

AD A103947

AFWAL-TR-81-2031



LOW MAINTENANCE HYDRAULIC ACCUMULATOR

BOEING MILITARY AIRPLANE COMPANY

JUNE 1981

FINAL REPORT FOR PERIOD AUGUST 1976 - DECEMBER 1980

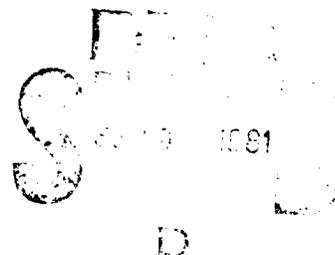
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

AERO PROPULSION LABORATORY

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



DTIC FILE COPY

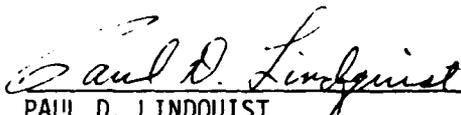
81 9 09 091

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.



PAUL D. LINDQUIST
Project Engineer
Power Systems Branch
Aerospace Power Division



RICHARD D. FRANKLIN, MAJOR, USAF
Chief, Power Systems Branch
Aerospace Power Division
Aero Propulsion Laboratory

FOR THE COMMANDER



JAMES D. REAMS
Chief, Aerospace Power Division
Aero Propulsion Laboratory

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/PCOS, W-PAFB, OH 45433 to help us maintain a current mailing list".

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-2031	2. GOVT ACCESSION NO. AD-A103	3. RECIPIENT'S CATALOG NUMBER 947
4. TITLE (and Subtitle) LOW MAINTENANCE HYDRAULIC ACCUMULATOR	5. TYPE OF REPORT & PERIOD COVERED Final Report, Aug 76 - Dec 80	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) E. C. Wagner W. E. Willard	8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-2088	
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Boeing Military Airplane Company	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 3145/38/23	
11. CONTROLLING OFFICE NAME AND ADDRESS Aero Propulsion Laboratory (AFWAL/POOS) Air Force Wright Aeronautical Laboratories Wright-Patterson AFB, Ohio 45433	12. REPORT DATE June 1981	
	13. NUMBER OF PAGES 65	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approval for Public Release, Distribution Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Hydraulic System Accumulator Metal Bellows		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of a program to develop a low maintenance accumulator, compatible with current MS envelopes and competitive in cost with conventional accumulators. The purpose of the program was to select and develop a metal bellows configuration/concept to replace the conventional moving piston and seal of conventional accumulators. The selected bellows is of welded construction and welded in place to allow bellows movement identical to piston movement. The accumulator housing is of welded construction to eliminate all possible leak points. The program goal was to develop an		

cont
20

accumulator to provide a ten year unserviced life. Test results indicate an accumulator design is possible to achieve a service life of 6 to 10 years based on installation on an F-16 aircraft.

PREFACE

This final report was submitted by The Boeing Military Airplane Company, under Contract F-33615-76-C-2088. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, under Project Number 3145 and Work Unit Number with Paul D. Lindquist, AFWAL/POOS, as Project Engineer.

The report covers work conducted between August 1976 and December 1980. The report was released by the author. The program was conducted with Mr. E. C. Wagner and W. E. Willard as Principal Investigators under the direction of Mr. J. D. Dudley and Mr. G. W. Albright, Program Manager and Chief of Secondary Power and Fuel Systems Staff, respectively.

The authors wish to acknowledge the assistance of Messrs. J. Horsely and M. Oldfather of The Boeing Military Airplane Company and Paul Campbell and J. Huffman, Metal Bellows Corporation, Chatsworth, California.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

DTIC
ELECTED
SEP 9 1981
S D
D

TABLE OF CONTENTS

	<u>PAGE</u>
1.0 INTRODUCTION	10
2.0 SUMMARY	11
3.0 DESIGN OBJECTIVES	12
4.0 CONCEPT TRADE STUDIES	13
4.1 Bellows Design Evaluation	13
4.2 Bellows Selection	13
4.3 Bellows Test Fixture	13
4.4 Bellows Test Requirement	14
5.0 BELLOWS TESTING	15
5.1 Preliminary Testing	15
5.1.1 MBC Capsule Testing	15
5.1.2 Sealol Capsule Testing	15
5.2 Additional Preliminary Testing (Capsule Redesign)	16
5.3 Preliminary Testing Conclusions	17
6.0 PROGRAM REVIEW	18
7.0 ADVANCED DESIGN TESTING	19
7.1 Advanced Design Bellows Testing	19
7.1.1 Advanced Design Bellows Testing	19
7.1.2 Endurance Testing	20
7.1.3 Vibration Testing	20
8.0 ACCUMULATOR DEVELOPMENT	21
8.1 Design Considerations	21
8.2 Accumulator Design Requirements	21
8.3 Accumulator Test Requirements	22
8.4 Accumulator Design	22

TABLE OF CONTENTS (Continued)

	<u>PAGE</u>
8.5 Accumulator Tests	22
8.5.1 Housing Tests (Appendix B)	22
8.5.2 Proof Pressure	22
8.5.3 Burst	23
8.5.4 Impulse	23
9.0 CONCLUSIONS AND RECOMMENDATIONS	24
9.1 Conclusions	24
9.2 Recommendations	24
Appendix A	42
Appendix B	46
Appendix C	52

LIST OF FIGURES

<u>FIGURE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1	METAL BELLOW DIAPHRAGM CONFIGURATION	25
2	BELLOWS NESTING CHARACTERISTICS	26
3	COINED BEAD BELLOWS CONFIGURATION	27
4	BELLOWS TEST FIXTURE	28
5	METAL BELLOWS CAPSULE TEST SET-UP	29
5a	METAL BELLOWS CAPSULE TEST SET-UP SCHEMATIC	30
6	METAL BELLOWS CAPSULE TEST FIXTURES	31
7	METAL BELLOWS CAPSULE TEST INSTRUMENTATION	32
8	METAL BELLOWS CORPORATION TEST CAPSULE	33
9	SEALOL INC. TEST CAPSULE	34
10	METAL BELLOWS CORP. TEST SET-UP	35
10a	METAL BELLOWS CORP. TEST SET-UP	36
11	ADVANCED DESIGN METAL BELLOWS ACCUMULATOR CONCEPT	37
12	PROTOTYPE ACCUMULATOR DESIGN	38
13	BELLOWS ACCUMULATOR, 100 CUBIC INCH	39

LIST OF TABLES

<u>TABLE NO.</u>		<u>PAGE</u>
1	BELLOWS TEST INFORMATION	40
2	ACCUMULATOR TEST SCHEDULE	41

This document presents the results of the Low Maintenance Hydraulic Accumulator research program conducted under contract to the Air Force Aero Propulsion Laboratory (AFAPL) by The Boeing Military Airplane Company.

The program objective consisted of analysis and evaluation of bellows shapes and characteristics, accumulator design studies and establishment of a prototype design for interchangeability with existing accumulators.

The program was conducted in two phases. The initial phase consisted of evaluation and testing of metal bellows configurations and the design of an accumulator. The final phase included testing and evaluation of a 100 cubic inch accumulator housing.

Present day aircraft in military and commercial service are using accumulators in hydraulic systems for a variety of purposes including energy storage, surge damping, hydraulic pump size reduction and to provide increased flow and pressure response to actuation subsystems. The number of accumulator applications has, however, been held to a minimum due to the demonstrated unreliability of these devices and the attendant high maintenance costs. The basic problem of existing accumulators can be generalized as the inability to retain the gas precharge for a reasonable length of time.

Recent advancements in metallic bellows technology including improved fatigue life, new welding techniques and improved fabrication methods have led to several successful applications in the aerospace industry. Current studies indicate that use of a metal bellows as a gas-oil separator has potential for providing a reliable and consequently low maintenance cost accumulator. Use of an all-welded construction and hermetically sealed gas chamber will eliminate periodic accumulator precharge maintenance.

Experience obtained in development of a metal bellows reservoir for the Boeing Supersonic Transport (SST) and a follow-on program at Boeing Military Airplane Company to develop a high pressure hydraulic accumulator provided background for this program.

This report presents the results of a program to develop a low maintenance accumulator using a metal bellows instead of a piston or bladder as the gas-oil separator. The purpose of the program was to develop an accumulator with a substantial increase in reliability and maintenance over existing conventional accumulators. Various concepts were evaluated for their ability to meet design objectives. Development of an appropriate metal bellows was considered to be the critical task.

A bellows manufactured by the Metal Bellows Corporation (MBC), Chatsworth, California, was selected after a series of evaluation tests on candidate metal bellows diaphragm configurations. Additional testing was conducted on MBC capsules to prove design capability prior to accumulator fabrication. Capsules testing indicated a diaphragm size of 2.97 O.D., 2.12 I.D. and a thickness of 0.004 inches offered the best design concept based on an evaluation of 21 capsules by MBC. Results of the capsule testing showed promise for attaining the accumulator design goal of a ten-year unserviced life, based on F-16 service activity.

Additional effort was expended to design a hermetically sealed (all welded) accumulator compatible with the selected bellows capsule. Designs were in accordance with criteria and requirements established in preceding studies, evaluations and tests. The accumulator was designed to be equivalent in function with existing standard MS accumulators. The final design is a 100 cubic inch accumulator similar to the MS envelope and interchangeable with MS 28797-4. This unit uses a metal bellows as the separator and is hermetically sealed to provide reliability and does not require gages or gas charging equipment. This aspect eliminates all possibility of seal leaks and provides an accumulator insensitive to environmental conditions.

Accumulator testing included housing tests (impulse and burst) and vibration of a full size bellows assembly. All tests were satisfactorily accomplished. Testing was concluded at this point due to time and budget constraints of the program. However, MBC will continue development with their own funds including full scale testing of a 100 cubic inch accumulator. This activity will include proof pressure, bottoming and endurance tests. Additional effort will be required to determine if precharge monitoring is required, based on test results and system utilization aspects.

3.0

DESIGN OBJECTIVES

The design objectives for the metal bellows accumulator were as follows:

- o Envelope
Form, fit and functionally interchangeable with the existing MS accumulator
- o Weight
Competitive with equivalent MS accumulator sizes
- o Environment
Operational over a temperature range of -65°F to +275°F (compatible with a Type II hydraulic system)
- o Maintenance
Zero leakage of fluid or gas precharge (10-year service life - no maintenance is the goal)

Simple precharge pressure monitoring methods
- o Reliability
The goal will be to provide the reliability required to attain full service life without failure
- o Cost
Life cycle costs significantly less than MS accumulator
- o General
Compatible with applicable fluids and meet or exceed existing Military Specifications (except in cases of obvious conflict between design and requirements which are directed specifically to MS cylinder type units)

Design life at least three times that required by Military Specifications for existing accumulators.

4.0 CONCEPT TRADE STUDIES

4.1 Bellows Design Evaluation

Technical data concerning the basic technology of welded metal bellows were reviewed concerning:

- o Types of construction
 - Welded
 - Formed material
- o Diaphragm configurations
- o Bellows characteristics
 - Spring rate
 - Resistance to pressure, nested/extended
 - Long stroke capability
 - Stroke linearity

Figure 1 illustrates the various types of diaphragm configurations available. Some configurations are unacceptable due to inability to withstand high differential pressure in the nested position. The only acceptable configurations are the single sweep and the nesting ripple. Analysis methods used to select metal bellows operational parameters are included in Appendix A. Figures 2 and 3 illustrate the critical problems during the discharged (nested) condition showing the critical load occurring on the diaphragm area adjacent to the inside diameter weld of the convolutions. Figure 2 illustrates nesting concepts and Figure 3 illustrates a coining concept designated to reduce the critical load area thus improving bellows life.

4.2 Bellows Selection

Proposals received from Metal Bellows Corporation (MBC), Flexible Metal Hose Manufacturing Company, Sealol Incorporated, and Parker-Hannifin Corporation were evaluated to select candidate suppliers of bellows capsule assemblies for development testing. MBC and Sealol were selected to provide metal bellows capsule assemblies for endurance (bottoming) testing of bellows configurations. The selections were made based on improvements in design technology exhibited by both companies, with an attendant increased possibility of achieving the design requirements. The MBC design incorporated a spacer providing a bearing column at the bellows I.D. The Sealol design utilizes "tilt-edge" to decrease the unsupported diaphragm gap at the bellows I.D.

4.3 Bellows, Test Fixture

A test fixture, Figure 4, for testing bellows capsules was designed and fabricated. This fixture enabled installation of a test capsule to evaluate endurance (bottoming) cycles to permit design optimization prior to full scale bellows development.

4.4

Bellows Test Requirement

The original test plan consisted of 32,500 bottoming cycles to represent 10,850 full stroke cycles in ten years, assuming F-16 usage of 355 sorties per year plus two additional accumulator pressurizations per day for engine and system ground operation. A factor of three was imposed on this requirement resulting in the 32,500 cycle requirement. The bottoming test simulates a normal pressure shut-down of the aircraft hydraulic system. With pressure shut-down, the bellows which is pressure balanced during operation of the hydraulic system, is compressed to its stacked position by the hermetically sealed gas charge. The gas charge then exerts an external differential pressure on the stacked bellows. The bottoming cycle goal/requirement was reduced later in the program to 15,000 cycles as the original objective of 32,500 cycles was considered too severe. This was agreed upon during discussions between Air Force and Boeing personnel relative to the actual usage of aircraft. The requirement for 15,000 cycles is considered to be representative of F-16 operation.

5.0 BELLOWS TESTING

5.1 Preliminary Testing

Preliminary testing included bottoming tests on four capsules from Metal Bellows Corporation and two capsules from Sealol Incorporated. The test fixture, Figure 4, was designed to accommodate 6 to 14 convolutions in order to standardize capsules. This fixture provides a fluid pressurization port, positive sealing external to the bellows and a center (dry) cavity for leak detection. The capsules were tested in the set up shown on Figures 5, 6, and 7. A Metal Bellows capsule is shown on Figure 8 and a Sealol capsule is shown on Figure 9.

5.1.1 MBC Capsule Testing

Test capsules were made with approximately 20 percent of the number of convolutions of a full size production capsule. Each test capsule consists of fourteen (14) convolutions and two (2) test terminals. The results of testing of the Metal Bellows Corporation capsules are tabulated below:

<u>Capsule No.</u>	<u>Cycle To Failure</u>	<u>Remarks</u>	<u>Diaphragm Thickness</u>
1	5,148	13 leaks; clicking noted on each cycle	.005
2	4,273	4 leaks; clicking noted on each cycle	.005
3	15,784	4 leaks; no clicking noted	.005
4	10,716	4 leaks; clicking noted and internal bellows area lubricated with MIL-H-5606 after 200 cycles. No clicking noted after lubricating.	.005

The failed capsules were analyzed by Metal Bellows and the cause of the leaks was identified as fatigue cracks in the diaphragm next to the I.D. weld. The cause of the fatigue cracks is the high stress generated by contour differences between adjacent diaphragms (those welded together at O.D.). Sample No. 4 clicked when originally installed (indicating a contour difference) and stopped clicking when the inside surface was lubricated. The lubrication allowed the diaphragms to shift with respect to each other at a lower stress level, increasing its cycle life. It should be noted that the test capsules were tested in reverse with respect to air and fluid side (oil outside/air inside) in an accumulator design. Therefore, lubrication of the inside surface of the capsules more closely represents an accumulator application. Consequently, capsules were lubricated for all subsequent tests.

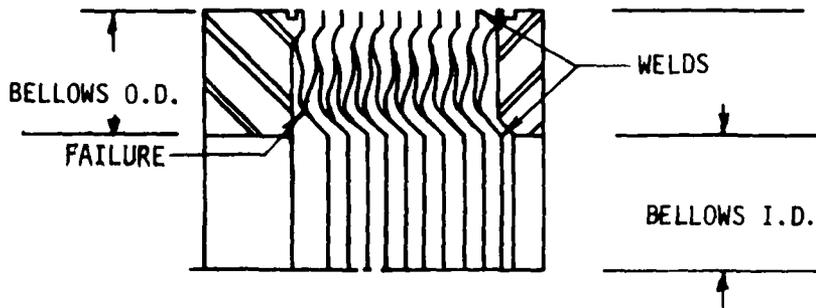
5.1.2 Sealol Capsule Testing

The results of the Sealol capsule tests are tabulated as follows:

Capsule No.	Cycle To Failure	Remarks	Diaphragm Thickness
1	5,029	2 leaks - (lubricated)	(.008)
2	3,359	1 leak - (lubricated)	(.008)

The failed capsules were analyzed by Sealol and the cause of the leaks was identified as fatigue cracks in the second diaphragm from the fixed terminal adjacent to the I.D. weld. This was attributed to irregular I.D. welds and heat distortion.

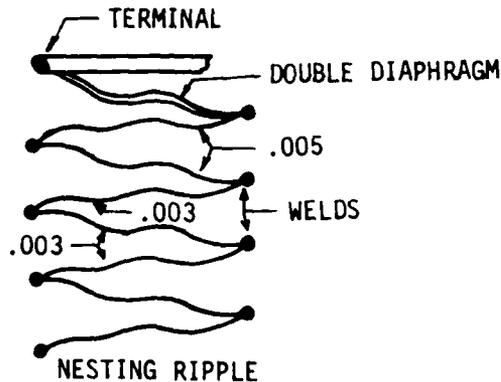
SEALOL REPRESENTATIVE CROSS SECTION



As seen from the above results, the four MBC capsules and the two Sealol capsules all failed to meet the required 32,500 pressure cycles.

5.2 Additional Preliminary Testing (Capsule Redesign)

Eight additional capsules were received and tested, four from MBC and four from Sealol. The MBC capsules were Hipress units of .003 inch thickness and were not heat treated in order to improve ductility and to reduce heat treat distortions. The Hipress design incorporates a metal flexible bellows to provide volumetric displacement without the use of any elastomeric material. Double diaphragm and increased thickness were added to test capsules to reduce stress diaphragm and increased thickness were added to test capsules to reduce stress failures where the diaphragm joins the sweeper terminal as illustrated.



Testing was accomplished on the MBC capsules and all four capsules failed to meet program objectives. Results are tabulated below.

<u>Capsule No.</u>	<u>Cycle To Failure</u>	<u>Remarks</u>	<u>Diaphragm Thickness</u>
5	1 5,126	Probable failure due to fatigue cracks generated by adjacent diaphragm contour differences.	.003
6	1 6,814		
7	6,562		
8	1,025	Manufacturing discrepancy	.003

1 floating terminal stop removed - floating terminal failed - bellows was okay.

The four Sealol units were "tilt-edge" configuration on the I.D. weld and straight configuration on the O.D.

The four Sealol capsules also failed to meet program objectives. Test results are tabulated below.

<u>Capsule No.</u>	<u>Cycle To Failure</u>	<u>Remarks</u>	<u>Diaphragm Thickness</u>
3	8,519	Probable fatigue crack failure	.008
4	7,643	Probable fatigue crack failure	.008
5	500	Failure mode not identified	.005
6	700	Failure mode not identified	.005

5.3 Preliminary Testing Conclusions

Preliminary testing has indicated problem areas in manufacturing techniques including die design and assembly practices.

- o Testing of capsules showed inability to meet the program objective (32,000 cycles at 0 - 2000 psi alternating pressure).
- o The MBC design, .005 diaphragm thickness, exhibited the greatest promise with one capsule reaching approximately 50 percent of the design goal.
- o All BMC capsules illustrated failures due to contour differences probably caused by a mismatched diaphragm, one concave, one convex, formed in different dies.
- o The Sealol "tilt-edge" design functioned best using .008 thickness for the diaphragm. However, testing indicated only 25 percent of the desired pressure cycles were achieved.

After completion of preliminary testing, program review was held at WPAFB with Boeing and AFAPL personnel to assess program results and to develop a follow-on plan. The following plan was developed as a result of this review.

- o Four additional advanced design MBC Hipress capsules would be designed, manufactured and tested. The four capsules would be matched, neutered pairs of diaphragms. The capsules would be assembled with close attention to the concentricity of the matched pairs since failures to date indicate contour interferences. This will require the design and manufacture of a special set of neutered dies, concentricity control of O.D. and I.D. during weldment and identification and matching of diaphragm pairs.
- o Testing will be conducted using 0 - 2000 psi alternating pressure cycles and internally lubricating the bellows.
- o Program continuation, including accumulator fabrication, will be determined based on results of the capsule testing.

7.0

ADVANCED DESIGN TESTING

The four bellows capsules were manufactured by MBC and tested at Boeing with the following results.

#1 failed after 7,063 cycles

#2 failed after 11,123 cycles

#3 failed after 7,727 cycles

#4 failed after 4,324 cycles

All leaks were in the first transition convolution from the floating end terminal. The cause of failure was determined to be a mismatch between the floating terminal ripple contour and the contour of the first transition diaphragm.

7.1 Metal Bellows Corporation Testing

Because of program cost considerations, all subsequent development testing was conducted at the Metal Bellows Corporation in Chatsworth, California.

7.1.1 Advanced Design, Bellows Testing

The MBC bellows tests were conducted on the test set up shown in Figure 10. New tooling was made for diaphragms with an O.D. of 3.25 inches and an I.D. of 2.40 inches. Tests 5 through 16, Table 1, were performed on test capsules made using the new tooling. Several design and manufacturing variations were evaluated. Tests 14 and 15 indicate that .004 inch thick material is suitable for meeting a 15,000 bottoming cycle requirement. The final diaphragm size, 2.97 I.D. by 2.12 I.D. was selected to satisfy envelope requirements of MIL-A-5498 specifications. Test No. 17 resulted in a bottoming cycle life of 12,000 cycles. A different manufacturing technique was used for Test 19 and 20, using the same material thickness as Test No. 17.

Two test capsules (see Test No. 19 and 20 of Table 1) were installed in a test housing. The gas side of the bellows (external) was pressurized to 2000 psig nitrogen and sealed off. The oil side of the bellows (internal) was pressure cycled to extend the test capsule to its normal operating length and back to the bottomed position with 2000 psig differential pressure acting across the compressed capsule. Test No. 19 was stopped after 32,5000 cycles for examination of the bellows. The gas charge pressure did not decrease from the start of the test. The capsule was found to have a leak detectable with a helium mass spectrometer. Test No. 20 was stopped after 20,000 cycles. A helium leak was also found, but the test was continued. After 31,000 cycles, a decrease in gas pressure was observed.

Inspection of Table I, (Test 14 through 21) indicates accomplishment of the design goal of 15,000 bottoming cycles. Test No.'s 14 and 15 of Table I shows that .004 inch thick diaphragm material is satisfactory in a 3.25 O.D. capsule. The production size, 2.97 O.D. is demonstrated by Test No.'s 19 and 20. Test No. 21 shows that .003 inch thick material may also be acceptable.

EW/75420/Disk 1/B10

7.1.2 Endurance Testing

The endurance test simulates normal operation of the hydraulic system. Capsules were not subjected to the endurance test as this requirement is considered to be met by analysis. The capsule is designed to be near its free length at operating conditions. The conditions of the endurance test produce a balanced pressure across the bellows resulting in no pressure stress on the bellows. The bellows motion resulting from pressure cycling between 2600 psig and 3000 psig does not produce a stress high enough to limit the life of the bellows.

7.1.3. Vibration Testing

The vibration test was conducted using a full-sized bellows assembly. An aluminum test housing, with inside dimensions identical to the flight housing, was used for the vibration test. The aluminium test housing was bolted together such that it could be disassembled to provide access for bellows examination. The test housing was also reusable for other types of testing.

Although not required by existing accumulator specifications, vibration testing per MIL-STD-810C, Method 514.2, Procedure I, Curve L was chosen to represent a possible severe environment. Test housing, P/N 77907, with a representative Bellows Assembly, P/N TC 77882, was subjected to adverse effects of the test.

The results of this test were satisfactory with the bellows showing no sign of physical damage (Reference Appendix B).

8.0 ACCUMULATOR DEVELOPMENT

8.1 Design Considerations

Various accumulator configurations were evaluated to determine optimum design considering the following variables:

- o Bellows outside diameter (limited to MS constraints)
- o Bellows inside diameter
- o Mean effective diameter of bellows
- o Number of bellows convolutions
- o Material selection
- o Material thickness
- o Heat treat effects
- o Position of bellows during heat treat
- o Precharge pressure
- o System pressure
- o Temperature

Results of these studies indicated a short, large diameter accumulator may afford the best configuration. However, due to design constraints of current MS accumulators, a configuration similar to the MS accumulator was designated. Figure 11 provides a conceptual description of an advanced design metal bellows accumulator.

8.2 Accumulator Design Requirements

The following design requirements were established to be in conformance with MS 28797-4, permitting interchangeability of accumulators with respect to envelope and function.

- o The 100 cubic inch accumulator design is interchangeable with either part number MS 28797-4 (Procurement Spec. MIL-A-8897) or part number MS 28700-4 (Procurement Spec. MIL-A-5498).
- o Clamps to install the Metal Bellows accumulator will be the same as those used with MS accumulator.
- o Operating Pressure: 3000 psi
- o Operating Temperature: -65°F to +275°F
- o Cold Start Conditions: 3850 psig and -65°F
- o Proof Pressure: 4500 psig at 100°F

- o Burst pressure: 12,000 psig at 100°F
- o Gas Charge Leakage: Below 10^{-8} cc/sec (lose 38 psig max in 10 years)
- o Gas Charge Volume: 10 ± 8 cu. in.
- o Installation: 3.219 Max Clamp Diameter
- o Housing Material: 4130 alloy steel
- o Bellows Material: AM350 Corrosion Resistant Steel

8.3 Accumulator Test Requirements

Test requirements for the accumulator are listed on Table II. Test requirements are directed at an accumulator life of seven to ten years based on 15,000 bottoming cycles.

8.4 Accumulator Design

A prototype accumulator design was accomplished for a 100 cubic inch accumulator as shown in Figures 12 and 13. This design featured a concept using a gas side charging tube to be crimped after proper precharge and a non-welded construction to provide disassembly and inspection after testing. The final design would be all welded construction to preclude leakage problems evident in standard accumulators.

The metal bellows accumulator design is a significant improvement in state-of-the-art accumulator design. No periodic checking of charge pressure or recharging to make up for lost gas charge are required. Also eliminated is the frequent complete overhaul to replace worn seals (O-rings). Additional efforts to evaluate means of monitoring precharge pressure were not accomplished due to budget and program constraints.

8.5 Accumulator Tests

Testing of an all-welded accumulator housing was performed. The housing was identical to the production unit and successfully demonstrated the integrity of the design concept. (Reference Table II.)

8.5.1 Housing Tests (Appendix B)

The 100 cubic inch flight accumulator housing, used for testing, is identical to the production design with the exception that the area of internal bellows attachment was not machined to match the bellows. The external finish of the test housing was left unplated. These two exceptions have no effect on the structural integrity of the accumulator housing. A bellows was not installed within the test housing for these units.

8.5.2 Proof Pressure

The accumulator housing (See Figure 12) was pressurized to 6000 psi for one minute. There was no evidence of leakage or permanent deformation.

8.5.3 Burst

The accumulator housing was subjected to a burst pressure of 12,000 psig. There was no evidence of leakage or rupture.

8.5.4 Impulse

The accumulator housing was subjected to the pressure cycling test in accordance with the requirements of MIL-A-8897A, paragraph 4.7.5, Table I, Step 7. There was no evidence of leakage or permanent deformation. (See Wyle Laboratories Data Sheet Report No. 55556, Appendix C.)

9.0 CONCLUSIONS AND RECOMMENDATIONS

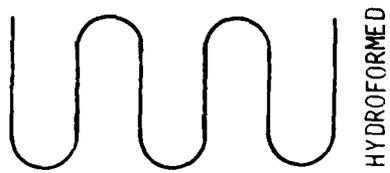
9.1 Conclusions

This program developed the critical portions of an advanced low maintenance accumulator. The design and testing of metal bellows test capsules demonstrate the capability to fabricate a metal bellows capsule capable of withstanding six to ten years of service life. Additional development and testing of a 100 cubic inch accumulator housing demonstrated the ability to manufacture an all-welded (sealed) accumulator. The evaluation included proof, burst and impulse testing of the accumulator housing with satisfactory results. Housing tests met requirements in accordance with MIL-A-8897-A.

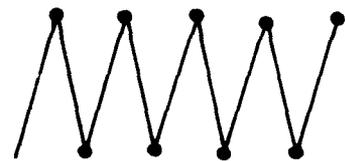
Life cycle cost analyses, conducted as part of the proposal effort, support the development and usage of an improved low maintenance accumulator incorporating a sealed housing and welded metal bellows gas/oil separator. Results of the studies showed a potential cost savings of \$11 million over the lifetime of the F-16 fleet.

9.2 Recommendations

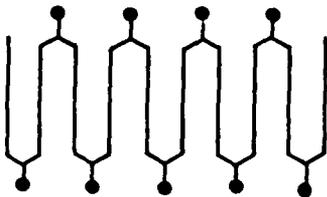
The program should be continued to fully develop and test a production, flight worthy accumulator. A prototype accumulator should be fabricated and subjected to bottoming and endurance tests. This unit should be monitored to provide test and design data for a flight worthy accumulator. At the conclusion of testing, several flight quality accumulators should be manufactured and subjected to flight clearance testing. Investigations should also be made to provide gas precharge monitoring capability using devices that will not compromise the integrity of the all-welded accumulator. Weight and cost reduction studies should be included to provide the best possible competitive unit.



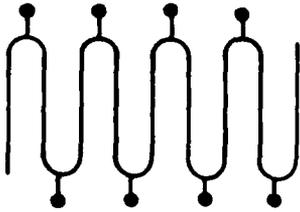
HYDROFORMED



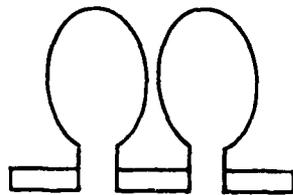
SIMPLE
FLAT PLATE



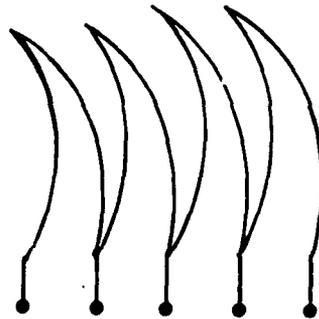
FLAT PLATE
CANTILEVER



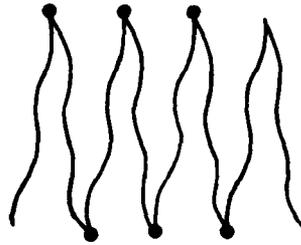
PERFORMED
CANTILEVER



TOROID



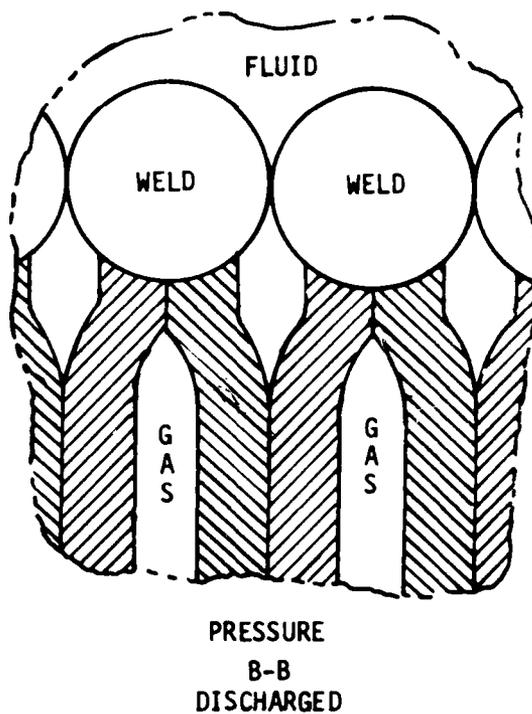
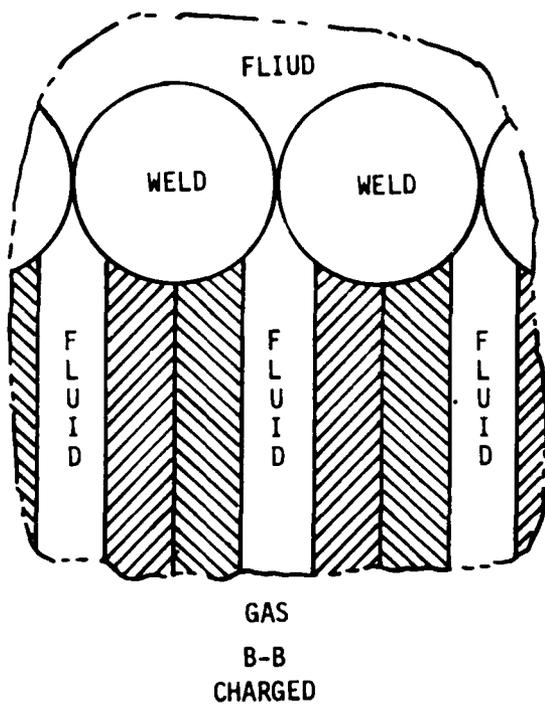
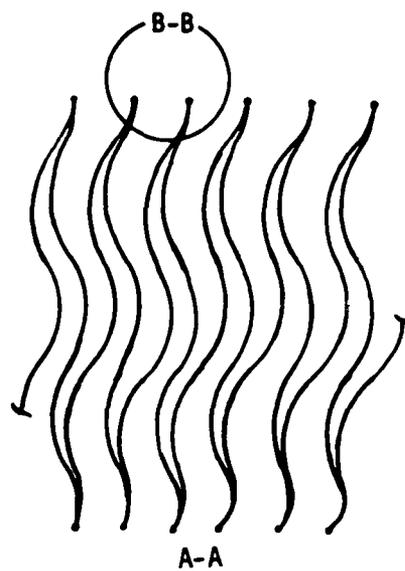
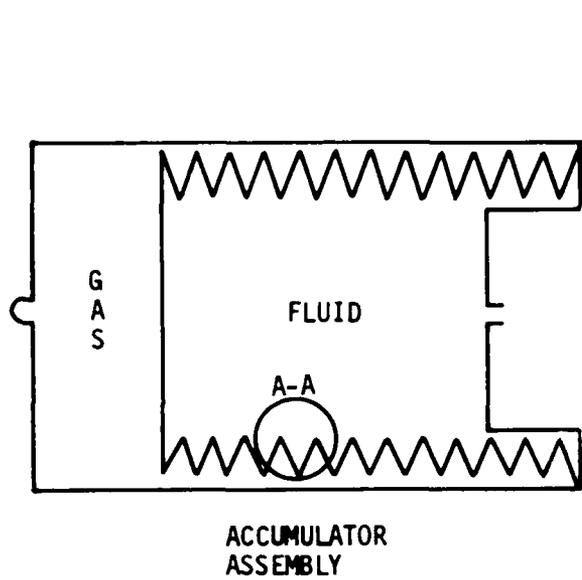
SINGLE SWEEP



NESTING RIPPLE
(ONE AND TWO PLY)

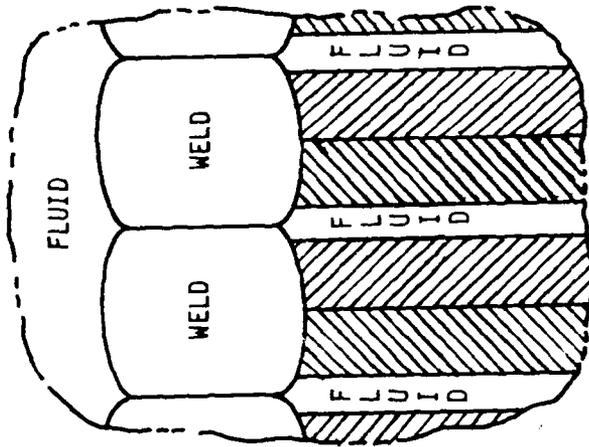
METAL BELLOWS DIAPHRAGM CONFIGURATIONS

FIGURE 1



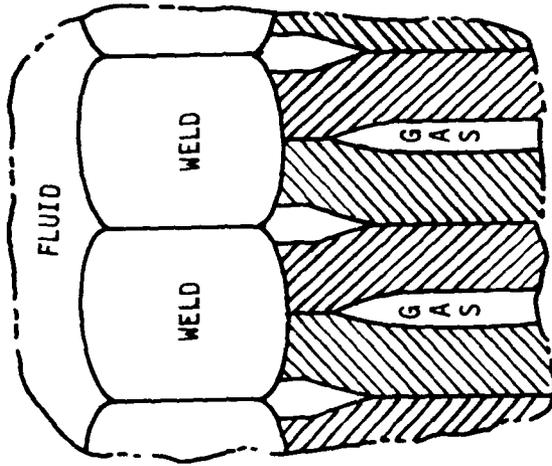
BELLOWS NESTING CHARACTERISTICS
FIGURE 2

I. D. SIDE OF BELLOWS



GAS

ACCUMULATOR WITH SLIGHT
CHARGE OF FLUID

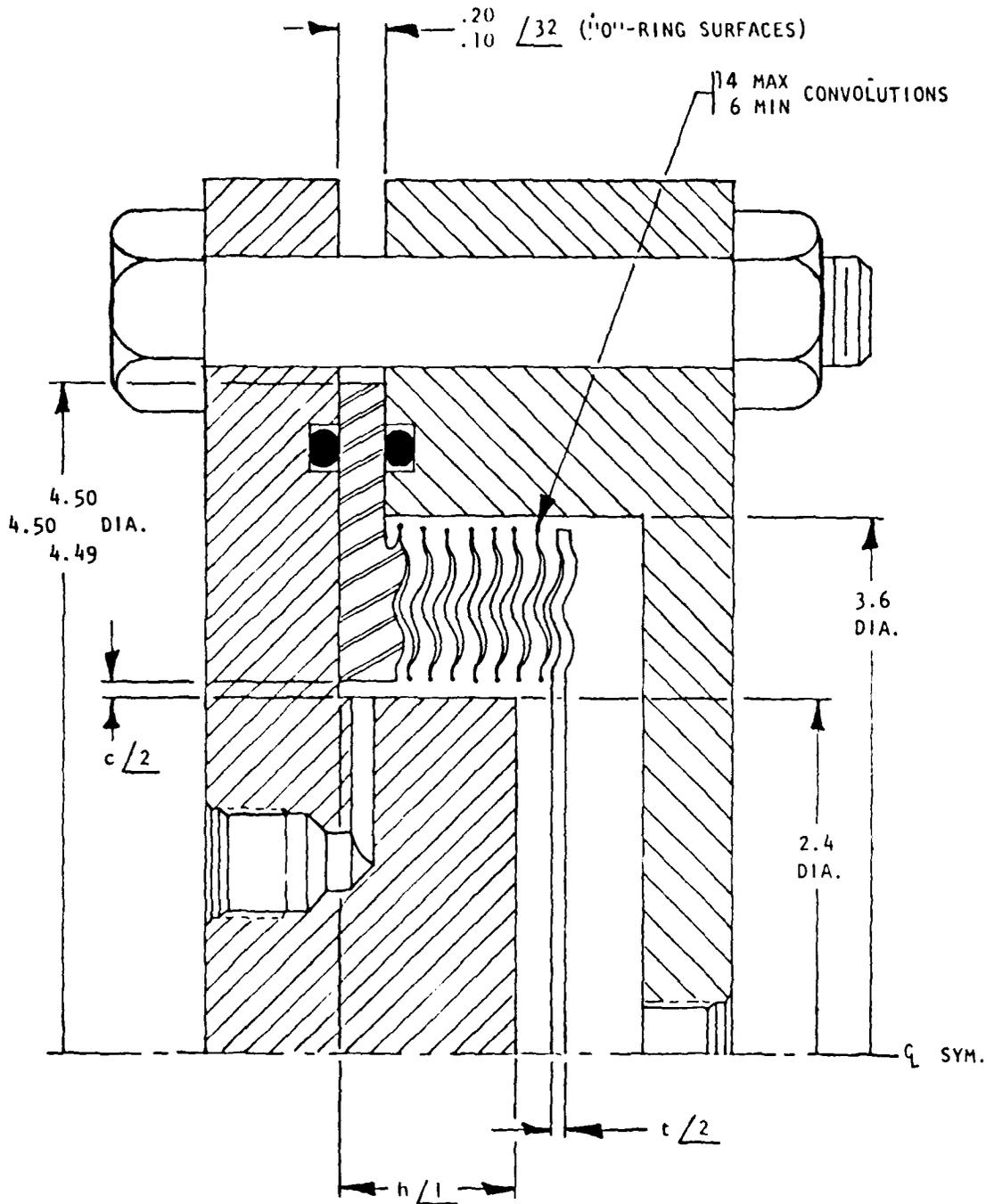


PRESSURE

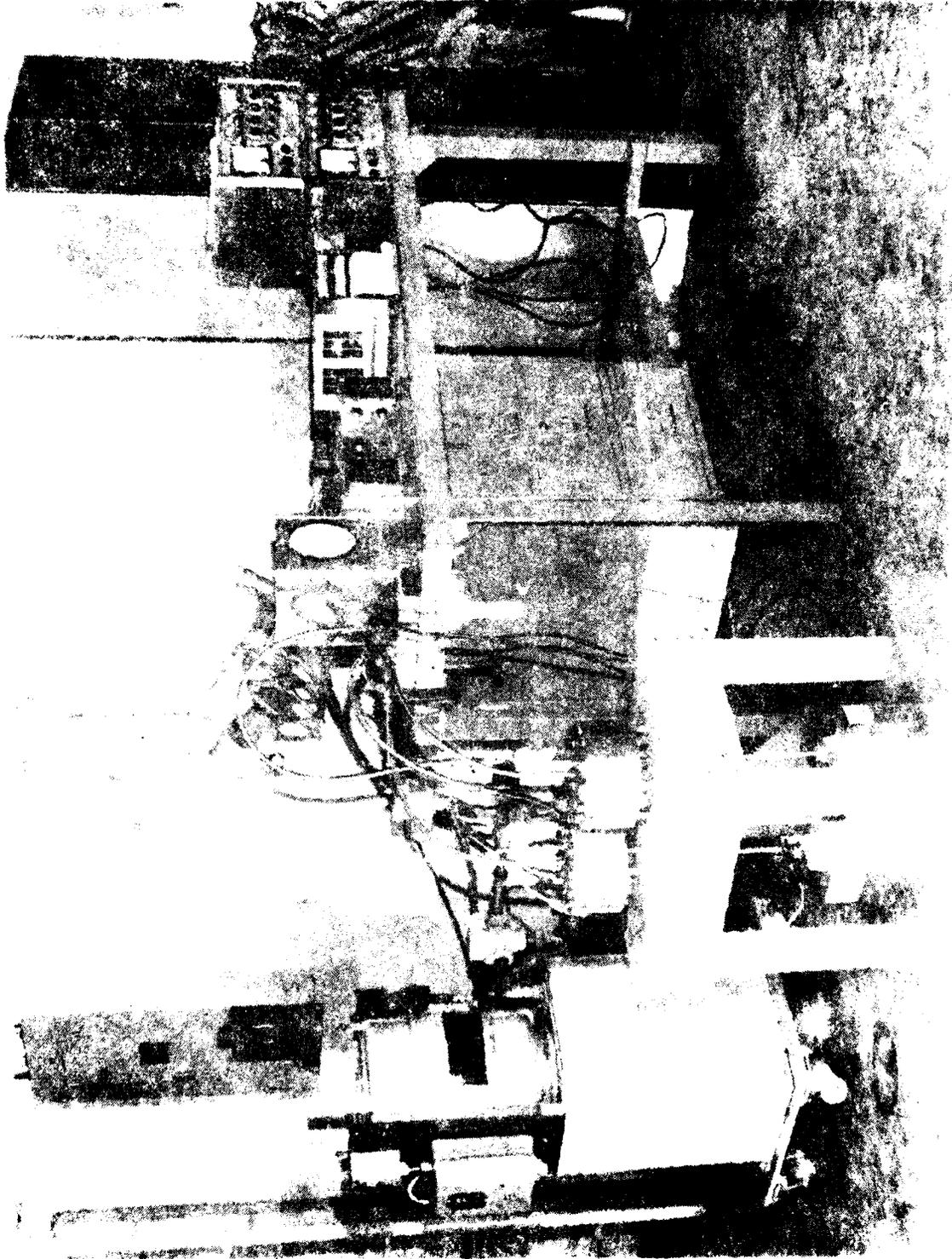
ACCUMULATOR
DISCHARGE

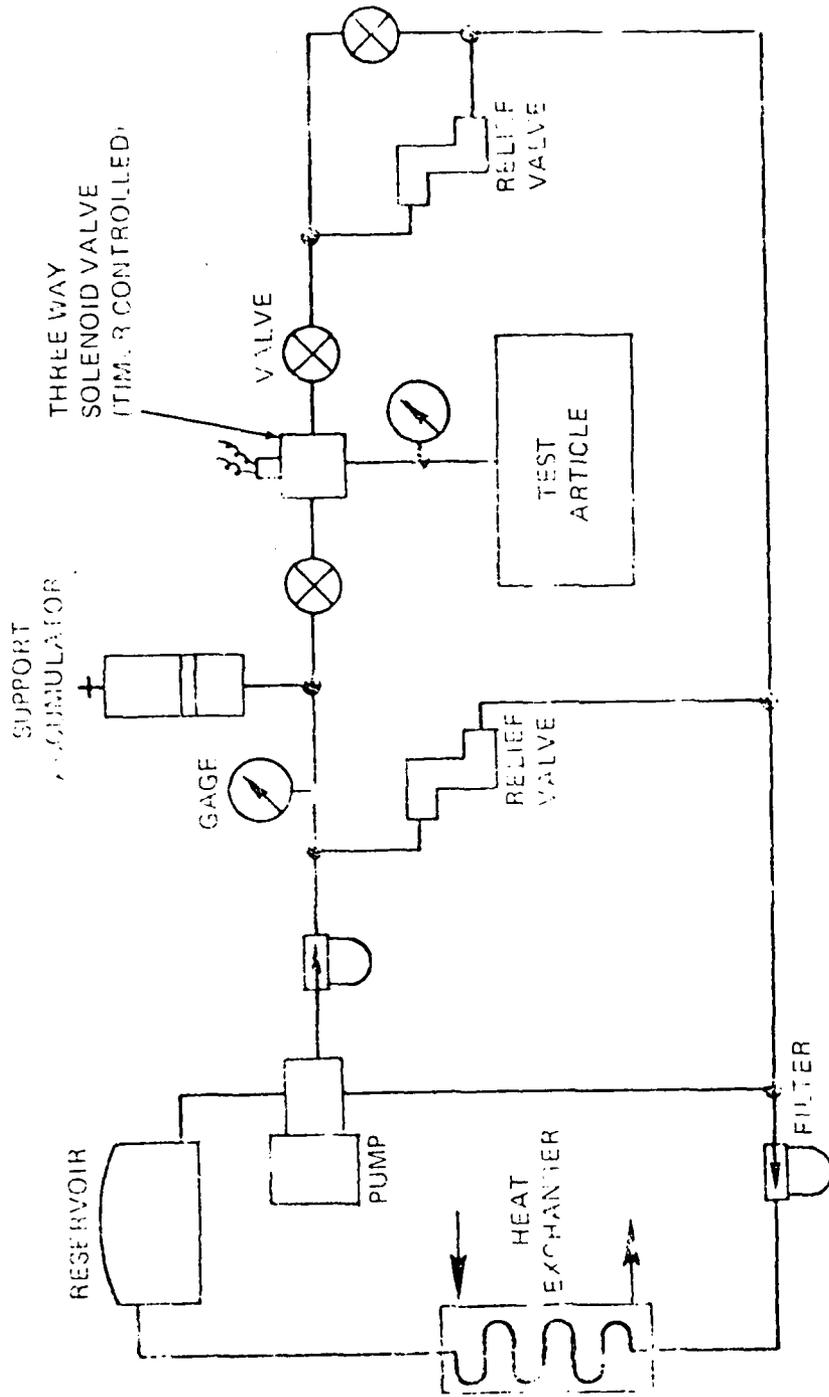
COINED BEAD BELLOWS CONFIGURATION

FIGURE 3

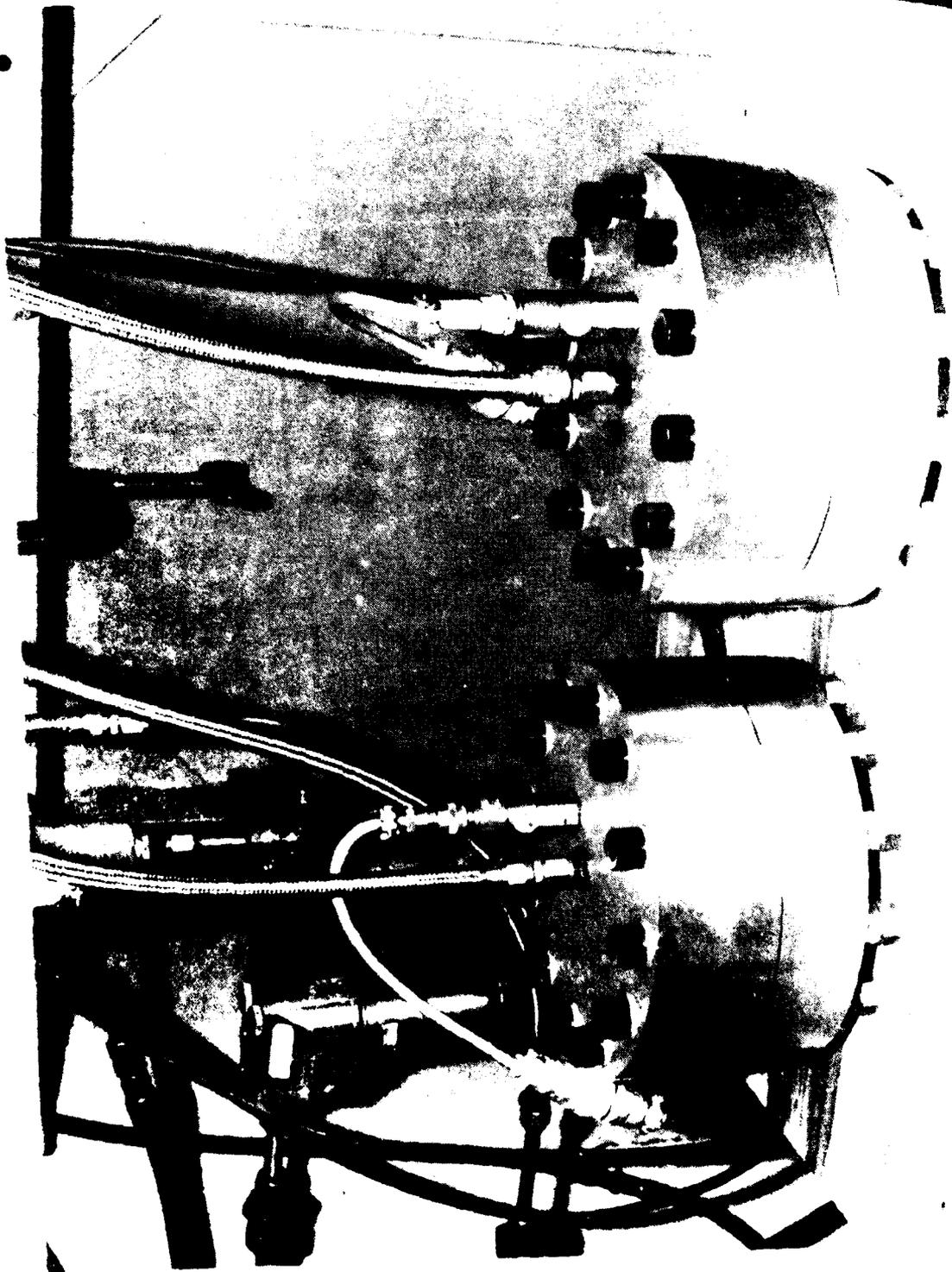


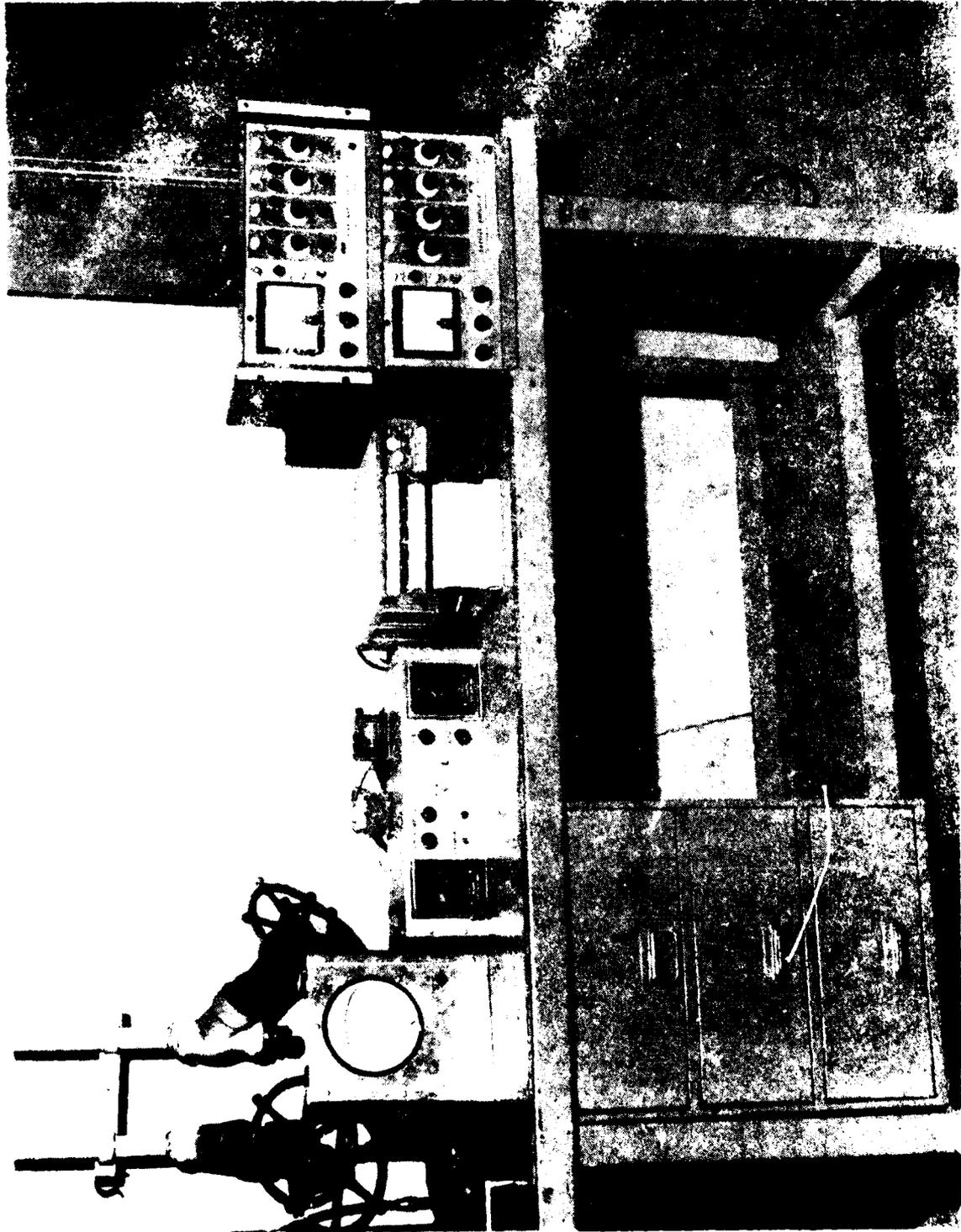
- 1 SWEEPER TERMINAL SUPPORT HEIGHT TO SPECIFIED FOR EACH SAMPLE (NESTED BELLOWS)
- 2 SWEEPER TERMINAL THICKNESS "t" MUST SPAN "c" DIMENSION WITHOUT PERMANENT DEFORMATION WITH 4000 PSI APPLIED TO THE OUTSIDE OF THE BELLOWS IN THE NESTED CONDITION

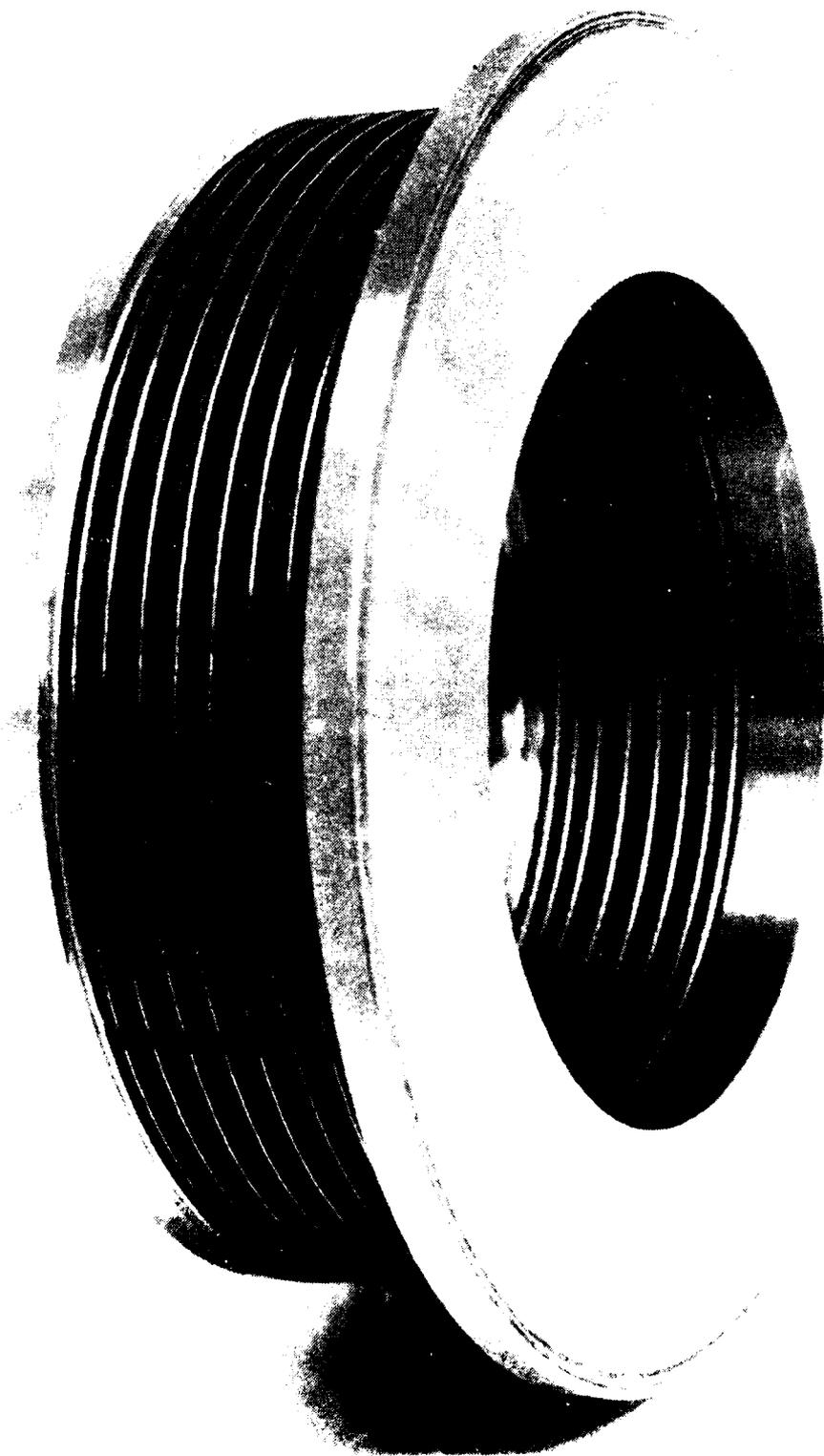




METAL FELLOWS ACCUMULATOR ASSEMBLY TEST SCHEMATIC
 FOR BOTTOMING AND NORMAL CYCLE TESTING
 FIGURE 5A



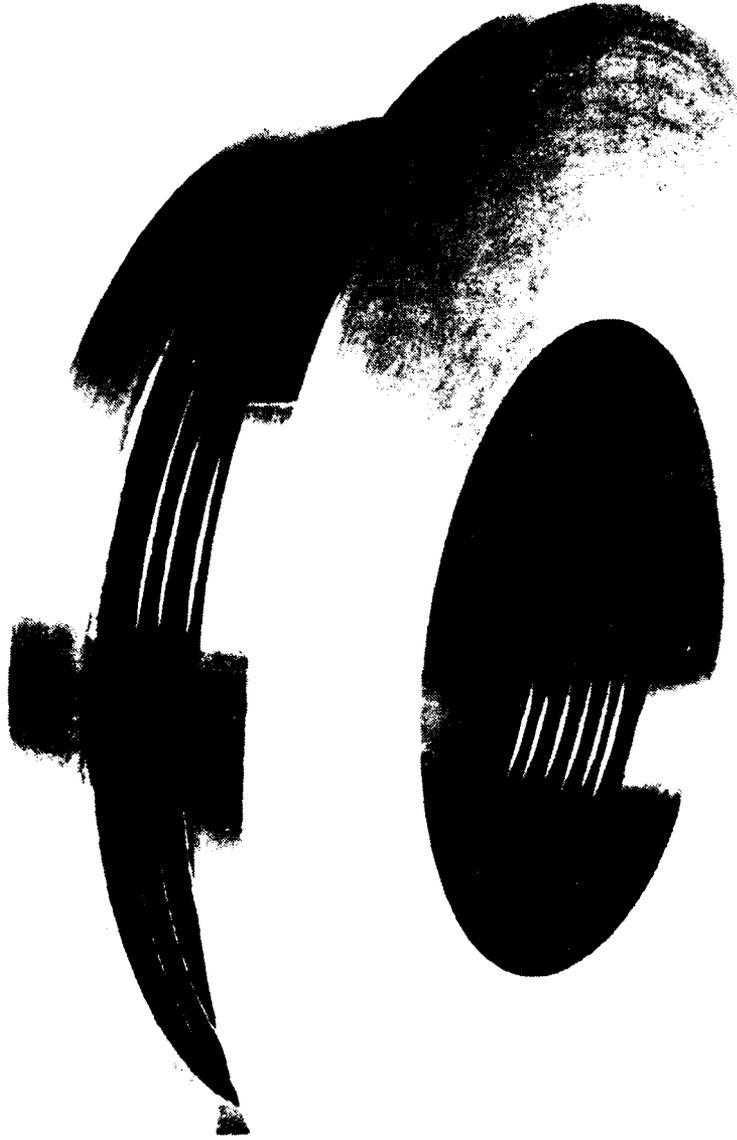




33

METAL BELLOWS CORR. TEST CAPSULE

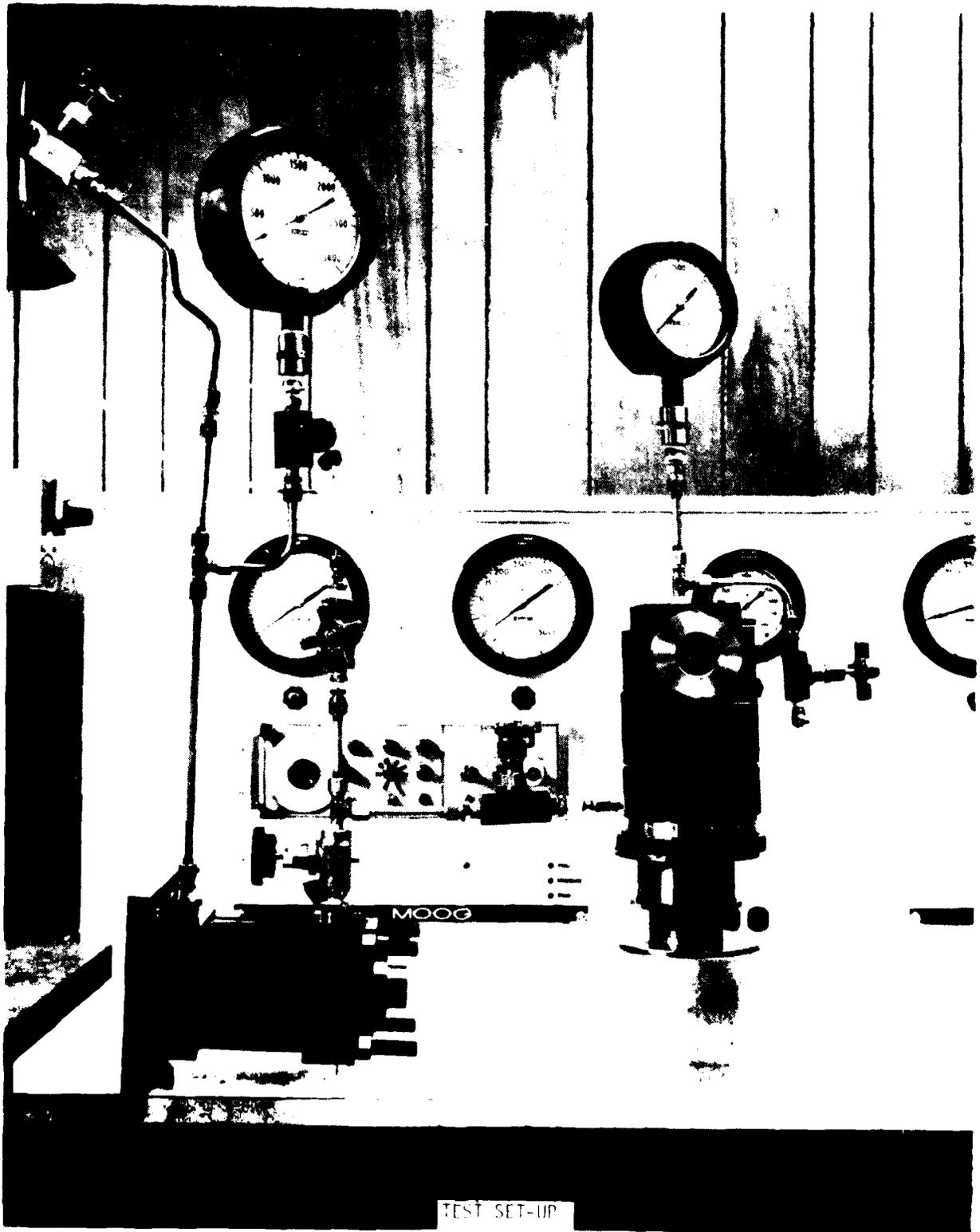
FIGURE 8



34

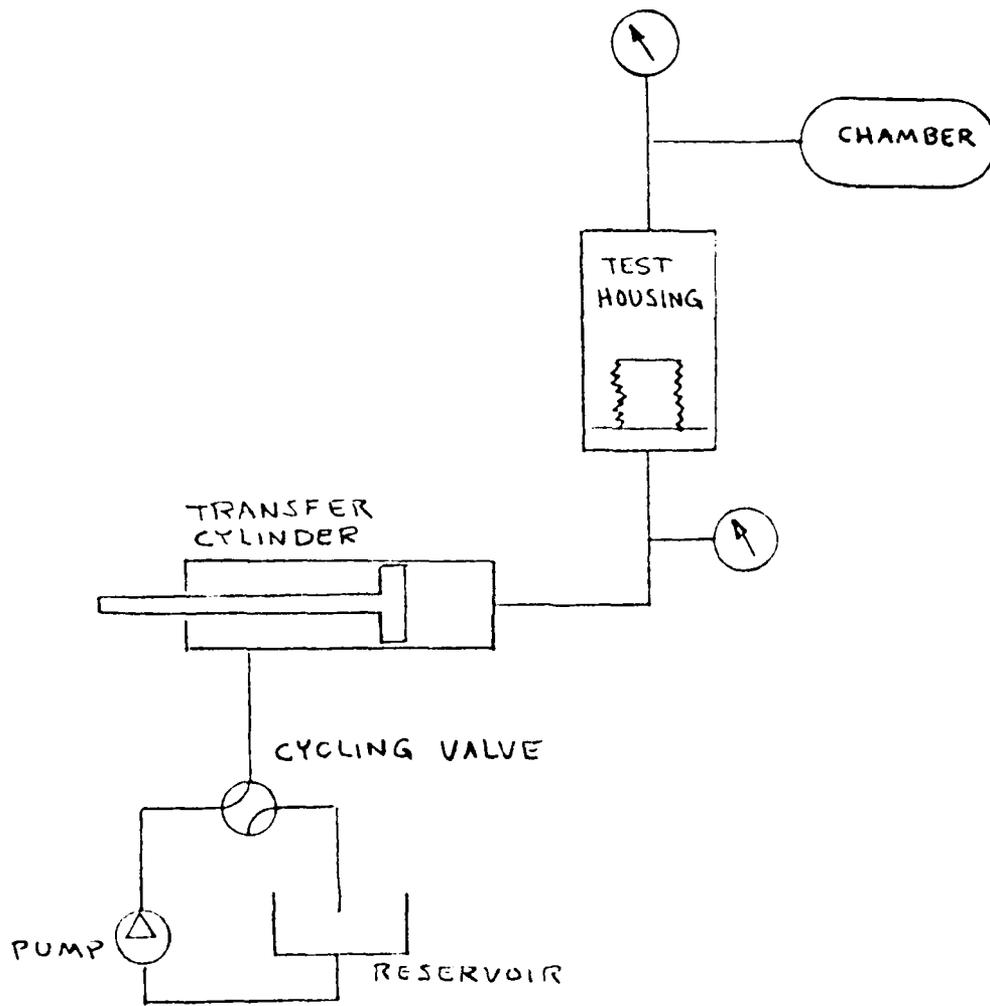
SEALOL INC. TEST CAPSULE

FIGURE 9



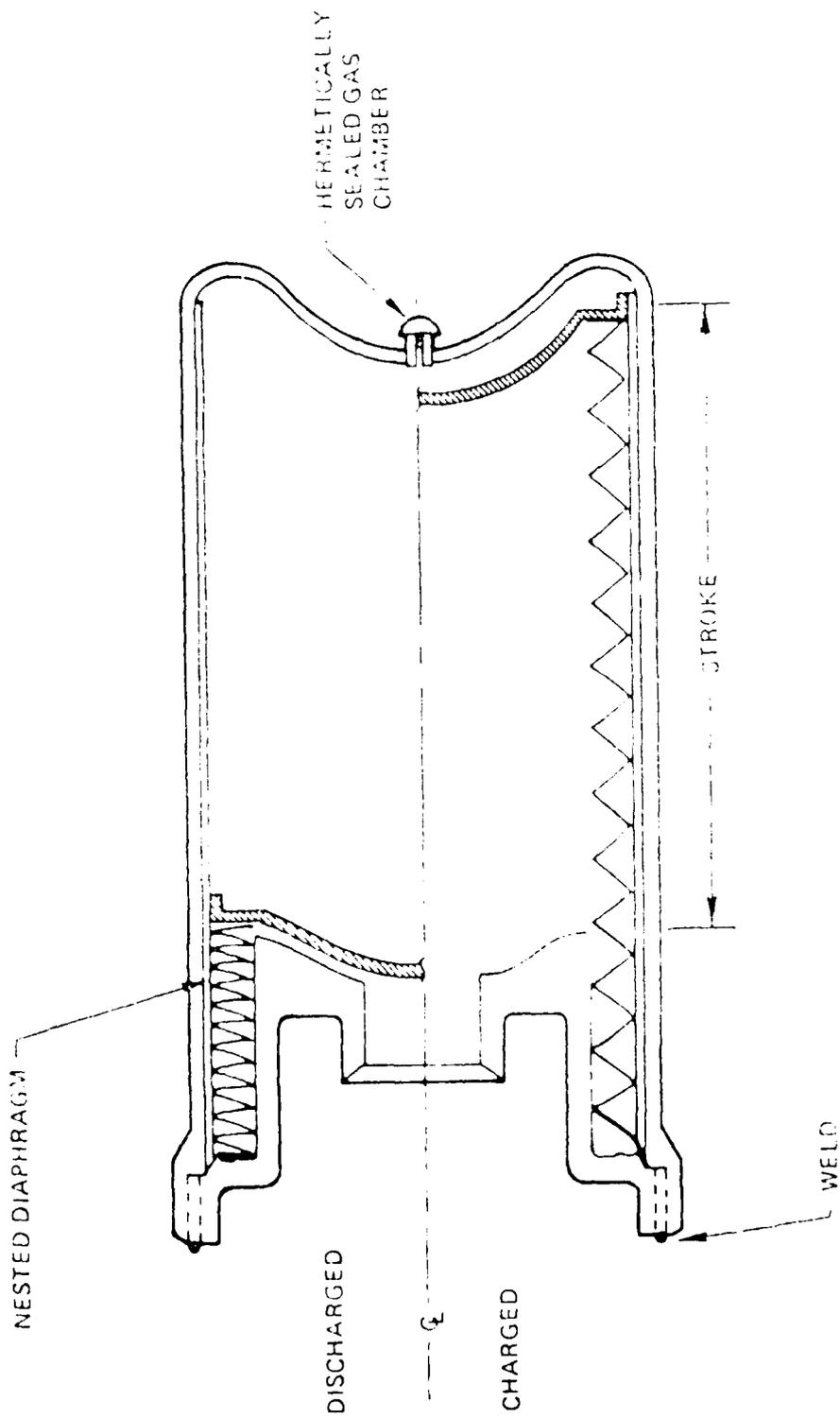
TEST SET-UP

FIGURE 10



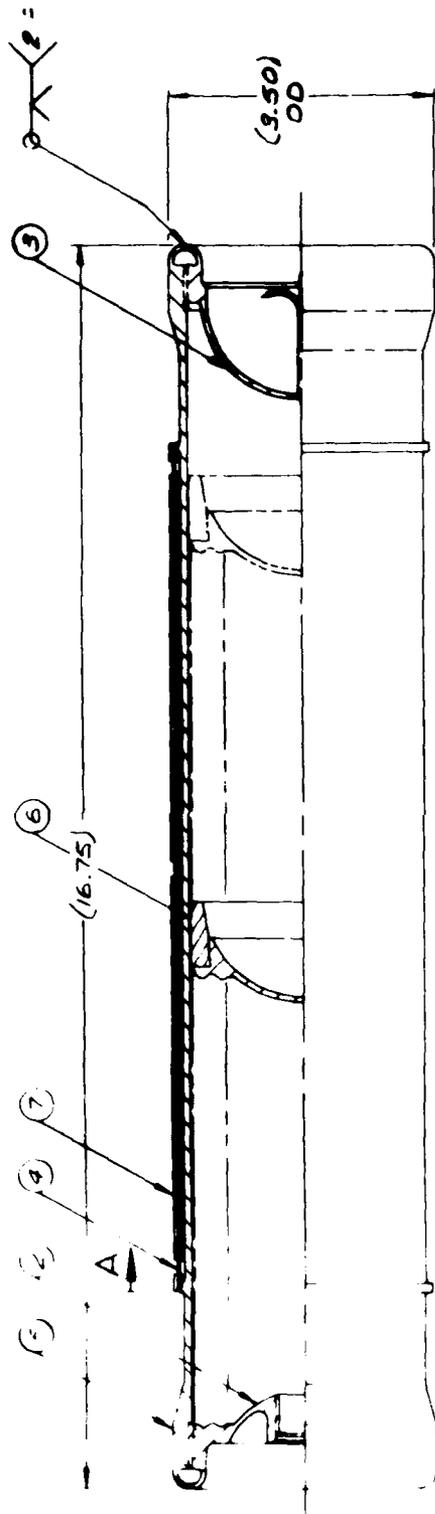
TEST SET-UP

FIGURE 10a



ADVANCED DESIGN METAL BELLOWS ACCUMULATOR CONCEPT

FIGURE 11



- 1 BELLOWS ASSEMBLY
- 2 TERMINAL
- 3 END
- 4 INDICATOR (OPTIONAL)
- 5 HOUSING
- 6 GUIDE
- 7 INDICATOR (OPTIONAL)

A



PROTOTYPE ACCUMULATOR DESIGN

FIGURE 12

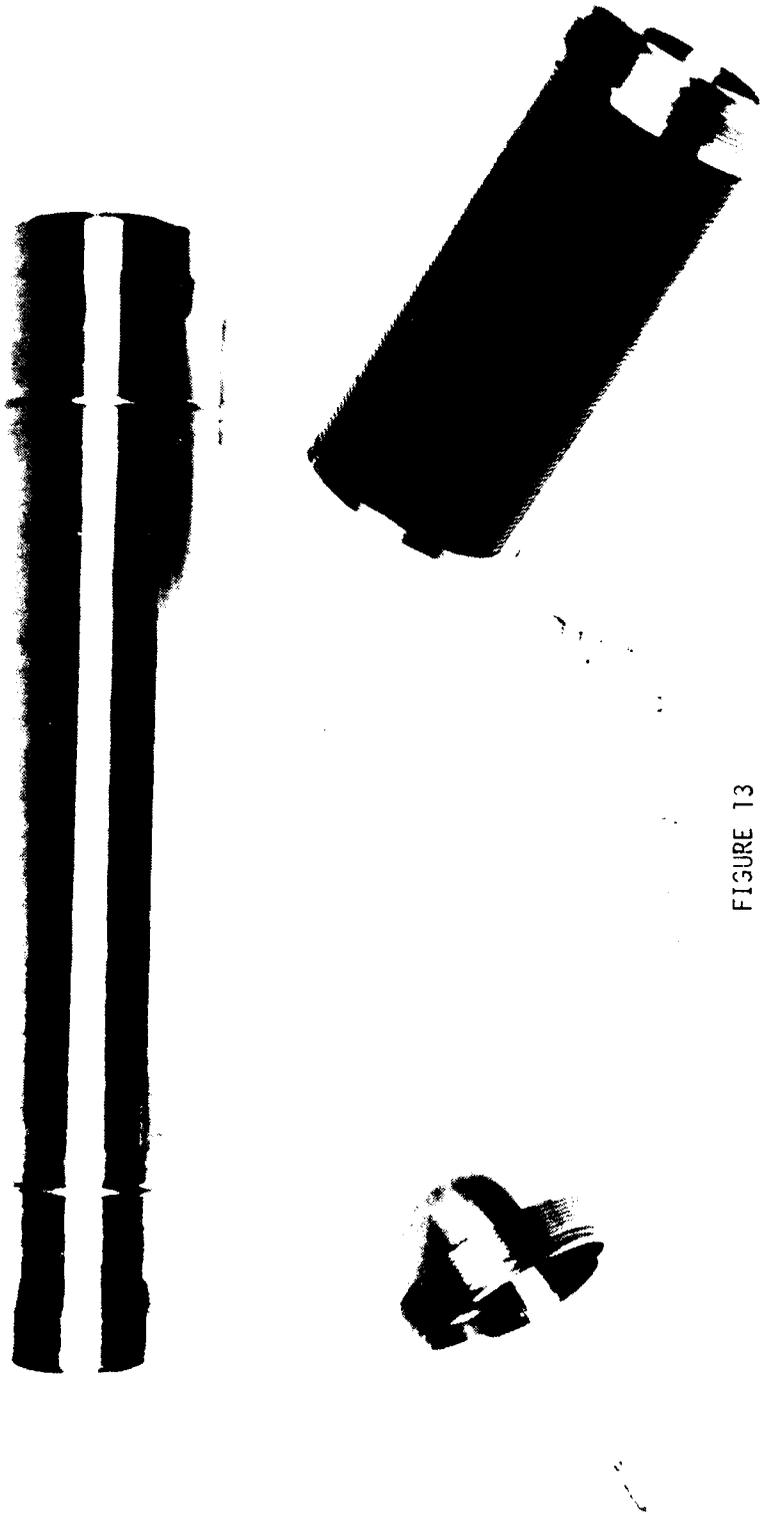


FIGURE 13



TABLE 1
BELLONTS TEST INFORMATION

TEST CAPSULE (14 CONVOLUTIONS)

Test	Part Number	Description	S/N	Pressure Ext. PSIG	Stroke IN.	No. Cycles	Remarks
1	75820	5.24 X 3.74 X .005	1	0-2000	0	7,063	Tested by BWC
2	75820	5.24 X 3.74 X .005	2	0-2000	0	11,123	All failed in transition
3	75820	5.24 X 3.74 X .005	3	0-2000	0	7,727	Convolution
4	75820	5.24 X 3.74 X .005	4	0-2000	0	4,324	
5	76239	3.25 X 2.40 X .005	1	0-2000	0	10,000	Bench marks not aligned
6	76239	3.25 X 2.40 X .005	2	0-2000	0	37,000	(without stop)
7	76239	3.25 X 2.40 X .005	3	0	0-1.0	3,132	Leak prior to test
8	76239	3.25 X 2.40 X .005	4	0-1200	0	24,777	(without stop)
9	76239	3.25 X 2.40 X .005	5	0-2000	0	12,913	(without stop)
							Random Diaphragms
10	76239	3.25 X 2.40 X .005	6	0-2000	0	18,160	Random Diaphragms
11	76843	3.25 X 2.40 X .004	4	0	0-1.2	73,500	Less spread for chill rings
12	76847	3.25 X 2.40 X .004	3	0	0-1.2	8,203	Non Hipres (spread I.D.)
13	76843	3.25 X 2.40 X .004	5	0-2000	0-1.2	10,300	Failed ID-Coining
14	76843	3.25 X 2.40 X .004	6	0-2000	0-1.2	25,000	I.D. Fatigue
15	76843	3.25 X 2.40 X .004	7	0-2000	0-.71	32,500	I.D. Fatigue
16	76843	3.25 X 2.40 X .004	8	0-2000	0-.71	14,500	I.D. Fatigue
17	77030	2.97 X 2.12 X .004	1	0-2000	0-.63	12,000	I.D. Fatigue
18	77168	2.97 X 2.12 X .005	1	0-2000	0-.63	14,000	I.D. at first Convolution
19	77030	2.97 X 2.12 X .004	3	0-2000	0-.63	32,500	He leak
20	77030	2.97 X 2.12 X .004	4	0-2000	0-.63	20,000	He leak, 31000 obvious leak
21	77346	2.97 X 2.12 X .003	1	0-2000	0-.63	19,400	Leak

TABLE 2
ACCUMULATOR TEST SCHEDULE

TEST NO.	ACCUMULATOR ASSEMBLY	ACCUMULATOR HOUSING	NUMBER CYCLES	PRESSURE PSI	CYCLE RATE CPM
1	PROOF PRESSURE	1 PROOF PRESSURE	-	6000	-
2	BOTTOMING	-	15,000	3000 200 DIFFERENTIAL	15
3	ENDURANCE	-	150,000	2600 TO 3000	10
4	-	1 IMPULSE	1,000,000	2000 TO 3000	100
5	-	1 BURST	-	12,000	-

- 1 ACCOMPLISHED SATISFACTORILY
- 2 ACCOMPLISHED ON CAPSULE ONLY
- 3 ACCOMPLISHED BY ANALYSIS

APPENDIX A
ACCUMULATOR ANALYSIS TECHNIQUES

APPENDIX A

The following is a description of the bellows analysis method to determine major operational parameters. Many of the details are available from metal bellows manufacturers and can be applied to the accumulator design.

Bellows Parameters

- Outside diameter
- Inside diameter
- Diaphragm span
- Effective area
- Diaphragm configuration
- Material
- Condition of material
- Number of convolutions
- Thickness of material
 - Standard convolutions
 - Two adapter convolutions at each end
- Spring rate
- Natural frequency (longitudinal) – dry
 - Both ends fixed

Calculate the bellows spring rate (K_B).

$$K_B = K_X \frac{h^3}{S^2} \text{ I. D.} \div N$$

Where: K_X is constant from empirical data
 h is material thickness (inches)
 $I.D.$ is inside diameter
 N is number of convolutions

Determine the differential pressure required to stroke the bellows from its free position to the completely compressed position.

$$\text{Differential Pressure} = \frac{X_B (K_B)}{A_B}$$

Where: X_B is bellows travel (In.)

A_B is bellows effective area (in.²)

Determine the initial precharge pressure and gas volume required at 75°F to provide the required fluid displacement with a system

fluid pressure of 3,000 psig at 75°F.

Taking the bellows spring rate into consideration

$$\text{Precharge Pressure} = P_2 + P_B$$

Where: P_2 is final precharge pressure (psig)

P_B is pressure to compress bellows (psig)

Calculate precharge gas volume (V_1)

$$V_1 = \frac{P_2 V_2}{P_1}$$

The equivalent bellows stroke (X_B) for a displacement of 100 cubic inches can be calculated as follows:

$$X_B = \frac{\Delta V}{A_B}$$

Determine the bellows separator displacement (ΔV_B) with a gas precharge of 1,500 ±50 psi at 75°F when charged with hydraulic fluid at -65°F and 3000 psi.

$$\Delta V_B = V_1 \cdot V_2$$

Where: V_1 is gas volume at 1,500 ±50 psi (in.³)

V_2 is gas volume at 3,000 psi (in.³)

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

Where: P_1 is initial pressure (psi)

P_2 is compressed pressure (psi)

T_1 is initial temperature °R

T_2 is final temperature °R

The equivalent bellows travel may be calculated as follows:

$$X_B = \frac{\Delta V}{A_B}$$

The gas end dome requires sufficient space to insure against the separator bellows bottoming out on the gas end.

Calculate the increase in the precharge pressure due to the rise in temperature from 75°F to 300°F.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = \frac{P_1 T_2}{T_1}$$

Calculate the decrease in the precharge pressure due to drop in temperature from 75°F to -65°F.

$$P_2 = \frac{P_1 T_2}{T_1}$$

Calculate the maximum differential pressure which may be applied internal to the separator at its maximum extended length without inducing "squirm" or canting of the convolutions.

$$P = \frac{C_S \pi K_B}{L}$$

Where: C_S is a constant from empirical data

Calculate the maximum fluid pressure (P_M) the bellows can withstand internally at the three temperature points: 275°F, 75°F and -65°F. The precharge pressure will be considered to be the minimum of 1500 psig at 75°F. The bellows maximum displacement will be taken at the position at -65°F and 3000 psig.

$$P_M = \frac{P_1 V_1 T_2}{V_2 T_1}$$

Calculate the natural frequency (N_f) of the bellows and gas charge system.

Bellows only, both ends considered fixed.

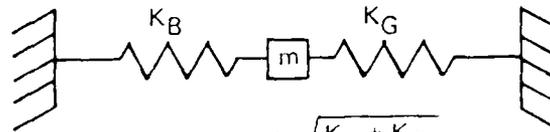
$$N_f = .5 \sqrt{\frac{386K}{W}}$$

Where: K is bellows spring rate (lb./in.)
 W is bellows weight (lbs.)

$$N_f = .5 \sqrt{\frac{386 (30)}{4.5}}$$

$$= 25 \text{ CPS}$$

Bellows and gas charge system, schematically represented as shown below:



$$f_n = \frac{1}{2\pi} \sqrt{\frac{K_B + K_G}{m}}$$

Where: m is mass of bellows moving header (lb./sec.²/in.)

K_g is spring rate of gas charge (lb./in.) and is defined as

$$K_g = \frac{\Delta P (A_B)}{X_B}$$

Bellows Life Cycle Equations

The alternating and mean stress levels are calculated as follows:

$$\text{Alternating Stress} = \frac{(\text{Max. Stress}) - (\text{Min. Stress})}{2}$$

$$\text{Mean Stress} = \frac{(\text{Max. Stress}) + (\text{Min. Stress})}{2}$$

The maximum and minimum stress levels are calculated by the following formulae using constants K_p , K_{pC} , and K_X derived from empirical data.

NOTE: The maximum and minimum stress levels given are for the I.D. weld joint. The I.D. joint is the maximum stressed joint in this application.

Pressure stress formula for proof and burst pressure conditions:

$$S_p = P K_p \left[\frac{\text{I.D.}}{t} \right]^2$$

Where: S_p is pressure stress (PSI)
 P is applied pressure (PSI)
 K_p is stress constant
 I.D. is bellows inside diameter (In.)
 t is material thickness (In.)

Pressure stress formula for bellows under pressure cycling conditions:

$$S_p = P K_{pc} \left[\frac{\text{I.D.}}{t} \right]^2$$

Deflection stress formula:

$$S_x = K_x \frac{X_t}{(N) \text{I.D.}^2}$$

Where: S_x is deflection stress (PSI)
 K_x is stress constant
 X is bellows deflection (In.)
 N is number of convolutions

Calculate the stress on the bellows I.D. joint under proof pressure external: (at 275°F)

NOTE: The pressure stress is tensional (+) and the deflection stress is compressive (-). They are summed algebraically.

Pressure stress at proof:

$$S_p = P K_p \left[\frac{\text{I.D.}}{t} \right]^2$$

CR 715

APPENDIX B

AETL REPORT NO. 543-8901

Report No. 543-8901
P.O. No. 90313
Date: 4 September 1980

Metal Bellows Corporation
20960 Knapp Street
Chatsworth, CA 91311

TEST SPECIMENS

One (1) High Pressure Housing Assembly, Part Number 77907, Serial Number 01.

SUMMARY

This report certifies that the test specimen identified above has been subjected to Vibration Testing in accordance with MIL-STD-810C, Method 514.2, Procedure I, Curve L. All results conformed to specification requirements and no adverse effects were noted.

TEST EQUIPMENT

<u>AETL No.</u>	<u>Manufacturer</u>	<u>Instrument</u>
D526V	Endevco Corporation	Accelerometer; M/N 2246
D613V	Unholtz-Dickie Corp.	Servo Programmer; M/N SP-5
D681V	Endevco Corporation	Charge Amplifier; M/N 2720PRS
D731V	F. L. Moseley	X-Y Plotter; M/N 135
D762V	Endevco Corporation	Charge Amplifier; M/N 2720PS
D763V	Hewlett-Packard	Log Voltmeter/Converter; M/N 7562A
D997V	Endevco Corporation	Accelerometer; M/N 2246
D1024V	MB Electronics	Power Amplifier; M/N T999 MOD
D1025V	Unholtz-Dickie Corp.	Sweep Oscillator; M/N OSC-1
D1115V	Spectral Dynamics Corp.	Dynamic Analyzer; M/N SD101A
D4018V	MB Electronics	Vibration Exciter; M/N C210
P628V	Ashcroft	Pressure Gauge; M/N 1079
P683V	Ashcroft	Pressure Gauge; M/N 5000PSI

NOTE: The equipment specified above was calibrated, as required, in accordance with MIL-C-45662A, with traceability to the National Bureau of Standards (NBS). The NBS traceability records are maintained on file in the AETL Quality Control Office.

TEST PROCEDURES AND TEST RESULTS

Vibration Test

Date Commenced: 7 August 1980
Date Completed: 14 August 1980

The Assembly was installed in a test fixture and rigidly mounted on a vibration exciter. The Assembly was then subjected to a sine resonance survey, in each of the three major orthogonal axes (refer to Figure 1), at an input level of 0.1-inch da up to a limiting value of 2 g's peak over the frequency range of 5 to 2000 Hz. The sweep rate was one octave per minute. Resonances were found in all three axes. During the resonance search, the housing was pressurized to 2000 psig with gaseous nitrogen and the bellows was pressurized to 3000 psig with oil.

On completion of the resonance search in each axis, the Assembly was subjected to 30 minutes of frequency dwell at each of the critical resonance frequencies (maximum of four) at the following levels:

<u>Frequency (Hz)</u>	<u>Levels</u>
5 - 14	0.1-inch da
14 - 23	1 g's peak
23 - 104	0.036-inch da
104 - 2000	20 g's peak

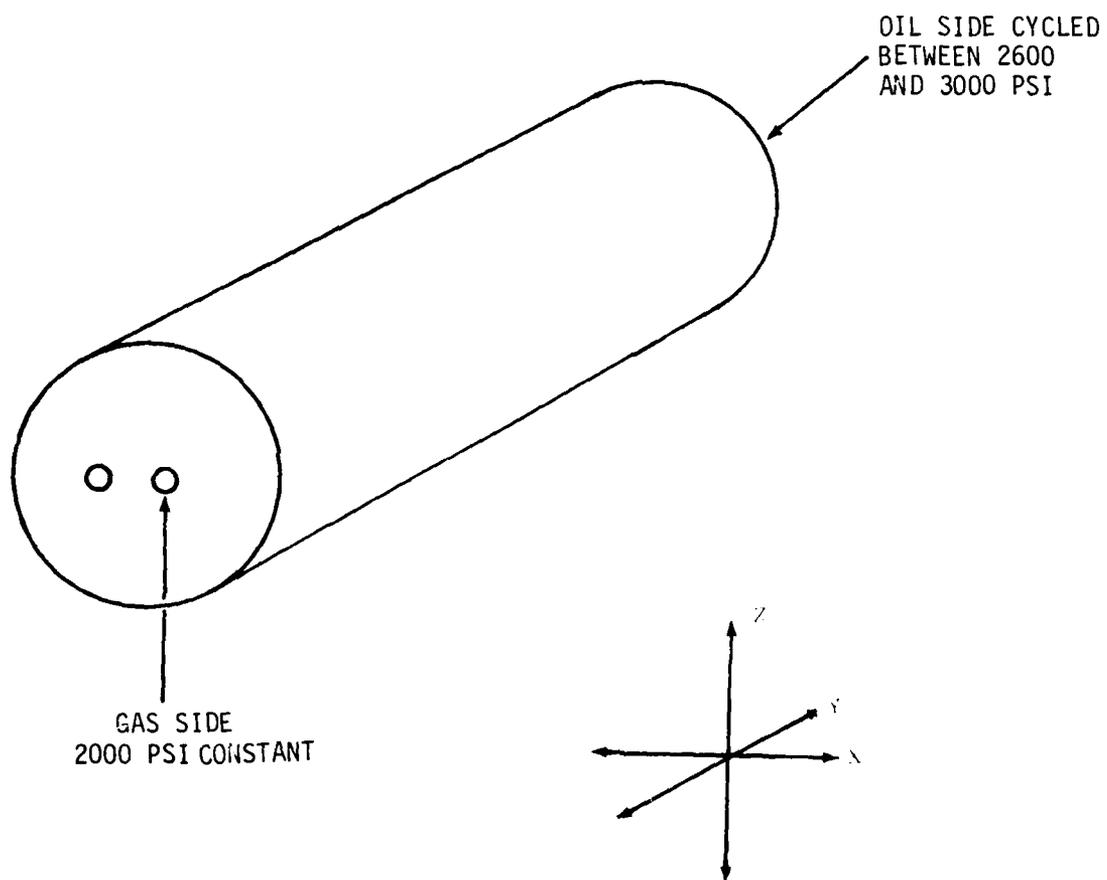
Refer to Table I for the Frequency Dwell Schedule. During the frequency dwells, the housing was pressurized to 2000 psig with gaseous nitrogen and the bellows oil pressure was cycled between 2600 and 3000 psig at a rate of 60 seconds per cycle.

The Assembly was then subjected to 2 hours of frequency cycling at the frequency dwell vibration levels. The sweep rate was 5 to 2000 to 5 Hz in 20 minutes. The combined cycling and dwell time in each axis was 3 hours.

Report No. 543-8901
P.O. No. 90313

The Assembly was visually examined on completion of testing, and no sign of physical damage was noted. X-Y Plots were recorded during testing and are presented in the Appendix. This concluded testing and the Assembly was returned to Metal Bellows Corporation.

WILLIAM H. HOYT, V.P. Quality Assurance



AXIS DEFINITION

TABLE I
Resonance Dwell Schedule

<u>Axis</u>	<u>Frequency (Hz)</u>	<u>Input Level (g's)</u>	<u>Output (g's)</u>	<u>Duration</u>
X	1187	20	96 - 100	30 min
	1398	20	130 - 140	30 min
Y	600	20	100 - 110	30 min
	981	20	110	1 min
	945	20	130	2 min
	942	20	120 - 110	11 min
	958	20	115	2 min
	934	20	110	6 min
	942	20	120	1 min
	920	20	105	7 min
Z	1200	20	80 - 82	30 min
	1575	20	190 - 170	30 min

APPENDIX B

X-Y Plots



APPROVED ENGINEERIN... LABORATORIES

M/C No. 543-8901

P/O No. 90313

Customer: METAL BELLOWS

Test Item: HIGH PRESSURE PUMPING ASSEMBLY

Part No. 77907

Serial No. 1

Date: 3-7-66

Test: SINE VIBRATION

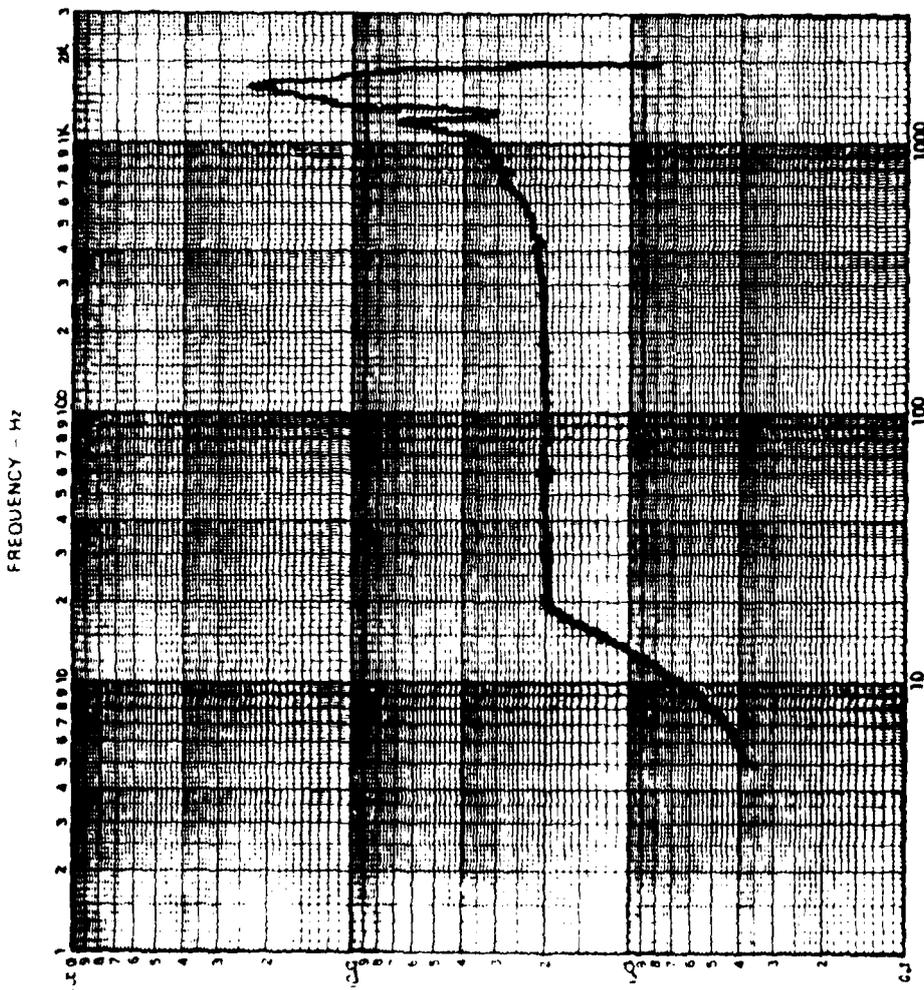
Spec. Ref.: MIL-STD-883C Method 5.4.2

PAR: PROCEDURE I

Performed By: D. W. STRATTON

Test Engineer: R. J. MARTIN

Witnessed By:



PLOT NO. 2

TEST POSITION 2 - AMS PICKUP S.N. & LOCATION RESIDUE PICKUP SENSITIVITY 100 mV RMS RMS 1000 Hz

TIME 1135

SAMPLE RANGE _____ CAL RANGE _____
 ENSEMBLES _____ AVG TIME _____ SEC ANALYZER FILTER _____ Hz BW
 OPERATOR *D. W. Stratton*
 SEC ANALYZER FILTER _____ Hz BW



APPROVED ENGINEERING LABORATORIES

Order No. 543-8901

Job No. 90313

Part Name METAL BELLOWS

Part Description HIGH PRESSURE HOUSING ASSEMBLY

Part No. 77907

Serial No.

Date

Test SINE VIBRATION

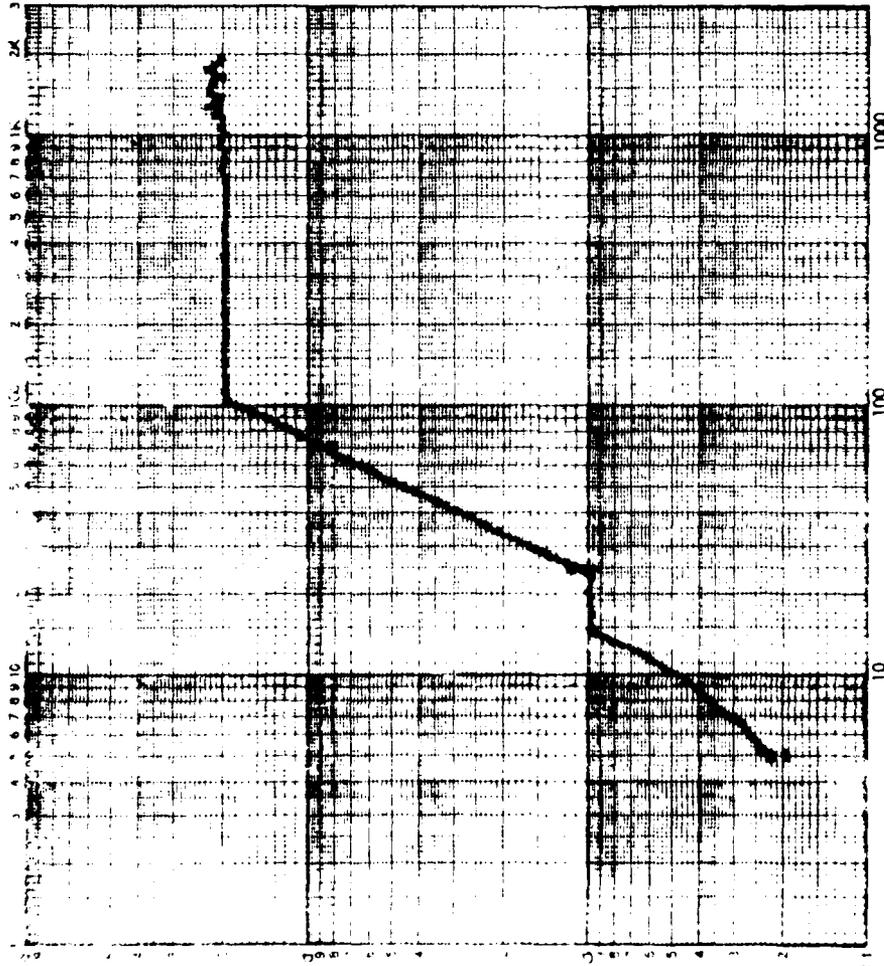
Part No. MIL STD 883C METHOD 2042

Test PROCEDURE I

Part Name By D. W. STANTON

Test Engineer R. MARTIN

Witness By



PILOT NO 2

1000 100 10

SCALE RANGE

SEE ANALYSIS REPORT FOR DATA

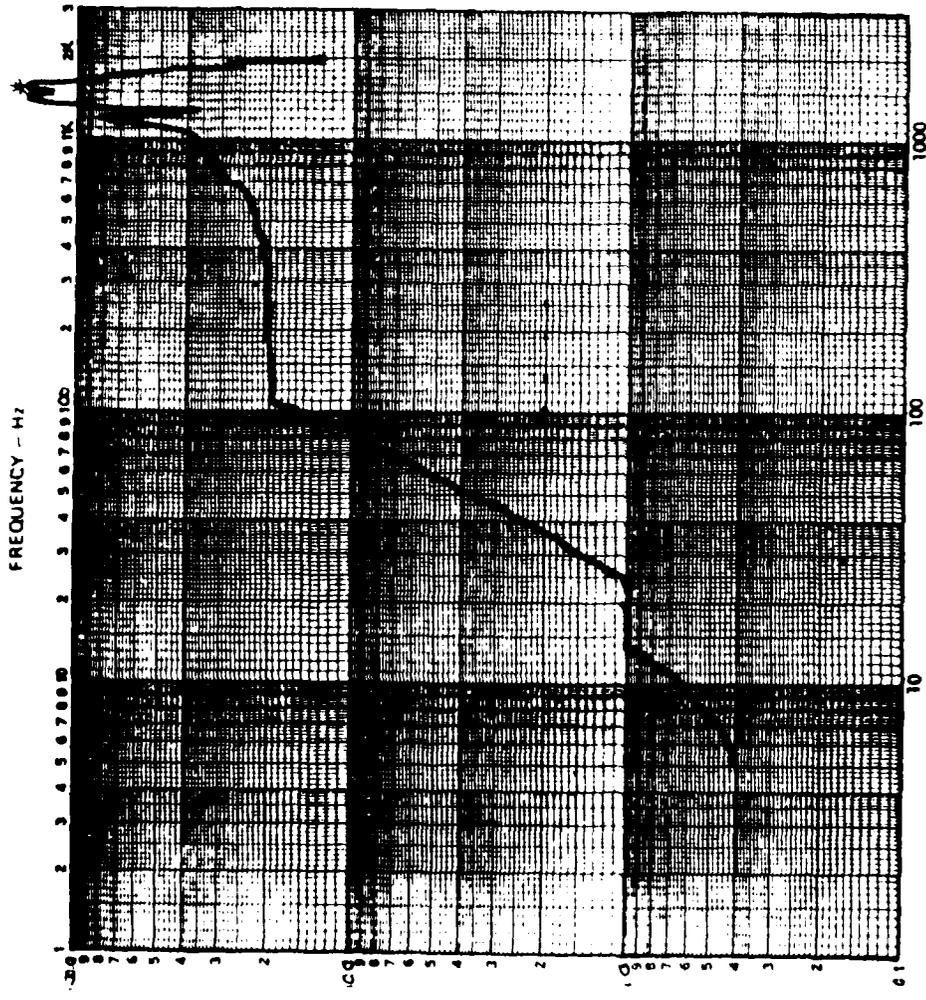
D. W. Stanton



APPROVED ENGINEERING TEST LABORATORIES

MO No **543-8901**
 P.O. No **90313**
 Customer **METAL BELLOW'S**
 Test Item **HIGH PRESSURE HOLDING ASSEMBLY**
 Part No **77907**
 Serial No **1**
 Date **8-2-58**

Test **SINE VIBRATION**
 Specification **MIL STD 883C Method 514.2**
 PAR **PROCEDURE I**
 Performer By **D. W. STANTON**
 Test Engineer **P. J. MARTIN**
 Witnessed By **...**
 * **...**



PLOT NO. **4**

CONDITION **Z-GRMS** PICKUP SENSITIVITY **100** m-RMS GRMS **100** TOP LINE **100** **g** peak
 TIME **1550**
 SAMPLE RANGE **...** CAL RANGE **...**
 ENSEMBLES **...** SEC ANALYZER FILTER **...** AVG TIME **...** Hz BW **...** Hz BW **...**
 OPERATOR **D. W. Stanton**

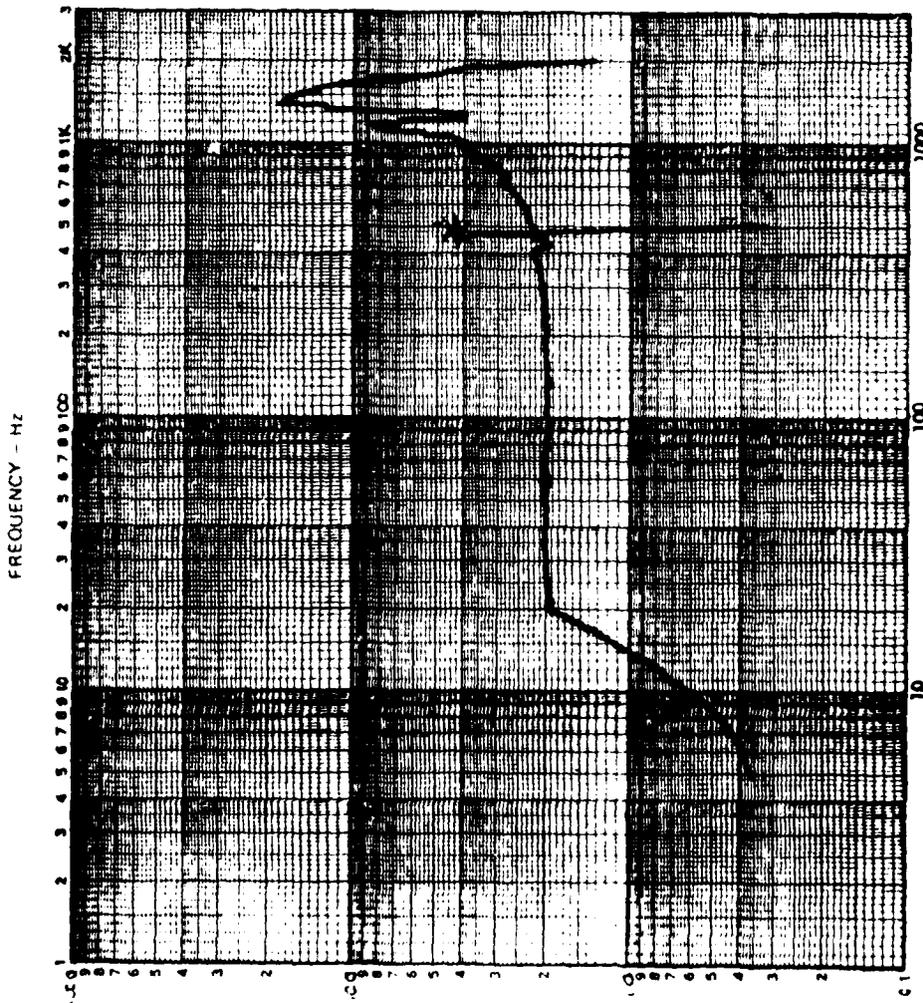


APPROVED ENGINEERIN S1 LABORATORIES

A NATIONAL BUREAU OF STANDARDS LABORATORY

MJO No. 543-8901
 P.O. No. 90313
 Customer METAL BELLONDS
 Test Item HIGH PRESSURE HOLDING ASSEMBLY
 Part No. 77907
 Serial No. 1
 Date 7/1/60

Test SINE VIBRATION
 Specification MIL-STD-883C Method 514.2
 Part PROCEDURE I
 Performed By D.L. STANTON
 Test Engineer B. MARTIN
 Witnessed By D.W. STANTON



TEST CONDITION X - RMS PICKUP SENS. LOCATION RESPONSE PICKUP SENSITIVITY 10.0 mRMS GRMS TOPLINE 100.0 g peak

DATE 11-29

SEPAR. M. RMS _____ GRMS _____ SAMPLE RANGE _____ CAL RANGE _____

ENSEMBLES _____ AVG. TIME _____ SEC ANALYZER FILTER _____ HZ BW _____ ENSEMBLES _____ AVG. TIME _____ SEC ANALYZER FILTER _____ HZ BW

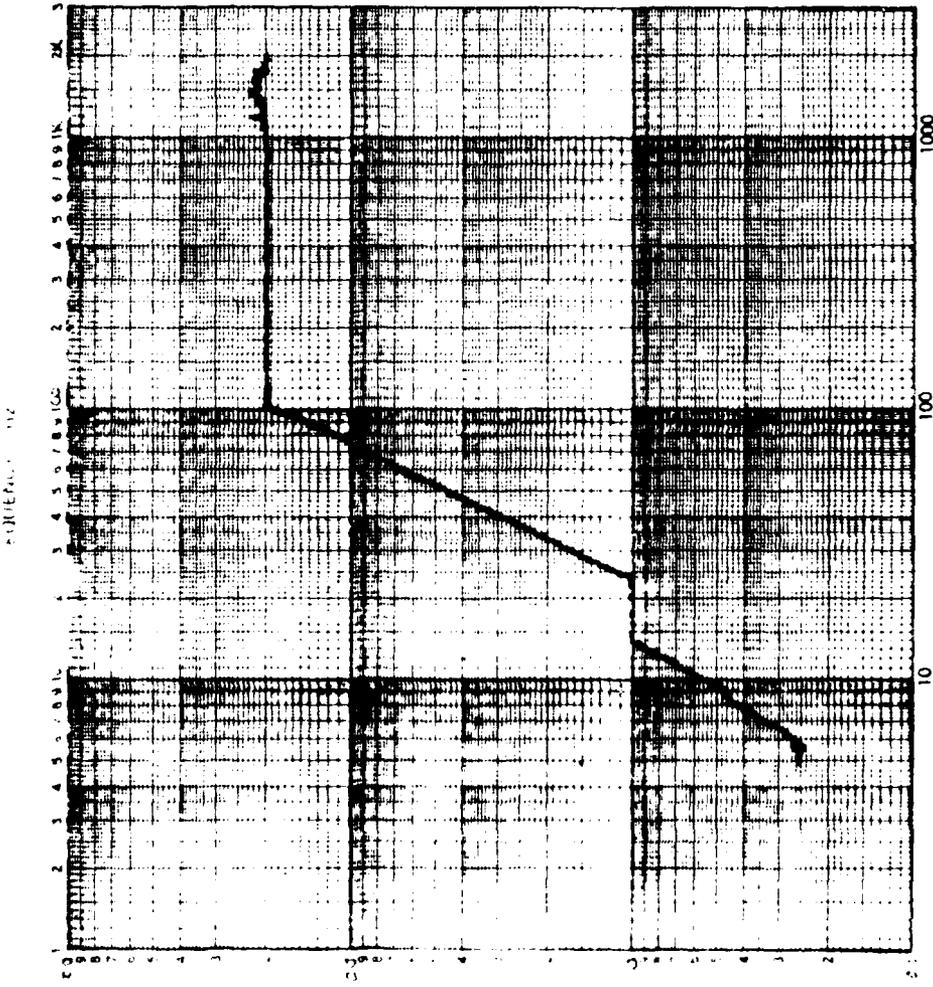
ENSEMBLES _____ AVG. TIME _____ SEC ANALYZER FILTER _____ HZ BW _____ OPERATOR D.W. Stanton



APPROVED ENGINEERING TEST LABORATORIES

Mfg No. 543-8901
 Part No. 90313
 Description METAL BELLOW
 Test Item HIGH PRESSURE PUMPING ASSEMBLY
 Part No. JF707
 Serial No. 1
 Date 11/15/50

Test SINE VIBRATION
 Spec. Reference MIL STD 883C Method 514.2
 Part PROCEDURE I
 Performed by T. M. B. [unclear]
 Test Engineer B. MARTIN [unclear]
 Witnessed by [unclear]



PLOT NO 6
 FULL-RESPONSE 100
 SAMPLE RANGE
 CAL RANGE
 SEC ANALYZER FILTER
 TIME SERVER



APPROVED ENGINEER IN TEST LABORATORIES

MJG No: 543-8901

P.C. No: 90313

Customer: METAL BELLOWS

Test Item: HIGH PRESSURE HOUSING ASSEMBLY

Part No: 77907

Serial No:

Date:

Test: SINE VIBRATION

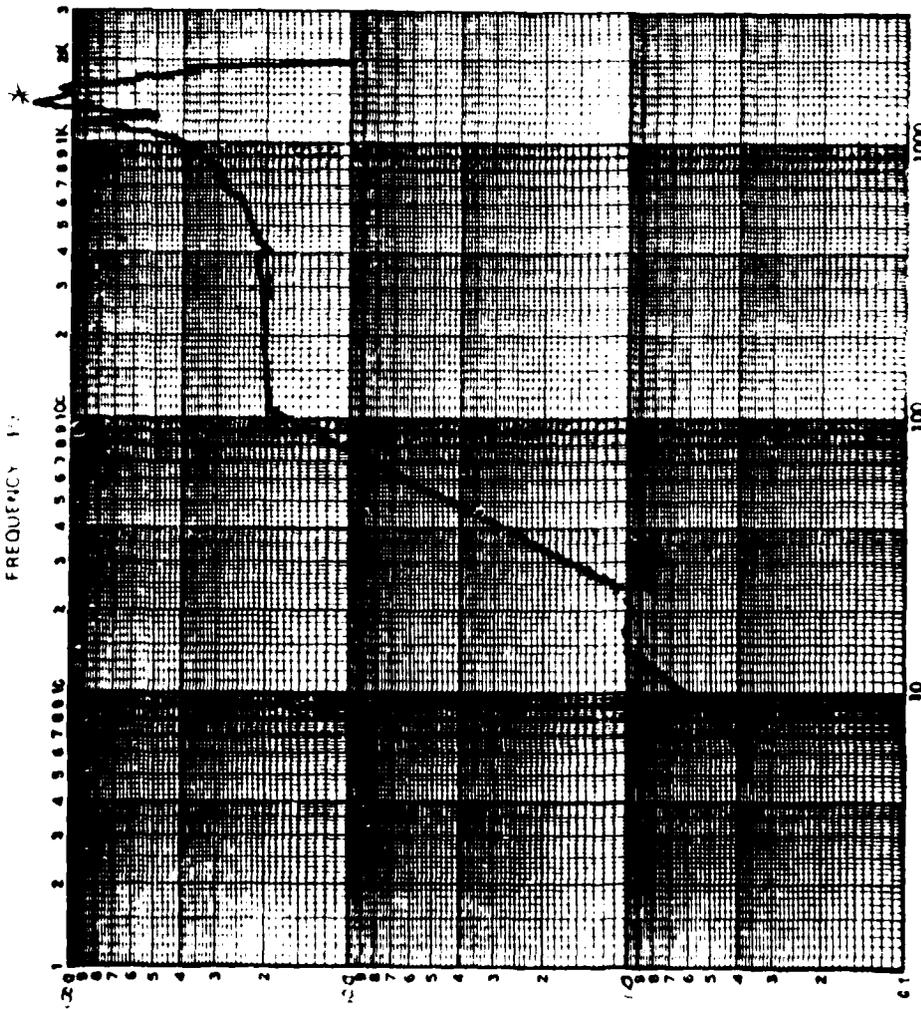
Specification: MIL STD 883C METHOD 5142

Procedure: I

Performed by: J. J. STEINBERG

Test Engineer: B. MARTIN

Witnessed by:



PILOT NO 7

AT'S & CONDITION: X - 612.2 - PICKUP SIN & LOCATION: RESISTANCE PICKUP SENSITIVITY: 100 CAL RANGE: 100 g/100
 TIME:

GENERAL MV RMS: GRMS: SAMPLE PERIOD: SEC ANALYZER FILTER: ENSEMBLES: AVG TIME: MV RMS: ENGLED TO: TIME: SEC ANALYZER FILTER: MV RMS:

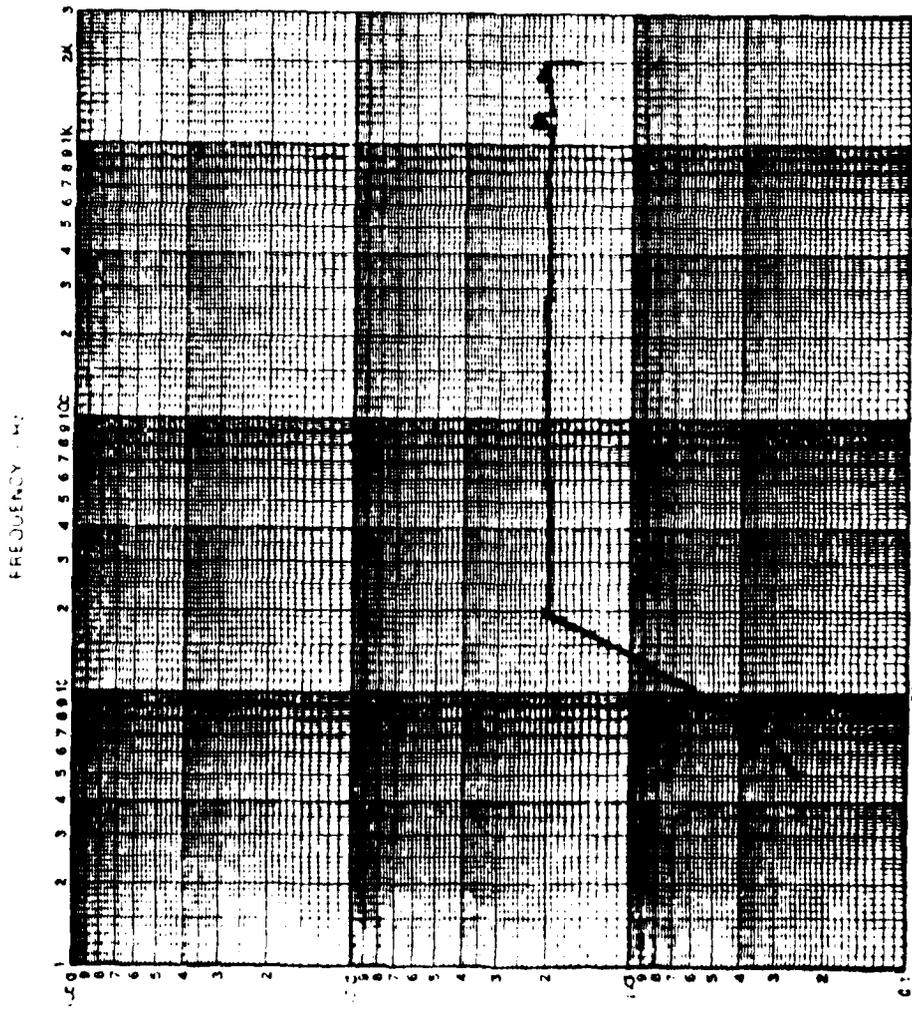
ENSEMBLES: AVG TIME: SEC ANALYZER FILTER: MV RMS: *J. J. Steinberg*



APPROVED ENGINEERIN... LABORATORIES

M/J N 543-8901
P/N 90313
MATERIAL BEHAVIOR
PART NUMBER 77907
DATE 8-18-80

TEST SINE VIBRATION
SPEC MIL STD 883C METHOD 2002
PART PROCEDURE I
PERFORMED BY J W STRATTON
TEST ENGINEER BJ MARTIN
WITNESSED BY



PLOT NO 8

AXIS CONDITION 2 - RMS PICKUP S/N & LOCATION CONTROL PICKUP SENSITIVITY 100
TIME 1104
OVERALL M/RMS GRMS SAMPLE RANGE CAL RANGE
ENSEMBLES AVG TIME SEC ANALYZER FILTER HZ BW ENSEMBLES AVG TIME SEC ANALYZER FILTER HZ BW
ENSEMBLES AVG TIME SEC ANALYZER FILTER HZ BW OPERATOR DJW Stanton



APPROVED ENGINEERING ESTABLISHMENTS

M/C N 543-2901

P.C. N. 90313

CUSTOMER METAL BELLOWS

TEST ITEM HIGH PRESSURE HYDRAULIC ASSEMBLY

PART NO. 77907

SERIAL NO.

DATE 9-13-82

TEST: SINE VIBRATION

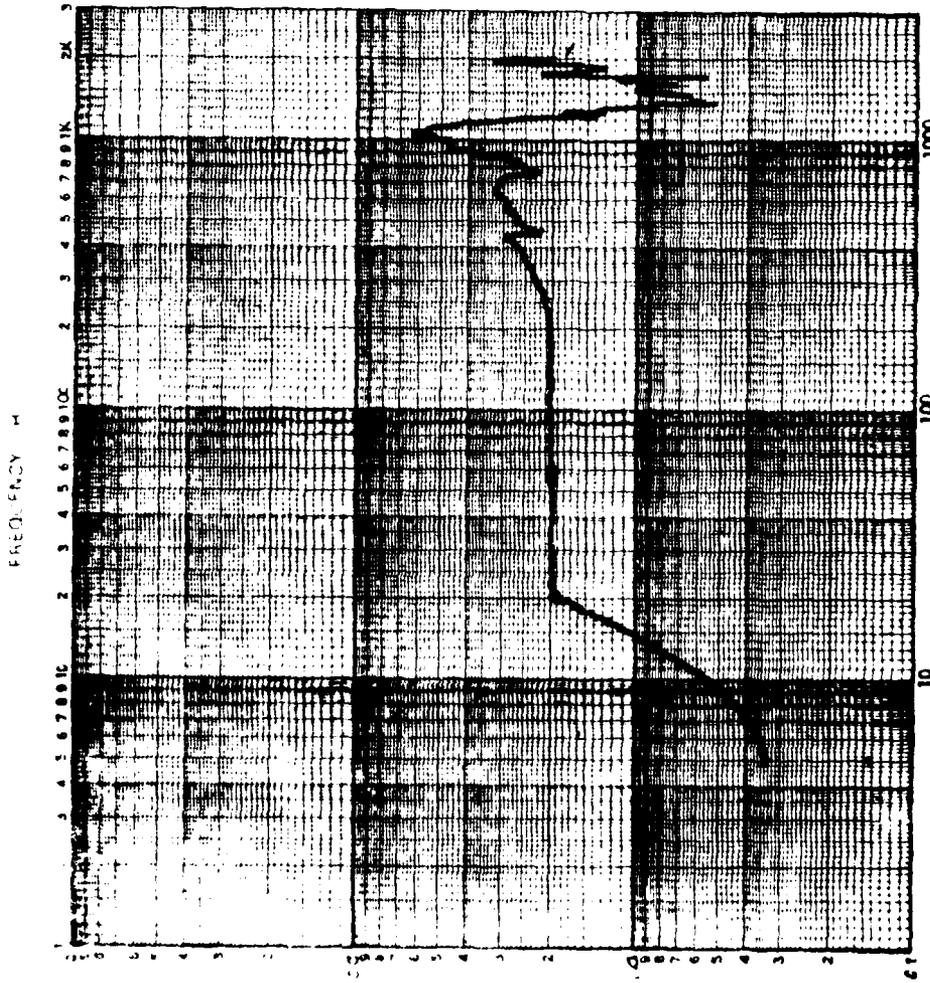
SPECIFICATION MIL-STD-883C METHOD 514.2

PROCEDURE I

PERFORMED BY D.W. STAMON

TEST ENGINEER R. MARTIN

WITNESSED BY



PLOT NO 9

AT C & CONDITION PICKUPS IN & LOCATION REVERSE PICKUP SENSITIVITY 10.0 GRMS GRMS TOP LINE 10.0 g peak

GENERAL MY RMS CAL RANGE

ENSEMBLE AVERAGE TIME SEC ANALYZER FILTER HI BW ENSEMBLES AVERAGE TIME SEC ANALYZER FILTER HI BW

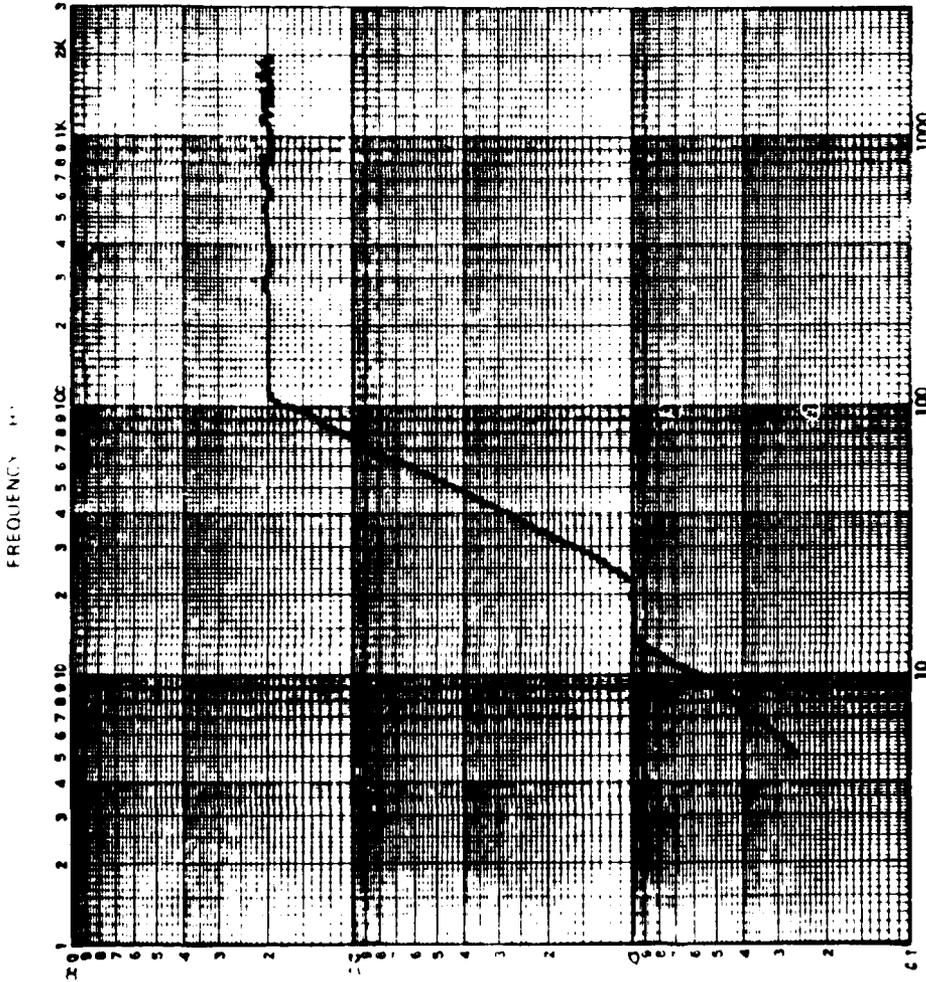
OPERATOR *D.W. Stamon*



APPROVED ENGINEERING LABORATORIES

MJG No: 543-2901
 P.O. No: 90313
 Customer: METAL BELLOWS
 Test Item: HIGH PRESSURE HOUSING ASSEMBLY
 Part No: 77907
 Serial No: 1
 Date: 9-14-50

Test: SINE VIBRATION
 Specification: MIL-STD-883C Method 514.2
 PAF: PROCEDURE I
 Performed By: J. COSTANTINO
 Test Engineer: B. MARTIN
 Witnessed By: [Signature]



PLOT NO. 10

AVG & CONDITION: V. RMS PICKUP SIN & LOCATION: CONTROL PICKUP SENSITIVITY: 100 mV/MS GRMS: TOP LINE 100.0 g/MS
 TIME: 10.00
 OVERALL MV RMS: GRMS: SAMPLE RANGE: CAL RANGE:
 ENSEMBLES: AVG TIME: SEC ANALYZER FILTER: HY BW: ENSEMBLES: AVG TIME: SEC ANALYZER FILTER: HY BW:
 ENSEMBLES: AVG TIME: SEC ANALYZER FILTER: HY BW: OPERATOR: J. Costantino



543 194

2053

METAL BEAM

MID-OF-2000-2000-2000

77967

5000-5000-5000

DINE V BRITV

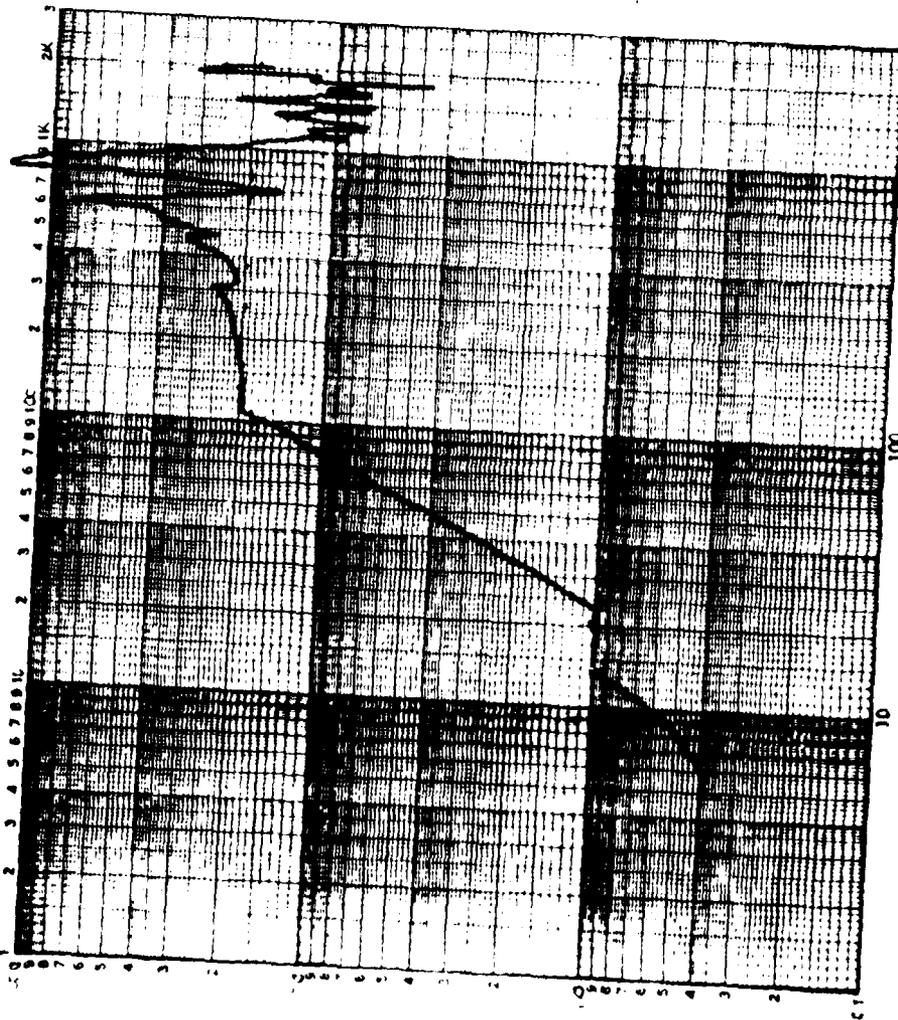
MUSTE... K...

PROCEED

200 STRAIGHT

2000 N 271

FREQUENCY - Hz



PLOT NO 71

PICKUP SITE & LOCATION

4 - 4MB

CONDITION

100

GRAMS

SAMPLE RANGE

SEC ANALYZER FILTER

4000

4000

4000

4000

4000

4000

4000

4000

4000

DATA SHEET REPORT No. 55556

WYLE LABORATORIES

May 23, 1980

Metal Bellows Corp.
20960 Knapp Street
Chatsworth, CA 91311

ATTENTION: Mr. John Huffman
TEST TITLE: Pressure Cycling and Endurance
REFERENCES: Your Purchase Order No. 89727
Wyle Laboratories Job No. 55556
Government Contract No. N/A

Gentlemen:

This is to certify that the enclosed Test Data Sheets contain true and correct data obtained in the performance of the test program as set forth in your purchase order.

Where applicable, instrumentation used in obtaining this data has been calibrated using standards which are traceable to the National Bureau of Standards.

Test Results:

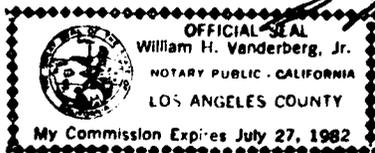
One Accumulator, P/N 77189, S/N Qual 1, was subjected to the Pressure Cycling and Endurance Test in accordance with the requirements of MIL-A-8897 A, Paragraph 4.7.5, Table I. Step 7. The specimen complied with specification requirements. The enclosed data is presented for your evaluation.

Enclosures: Data Sheets (1 Pages) ; Equipment List (1 Page)

STATE OF CALIFORNIA }
COUNTY OF LOS ANGELES } ss.

C. D. Yiakas, Department Manager, being duly sworn, deposes and says: That the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

SUBSCRIBED and sworn to before me this 27 day of May, 1980



W-781

64

DEPARTMENT Mechanical Systems

TEST ENGINEER *A. Snow*
A. Snow

TEST WITNESS

Not Applicable

DCAS-QAR VERIFICATION

QUALITY CONTROL *W. B. ...*

DATA SHEET

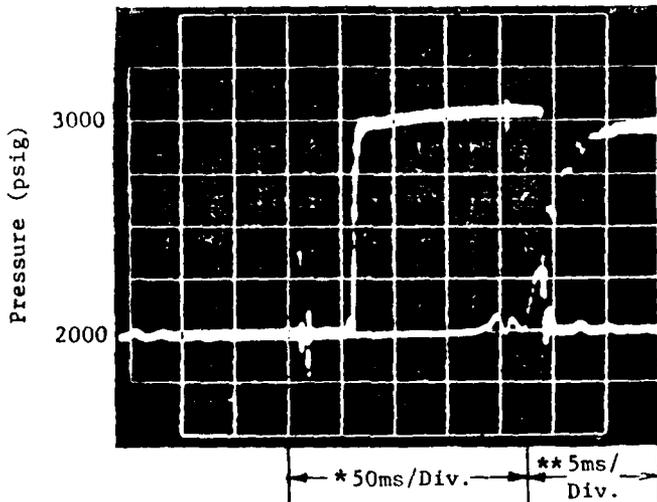
Test Title: Pressure Cycling and Endurance

Customer Metal Bellows Corp.
 Specimen Accumulator
 Part No. 77139
 S/N Qual 1
 Spec. MIL-A-8897A
 Para. 4.7.5, Table I, Step 7

Job No. M55556
 Date Test Started 5-16-80
 Date Test Completed 5-22-80
 Amb. Temp. 70 ± 10°F
 Photo No.
 Test Med. MIL-H-5606
 Specimen Temp. Room Ambient

Procedure and Results:

The specimen was installed in a test system similar to that depicted in Figure 2 of the above referenced specification. The system was adjusted so that a pressure rise rate of 125,000 to 200,000 psi per second was achieved. The specimen was then subjected to 1,000,000 pressure cycles from 2,000 psi maximum to 3,000 psi minimum at a cycle rate of 143 ± 2 cpm. The test fluid was maintained at $100 \pm 15^\circ\text{F}$ for the duration of the test. Upon completion of the 1,000,000 pressure cycles, the specimen was removed from the test system and visually examined. There was no apparent damage, degradation or deformation. A typical pressure cycle, including the rise rate, is shown below.



*Typical Cycle
 **Typical Rise Rate

Specimen Meets Spec. Requirements YES NO

Q. C. Form Approval Art

Tested By D. L. Haynes Date: _____
 Witness _____

65 Sheet No. 6 of _____
 Approved W. A. ... Date: 5-23-80

DATE
ILME