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DEVELOPMENT OF A FLEXIBLE MAGNETIC PRESSURE SEAL

M. W. OLSON

R. A. FOWKES

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FOREWORD

This exploratory development effort was conducted by Uniroyal, Inc. at their Research Center, Wayne, New Jersey 07470. The work was performed under Air Force Contracts F33615-67-C-1210 and F33615-68-C-1151 and was identified with Project No. 7164, "Aerospace Protective Technology," and Task No. 716411, "Aerospace Pressure Outfits." The work was conducted during the period from February 1967 to December 1968.

Mr. D. Shickman was the Principal Investigator until leaving Uniroyal after which the work was directed by Mr. M. W. Olson and Mr. R. A. Fowkes. The contract monitor for the Aerospace Medical Research Laboratory, Altitude Protection Branch was Mr. D. A. Rosenbaum until his retirement in the summer of 1968 after which the effort was monitored by Mr. J. D. Bowen.

This technical report has been reviewed and is approved.

C. H. KRATOCHVIL, Colonel, USAF, MC
Commander
Aerospace Medical Research Laboratory

ABSTRACT

The application of flexible magnetic rubber seals to slide fasteners to form pressure tight closures was investigated. Several configurations were fabricated using flexible permanent magnet strips of neoprene rubber loaded with barium ferrite. In an attempt to increase attractive forces, neoprene rubber was loaded with carbonyl reduced iron particles to increase magnetic permeability, but the material lacked adequate tear strength. Excess bulk and lack of flexibility constitute the most serious deficiencies. Leakage also was a difficult problem particularly with circumferential closures where bending caused rippling of the seal lips. The final and most successful design utilized magnetic rubber blocks cemented to the back of a flexible rubber strip for the inner seal. Further development will be required prior to application of magnetic seals to closures.

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OBJECTIVE

To develop a flexible magnetic seal that will operate in cooperation with a zipper closure to seal gas in a flexible container at pressures between zero and 12 psig.

DISCUSSION

The problem of developing a magnetic seal for a flexible closure involves: (a) developing materials, (b) developing a design, and (c) fabricating and testing prototypes.

It was assumed from the start that the seal would operate in conjunction with a mechanical zipper which would align the sealing surfaces sufficiently for the magnetic forces to take over. The zipper would bear the loop or burst stress associated with the container configuration and the pressure differential of the system, and the magnetic force would simply have to be sufficient to counteract alignment distortions in the pressurized assembly.

Initial seal designs involved the use of two flexible, overlapping, magnetized flanges positioned to attract one another and seal the gap between them. Rubber impregnated with magnetic particles was used initially. Later, it was found that a single magnetized flange combined with a mating part filled with iron particles was more practical.

MATERIAL DEVELOPMENT

Because of the preponderant usage of Neoprene in other types of flexible structures (fuel cells, pressure suits, containers, shelters, etc.) it was deemed advisable to use this elastomer as the binder for a flexible magnetic material. It was used in the following recipe:

Binder Compound (MB#1)

Neoprene W	100 parts
Circle processing oil	10
Stearic acid	0.5
Neozone A	2
Magnesia (MgO)	2
Zinc oxide	5
NA 22	0.5

The most promising magnetic powder for incorporating in the binder was determined, from a literature search, to be barium ferrite ($BaFe_{12}O_{19}$). Various amounts were milled into the binder and samples were molded, magnetized and tested. Test samples were processed using barium ferrite powder from two manufacturers. A wide loading range was involved and samples were magnetized in two configurations. Test results on these samples are summarized in Table I.

Table I

Magnetic Rubber

Sample Code	A	B	C	D	E
Binder	← MB #1 →				
Magnetic particle	BGl(1)	BGl	BGl	BGl	Ferromag(2)
Particle/binder wt. ratio	1:1	4:1	4:1	5:1	5:1
Thickness (inches)	.122	.125	.130	.136	.142
Magnetized configuration	multiple	single	multiple	single	multiple
Magnetic holding force (3) (oz./sq.in.)	2.13	6.7	5.6	8.64	4.24
Adjusted force for 1/8" gauge	2.16	6.7	5.47	8.46	3.95

(1) Product of Stackpole Carbon Co., Kane, Pa.
(2) Product of Crucible Steel Co. of America, Pittsburg, Pa.
(3) The force required to separate a matched pair of magnets in a direction normal to their magnetically matched faces.

The multiple magnetized configuration comprised a repetition of North-South-North-South poles spaced on approximately 3/8-inch centers along the length of the magnetized strip. The single pattern configuration incorporated a single North pole on one edge of the strip and a South pole on the opposite edge. These are shown schematically in Figure 1.

Multiple Pattern Single Pole Pattern

Sealing Strip Magnetized Configurations

Figure 1

The multiple pole magnet was particularly sensitive to alignment errors. In a circular seal where the mating parts do not fall on the same radii, the problem became acute. Hence, the single pole configuration was judged to be superior.

Of the two samples of barium ferrite tried, BG1 appeared to hold a slight edge. The tests did not provide a basis, however, for determining what the loading should be. As the loading was increased, the magnetic pull went up but so did the stiffness.

A second test was performed to more accurately relate thickness to magnetic holding force. The ratio of barium ferrite particles to rubber masterbatch was held constant at 5.5 to 1. A gauss reading was obtained on each magnetized sample of this series by placing the probe midway between the north-south poles. Samples 7/8 inch wide by 1-1/2 inches long were fabricated and the holding force required to separate a matched pair was measured as before. The data are given in Table II and plotted in Figure 2. Within the range of thickness tested, doubling this dimension caused the holding force to increase by approximately 1.6 times. The holding force was equal to the gauss reading divided by 75.

On a separate occasion, additional samples similar to those tested and reported in Table II were magnetized. The results are summarized in Table III.

The gauss readings are lower in this series of samples even though the equipment and method used to magnetize them were the same as used for the samples listed in Table II. Since the reason for this discrepancy is unknown it behooves the reader not to make comparisons of samples outside the limits of an individual test series.

In a third test the loading of barium ferrite particles in the rubber master batch was increased stepwise in a series of compounds from which 1/16-and 1/8-inch thick samples were processed. In this series both the physical and magnetic properties of the samples were determined so that a decision on trade-off could be made. The results are summarized in Table IV. The samples reported in Tables III and IV were processed and magnetized concurrently (from a single batch) which explains why samples 11, 12, 15, and 16 are included in both tables.

Above a loading ratio of 6:1 the physical properties of the magnetic stock fell off sharply. The highly loaded samples were particularly susceptible to cracking on being flexed. The magnetic properties tested out as expected and are plotted in Figure 3.

While magnets properly oriented do attract one another, they are normally used individually to develop attractive forces to iron. A brief effort was therefore directed at incorporating iron particles(1) into the Neoprene binder compound. Such a material could be used in cooperation with a magnetic strip as the mating half of a seal.

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(1) General Analine GAF carbonyl iron TH powder.

Table II

Magnetic Rubber

Sample No.	Thickness (inches)	Gauss Reading	Pull to Separate (lbs.)	Holding Force (oz./in.^{2})
1	1/32	170-180	.1975 .2025 .2	2.37
2	1/32	170-200	.21 .22 .2125	2.54
3	1/16	275-285	.3225 .3225 .3225	3.82
4	1/16	280-300	.305 .3075 .31	3.64
5	3/32	360-370	.3875 .3925 .39	4.62
6	3/32	340-345	.4 .405 .4025	4.77
7	1/8	440	.5 .505 .51	5.98
8	1/8	440-450	.51 .5125 .51	6.05

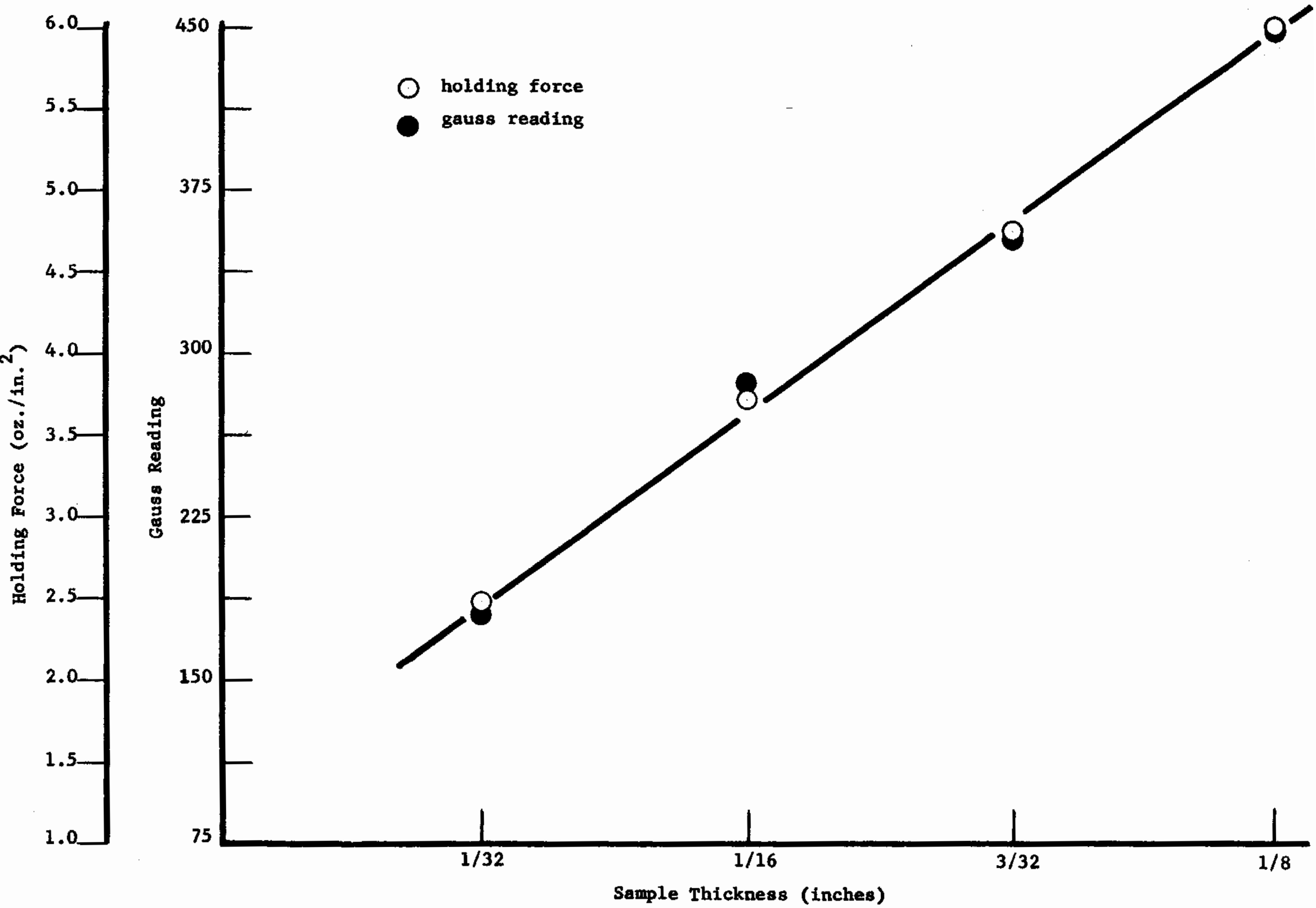


Figure 2. Effect of sample thickness on magnetic holding force.

Table III

Magnetic Rubber

Sample Pair Number	Thickness (inches)	Gauss
9	1/32	120-130
10		120-125
11	1/16	200
12		210
13	3/32	275
14		275
15	1/8	360
16		370

Table IV

Magnetic Rubber

Sample Code	Loading Ratio	Thickness (inches)	Gauss Reading	Tensile Strength psi	Elongation @ Break(%)
11	5.5:1	1/16	200	381	31
12	5.5:1	1/16	210		
15	5.5:1	1/8	360	367	32
16	5.5:1	1/8	370	415	30
17	6:1	1/16	255	533	26
18	6:1	1/16	255		
19	6:1	1/8	370		
20	6:1	1/8	370		
21	6:1	1/8	370		
22	6.75:1	1/16	250	592	14
23	6.75:1	1/16	260		
24	6.75:1	1/8	380		
25	6.75:1	1/8	380		
26	6.75:1	1/8	370		
27	7.5:1	1/16	280	329	1.5
28	7.5:1	1/16	285		
29	7.5:1	1/8	425	431	3
30	7.5:1	1/8	425		
31	8.25:1	1/16	300	716	3.5
32	8.25:1	1/16	295		
33	8.25:1	1/8	435		
34	8.25:1	1/8	435	591	4
35	8.25:1	1/8	420		

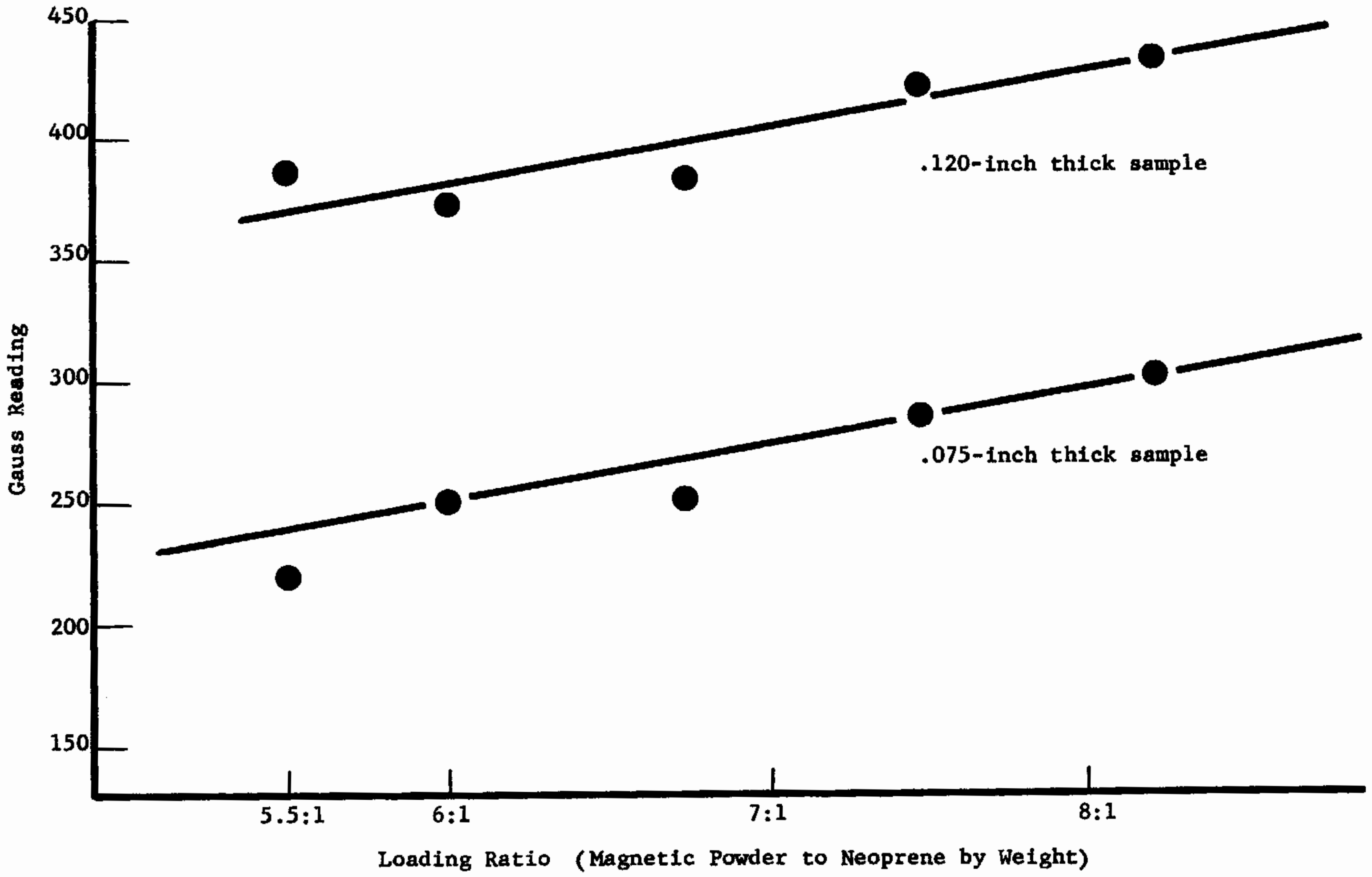


Figure 3. Effect of loading on magnetic properties of rubber samples.

There is little or no affinity between iron and rubber. An attempt was made, therefore, to precoat the iron particles with Hughson Chemical Company's Chemlock 220 metal-to-rubber adhesive. The particles were wetted with the adhesive and allowed to dry. The resultant rigid mass was then pulverized to the original particle size and incorporated into the rubber masterbatch by milling. Results of this procedure were erratic. Some samples cracked on removing from the mold while others exhibited fairly encouraging properties. The material had a tendency to stick to the aluminum molds in which it was cured. Data collected on the best of these samples is summarized in Table V.

Table V

Iron-Loaded Rubber

Sample Number	Loading Ratio (by wt.)	Specific Gravity	Thickness (inches)	Pull to free from 370 gauss magnet (oz./sq.in.)	Tensile Strength (psi)	Elongation @ Break(%)
1	3:1	3.0	.150	1.33		
2		3.5	.148	1.32		
3		4.5	.106	1.60		
4	6:1	4.0	.098	1.40	428	310
5		4.2	.092	1.40		
Magnet	6:1	3.4	.114	3.89(1)	533	26

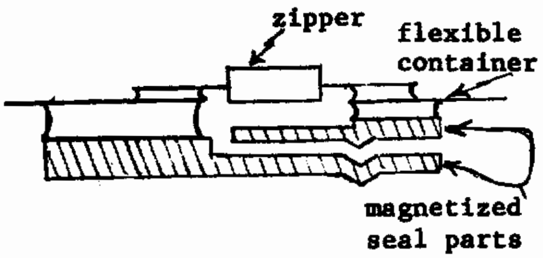
(1) Pull to free from itself.

SEAL DESIGN

The evolution of a seal design was influenced to a considerable degree by the properties of the materials being developed. It was early apparent that the zipper and its slide presented irregularities which made a semi-rigid construction highly impractical. Unfortunately, the minimum magnetic pull considered reasonable for this application dictated the selection of a highly loaded stock (barium ferrite to rubber masterbatch = 6:1) which has a durometer hardness of 90 and is not a flexible rubber-like material.

Design No. 1

This seal is shown in Figure 4 and in the exploded sketch to the right. The two magnetic strips were cemented to a 12-inch dia., 18-inch long flexible container to seal a 10-inch long axial zipper. Leakage was excessive, as shown by the following data:

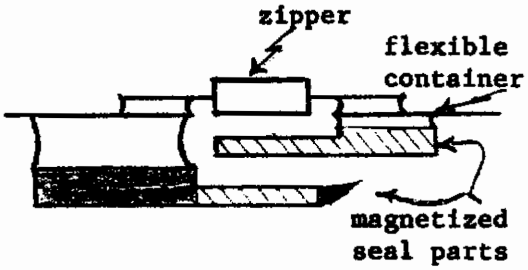


Leakage (cc/min.)	Pressure (psi)
7,000	3
10,000	5
16,000	7-1/2

It is surmised that alignment of the two sealing strips was disturbed by the pressure application and the strips were too stiff to realign themselves with the small magnetic force available for the task.

Design No. 2

This design is shown in Figure 5 and the exploded sketch to the right. A soft unloaded Neoprene stock was used for the feather edge and base of the outboard sealing strip to improve its overall flexibility. The relatively soft lip could be expected to encounter small distortions without losing contact with the mated part.



A seal of this design was made for the 10-inch axial zipper in the 18-inch long test bag. Leakage through the seal was as follows:

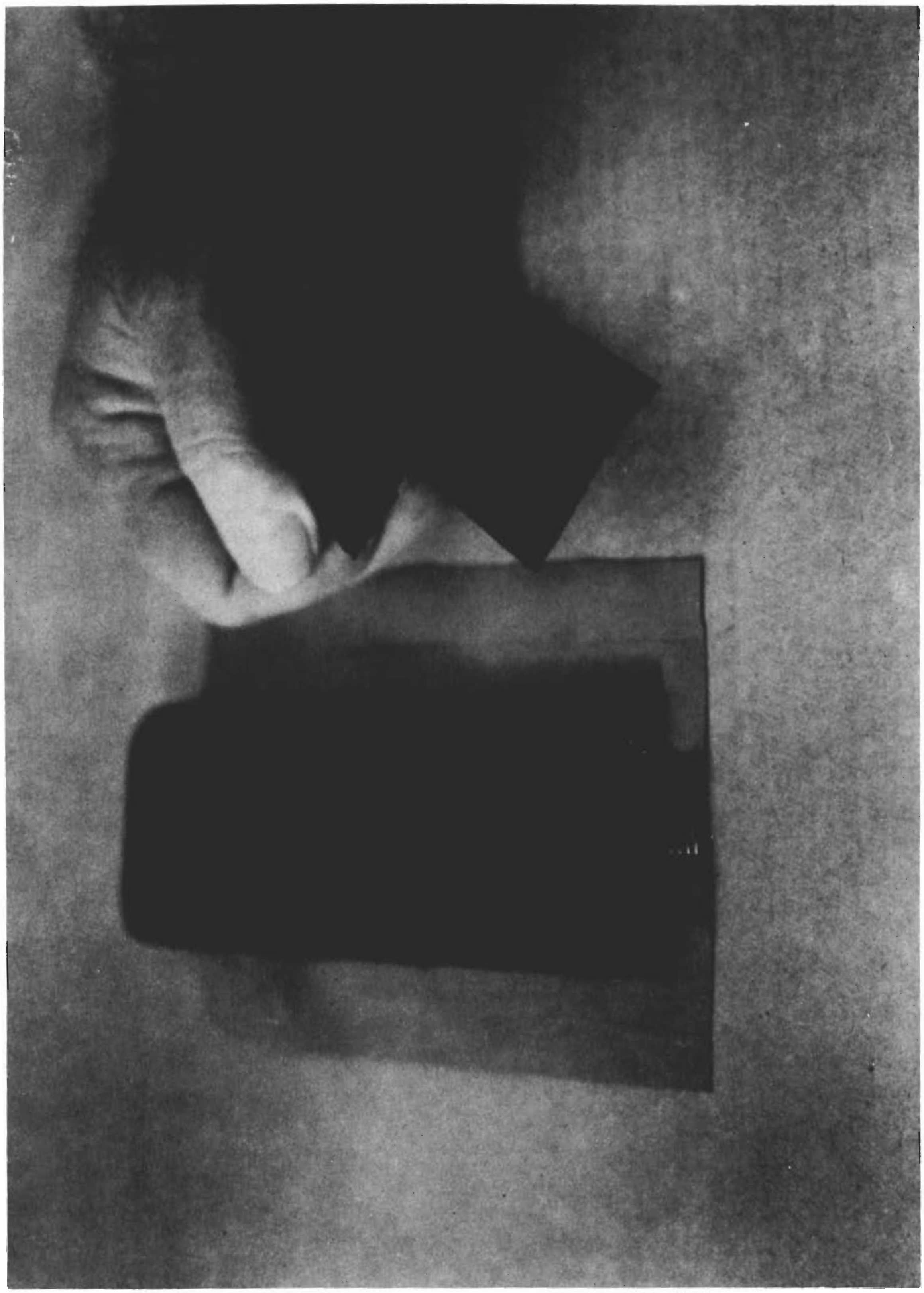


Figure 4. Magnetic Seal Design #1

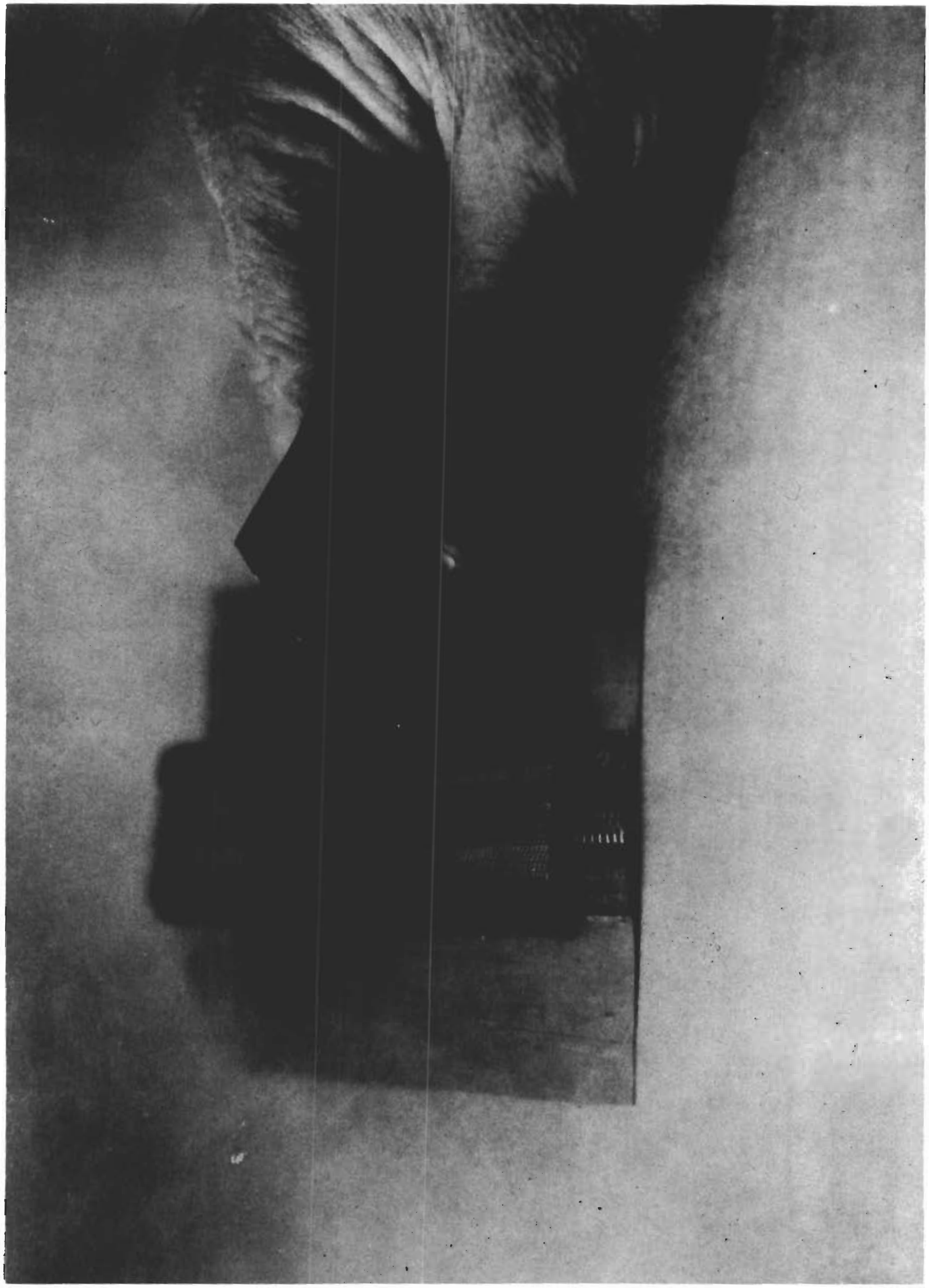


Figure 5. Magnetic Seal Design #2

Leakage (cc/min.)	Pressure (psi)
195	3
195	5
230	7
265	9
700	12

A replacement seal gave the following results:

Leakage (cc/min.)	Pressure (psi)
316	3
330	4
325	5
400	6
460	7
490	8
475	9
535	10
555	11
610	12

A 30-inch long axial seal was installed in a flexible container(1) 12 inches in diameter and 36 inches long. It permitted the following leakage:

Leakage (cc/min.)	Pressure (psi)
1000	3
1300	4
1400	5
1600	6
2100	7
2250	8
2400	9
2700	10
3200	11
3500	12

The same type of seal installed circumferentially in a 4-inch diameter 16-inch long flexible container(1) was less effective. Leakage measured was:

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(1) Supplied to WPAFB under Contract F33615-67-C-1210.

Leakage (cc/min.)	Pressure (psi)
6000	3
6400	4
6800	5
7200	6
7800	7
8500	8
9000	9
high and variable @ 10 and above	

Above 9 psi the mating parts of the circumferentially installed seal seemed to separate completely. When this happened the test pressure would fall off rapidly. Then, from a depressed level it would slowly climb back until 9 psi was again exceeded and the cycle repeated itself. It appeared that the bag would grow but the seal resisted, causing a distortion that ultimately separated the mated parts.

Design No. 3

This seal is simply a scaled variation of Design No. 2. The soft Neoprene sealing lip is more acutely tipped, the zipper relief is slightly larger, and the overall assembly is slightly narrower. A 10-inch axial seal installed in the 12-inch diameter by 18-inch long test bag gave very good results. Leakage measured was as follows:

Leakage (cc/min.)	Pressure (psi)
10	3
5	4
7	5
20	6
10	7
50	9

It was recognized, however, that this design would have the same shortcomings as Design No. 2 when used as a circumferential seal. An attempt was therefore made to make the design more flexible by cutting the magnetic portion into blocks, followed by remolding in a matrix of soft unloaded Neoprene rubber. A typical element is shown in Figure 6. These were also tested as an axial seal but produced much less encouraging results.

Flexible Seal A		Flexible Seal B		Flexible Seal C	
cc/min.	psi	cc/min.	psi	cc/min.	psi
1210	3	510	3	1210	3
1420	4	520	4	1710	4
1630	5	630	5	2000	5
1870	6	620	6	2120	6
2120	7	780	7		

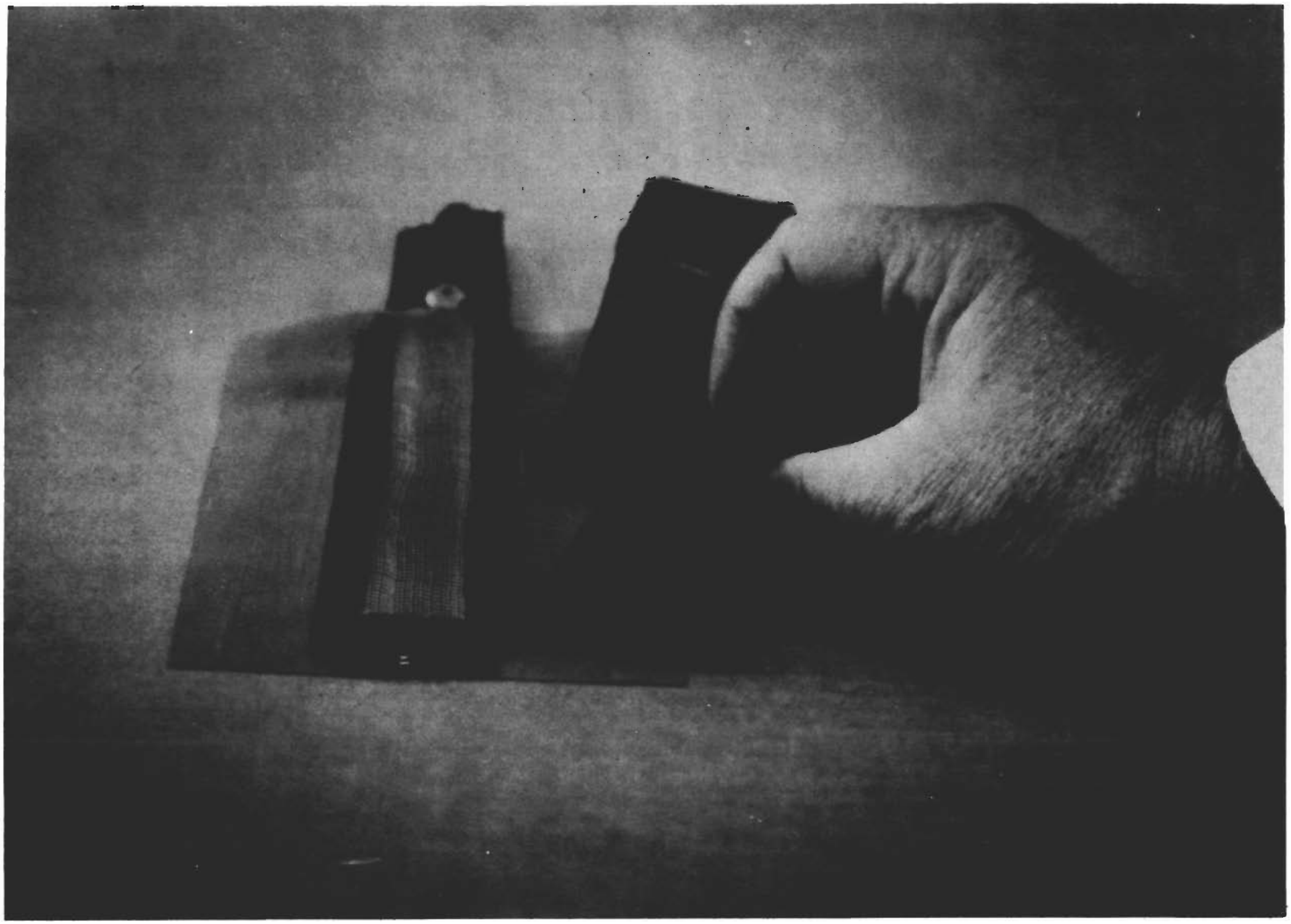
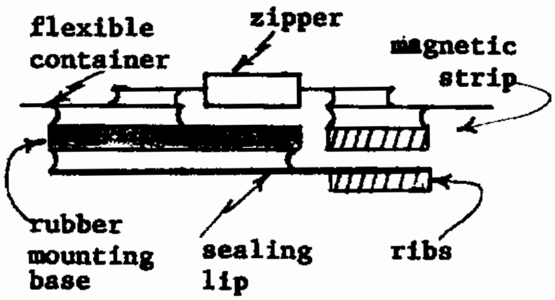


Figure 6. Magnetic Seal Design #3.

The study of Design No. 3 was concluded with an attempt to install the original model (which worked so well in the axial configuration) in a 4-inch diameter circumferential closure. As anticipated for this configuration, it was excessively stiff and was damaged when the building form was being removed from the test container. The soft lip separated from the magnetic stock it was cured against, and the strip itself broke loose from the container.

Design No. 4



The original intent here was to incorporate a lay-flat sealing lip with back-up ribs that could be molded as a single piece of iron-loaded rubber and still be reasonably flexible. A seal of this design applied to a 10-inch axial closure limited leakage against a pressure differential of 3 psi to less than 100 cc/min. After only a minimum of handling, however, the iron-loaded part failed by cracking. It was replaced with a high-quality Neoprene sheeting on which iron-loaded ribs (blocks) were attached by cementing. To improve the holding power, the final version incorporated 1/8 x 1/8 x 1/2-inch rubber magnets as ribbing. These were separated from each other only sufficiently to avoid interference when used in a 4-inch diameter circumferential closure. This final version is shown in Figure 7.

The mounting base of Design No. 4 (shown in the exploded schematic) completely covers or shields the zipper. It is perfectly flat and is expected to rest against and conform to the zipper rather than bridge it as in previous designs. The bar magnets (ribbing) are placed as close to one another as is possible without causing interference between them when the seal is used on a 4-inch diameter circumferential closure. A 10-inch long axial seal made in this way gave the following encouraging test results:

Pressure Differential Across Seal (psi)	Leakage (cc/min.)	Condition of Sealing Surfaces
3	110	dry
6	150	dry
3	45	coated with silicone vacuum grease

A 30-inch long axial seal applied to a closure in a 12-inch diameter 36-inch long flexible container(1) allowed the following leakage:

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(1) Supplied to WPAFB under Contract F33615-68-C-1151

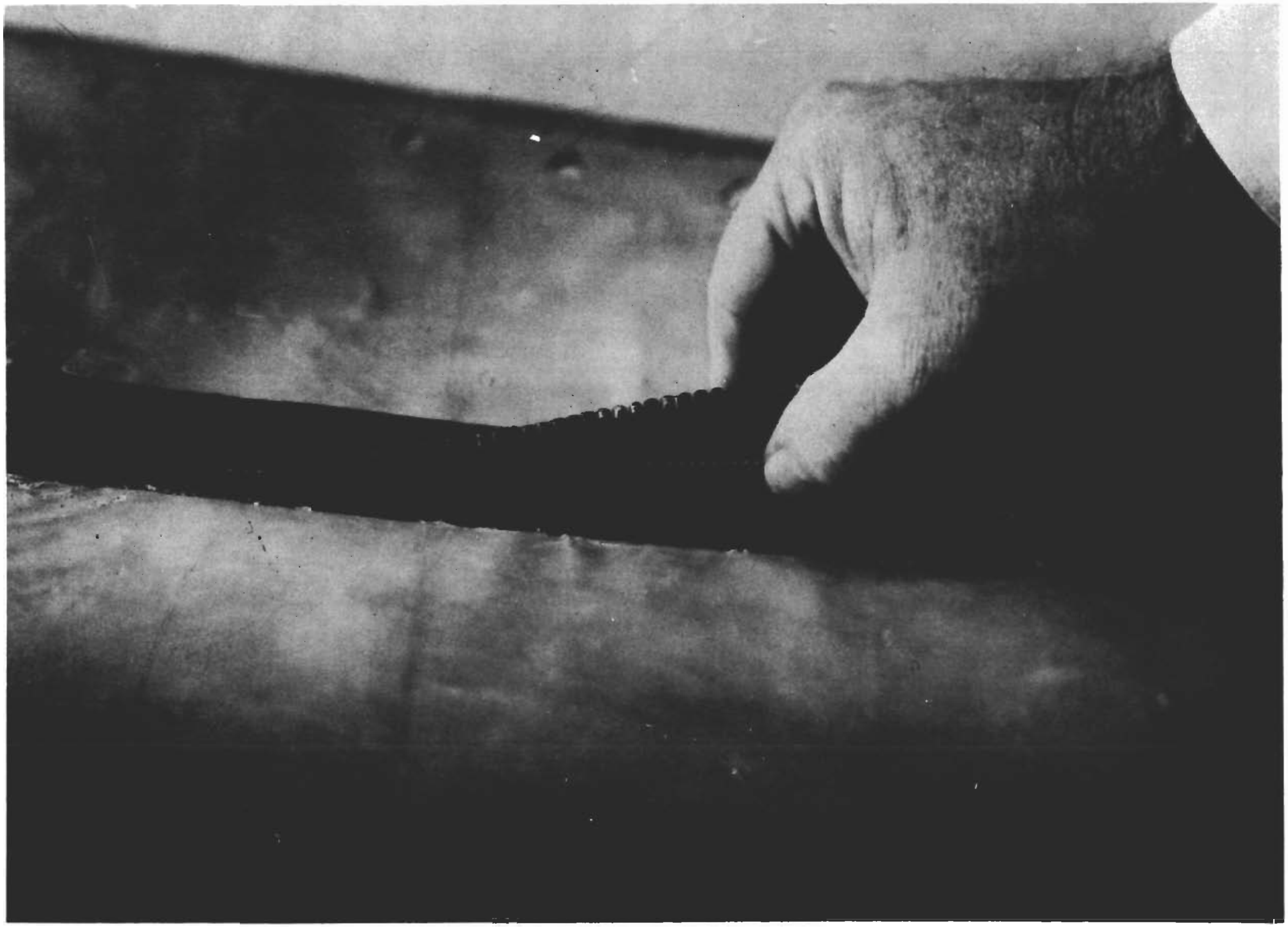

Figure 7. Magnetic Seal Design #4

Pressure Differential Across Seal (psi)	Leakage (cc/min.)	
	With Dry Untreated Sealing Surface	With Vacuum Grease Applied to the Sealing Surfaces
3	290	110
4	360	180
5	420	200
6	500	280
7	640	290
8	590	290
9	670	360
10	750	370
11	840	430
12	870	520

As a 12-inch long circumferential seal in a 4-inch diameter by 16-inch long container(1), the measured leakage was:

Pressure Differential Across Seal (psi)	Leakage (cc/min.)	
	With Dry Untreated Sealing Surface	With Vacuum Grease Applied to the Sealing Surfaces
3	960	400
4	1040	520
5	1200	600
6	1160	620
7	1250	690
8	1350	720
9	1440	810
10	1550	840
11	1830	910
12	1960	940

The leakage in the above circumferential seal was quite sensitive to thumb pressure at one end of the zipper. Leakage could essentially be stopped by this technique, but the leakage reported above was measured without the thumb pressure applied.

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(1) Supplied to WPAFB on Contract F33615-68-C-1151.

CONCLUSIONS

While an occasional seal in a flat axial configuration approached the performance (less than 100 cc/min leakage) that the contract specifications described as desirable, none of the designs tested achieved this in the circumferential configuration. Magnetic rubber compounded to give a reasonable holding force was excessively stiff. At reduced loading levels the holding force became inadequate.

Design No. 4 came closest to overcoming the material dilemma. The flexible rib-backed seal adhered very well to the magnetic strip in this design. The sealing face of the ribbed sealing lip, however, appeared to dip slightly between the ribs so it is reasonable to assume that the sealing effectiveness would have been improved had the ribs been molded into the part.

Theoretically the sealing force resulting from the pressure differential across a closure is many times greater than can possibly be obtained with a flexible magnet. More attention must be given to the effect of this larger force in future seal designs. In Design No. 4 the basic contribution that can be made by the magnet appears to have been achieved.

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13. ABSTRACT

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