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MANUFACTURING AND TEST PROCEDURES FOR AEROBEE 350 BURST DIAPHRAGMS

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BY

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OCTOBER 1966

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

X-284-66-479

MANUFACTURING AND TEST PROCEDURES FOR AEROBEE 350 BURST DIAPHRAGMS

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Experimental Fabrication and Engineering Division

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Greenbelt, Maryland

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MANUFACTURING AND TEST PROCEDURES FOR AEROBEE 350 BURST DIAPHRAGMS

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ABSTRACT

A manufacturing process developed for producing high quality fuel and oxidizer burst diaphragms for the Aerobee 350 propellant start valves is described. It is shown that extremely close control of material and processing variables is necessary to attain the high degree of repeatability of burst pressures required.

MANUFACTURING AND TEST PROCEDURES FOR AEROBEE 350 BURST DIAPHRAGMS

OBJECTIVE

The goal of this program was to develop a method for fabricating high quality burst diaphragms for use in the Aerobee 350 propellant start valves. The diaphragms were made in accordance with GSFC drawing GC1182577 which was based on the dimensional requirements of Space General Corporation drawing 1103290. Desired burst pressures were 350 psi ± 25 psi (fuel) and 200 psi ± 25 psi (oxidizer).

A pressure testing capability was required during production to establish the proper depth of the shear groove; in addition, the desired test plan included bursting numerous diaphragms as production proceeded.

AUTHORIZATION

The Experimental Fabrication and Engineering Division was authorized by Work Request No. 72-1170-6 of February 28, 1966, submitted by the Flight Performance Section, Sounding Rocket Branch, Spacecraft Integration and Sounding Rocket Division, to develop, manufacture, test, and deliver suitable burst diaphragms.

INTRODUCTION

Burst diaphragms furnished by Space General Corporation for use in the Aerobee 350 propellant start valves were found to have erratic burst pressures, resulting in unpredictable oxidizer-fuel start sequences. Cross sections of several diaphragms revealed wide variations in the geometries and depths of the shear sections, indicating a lack of process control and inspection. The required test sequence should have resulted in rejection of these diaphragms, but they were somehow accepted and delivered. The validity of the pressure tests used for statistical acceptance testing was, to say the least, questionable.

In an effort to secure diaphragms having acceptable reliability and consistency, the Sounding Rocket Branch authorized both the Experimental Fabrication and Engineering Division and Space General Corporation to manufacture and test additional burst diaphragms. Space General Corporation elected to machine or engrave, while the Experimental Fabrication and Engineering Division preferred to stamp or coin the shear groove. Regardless of the method used, it was realized that rigid process control would be required throughout the manufacturing sequence to attain the required consistency of burst pressures.

GSFC PROCEDURE

Description of Diaphragm

The burst diaphragms for use in the Aerobee 350 fuel and oxidizer start valves were designed to rupture through an annular shear groove upon being subjected to a predetermined pressure differential. The diaphragms were made by coining the shear groove into premachined blanks in accordance with Figure 1, GSFC drawing GC 1182577.

Material Selection

Flat sheets of 0.020-inch thick aluminum alloys 1100-H14 and 3003-H14 meeting the requirements of Federal Specification QQ-A-250 were procured for this project. Previous drawings for the diaphragms had specified alloy 3003-H14, but alloy 1100 seemed a better choice to us because of its lower strength and inherently better homogeneity. A low shear strength was desired to maximize the thickness of the shear section. The thickness tolerance of the sheet material, although well within the allowable limits of Federal Specification QQ-A-250, was of no concern because the coining die was designed to leave a predetermined shear section in material up to 0.032-inch thick.

Samples were cut from representative sheets of each alloy for chemical analyses to confirm that the material met the chemical requirements of Federal Specification QQ-A-250. Results of the chemical analyses are shown in Appendix A.

Tensile test specimens were made from representative sheets of each alloy to determine the mechanical properties. Type F2 tensile specimens were machined and tested in accordance with Federal Test Method Standard 151a. Since the diaphragms were to be annealed after coining, some of the tensile specimens were annealed before tensile testing. Results of the mechanical tests are shown in Appendix B.

NOTES:

1. REMOVE ALL BURRS & SHARP EDGES
2. APPLY CHROMATE CONVERSION COATING PER MIL-C-5541
3. THE "T" DIM SHALL BE DETERMINED ON TEST PARTS USING THE SPECIFIED BURST PRESSURE AS THE CONTROLLING FACTOR. 10-PARTS COINED FROM IDENTICAL SET-UP MUST FALL WITHIN SPECIFIED RANGE BEFORE MAKING A PRODUCTION RUN.
4. MATL TO BE ANNEALED AT 700°F FOR 1/2 HOUR PRIOR TO AND FOLLOWING COINING.
5. MARK PARTS WITH RUBBER STAMP IN COLORED INK AS PER NOTES IN LEGEND BLOCK. STAMP DIAPHRAGMS IN AREA NOTED. PART NO., DASH NO. AND NOMINAL BURST PRESSURE.
6. FOR REF ONLY [SIM. TO SPACE GENERAL CORP. DWG. NO. C-1103290-]

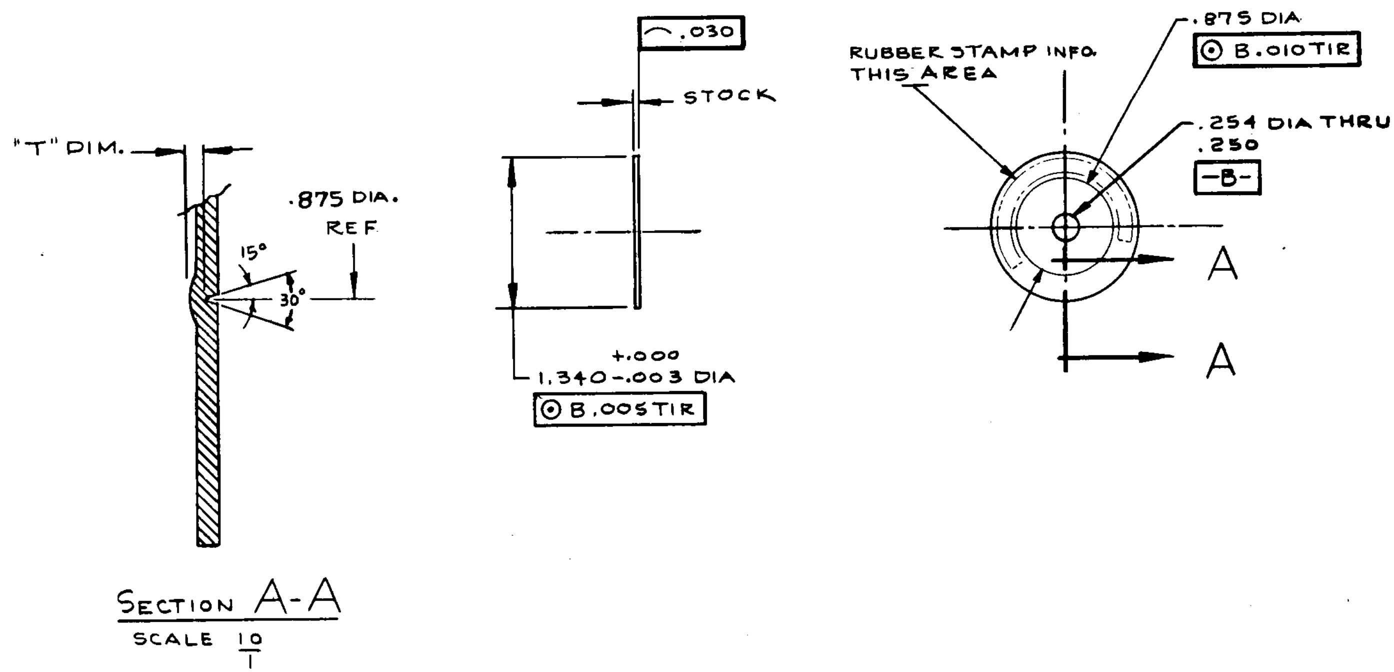


Figure 1–Drawing, Burst Diaphragm

Coining Die Design

The coining die assembly used for imparting the shear groove into the premachined blanks was designed by the Fabrication Engineering Branch, GSFC, and fabricated per Figure 2, GSFC drawing GF 1182156. The thickness of the shear section is determined by the thickness of shim strips placed under the spacer ring (Find No. 6, Figure 2). Since the die assembly leaves a predetermined section under the groove rather than a predetermined groove depth, thickness variations of the aluminum disks have no effect on the resulting burst pressure. The die assembly is capable of accepting disks up to 0.032-inch thick.

Design of Pressure Test Assembly

A burst pressure testing capability was required to determine the thickness of the shim required under the spacer ring, and for acceptance tests of randomly selected diaphragms from production runs. A semiautomatic pressure test assembly was designed by the Fabrication Engineering Branch, and assembled in accordance with the schematic shown in Figure 3, GSFC drawing GC 1182580. A pneumatically operated diaphragm clamping assembly that simulated the Aerobee valve body was incorporated into the pressure test assembly to provide repeatability of the clamping force and a rapid testing rate. The machined parts simulating the Aerobee valve are shown in Figure 4, GSFC drawing GE 1182020. An actual Aerobee valve body was also included in the pressure test assembly for use in final acceptance tests.

Fabrication Procedure

A. Outline

1. Blanked oversize disks with 0.250-inch center hole.
2. Stacked on mandrel, reduced OD to 1.340 inches ± .002-inch.
3. Solvent cleaned
4. Annealed
5. Coined
6. Annealed
7. Applied chromate conversion coating
8. Applied part number and pressure rating with rubber stamp
9. Tested.

NOTES:

1. UNLESS OTHERWISE SPECIFIED:

   REMOVE ALL BURRS AND SHARP EDGES.

   INSIDE RADII .010 ± ___ OUTSIDE RADII .010 ± ___

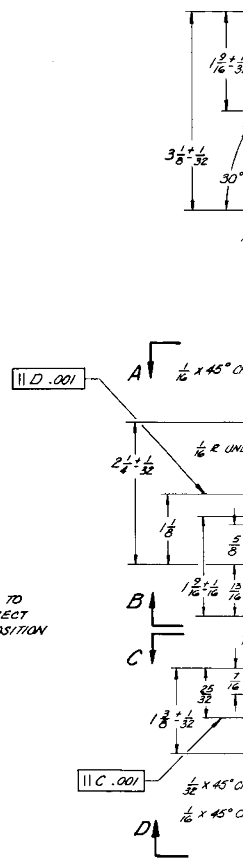
   SURFACE ROUGHNESS ______ 125 ______ AA FINISH

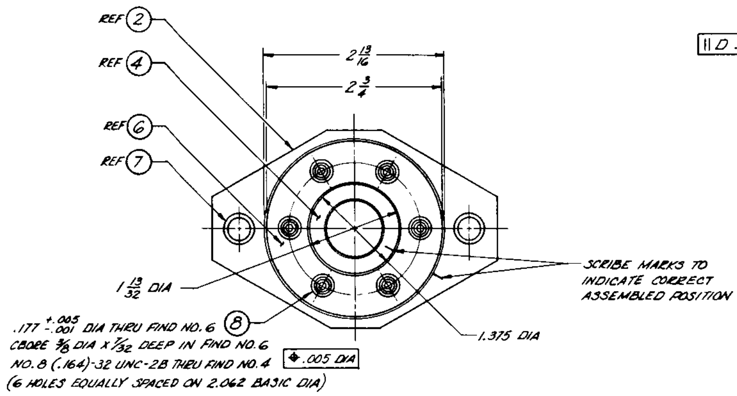
2. INTERPRET DRAWING IN ACCORDANCE WITH THE FOLLOWING DOCUMENTS: (WHERE APPLICABLE)

DIMENSIONS AND TOLERANCES	MIL-STD 8
SCREW THREAD SYMBOLS	MIL-STD 9
SURFACE ROUGHNESS	MIL-STD 10
ABBREVIATIONS	MIL-STD 12
SCREW THREAD STANDARD	NAT. BUREAU STD. HANDBOOK H-28
WELDING SYMBOLS	AWS A2.0-58
HEAT TREATMENT	MIL-H-6875C

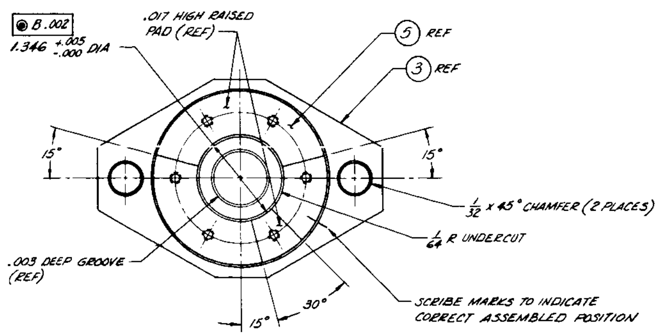
3. HEAT TREAT FIND NUMBERS 4, 5 & 6 AS FOLLOWS:
   (A) HOLD AT 1800°-1900° F FOR 30 MINUTES.
   AIR QUENCH.
   STRESS RELIEVE AT 375° F FOR ONE HOUR
   (HARDNESS AFTER TREATMENT TO BE ROCKWELL C56, OR ABOVE)

4. MACHINING CENTERS ARE PERMISSIBLE IN BOTH ENDS OF FIND NO. 4 & 5





VIEW B-B



VIEW C-C

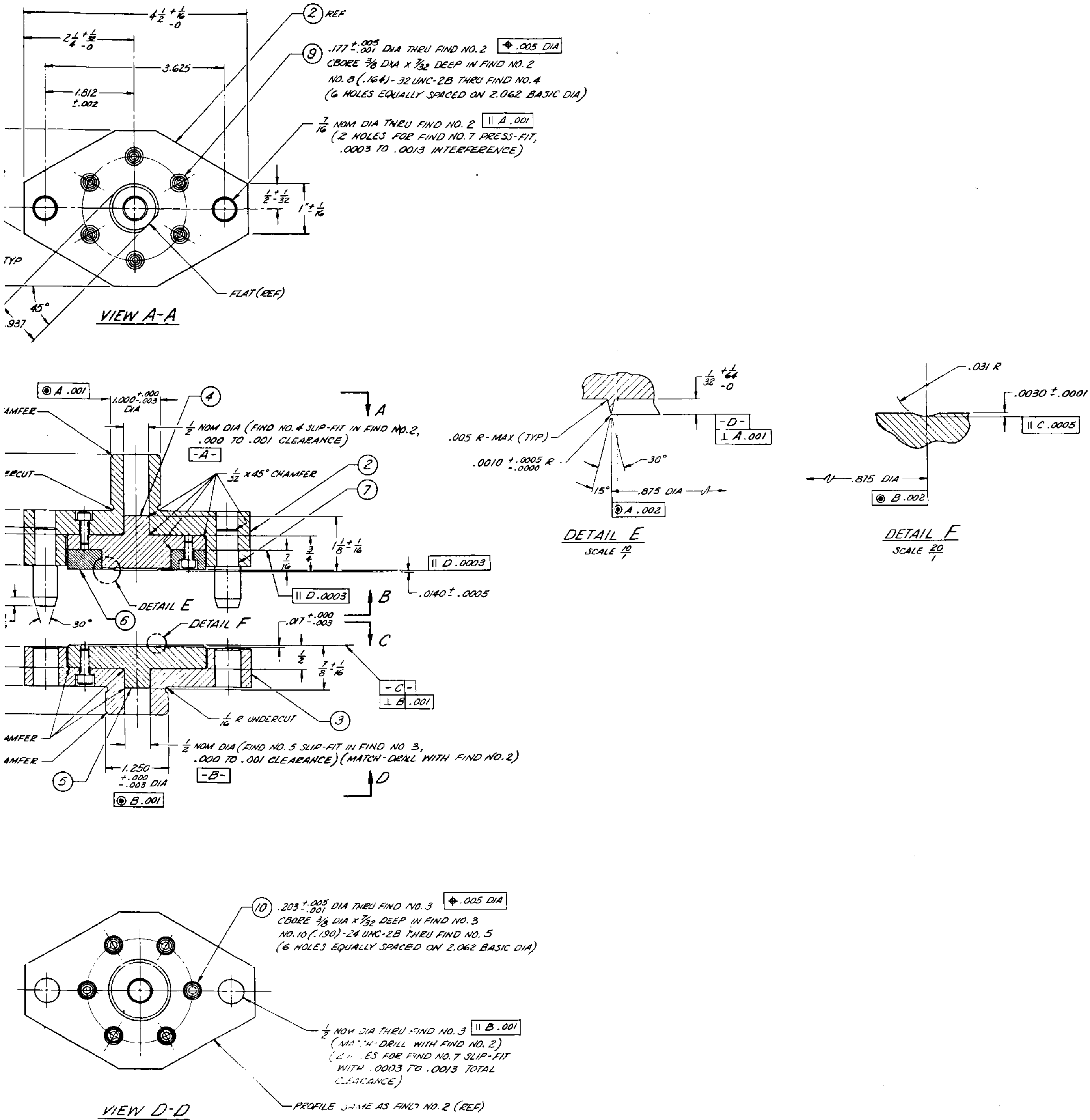


Figure 2–Drawing, Coining Die

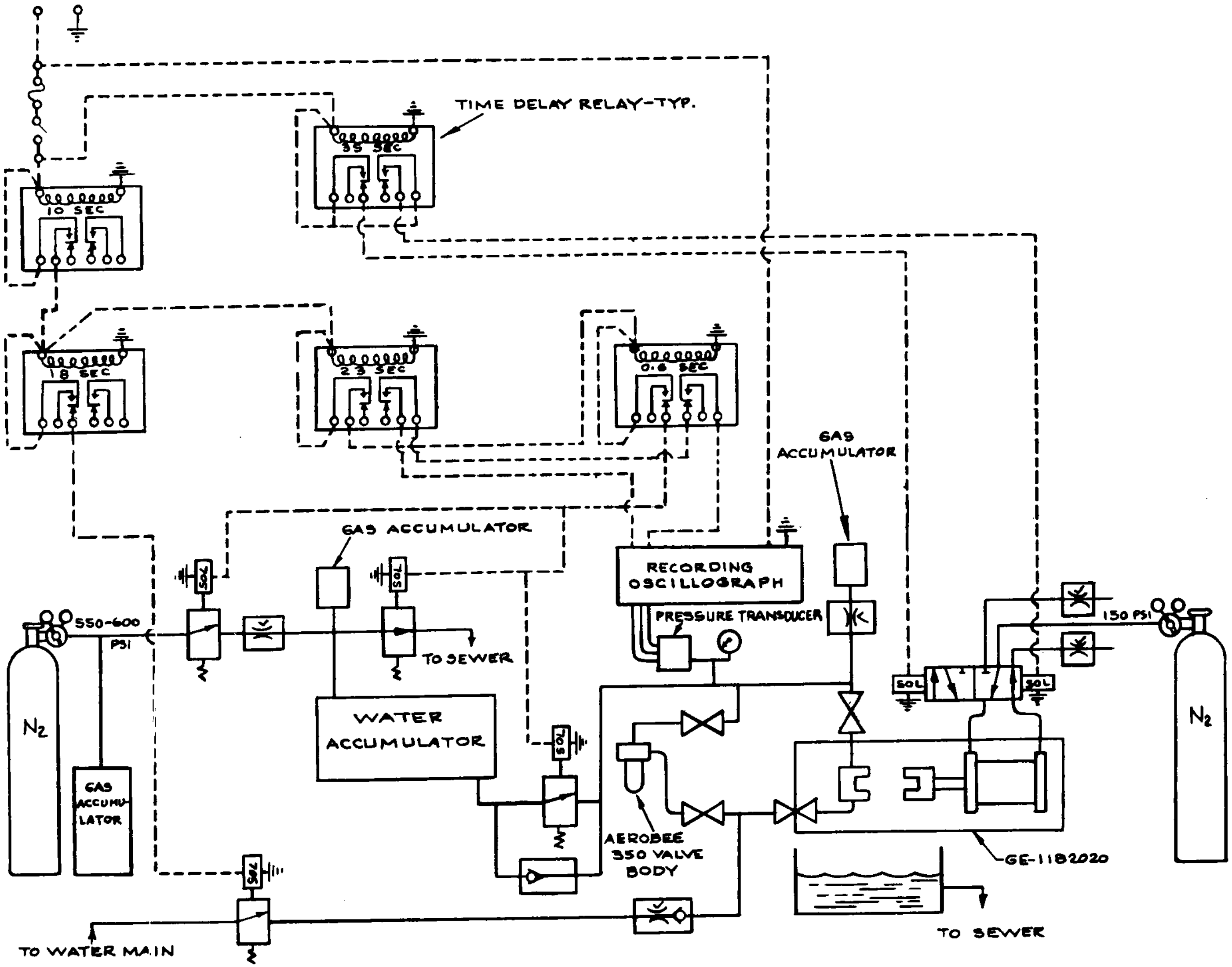


Figure 3–Drawing, Pressure Test Assembly

NOTES:

1. UNLESS OTHERWISE SPECIFIED:

   REMOVE ALL BURRS AND SHARP EDGES.

   INSIDE RADII .005 ± OUTSIDE RADII .015 ±

   SURFACE ROUGHNESS 125 AA FINISH

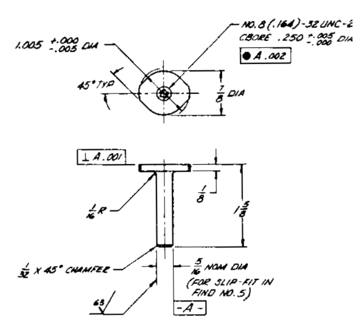
2. INTERPRET DRAWING IN ACCORDANCE WITH THE FOLLOWING DOCUMENTS WHERE APPLICABLE

DIMENSIONS AND TOLERANCES	MIL-STD 8
SCREW THREAD SYMBOLS	MIL-STD 9
SURFACE ROUGHNESS	MIL-STD 10
ABBREVIATIONS	MIL-STD 12
SCREW THREAD STANDARD	NAT. BUREAU STD. HANDBOOK H-28
WELDING SYMBOLS	AWS A2.0-58

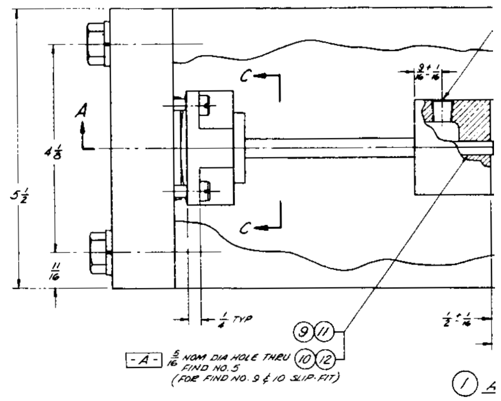
3. SUGGESTED SOURCE: HYDRO-LINE MANUFACTURING CO., ROCKFORD, ILLINOIS

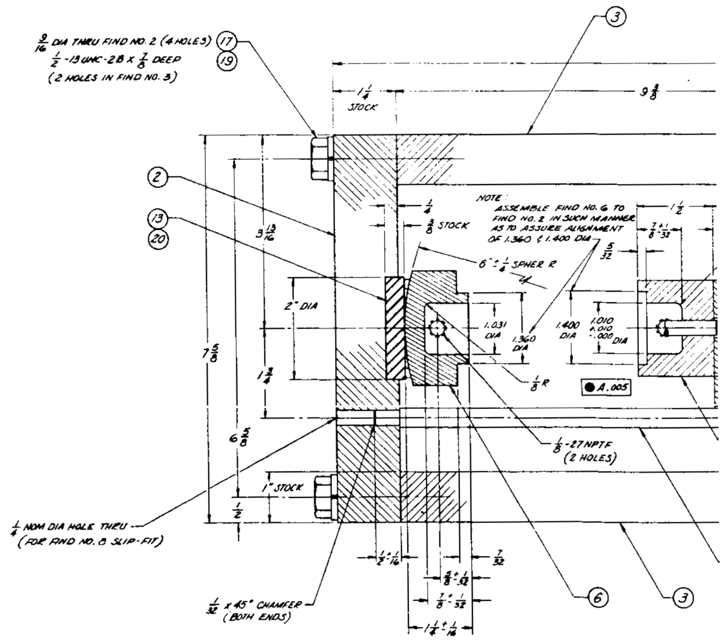
4. PASSIVATE PER MIL-F-14072, TABLE III, FINISH NO. E300

5. SUGGESTED SOURCE: PIC DESIGN CORP, EAST ROCKAWAY, NEW YORK, (OR EQUAL)



E1182020-9 DETAIL





SECTION A-A

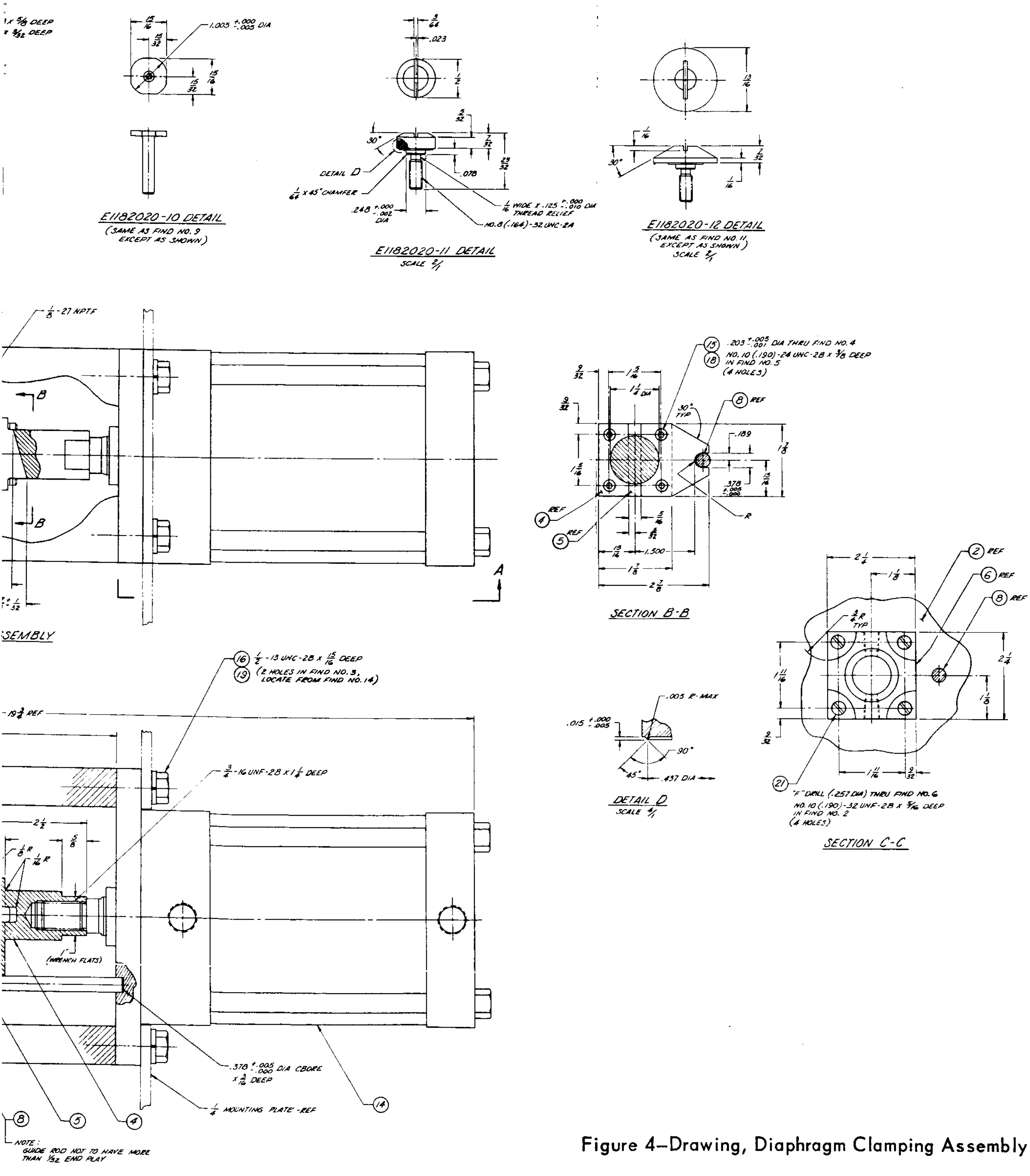


Figure 4–Drawing, Diaphragm Clamping Assembly

B. Details

1. Oversize blanks with the 1/4 inch diameter center hole were punched from 0.020-inch 1100-H14 sheet material. All blanks used for adjusting the coining die, testing, and hardware were blanked from the same sheet of material to eliminate the possibility of variations in burst pressures caused by slight variations in strength from sheet to sheet.

2. The oversize blanks were aligned on a mandrel and the outside diameters reduced to 0.001-inch less than the drawing requirement. A slight increase in the outer diameter occurs during coining. This operation centers the 1/4-inch diameter hole with the outside diameter in addition to providing a burr free edge. Future diaphragms having locating lugs or "ears" will require fabricating two blanking die sets. Blanking and deburring would then follow.

3. Marking ink, grease, oil, etc., were removed by ultrasonic cleaning in trichloroethylene.

4. Blanks were annealed by holding at 700°C for 30 minutes. Annealing was done at this time to allow the coining operation to be performed in soft material. This offered the advantages of less die wear and less spring-back of the material under the coined area.

5. The coining operation was performed in a single throw 5-ton punch press using the bottoming die set. Precautions were taken to insure that the die faces slammed together at the bottom of each coining stroke.

6. After coining, the blanks were again annealed at 700°F for 30 minutes to relieve the effects of work hardening in the shear section.

7. All diaphragms were subjected to a chromate conversion treatment to increase corrosion resistance. It was determined that with even the utmost care in cleaning prior to coating, enough metal was etched from the shear section to reduce the average burst pressure by 7 to 10 psi. The complete cleaning and chromate conversion coating procedure was as follows:

   a. Disks were racked on a wire frame to allow all surfaces to be exposed.

   b. Vapor degreased in trichloroethylene.

   c. Ultrasonically cleaned in a hot detergent solution.

   d. Rinsed in hot water.

e. Etched in sodium hydroxide solution. Extreme care was necessary to minimize the etching action. A two-second time interval between entering the etch cleaner and entering the rinse tank was used as a guideline.

f. Rinsed in water.

g. Desmutted in sodium dichromate solution for 30 seconds.

h. Spray rinsed.

i. Immersed in agitated Iridite[1] chromating bath.

j. Rinsed in hot water.

k. Dried.

8. Part numbers and nominal burst pressure ratings were rubber stamped on each diaphragm.

9. The required number of samples were tested in the pressure test system. In tests for die shim settings, 10 samples were fabricated and tested. After the desired die setting was established, production began. Diaphragms were coined in batches of thirty which were segregated throughout the manufacturing process. Ten samples, randomly selected from each batch, were tested; the remainder of each batch was held for delivery pending results of these burst pressure tests.

RESULTS

Table 1 contains burst pressure data recorded in tests to determine the size of the shim required under the die spacer ring for the 350 psi diaphragm. Group H consisted of both bare and coated samples to determine the effect of the coating process.

[1]Registered Trademark "Allied Research Products, Inc."

Table 1
Burst Pressure Data 350 Psi Die Setting Tests

TEST CONDITIONS	RATE 700 psi/sec									
	PNEUMATIC RAM									
	40 psig									
GROUP	A	B	C	D	E	F	G	H		I
								(Bare)	(Coated)	
	285 psi	310 psi	390 psi	350 psi	370 psi	368 psi	352 psi	350 psi	340 psi	348 psi
	285	330	380	355	365	365	362	345	345	358
	275	310	390	355	375	355	358	350	345	352
	275	320	360	355	390	360	358	342	340	348
	235	335	370	360	375	350	355	355	325	348
	280	300	390	360	365	360	358	342	315	342
	280	320	375	360	370	358	362	342	335	345
	260	315	380	360	375	362	355	355	340	350
	265	300	385	360	370	358	352	340	335	362
	275	320	390	360	375	362	348	352	338	
				365		362	362	340	338	
				365		352		340	335	
				365				345	338	
				375				355	335	
				380				350	340	
								352	345	
								348	335	
								358	345	
								350	350	
								358	340	
								352	345	
								358	345	
								352	345	
								358	340	
								345	340	
AVERAGE (psi)	271.5	316.0	381.0	361.6	373.0	359.3	356.3	349	339	350.3
STD. DEVIATION (psi)	14.62	10.90	9.81	7.45	6.78	4.9	4.4	7.93	6.64	8.1

After arriving at a suitable shim setting, the burst pressures in Table 2 were recorded for samples selected from production runs:

Table 2
Burst Pressure Data Production Runs

TEST CONDITIONS	RATE 700 psi/sec								
	AEROBEE VALVE BODY							PNEUMATIC RAM	
	78 in-lb Torque						45 in. lb. Torque	150 psig	
GROUP	HP1	HP2	HP3	HP4	HP5	HP9	HP6	HP7	HP8
	352 psi	370 psi	390 psi	360 psi	360 psi	370 psi	390 psi	375 psi	372 psi
	368	360	355	355	341	380	379	375	360
	355	360	358	360	345	355	369	365	365
	350	350	358	355	355	355	355	365	370
	372	360	348	368	365	355	382	370	370
	342	355	365	371	365	355	358	365	360
	345	360	370	365	360	370	360	362	370
	357	368	365	361	348	380	370	360	355
	348	370	365	352	369	355	370	375	375
	342	355	–	355	341	360	355	368	365
							370		
							358		
AVERAGE (psi)	353.1	360.8	363.7	360.2	354.9	363.5	368	368	366.2
STD. DEVIATION (psi)	9.74	6.39	10.8	5.91	9.93	10.0	10.86	5.19	6.0

The die was prepared for oxidizer diaphragm production by changing the spacer ring and repeating the shimming and testing procedure until the desired burst pressure was obtained. The burst pressures in Table 3 were recorded in the shim setting tests:

Table 3
Burst Pressure Data 200 Psi Die Setting Tests

TEST CONDITIONS	RATE 700 psi/sec				
	PNEUMATIC RAM				
	40 psig				
GROUP	J	K	L	M	N
	130 psi	185 psi	202 psi	205 psi	192 psi
	125	190	188	208	195
	125	195	192	215	195
	135	190	185	225	198
	125	195	185	210	202
	138	200	175	210	196
	133	180	200	210	205
	128	182	190	208	199
	128	185	192	205	202
	132	185	188	208	215
	130		212		
	140				
	135				
	132				
	130				
AVERAGE (psi)	131.1	188.7	191.4	210.4	199.9
STD. DEVIATION (psi)	4.6	6.1	9.8	5.6	6.3

With the die shim setting established, the burst pressures in Table 4 were recorded for samples selected from the production runs:

Table 4
Burst Pressure Data 200 Psi Production Runs

TEST CONDITIONS	RATE 700 psi/sec					
	PNEUMATIC RAM					
	40 psig					
GROUP	A2	B2	C2	D2	E2	F2
	195 psi	205 psi	200 psi	198 psi	195 psi	198 psi
	205	192	198	200	209	195
	200	195	198	193	195	205
	198	205	200	195	199	200
	195	195	202	202	208	200
	198	202	200	201	200	210
	200	212	195	215	200	200
	195	210	195	198	200	202
	198	198	202	199	208	208
	198	199	199	212	208	199
AVERAGE (psi)	198.2	201.3	198.9	201.3	202.2	201.7
STD. DEVIATION (psi)	2.89	6.3	2.3	6.6	5.2	4.4

Two additional groups of 10 diaphragms each were tested to determine the effect of the pressurization rate upon the burst pressure. One group was tested using double the desired rate, the other using one-half the desired rate. The burst pressures recorded are shown in Table 5.

Table 5
Burst Pressures Recorded in Pressurization
Rate Sensitivity Tests

TEST CONDITIONS	RATE 1400 psi/sec	RATE 350 psi/sec
	AEROBEE VALVE BODY	
	45 in. lb Torque	
GROUP	P	Q
	361 psi	365 psi
	361	350
	356	355
	356	365
	365	351
	348	350
	352	345
	349	368
	370	345
	362	358
AVERAGE (psi)	358.0	355.2
STD. DEVIATION (psi)	6.72	8.0

One sample from each of several lots was quartered and metallurgically cross-sectioned. Microscopic measurements of the shear sections at 4 locations were averaged and are shown in Table 6.

Table 6
Microscopic Measurements of Shear Sections

GROUP	BURST PRESSURE (psig) Ave.	SHEAR SECTION (mils) Ave.
A	271.5	8.01
B	316.0	8.72
C	381.0	9.18
D	361.6	9.01
H	339.0	8.90
I	350.3	8.90
J	131.1	5.43
M	210.4	7.10
N	199.9	6.89

DISCUSSION

A statistical analysis of the data in Table 2, Table 4, and Table 5 indicates that the slight variations in average burst pressures between production groups of diaphragms is due to chance rather than to a change in a processing variable. The clamping force was found to be the only test variable having an appreciable effect on the burst pressure. The method of testing (pneumatic ram or Aerobee valve body) did, however, affect the burst pressures because the clamping forces were not duplicated. Subsequent calculations showed that approximately 160 psig is required on the 5-inch diameter piston of the pneumatic ram to duplicate the clamping force provided by four 1/4-28 bolts at 45-inch-pounds torque in the Aerobee valve body.

A low clamping force allows the edge of the diaphragm to slide over the Teflon washers and the resulting bulge in the diaphragm allows the fracture to occur partially in tension. High clamping forces restrain the edge and failure occurs in shear. Since the tensile strength of the material is inherently higher than the shear strength, low clamping forces produce higher burst pressures. Higher clamping forces produce lower burst pressures until the minimum force required to restrain the edge is reached, beyond which point no further change occurs.

The analysis also indicates that die wear is not significant for the relatively small number of diaphragms produced. Metallographic sections through the shear groove of numerous diaphragms indicated no discernable wear or dulling of the cutter ring. The complete statistical analysis is presented in Appendix C. A photomicrograph of a typical cross section through the shear groove is shown in Figure 5.

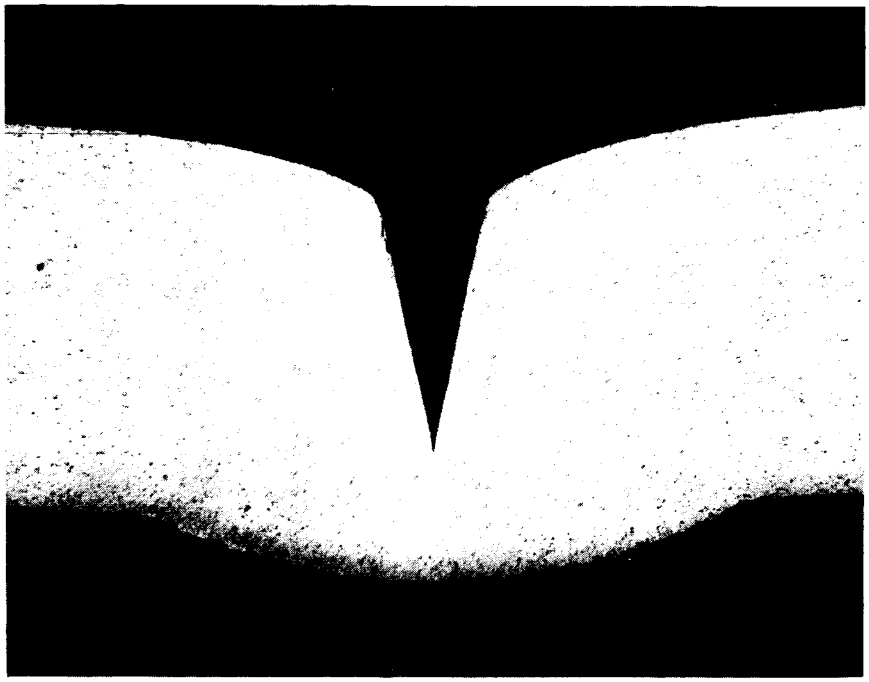


Figure 5—Photomicrograph of Coined Groove

The average burst pressure exhibited a parabolic relationship to the shear section as shown in Figure 6. The shear section t was found to be related to the average burst pressure P by the empirical equation

$$t = \frac{P}{15.03 + 0.0695\,P}$$

for sheet material having the mechanical properties of alloy 1100-0 described in Appendix B.

CONCLUSIONS

1. The coining method of manufacturing provides a simple and repeatable fabrication technique for producing high quality burst diaphragms.

2. The cleaning operation associated with the chromate conversion coating process must be very closely controlled in order to obtain predictable burst pressures.

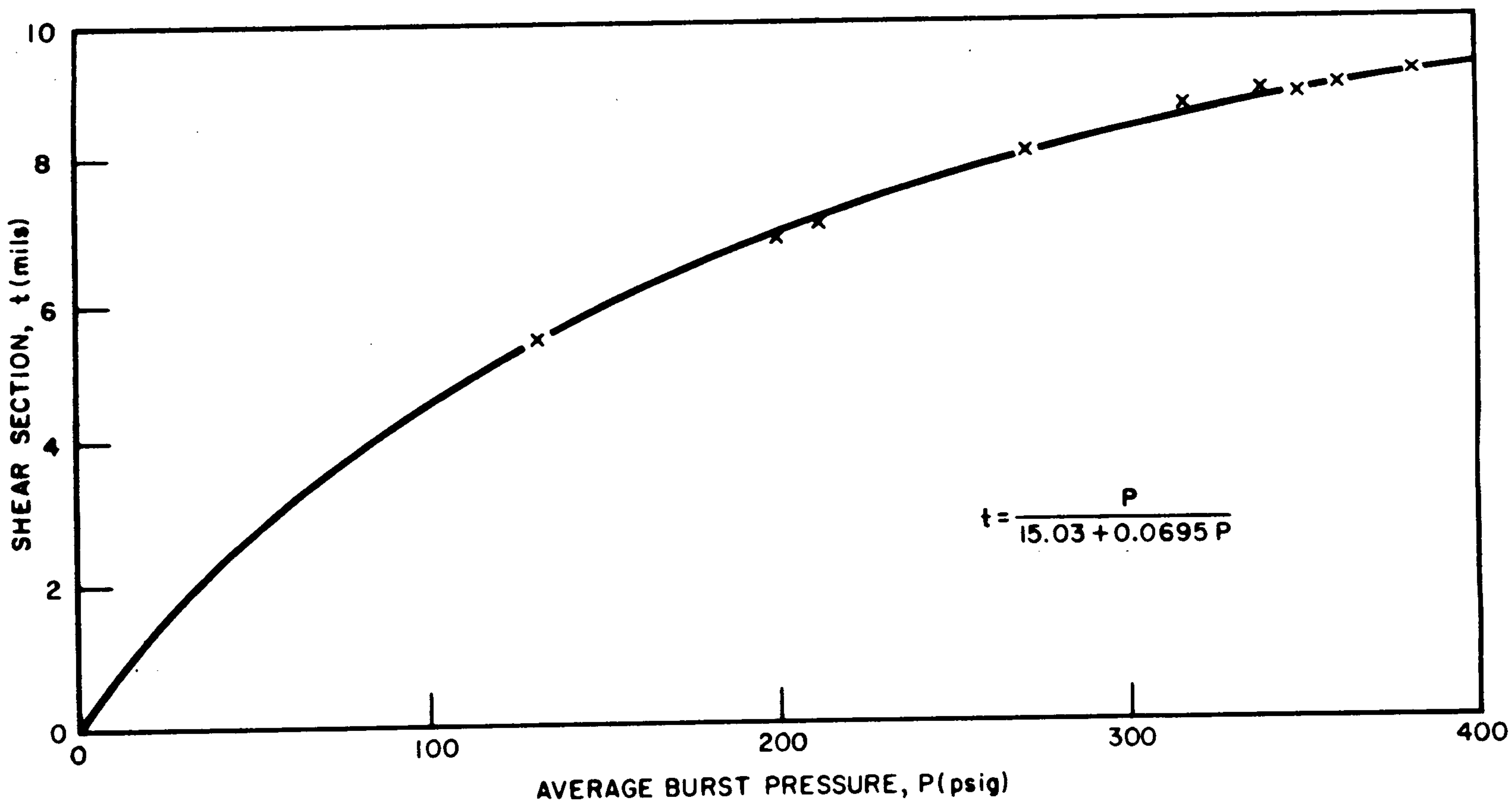


Figure 6–Relation of Burst Pressure and Shear Section

3. The burst pressure is dependent upon the clamping force in the test assembly but is independent of the pressurization rate in the range from 350 to 1400 psi/sec.

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APPENDIX A

RESULTS OF CHEMICAL ANALYSES

Element	Alloy 1100	Alloy 3003
IRON	0.30	0.62
MANGANESE	0.0094	1.27
SILICON	0.14	0.265
MAGNESIUM	0.003	0.003
COPPER	0.15	0.155
TITANIUM	0.0107	0.026
NICKEL	0.000	0.002
CHROMIUM	0.000	0.003
ZINC	0.1	0.060
ALUMINUM	BALANCE	BALANCE

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APPENDIX B

Results of Mechanical Tests 0.020-inch Sheet Material

Specimen No.	Alloy No.	Temper Designation	Direction	Yield Strength (psi)	Tensile Strength (psi)	Hardness Brinell*
1	1100	H14	Longitudinal	15,700	17,375	31-33
2	1100	H14	Longitudinal	15,650	17,825	31-33
3	1100	H14	Transverse	17,350	18,850	31-33
4	1100	H14	Transverse	16,350	19,010	31-33
5	1100	0	Longitudinal	3,540	12,275	20-22
6	1100	0	Longitudinal	3,460	11,905	20-22
7	1100	0	Transverse	3,170	11,385	20-22
8	1100	0	Transverse	2,470	10,395	20-22
9	3003	H14	Longitudinal	21,500	23,000	41-43
10	3003	H14	Longitudinal	20,100	23,200	41-43
11	3003	H14	Transverse	21,300	24,050	41-43
12	3003	H14	Transverse	21,600	23,800	41-43
13	3003	0	Longitudinal	10,300	17,000	28-30
14	3003	0	Longitudinal	8,520	17,035	28-30
15	3003	0	Transverse	10,000	16,500	28-30
16	3003	0	Transverse	8,420	16,435	28-30

*500 kg Brinell, converted from 500 gm Knoop.

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APPENDIX C

STATISTICAL ANALYSIS OF TEST RESULTS OF FUEL DIAPHRAGMS FOR AEROBEE 350 FUEL START VALVE

Prepared by

MELPAR, INC.

On-site Contractor
for
Experimental Fabrication and Engineering Division

Goddard Space Flight Center
Greenbelt, Maryland

SUMMARY

This report presents the results of a statistical analysis of data obtained by NASA/Goddard during the testing of fuel valve diaphragms. Burst strength data were obtained by two different test methods and under various clamp pressures and speeds. The purpose of the analysis was to determine whether:

a. There are differences in burst strength among diaphragms from different process batches,

b. There is a difference in results between the two methods of test, i.e., valve and ram,

c. There is a difference, within either method, in the burst strength between high and low clamp force,

d. There is a difference in burst strength results obtained as the speed of the pressure is varied.

The statistical analysis indicated that there are no differences among batches. All diaphragms of a given type can be considered as members of the same parent population regardless of batch as long as the process is carefully controlled and the diaphragm material is from a uniform source.

There is no difference in the results obtained from the two test methods. However, there is an apparent difference in test results as the clamp force is varied. In the case of both the valve method and the ram method, the higher clamping force resulted in lower burst strengths. The difference was more pronounced in the ram method.

The effect of variations in the speed with which the pressure is applied is not clear. Although the differences in the results obtained at three levels of speed are marginally significant, the highest burst strengths were recorded at the "medium" speed; lower results were noted as the speed was increased or decreased. If a clear picture of the burst strength is desired, then a statistically designed experiment should be performed. Until then, it is recommended that the observed differences be interpreted as due to chance.

INTRODUCTION

It is important to note that this was not a statistically designed experiment. Therefore, the analysis of the data does not follow the classic approach.

Nevertheless, the data was generally useful for the application of statistical methods to arrive at the conclusions listed in the summary. The raw data is available at NASA/Goddard.

Differences Among Batches

In order to safely proceed with the analysis of the data as they pertained to the question of test methods, it was first necessary to establish that data from different batches could be pooled or compared without biasing the results because of real differences among batches. Test results on 350 psi diaphragms using the valve method with high clamp force were available from seven distinct batches. The analysis of variance indicated that there were no differences among batches. Since this type of analysis is predicated on the homogeneity of the variances of the different groups, Bartlett's test for homogeneity was performed. The result validated the analysis. Following, in Table A, is a summary of the analysis of the data. Note that 300 psi was subtracted from each data point to facilitate the mechanics of the analysis.

The same approach was used to analyze the test results on 200 psi diaphragms from six distinct batches. These diaphragms had been tested using the ram method with low clamping force. The analysis indicated that there were no differences among batches. Although Bartlett's test for homogeneity of variances was not significant at the 1% level, there was some evidence that this assumption might not be correct. One type of deviation from homogeneous variance which is serious in terms of invalidating the analysis-of-variance test for means occurs when one variance is very much larger than the others. Cochran's test to evaluate this situation was negative. Therefore, we can feel safe in the conclusion reached on the basis of the analysis which is summarized in Table B. Note that 200 psi was subtracted from each data point to facilitate the mechanics of the analysis.

Differences Between Test Methods and Clamp Forces

In the case of the 350 psi diaphragm, data were collected using two different test methods and, within each method, two different clamp forces were employed. As is frequently the case, little attention was given to the data analysis until the data had been completely collected. Often, such data are difficult, if not impossible, to analyze. However, this particular set of data falls into a form which can be regarded as a nested experiment.

Table A

Batch	n	ΣX	ΣX^2
1	10	531	29143
2	10	608	37374
3	9	574	37732
4	10	602	36590
5	7	391	22381
6	10	635	41325
7	8	517	33865
Total	64	3858	238410

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Means	1019.9	6	169.9	2.01
Within	4825.0	57	84.6	
Total	5844.9	63		$F_{.99}(6, 57) = 3.14$

Table B

Batch	n	ΣX	ΣX^2
1	10	-18	116
2	10	13	417
3	10	-11	67
4	10	13	457
5	10	22	324
6	10	17	223
Total	60	36	1604

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Means	134.0	5	26.8	1.00
Within	1448.4	54	26.8	
Total	1582.4	59		$F_{.99}(5, 54) = 3.38$

Since it had already been established that there were no differences among batches, all data, regardless of batch, were classified by test method, and then further classified by the clamp force within each test method. When the data were so treated and analyzed, the results showed that although there was no difference between responses due to test method, i.e., valve vs. ram, the responses were sensitive to the clamp force. When using the valve method of test, the average burst strength was about 6 psi greater at 45 inch lbs. than at 78 inch lbs. The difference was even greater when using the ram method. Here, the lower clamp force yielded burst strengths of almost 16 psi greater than the higher clamp force.

The test for homogeneity of variances supported the analysis. Table C which follows is a summary of the analysis. Note that 350 psi was subtracted from each data point to facilitate the mechanics of the analysis.

Data were collected for the 200 psi diaphragm using the ram method with low clamping force and the valve method with low clamping force. Statistical methods were not used to compare the two groups because it was quite obvious that the responses in the two groups were very much different. The mean of the 60 observations using the valve method was 200.6 psi; the mean of 20 observations using the valve method was only 178.4 psi. These results are not consistent with those obtained for the 350 psi diaphragm. In the latter, there was no difference in test results due to the test method. In fact, the difference between the results for the 200 psi diaphragm, using the two methods, is so large that one might suspect that some other variable is responsible. However, until this has been determined, one can only conclude that, in the case of the 200 psi diaphragm, the method of test does affect the response.

Differences Among Speeds of Pressure

In addition to the 16 observations on the 350 psi diaphragm which were taken using the valve method at 45 inch lbs clamp force with the pressure applied at 700 psi/sec, 12 observations were also taken at 350 psi/sec and 10 observations at 1500 psi/sec. The mean burst strengths were 365 psi, 355 psi, and 358 psi, respectively. The differences in these values were significant at the 5% level but not at the 1% level. This leaves some doubt as to which conclusion is correct. (See Appendix A.) Since the values of the means do not follow either a positive or negative sequence as the speed is increased, it is recommended that we accept the conclusion of no differences among means. It is further recommended that, if the speed is not a controlled parameter, then a test program specifically designed to investigate its effect on the burst strength should be implemented.
A summary of the analysis is shown in Table D. Note that 350 psi has been subtracted from each data point to facilitate the mechanics of the analysis.

Table C

	n	ΣX	ΣX^2
Valve	86	1014	21180
High Clamp Force	64	658	12610
Low Clamp Force	22	356	8570
Ram	31	356	7664
High Clamp Force	11	14	1162
Low Clamp Force	20	342	6502
Total	117	1370	28844

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Total	12802.1	116		
Test Methods	2.1	1	2.1	2.1/1173.9 = 0.0
Clamp Force within Test Methods	2347.8	2	1173.9	1173.9/92.5 = 12.6
Error	10452.2	113	92.5	$F_{(2,\ 113).99} = 4.8$

Table D

	n	ΣX	ΣX^2
350 psi/sec	12	62	1014
700 psi/sec	16	242	6074
1500 psi/sec	10	80	1092
Total	38	384	8180

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Means	740.2	2	370.1	3.64
Within	3559.4	35	101.7	
Total	4299.6	37		

$F_{(2, 35).95} = 3.27$

$F_{(2, 35).99} = 5.27$

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APPENDIX A_1

Whenever we have to make a decision about a general situation based on some incomplete information, we have to recognize the risk of making the wrong decision. If we have to decide whether two test methods are the same or different based on a sample of information taken from both test methods, then there are two types of risks:

1. We can conclude that they are different when, in fact, they are the same. This mistake is called error of Type I. The probability of making this mistake is designated as α .

2. We can conclude that they are the same when in fact they are different. This mistake is called error of Type II. The probability of making this mistake is designated as β .

We can preassign these risks. However, for a given sampling plan, the two risks are inversely related, i.e., if we want to reduce the probability of making one type of mistake, we must be willing to tolerate a larger risk of making the other type of mistake. The only way to decrease both risks is to increase the sample size.

In the statistical analysis where we have concluded that the means were different at a 1% level of significance, we have in effect agreed that we are willing to take a 1% chance that we have made the wrong decision. The analysis tells us that if the means were really the same, there would be less than a 1% chance of obtaining the test results that were recorded. We are therefore 99% confident that a real difference exists.

In those analyses where we have established a 1% level of significance and have concluded no difference between means, we cannot rule out the possibility that a true difference does exist. However, the analysis has told us that there is better than 1% chance that the test results could have come from a situation in which the means were the same. Since we have set a level of significance of 1%, we are not willing to take a chance of 1% or more of concluding that the means are different when they are really the same. Therefore, we accept the conclusion that they are the same.