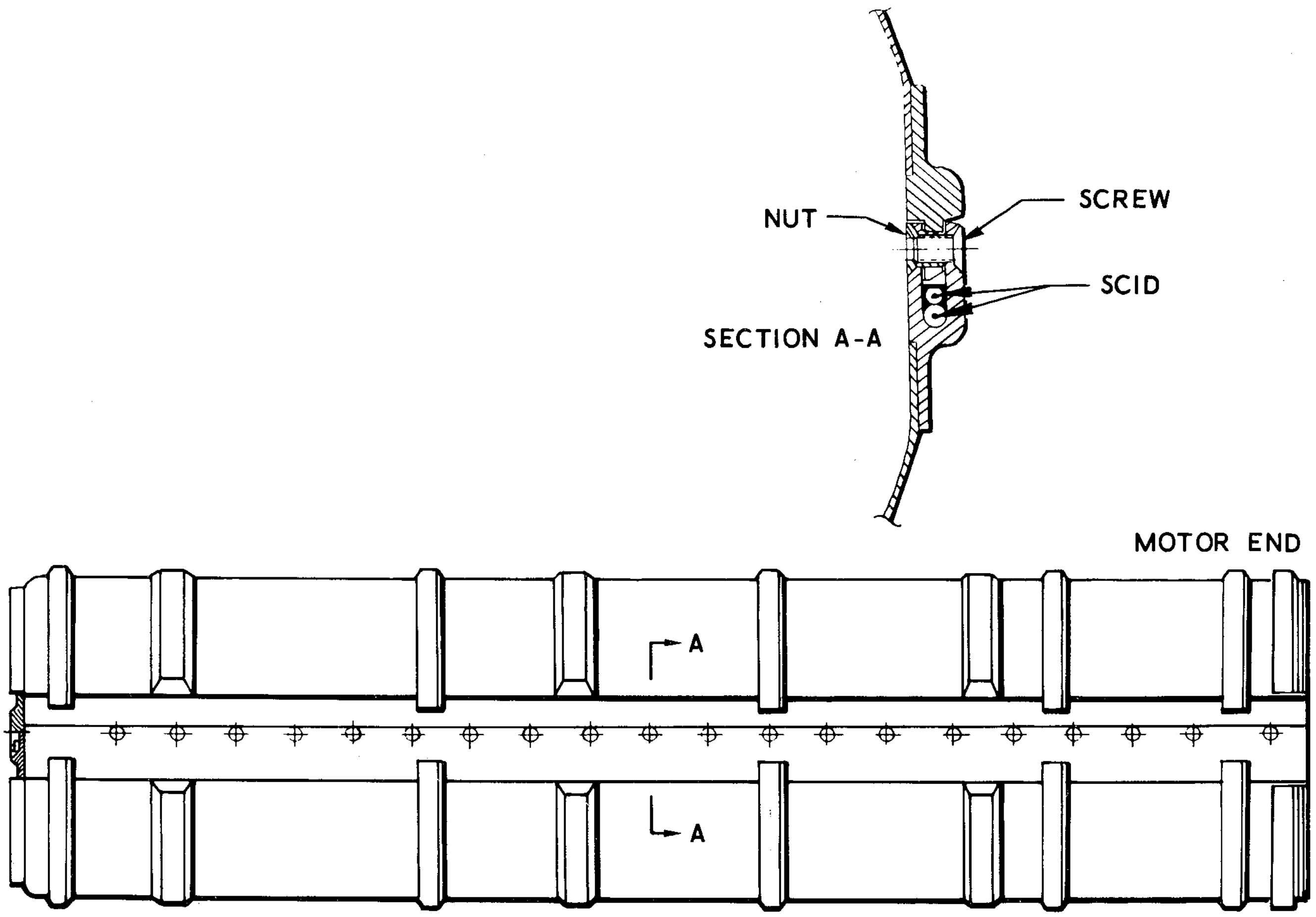

Figure 1. - Metallic canister.

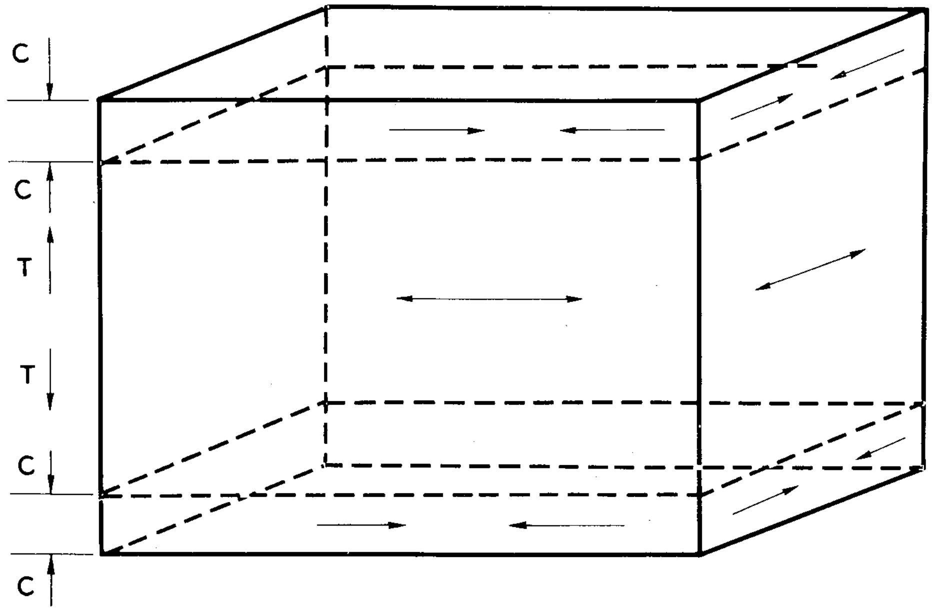

Figure 2. - Idealized stress layers in chemically strengthened glass.

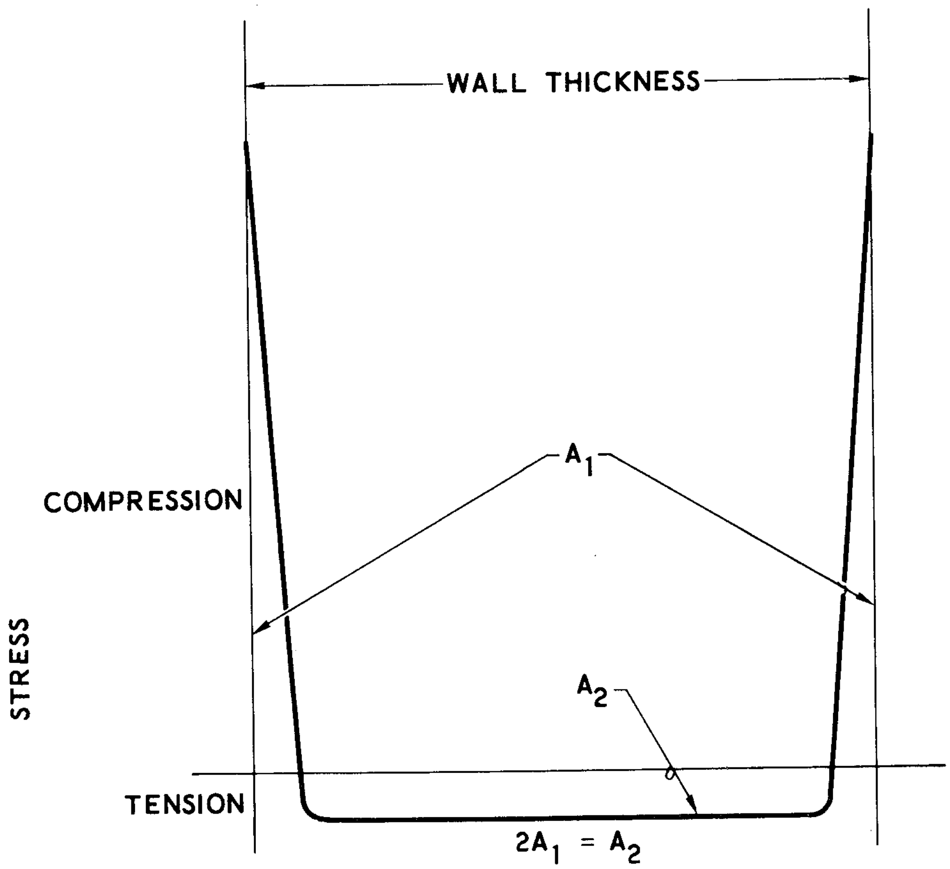

Figure 3. - Residual stress distribution in chemically strengthened glass.

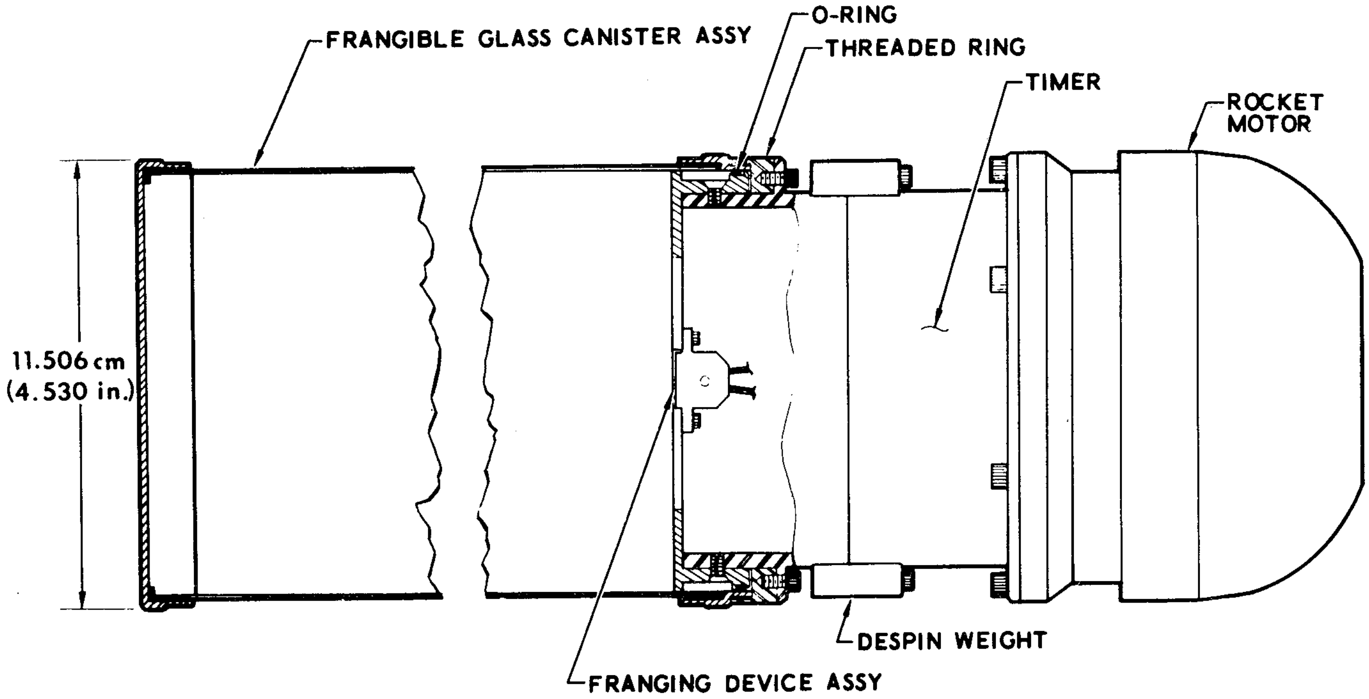

Figure 4. - Glass canister.

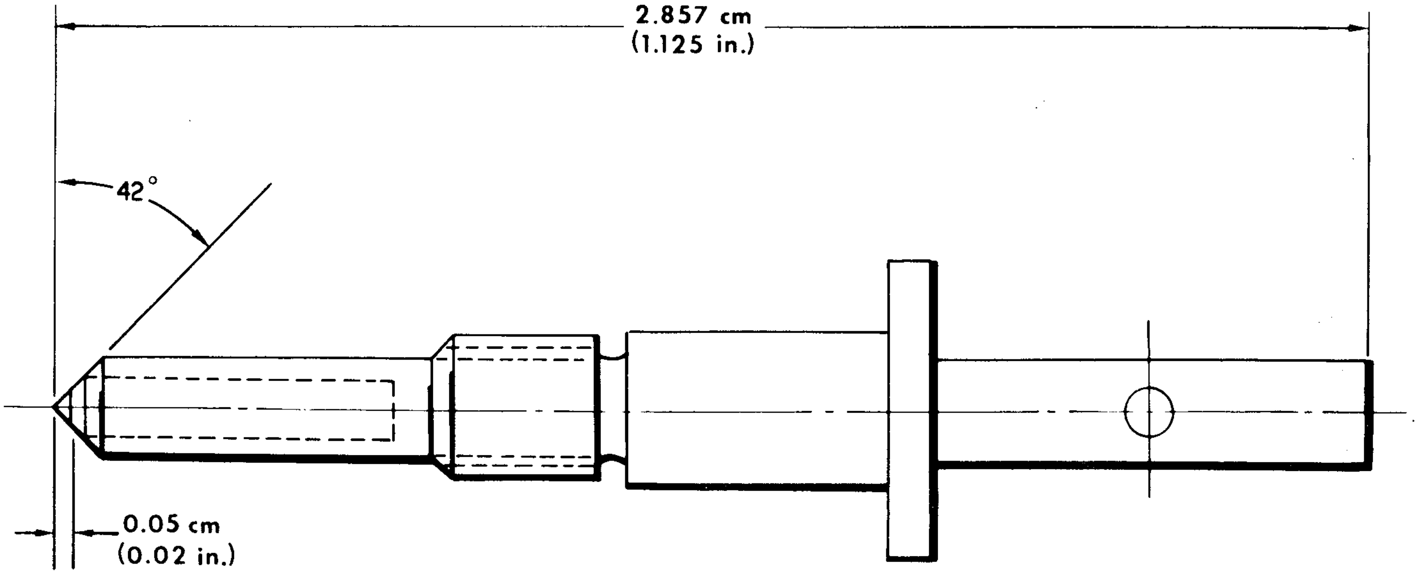

Figure 5. - Diamond-tipped franging pin.

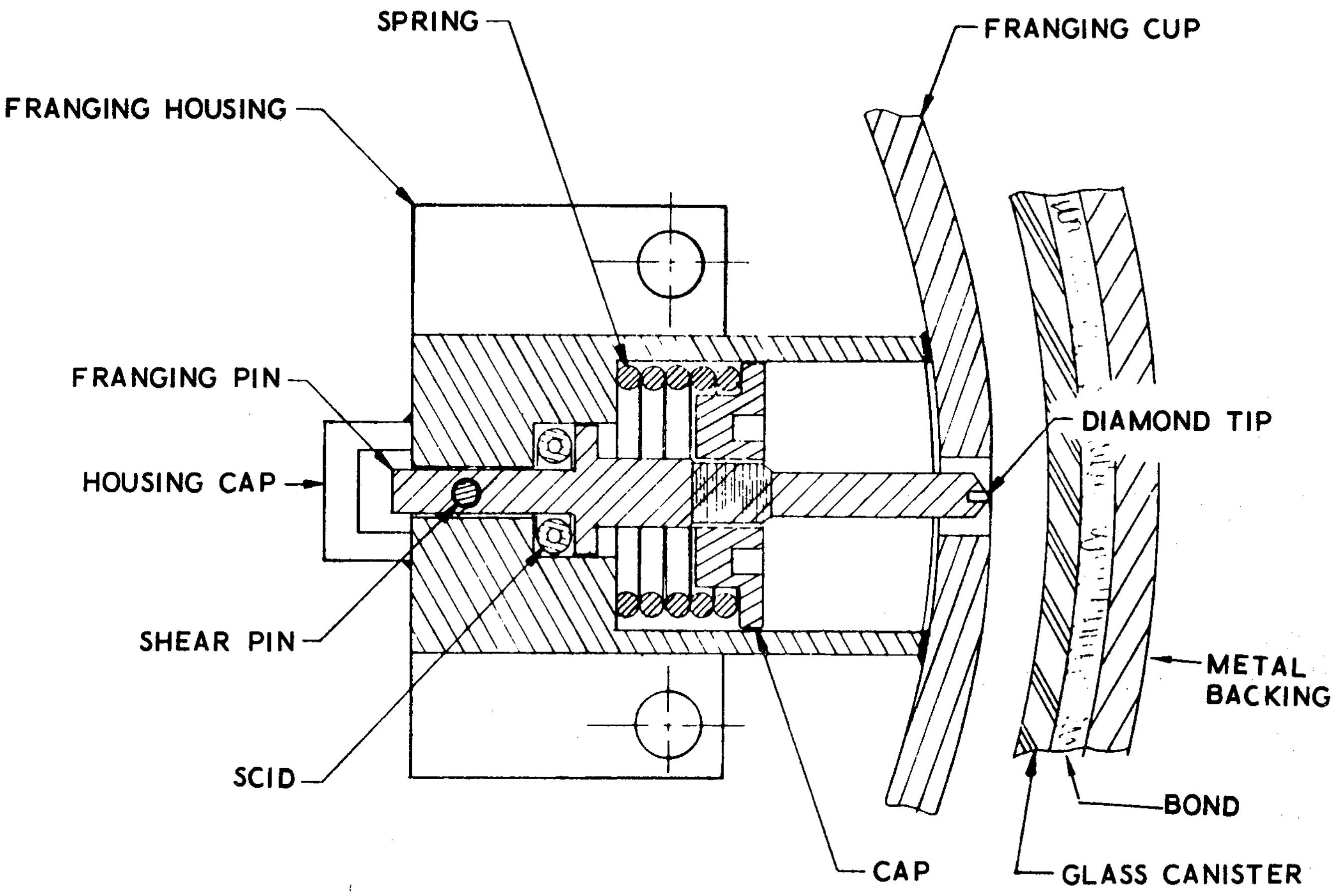

Figure 6. - Pinger installation.

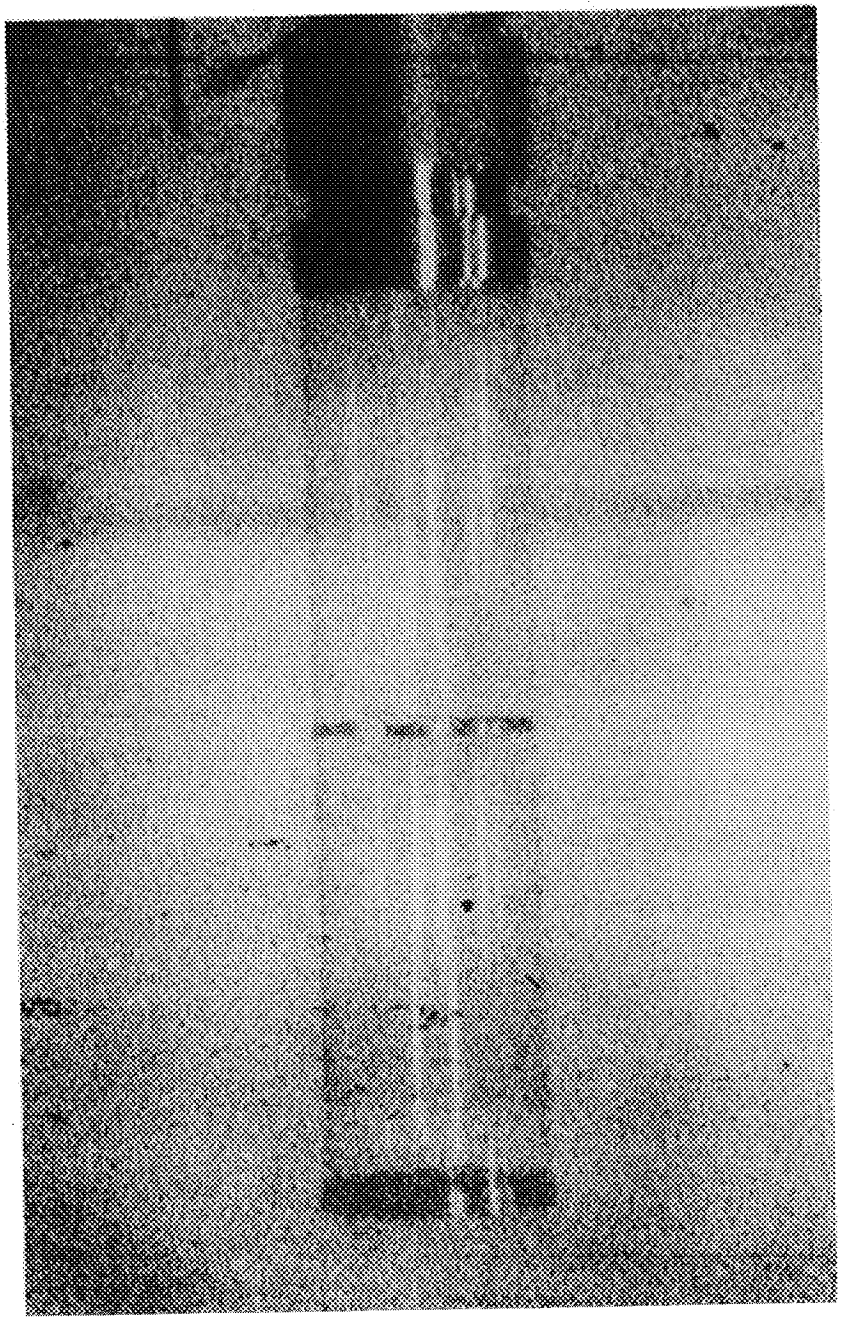

Figure 7. - Glass cylinder before franging.

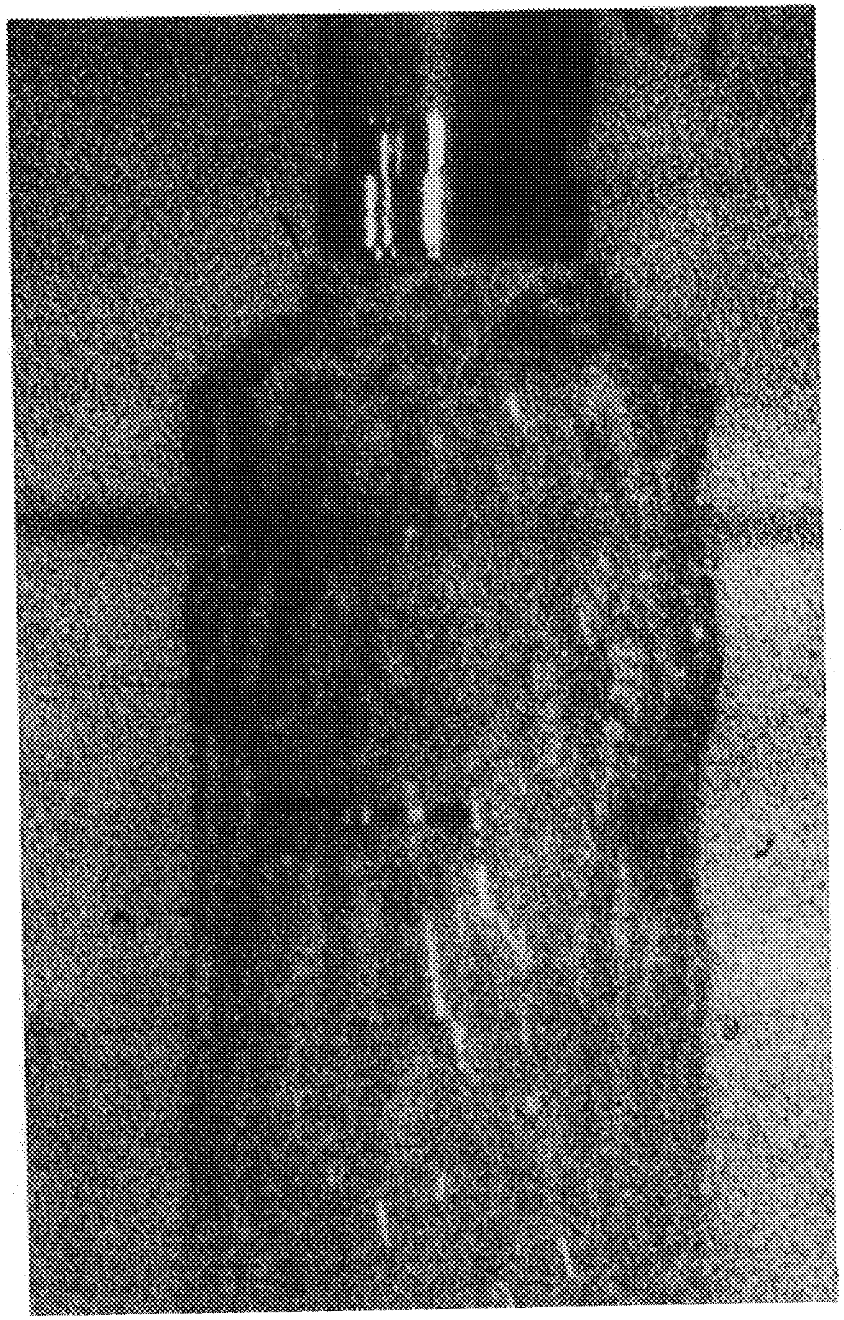

Figure 8. - Glass cylinder undergoing franging.