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APPLIED MANUFACTURING RESEARCH
AND PROCESS DEVELOPMENT
DEPARTMENT 290

REPORT NO. AN61AMR3032
PROPOSED MODIFICATIONS TO LIQUID
OXYGEN BOIL-OFF VALVE
(SERIES D AND E ATLAS MISSILE)

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APPLIED MANUFACTURING RESEARCH
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ABSTRACT

The object of this project was to provide the Atlas missile (D and E Series), with an improved fool-proof liquid oxygen boil-off valve to prevent the present high rate of failures during assembly of the control valve.

In order to understand the corrective measures taken to resolve this problem a detailed description of the principle and functioning of the valve is provided at the commencement of the discussion under "Development". An assembly drawing of the valve is also shown in Fig. 1.

A thorough investigation of the problem disclosed that friction was causing plating break-down of the valve plunger which, combined with reduced pull-power caused failure of the solenoid. The experimental portion of this investigation involving plating and testing was conducted at both the Astronautics and outside vendor's facilities.

The tests performed on six sets of solenoid plungers were as follows: (a) Heating the solenoid valve by energizing both solenoids for $30 \pm {}^{10}_{0}$ minutes and then cycling the valve and recording the required voltage to actuate the solenoids. (b) Cooling the solenoid valve by packing dry ice in a box holding the cycling at 26 psig inlet pressure every two minute- for two hours. Leakage was checked during cycling. (c) Static testing the solenoids for lifting a one and five pound weight. (d) Examination of plungers after each test for wear patterns.

The six sets of solenoid plungers tested were plated or finished with the following materials: (a) Porous chrome with dry film lubricant; (b) Teflon (sprayed as a Teflon suspension and then baked at 580°F ± 10°F in the oven); (c) Hard chrome plating; (d) Electroformed hard chrome; (e) Chem-Nickel plating.

Results of the tests were as follows:

(a) After heating the boil-off valve assembly the solenoids required 25 to 30 volts for actuation. This did not meet the specification which requires the solenoids to actuate with a minimum of 24 volts.

(b) The valve performed within specification requirements during the cooling stage of the test. The solenoids required less voltage and the plungers showed less wear than during the heating portion of the test. The leakage measured during this test increased as new sets of plungers were installed. This increase in leakage had no relation to the plating of the plunger but was caused by increasing wear on the poppet seat.

(c) During the static lift test the solenoids lifted the one pound weight but failed to lift the five pound weight over the required distance of poppet travel until the poppet travel was shortened, indicating that solenoid "A" was barely meeting specification requirements.

(d) Examination of the plungers showed electroformed hard chrome to be the best metal finish for resisting wear, Teflon finish was next best.

(e) All sets of plungers after being cycled 90 times showed signs of wear at the locking surfaces, but not enough to be considered damaging.

It is concluded, friction tests revealed that only those plungers with plated surfaces and coated with Microseal lubricant were able to pass in accordance with section 4.5 of GD/A Spec. 0-75045.

The Value Analysis states, "The corrective action outlined in this report will attain large savings in man hours and rejected parts involving considerable dollar savings. The overall missile performance will be automatically improved".

Report No. AN61AMR3032, Proposed Modifications to Liquid Oxygen Boil-Off Valve, (Series D and E Atlas Missile). [redacted]

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ACKNOWLEDGEMENTS

Acknowledgement is extended to the Allied Research and Engineering Co., Hollywood, 38, California, for their assistance in electroforming operations at no charge to GD/Astronautics.

Acknowledgement is also extended to the following personnel for their assistance and cooperation.

Department 290-2

E. Shiwanov - Chemistry Section

Technical Services Department 290-3

W. A. Nichols - Engineering Writer

T. Rodriguez - Art Work

TITLE

PROPOSED MODIFICATIONS TO LIQUID OXYGEN BOIL-OFF VALVE (SERIES D AND E ATLAS MISSILE)

OBJECT

To provide the Atlas Missile, D and E series, with a fool-proof boil-off valve to prevent the present high rate of failures during assembly of the control valve.

INTRODUCTION

The Liquid Oxygen Boil-Off (Relief and Shutter Valve - See Fig. 1) is used to relieve excess LO_2 Tank pressure resulting from the boiling of Liquid Oxygen during propellant loading. In addition, it is used to relieve Liquid Oxygen Tank pressure during transportation and as a standby in the event of a low differential pressure across the intermediate bulkhead. At all times the valve is closed.

Between May 1960 and May 1961, seventy-two failures occurred during assembly of the control valve in the D Series Missile alone, in the factory, at one of the bases, and during the final check out. At least two field failures also occurred during this time.

A thorough investigation disclosed that friction was causing plating break-down of the plunger, which, when combined with reduced pull-power caused failure of the solenoid.

CONCLUSIONS

(a) Friction and corrosion patterns have caused breakdown of the plunger plating with consequent failure of the LO_2 Boil-Off Valve performance.

(b) Friction tests revealed that only those plungers with plated surfaces and coated with Microseal lubricant were acceptable in accordance with section 4.5 of GD/A Spec. 0-75045.

RECOMMENDATIONS

1. The entire surface of the plunger including the ends should be electroformed with hard chrome and coated with Microseal dry film lubricant per GD/A Spec. No. 0-75045.

2. The solenoid "A" should operate at 28 volts instead of 24 volts as per *EOP 310.10.

*Equipment Operating Procedure

DEVELOPMENT

In order to understand the corrective measures taken to resolve this problem, one should be familiar with the LO_2 Boil-Off Valve mechanism and functioning as described in the following paragraphs.

The Liquid Oxygen when loaded must be dense enough to give the expected missile performance, therefore it is necessary that the ullage pressure during LO_2 topping be maintained as low as possible without endangering the structural integrity of the missile. For operational "D" and "E" series missiles, the minimum pressure is 1.2 psig for structural safety under the worst conditions such as maximum launcher and nose cone misalignement, maximum wind velocity, and the worst climatic conditions. Allowing a margin to prevent interference with the ground support emergency equipment, a reseat pressure of 2.0 psig is used for the Boil-Off Valve.

In addition to maintaining a low ullage pressure during topping, the valve must be capable of handling the high flow rates of gaseous oxygen which are formed during chilldown and rapid load. Studies have shown that in order for the valve to maintain satisfactory pressure level during these periods of tanking, it must be able to flow 15 pounds per second of gaseous oxygen at - 290°F and approximately 4 psig. Problems encountered on earlier valves indicated the necessity for a fail safe type operation, that is, if the electrical power should fail, it is important that pressure would remain in the Liquid Oxygen Tank to provide structural integrity. In addition to these requirements which are necessary for the functional operation of the missile system, other factors were taken into consideration in the valve design, for example; ease of manufacture and maintainance of the unit.

The requisites for Boil-Off Valve design may be summarized as follows:

1. Reseat pressure of 2.0 - 3.5 psig

2. Flow capacity of 15 pounds per second of gaseous oxygen at - 290°F and 4 psig tank pressure

3. Fail safe operation

4. Ease of manufacture and ease of maintainance

To satisfy the required design criteria the valve (Fig. 1) was chosen. The operation of this unit is similar to a common spring-loaded poppet valve except the spring load is provided by two concentric bellows. These bellows are welded to steel plates at both the top and bottom to form a sealed chamber between the bellows. A "spider" member containing a threaded hub is fastened in the center of the valve and a threaded column/cone member is screwed into the hub. The periphery of the cone contains a Teflon seal which matches with the lower surface of the bellows chamber and forms the sealing surface. The entire valve is mounted on the forward bulkhead access door.

The valve operates under two conditions:

1. Relief position, during which the valve has the capacity to relieve pressure above 2.0 - 3.5 psig

2. The shut-off position during which the valve will remain closed regardless of tank pressure

The valve position is selected by a three-way, two position solenoid valve mounted on the door. For the Boil-Off Valve to reach the relief position, solenoid "B" is energized, unlocking the poppet which is then spring-driven to the forward position, thereby sealing off the line from the tank, allowing the bellows chamber to vent to atmosphere. As the tank pressure increases, the force exerted by the pressure acting over the exposed area overcomes the preload force of the bellows and the bellows are compressed further, allowing gas to vent out of the tank. The cracking pressure can be adjusted by advancing or extending the column/cone assembly in the threaded hub, which in turn increases or decreases the bellows reaction load.

In order for the valve to reach the shut-off position, solenoid "A" is energized drawing the poppet back. Solenoid "B" is then spring-driven down, latching the poppet in position. When in the shut-off position, the poppet closes off the vent and allows the tank and bellows chamber pressures to equalize. This pressure balance, plus an area difference and the bellows pre-load, provide the force necessary to maintain the valve in the shut-off position. With the exception of Liquid Oxygen Tanking, emergency conditions and checkout, the Boil-Off Valve is always in the shut-off position.

During transportation and standby the Liquid Oxygen and Fuel tank pressure are nominally 6 psig and 12 psig respectively. In the event of a condition which either raises Liquid Oxygen Tank pressure or lowers Fuel Tank pressure, and thereby produces an emergency differential condition ($.9 \pm .4$ psid across the intermediate bulkhead), the differential pressure switch will put the Boil-Off Valve in the relief position which will vent Liquid Oxygen Tank pressure to 2.0 - 3.5 psig. In addition to opening the valve, the switch will also sound a warning horn.

During propellant loading, several safety devices are employed to prevent missile failure. In the event LO_2 tank pressure drops, the LO_2 low pressure switch will place the Ground Pressurization System in emergency at $1.65 \pm {}^{.15}_{0}$ psig. It should be noted that this level is substantially above the pressure (1.2 psig) required for structural integrity during the worst launch conditions. If pressure should increase during Liquid Oxygen loading, the LO_2 high pressure switch will stop the loading cycle when the LO_2 tank pressure reaches 17 psig.

Review of Boil-Off Valve malfunction reports have indicated the most prevalent problem with this unit is low reseat pressure. It must be emphasized that, even under the worst conditions, the missile tanks are not in danger until LO_2 tank pressure drops below 1.2 psig, therefore, the valve reseat of 2.0 psig gives an ample margin of safety. It should also be noted that in case of electrical power failure, the valve will remain in the position which it was last placed. If in the relief position, it will continue to maintain pressure above 2.0 psig; if in the shut-off position, it will hold tank pressure to any level.

The experimental portion of this investigation involving plating and testing was conducted at the Astronautics facility, and at outside vendor's facilities.

The tests performed on six sets of solenoid plungers were as follows:

(a) Heating the solenoid valve by energizing both solenoids for $30 \pm {}^{10}_{0}$ minutes and then cycling the valve and recording the required voltage to actuate the solenoids. (See Fig's. 2 & 3).

(b) Cooling the solenoid valve by packing dry ice (see Fig's. 4 & 5) in a box holding the cycling at 26 psig inlet pressure every two minutes for two hours. Leakage was checked during cycling.

(c) Static testing the solenoids for lifting a one and five lb. weight. (See Fig. 6)

(d) Examination of plungers after each test for wear patterns.

The six sets of solenoid plungers tested were plated or finished with the following materials:

(a) Porous chrome with dry film lubricant

(b) Teflon (sprayed as a Teflon suspension and then baked at 580°F ± 10°F in the oven)

(c) Hard chrome plating

(d) Electroformed hard chrome

(e) Chem-Nickel plating

RESULTS

The results of the tests outlined under "Development", and performed in the Gas-Flow Laboratory at the Astronautics facility were as follows:

(a) After heating the Boil-off valve assembly the solenoids required 25 to 30 volts for actuation. This did not meet the specification which requires the solenoids actuate with a minimum of 24 volts.

(b) The valve performed within specification during the cooling stage of the test. The solenoids required less voltage and the plungers showed less wear than during the heating portion of the test. The leakage measured during this test increased as new sets of plungers were installed. This increase in leakage had no relation to the plating of the plunger but was caused by increasing wear on the poppet seat.

(c) During the static lift test the solenoids lifted the one pound weight (see Fig. 6) but failed to lift the five pound weight over the required distance of poppet travel. The solenoid lifted the five pound weight when the poppet travel was shortened. This portion of the test showed that solenoid "A" was barely meeting the specification requirements.

(d) The examination of the plungers showed electroformed hard chrome to be the best metal finish for resisting wear, (see Fig. 7). Teflon finish was next best although showing signs of pealing.

(e) The plunger with porous chrome plating plus dry lubricant film showed the dry film lubricant wore off at the bearing surface. The plunger with a chem-nickel plated finish showed signs of wear.

(f) All sets of plungers, after being cycled 90 times, showed sign of wear at the locking surfaces but not enough to be considered damaging.

VALUE ANALYSIS

This task was primarily undertaken to prevent high failure rate during assembly of the control valve of the Atlas missile (D and E series) LO_2 boil-off valve.

The corrective action outlined in this report will attain large savings in man hours and rejected parts, involving considerable dollar savings. The overall missile performance will be automatically improved.

SUMMARY

The foregoing experimental data have shown that significant changes in the mechanics of the LO_2 Boil-Off Valve occur as a result of corrective action taken in the development of this project.

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6. Space Lubrication - Microseal Products Co., 1961.

FIGURE INDEX

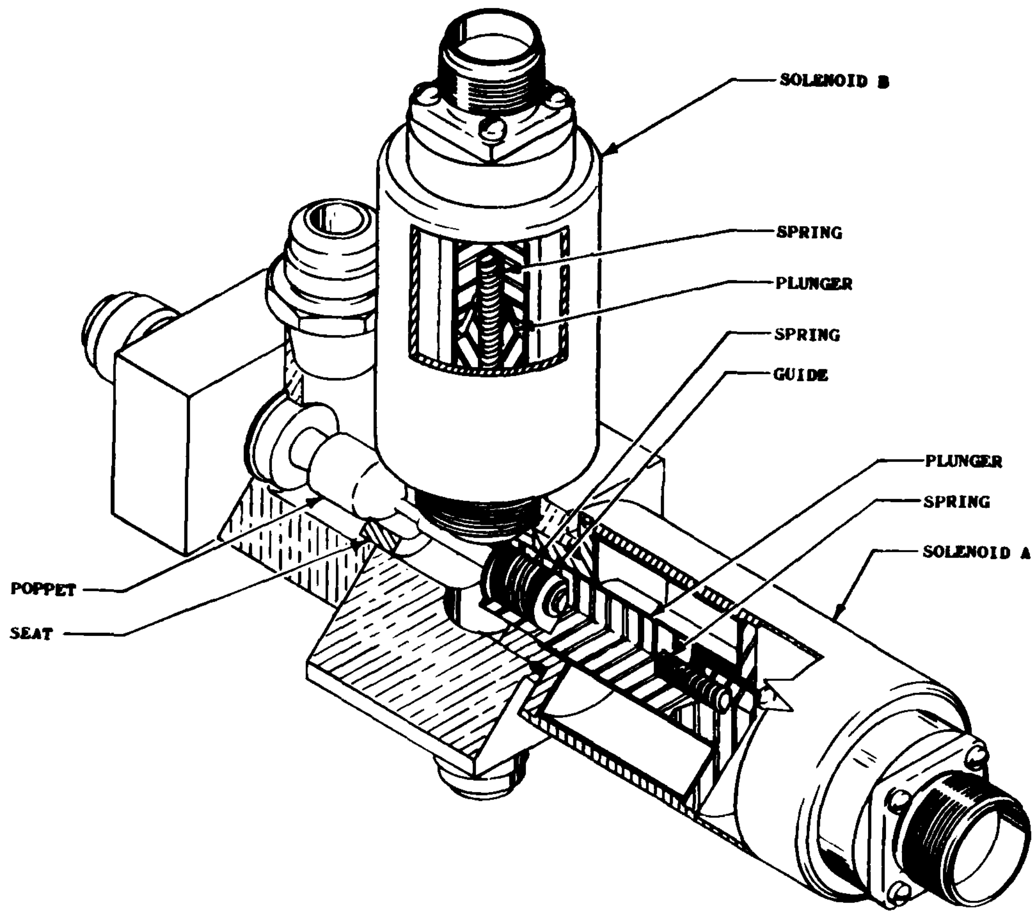

FIGURE 1. ASSEMBLY OF LIQUID OXYGEN BOIL-OFF VALVE

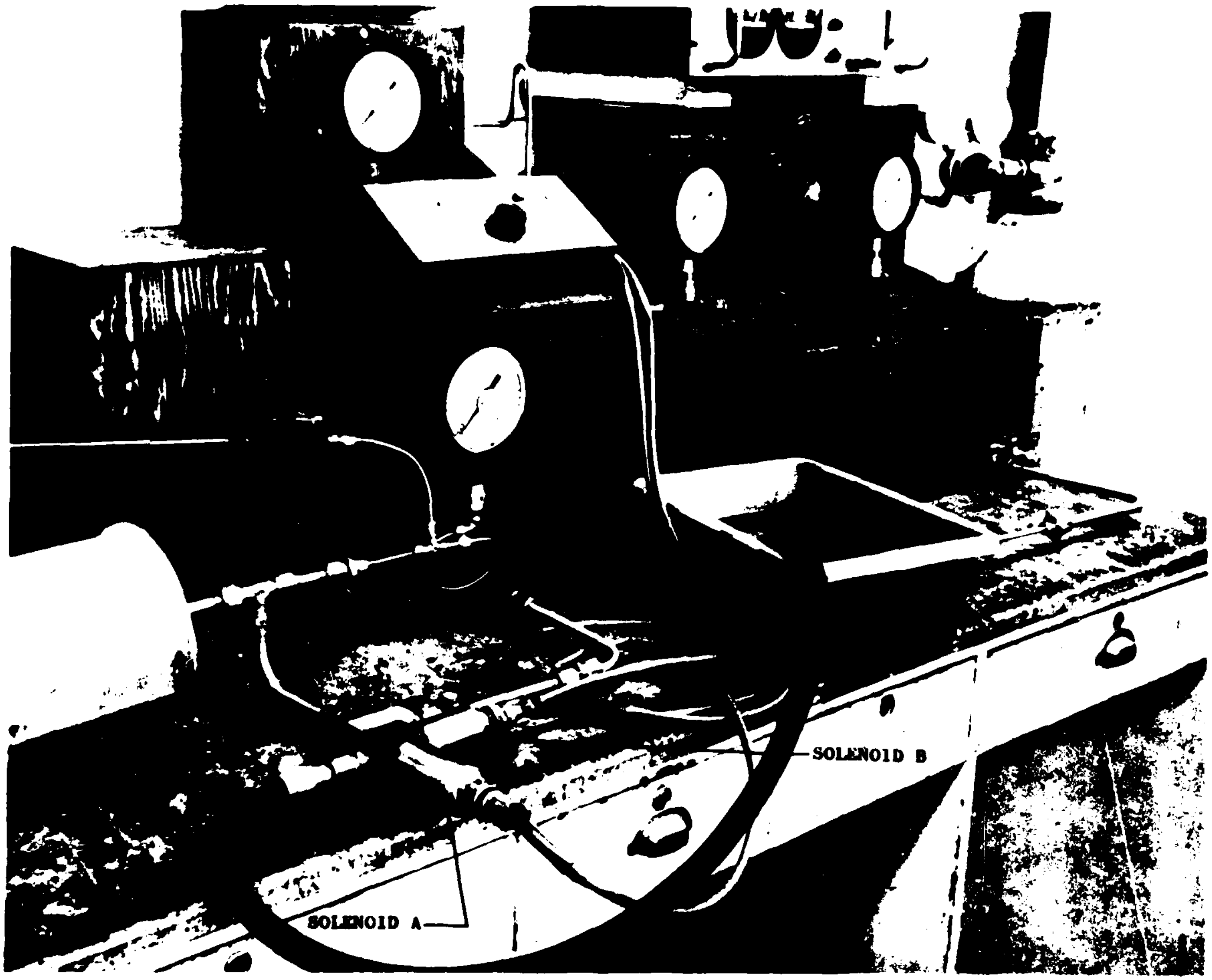

FIGURE NO. 2 STATIC CYCLING TEST APPARATUS
SOLENOID "A" AND "B" ARE ENERGIZED (NO INLET PRESSURE)

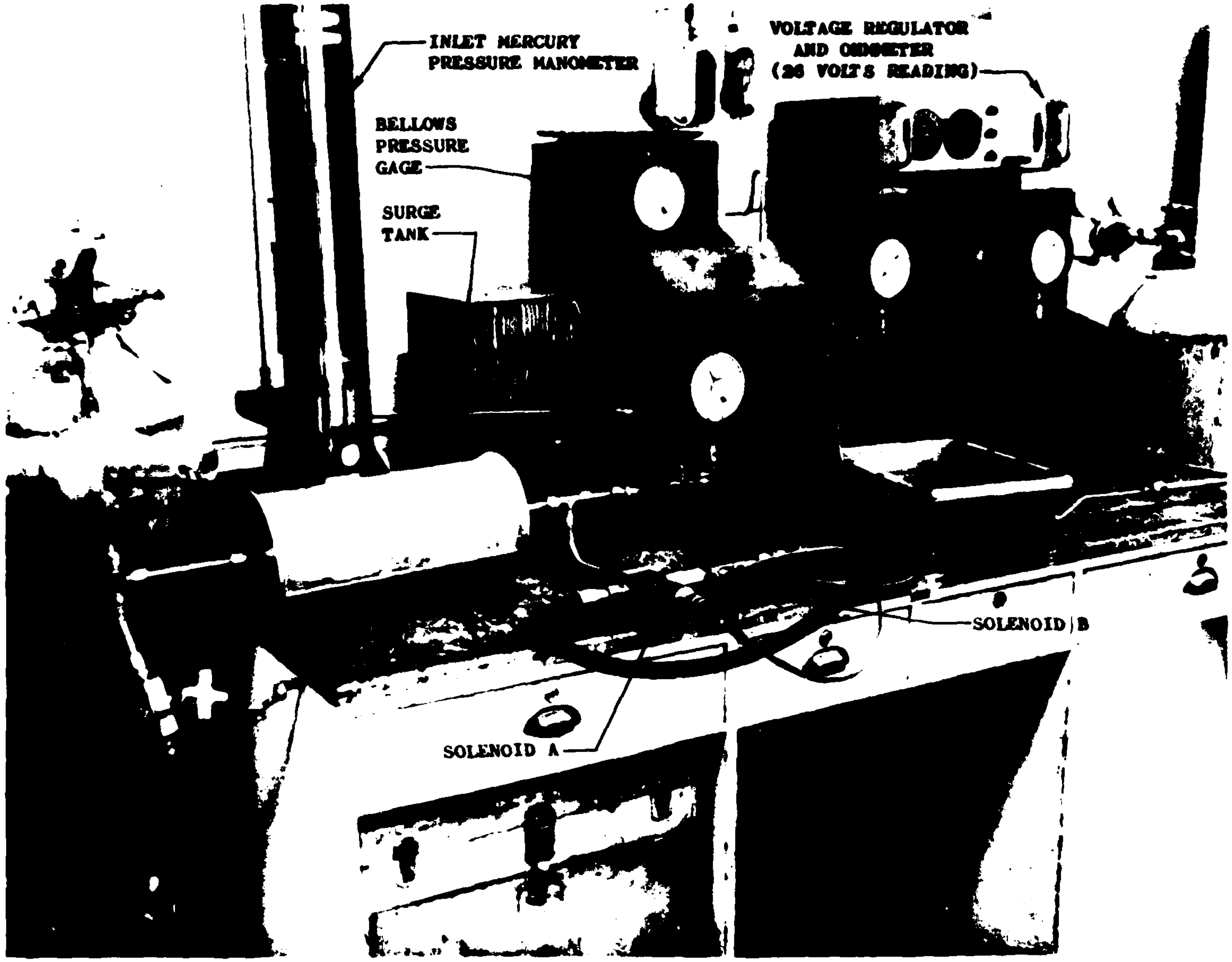

FIGURE NO. 3 STATIC CYCLING TEST APPARATUS
SOLENOID "A" IS ENERGIZED (BELLOWS ARE PRESSURIZED)

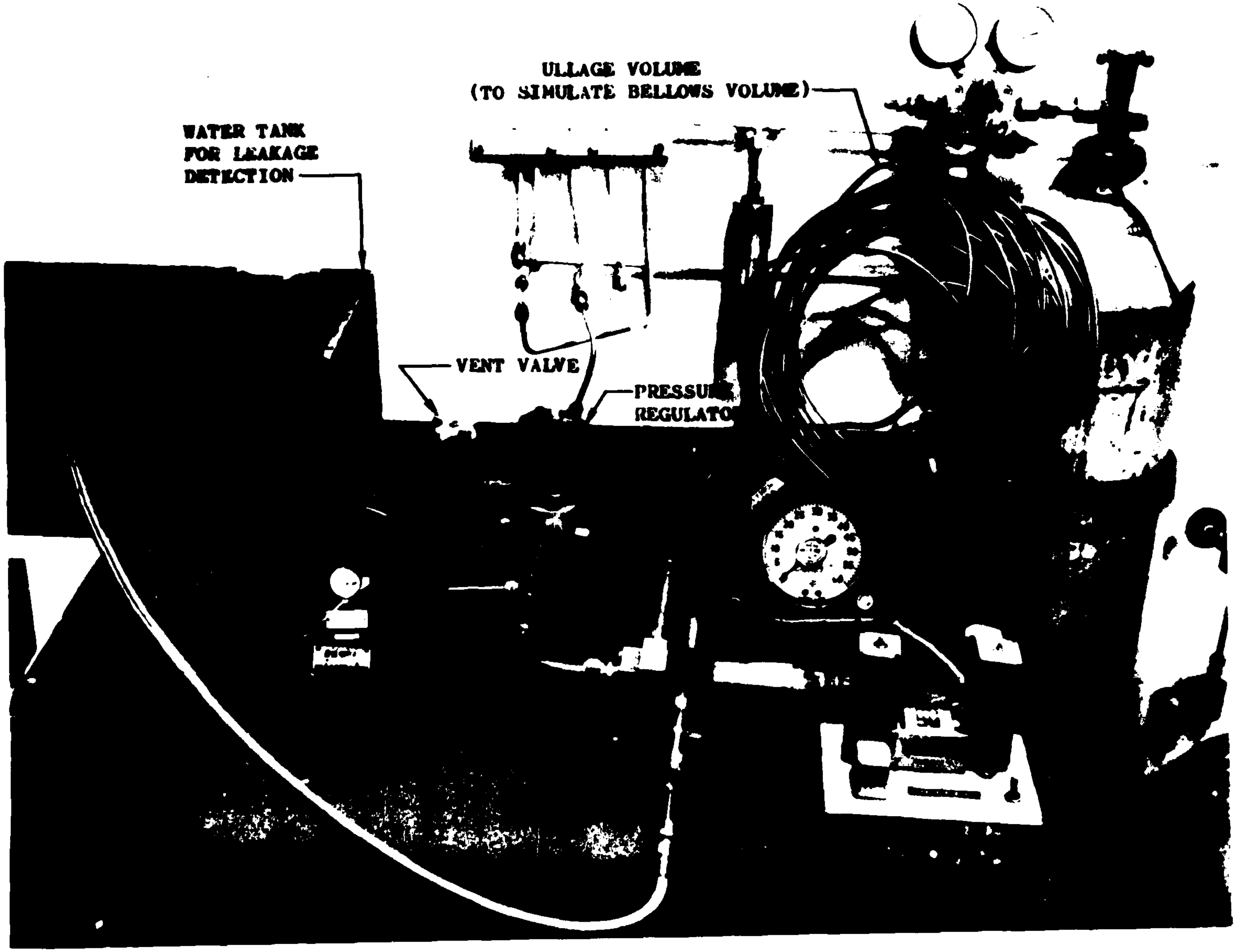

FIGURE NO. 4 CRYOGENIC CYCLING TEST APPARATUS
(WITHOUT DRY ICE PACKING)

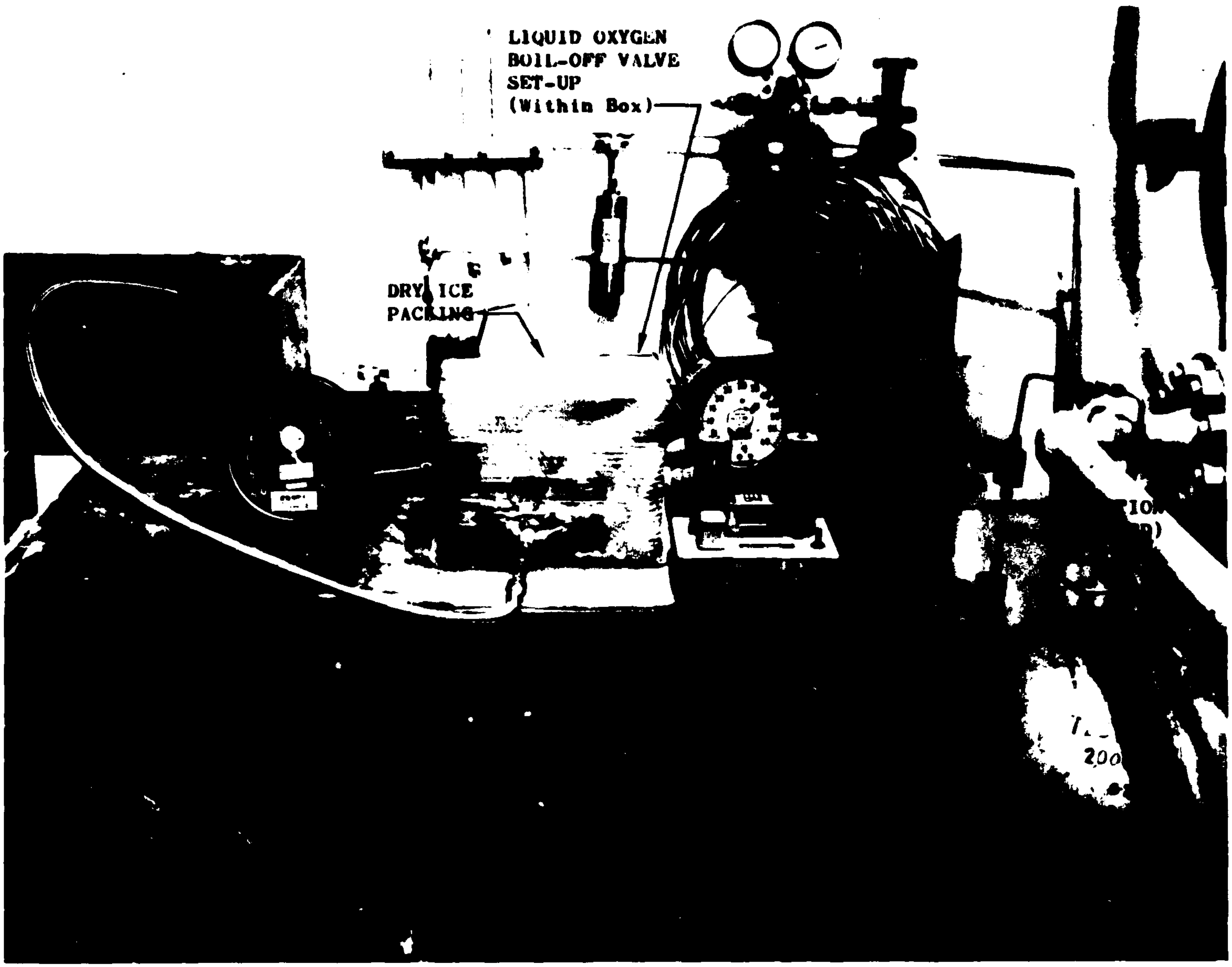

FIGURE NO. 5 CRYOGENIC CYCLING TEST APPARATUS
(With Dry Ice Packing)

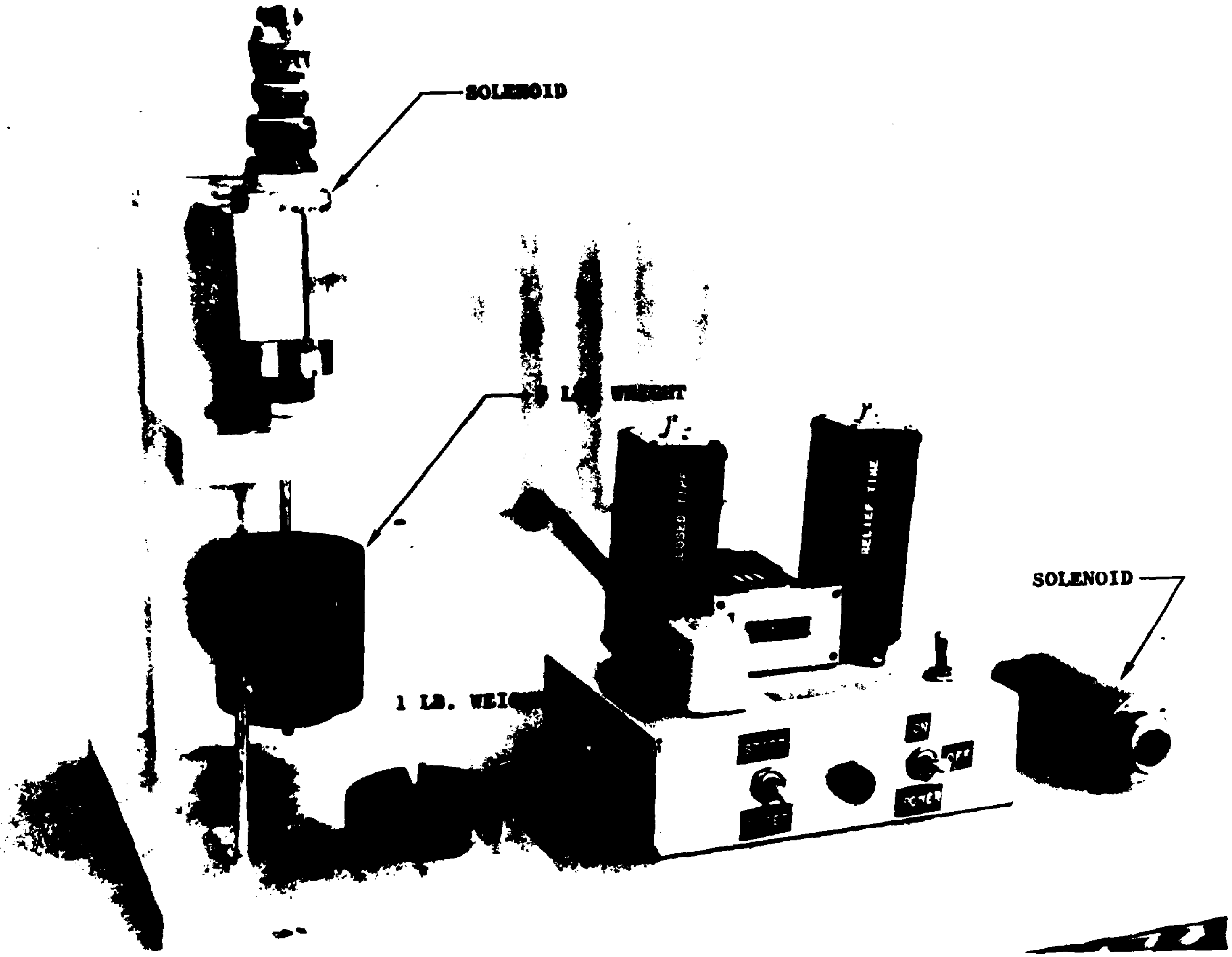

FIGURE NO. 6 CYCLING BOX, STATIC LIFT TEST

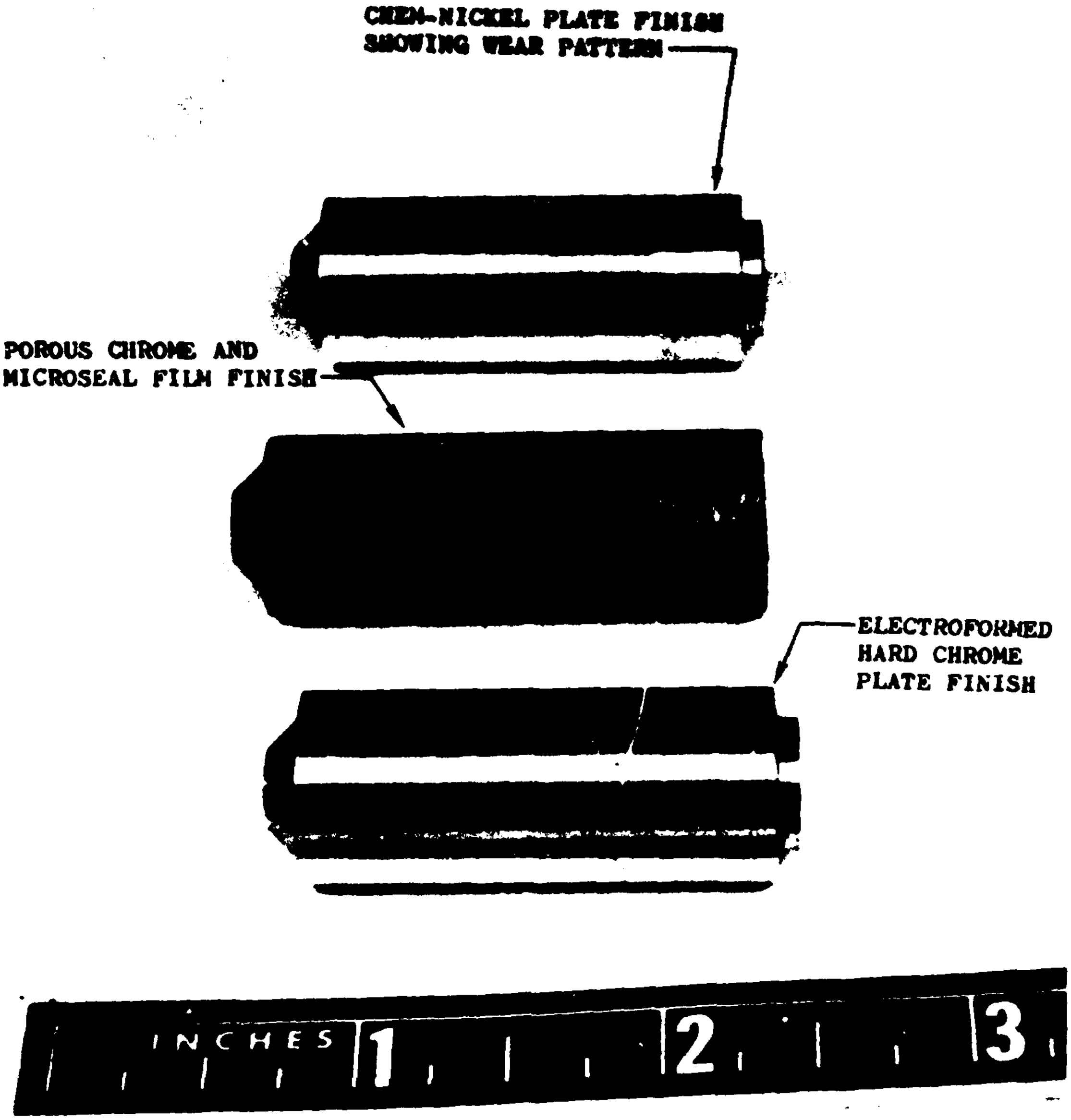

FIGURE NO. 7 LIQUID OXYGEN BOIL-OFF VALVE PLUNGERS