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DEVELOPMENT OF LOW-FRICTION ELASTOMERS FOR STERN-TUBE BEARINGS.(U)

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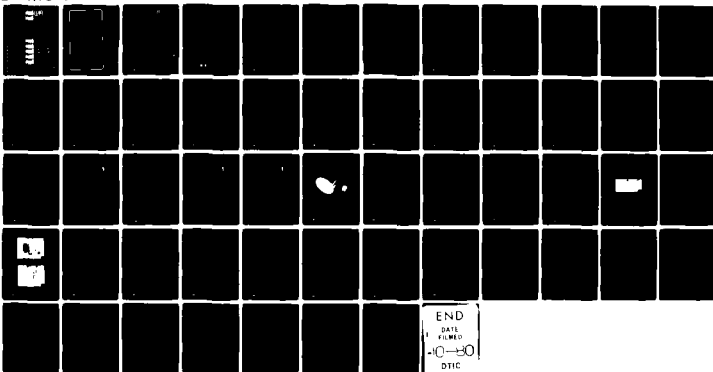
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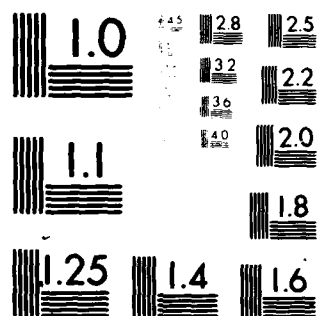


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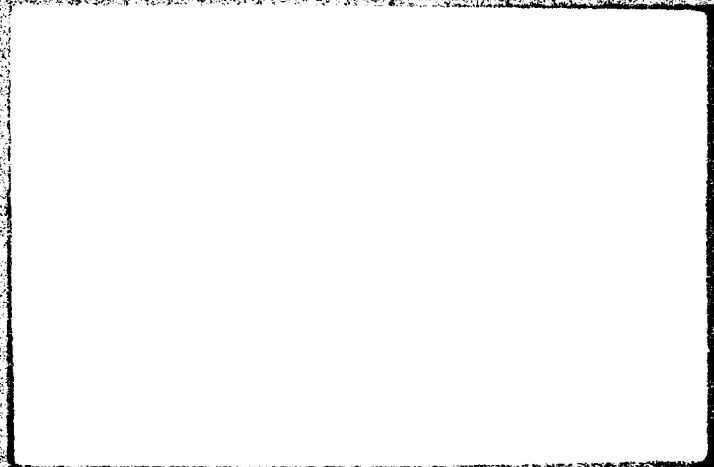
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**LEVEL** *II*

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DEVELOPMENT OF LOW-FRICTION ELASTOMERS  
FOR STERN-TUBE BEARINGS

Prepared By:

Dr. Bharat Bhushan

Prepared Under:

Contract No. N00014-79-C-0041

July 1980

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Latham, New York 12110

**MTI** MECHANICAL  
TECHNOLOGY  
INCORPORATED

NO. 80TR44  
DATE: July 1980

## TECHNICAL REPORT

### DEVELOPMENT OF LOW-FRICTION ELASTOMERS FOR STERN-TUBE BEARINGS

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The objective of the program was to develop lubricant-filled nitrile rubber to obtain low friction and possibly low wear for seawater-lubricated sliding applications. Limited work has been done in industry on adding solid and/or liquid lubricants to the elastomers during compounding. Not much data have been published due to the proprietary nature of the work; but, based on what has been published and discussions with experts in the lubrication field, it is believed that no systematic study had previously been undertaken. This is |                                   |                                                                                   |

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probably the first systematic study to discover what has been done in the field and to further develop lubricant-filled elastomers.

The base elastomer selected was butadiene acrylonitrile copolymer (per MIL-B-17901, Class I). Two lubricant approaches were taken. First, an incompatible and lubricating oil was added in the elastomer during compounding. As a result of aging, these oils migrate to the surface and continuously provide a lubricant film. In another approach, the solid lubricant particles were added during compounding. As the elastomer wears, it will expose newer solid-lubricant particles. The following solid lubricants were selected: MoS<sub>2</sub>, graphite, cadmium oxide-graphite-silver, and other proprietary additives. The fillers ranged in quantity from 5% to 20% by weight. The compositions were made by three experienced molders based on MTI's recommendations.

The specimens were subjected to static submersion tests to determine the geometric stability and compatibility of the elastomers with the operating fluids (synthetic seawater) at 0°C, 22°C, and 66°C. Based on physical and mechanical tests of specimens after submersion for two months, changes in physical and mechanical properties of lubricant-filled elastomers were comparable to unfilled elastomers within experimental scatter. Therefore, there was no apparent degradation of the elastomers due to lubricant fillers. The test specimens were further subjected to friction and wear tests in synthetic seawater. The kinetic coefficient of friction of lubricant-filled elastomers (0.015-0.06) was lower than that of unfilled specimens (0.07-0.09). The wear rates of all specimens were the same within the experimental error so no judgments of wear rates were made.

Results reported here, while encouraging, are only the first step. It is recommended that this work should be continued with other fillers and other base elastomers.

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## SUMMARY

The objective of the program was to develop lubricant-filled nitrile rubber to obtain low friction and possibly low wear for seawater-lubricated sliding applications. Limited work has been done in industry on adding solid and/or liquid lubricants to the elastomers during compounding. Relatively little data has been published due to the proprietary nature of the work; but, based on what has been published and discussions with experts in the lubrication field, it is believed that no systematic study had previously been undertaken. This is probably the first systematic study to discover what has been done in the field and to further develop lubricant-filled elastomers.

The base elastomer selected was butadiene acrylonitrile copolymer (per MIL-B-17901, Class I). Two lubricant approaches were taken. First, an incompatible and lubricating oil was added in the elastomer during compounding. As a result of aging, these oils migrate to the surface and continuously provide a lubricant film. In another approach, the solid lubricant particles were added during compounding. As the elastomer wears, it will expose newer solid-lubricant particles. The following solid lubricants were selected:  $\text{MoS}_2$ , graphite, cadmium oxide-graphite-silver, and other proprietary additives. The fillers ranged in quantity from 5% to 20% by weight. The compositions were made by three experienced molders based on MTL's recommendations.

The specimens were subjected to static submersion tests to determine the geometric stability and compatibility of the elastomers with the operating fluids (synthetic seawater) at 0°C, 22°C, and 66°C. Based on physical and mechanical tests of specimens after submersion for two months, changes in physical and mechanical properties of lubricant-filled elastomers were comparable to unfilled elastomers within experimental scatter. Therefore, there was no apparent degradation of the elastomers due to lubricant fillers. The test specimens were further subjected to friction and wear tests in synthetic seawater. The kinetic coefficient of friction of lubricant-filled elastomers (0.015-0.06) was lower than that of unfilled specimens (0.07-0.09). The wear rates of all specimens were the same within the experimental error so no judgments of wear rates were made.

Results reported here, while encouraging, are only the first step. It is recommended that this work should be continued with other fillers and other base elastomers.

## 1.0 INTRODUCTION

Elastomers are commonly used in the construction of staves for stave-type stern-tube bearings in marine propeller-shaft applications. The elastomers have been selected because of their tolerance to abrasive particles, low wear in seawater environment, resilience in distributing the load under misaligned conditions thus preventing seizure, low cost, and easy availability. Because of the high degree of resilience, elastomers are also used in lip-type seals (on various ships) and O-rings. Butadiene acrylonitrile copolymer (nitrile rubber) is a commonly used elastomer for many of these applications. Because of their wide use, extensive research has been conducted to study the tribological behavior of elastomers, e.g., see Schallamach [1] and Bartenev and Lavrentijev [2].

Audible vibrations or "bearing squeal" sometimes originate in water-lubricated bearings in marine propeller-shaft applications during operations at low values of shaft rpm (Padden [3]). Bhushan [4] found that this undesirable noise was generated by a stick-slip in the rubber at the rubber surface where it contacts the shaft. As might be expected in a stick-slip phenomenon, the intensity and the proclivity for the phenomenon was a function of the coefficient of friction of the rubber surface. Low coefficient of friction on the rubber surface made it difficult or impossible to generate squeal. Therefore, the objective of this program was to formulate elastomeric compounds which retain the low-wear characteristics of the current material while carrying low-friction materials which generate low-friction surfaces.

It is hoped that the development of low-friction elastomers will also be applicable to seals. Brink [5] and others have shown that the ultimate life of the seal is determined by its ability to resist the degrading effects of heat derived from friction at the seal/shaft interface and by the rate of wear. Alternate approaches to this problem of reducing the friction and wear are to:

- Select a new elastomer
- Modify the elastomer by adding desirable ingredients during molding; e.g., solid lubricant particles, migrating oils, etc.

- Modify the mating surface; e.g., improve finish, try ceramic coatings, try a porous chrome plate or a thin layer of fused PTFE
- Change the design to reduce heat buildup and wear.

A program, recently completed by Bhushan and Winn [6] on selection of elastomers for lip seals for marine propeller-shaft applications, indicated that there are no elastomers commercially available which perform significantly better than nitrile rubber; therefore, other ways of obtaining elastomeric materials having low friction and wear should be explored. One recommended approach is to add lubricant fillers during molding of elastomers to reduce friction, interface temperature and, thus, wear during sliding. The improved materials should also help improve the performance of other types of seal applications, e. g., eccentric seals.

A number of elastomer samples with lubricant fillers were developed and tested in submersion tests to ensure there is no degradation of mechanical properties and in friction tests to determine if friction has decreased. The results of the research are reported here.

## 2.0 SELECTION OF LUBRICANT-FILLED FORMULATIONS

A search of published data was conducted to determine the state of the art. A number of industrial molders and compounders were also contacted to establish the industrial knowledge of lubricant-filled elastomers. Based on these findings and on past experience, a number of formulations were selected and compounded by several suppliers.

### 2.1 Prior Research

Only limited work has been done by the industry on adding solid and/or liquid lubricants to the elastomers during compounding and, due to the proprietary nature of the work, not much published data are available.

Ksieski [7] stated that the incorporation of graphite, molydisulfide, or PTFE in elastomers can significantly reduce the dry friction of elastomers but no details on the percent additives and percentage of the friction reduction were given. Zaprivoda et al. [8] proposed a method of applying an antifriction coating to the working seal surfaces. The antifriction PTFE coating is made in the form of a porous film and is pressed onto a rubber base in the process of forming the sealing element, where adhesion of the coating with the base is accomplished by the rubber mass flowing into the pores of the film and by subsequent vulcanization.

Another work with fillers in elastomers is reported by Theberge et al. [9]. They added glass fibers to thermoplastic elastomers such as polyurethane and olefin-based rubber to improve resistance to deformation of the rubber seals. These fibers can be replaced by lubricating fibers to improve lubrication of seals.

Nersasian [10] added lubricating oil additives in the elastomers during compounding for a combination of excellent heat and fluid resistance and sealability required for many automotive applications. The samples passed the accelerated aging tests at elevated temperatures.

An extensive computer search was conducted but no additional references were found.

A number of people active and knowledgeable in the field of elastomers were contacted [11 to 14] and they reported no ongoing programs. They believed the comprehensive study to explore and develop suitable solid and/or liquid lubricant-filled elastomers was pioneering and unique.

## 2.2 Industrial Contacts

Comments from the companies contacted during the program are listed in Table 2.1. Companies 1 to 11 had some knowledge and/or experience in the field, but 12 to 17 had none. According to Triolo [15], 4.5% graphite is being used in seals, and nitrile rubber with graphite fillers have been used in bearings for industrial equipment. According to Molan [16], nitrile and Viton samples have been compounded with Molykote and graphite. Kyker [17] advised that PTFE-filled phosphonitrilic fluoroelastomer has performed better than unfilled when used as a shaft seal in laboratory testing. Parker Seal Company commercially makes O-rings with solid-lubricant particle fillers. O-rings of Neoprene and nitrile rubber have also been developed with graphite and  $\text{MoS}_2$  fillers (Eggers [18]). Nitrile rubber bearings with 10% graphite powder were made for industrial pumps used for cold water and sewage pumps. No performance data are available (Toth and Brakey [19]).

Dupont is doing work on viton filled with  $\text{MoS}_2$ , graphite, and other proprietary compositions. Some correspondence from Dupont, considered to be of general relevance to this program, is included in Appendix B.

The limited development done in industry has been for specific products and no systematic development or laboratory testing recorded. There seems to be limited inter-industry technology transfer.

## 2.3 Selection of Fillers and Concepts

### 2.3.1 Solid-Lubricant Additives

A number of solid-lubricant fillers have been developed for plastics which provide low friction and low wear (Bhushan et al. [20]). Some of the fillers which are considered suitable for elastomers based on prior experience with reinforced plastics and lubricant coatings (Bhushan [21]) are:

TABLE 2.1

Information from Industries Contacted to Establish  
State of the Art of Lubricant-Filled Elastomers

1. Astro Molding Inc.  
RD #1  
Old Bridge, NJ 08857  
L. Triolo  
(201-727-2900)

They have compounded nitrile, Viton, Neoprene bearings with 5 to 14% by-weight graphite powder to be used in oil and water-oil environment for industrial equipments. They have also compounded seals with 4.5% graphite powder.

2. Minnesota Rubber Company  
3630 Wooddale Avenue  
Minneapolis, Minnesota 55416  
Mr. Robert Eggers  
(612-927-1400)

They have developed Neoprene and nitrile rubber O-rings with graphite and MoS<sub>2</sub> fillers.

3. The Johnson Rubber Company  
16025 Johnson Street  
Middlefield, Ohio 44062  
Messrs. Mike Brakey and W. J. Toth  
(216-632-1611)

They have made nitrile rubber bearings with 10% graphite powder for industrial pumps used for cold water and sewage pumps. No data are available. They made samples with MoS<sub>2</sub> but no tests were conducted. Their general concern was the bond of elastomer with bearing/seal housing.

4. Irving B. Moore Corporation  
30 Rindge Avenue Ext.  
Cambridge, Massachusetts 02140  
Mr. John Ebinger  
(617-491-0100)

They have compounded nitrile parts with graphite and PTFE powder for customers. No engineering or performance data are available. They recommended mechanical locking to improve adhesion problem either by forming several dovetails on the interface or bolting it down.

TABLE 2.1 (Cont'd)

5. International Polymer Services  
P. O. Box 327  
N. Brunswick, NJ 08816  
Mr. R. Grosman  
(201-257-9600)

They have compounded nitrile rubber with 10 parts by weight graphite powder for transmission shaft seals operating in oil at 300°F.

6. B. F. Goodrich Company  
Engineering Systems Division  
500 So. Main Street  
Akron, Ohio 44318  
Mr. M. H. Wyland  
(216-379-2364)

They have made nitrile rubber samples with solid lubricants. They find that lubricant forms emulsion at interface which hinders film generation at high speed. PTFE was difficult to stick to the elastomer.

7. Acushnet Company  
Rubber Division  
New Bedford, Massachusetts  
Mr. Art Molan  
(617-997-2811)

They have worked with nitrile and Viton elastomers with Molykote and graphite, etc., additives.

8. LNP Corporation  
412 King Street  
Malvern, Pennsylvania  
Messrs. J. Theberge and C. Goebel  
(215-644-5200)

They have worked with thermoplastic elastomers with additives such as PTFE, fibers, and silicone fluid. Their approach to lubricants is different from others. They start with synthesized rubber pellets, add lubricants, and mold it. After initial synthesizing, there are enough functional groups left for further polymerization.

9. E. I. Dupont DeNemours & Company, Inc.  
Elastomer Division  
Akron Laboratory  
4330 Allen Road  
Stow, Ohio 44224  
Ms. A. C. Zaragoza/R. H. Vanderlann  
(216-929-2961)

They have worked with additives such as graphite (KS-2), PTFE (TL-115), F-5) and silicone oil (Dow DC7-10, Maclube 7808). They found that PTFE is compatible with Viton. For more details see Appendix B.

TABLE 2.1 (Cont'd)

10. Firestone Tire and Rubber Company  
Phosphazene Rubber Marketing  
1200 Firestone Parkway  
Akron, Ohio 44317  
Mr. Joseph Beckman  
(216-379-4443)

They manufacture phosphonitrilic fluoroelastomer (PNF). They have added PTFE to PNF. In dynamic shaft seal testing, these improved seal materials in oil environment up to 300°F provided low wear.

11. Parker Seal Company  
Lexington, Ky  
Mr. J. Hunter  
(606-269-2351)

They commercially make O-rings with solid-lubricant particles which are used in applications such as petroleum products and water lubrication areas.

12. Burke Industries  
2250 S. Tenth Street  
San Jose, California 95112  
Mr. D. Kutnewsky  
(408-297-3500)

Have no experience in the lubricant-filled elastomer area.

13. Sealostomer Company  
Birmingham, Michigan  
Mr. Edward Budzinski  
(313-647-1600)

Have no experience in the lubricant-filled elastomer area.

14. Minor Rubber Company  
Bloomfield, NJ  
(201-338-6800)

Have no experience in the lubricant-filled elastomer area.

15. Connecticut Hard Rubber Company  
New Haven, Connecticut  
(203-777-3631)

Have no experience in the lubricant-filled elastomer area.

16. Waukesha Bearing Corporation  
Waukesha, Wisconsin  
Mr. W. W. Gardner  
(414-547-3381)

Have no experience in the lubricant-filled elastomer area.

TABLE 2.1 (Cont'd)

17. Microdot/Polyseal  
Salt Lake City, Utah  
Mr. Gerald Beck  
(801-973-9171)

Have no experience in the lubricant-filled elastomer area.

Powders:

Molybdenum Disulfide  
Natural or Synthetic Graphite  
Cadmium Oxide-Graphite-Silver  
Powdered PTFE  
Powdered Compounded PTFE  
Bronze  
Silver

Fibers:

Graphite  
Kevlar  
PTFE

The finest particle sizes of powdered fillers were selected because of the analogous behavior of carbon. It has been found that very fine carbon black has greater reinforcing effect on nitrile rubber. PTFE particles can be etched with sodium compounds (Tucker [22]) before compounding so they are chemically receptive to the elastomer and result in strong adherence of these particles to the elastomer.

2.3.2 Incompatible Oil Additives

Another concept pursued in the program was 'blooming'. The incompatible and lubricating oils are added to the elastomers during compounding. As a result of aging, these oils migrate to the surface and provide a lubricant film.

2.4 Preparation of Test Samples

Three companies agreed to make test samples. The base elastomer selected was butadiene acrylonitrile copolymer, commonly known as nitrile (32-33 percent acrylonitrile, thermoplastic, balance butadiene rubber; acrylonitrile is added to increase oil resistance and increase hardness), per Mil Spec MIL-B-17901 Class I (see Appendix A). The companies are listed below with the compositions made by them:

Astro Molding Inc. (Supplier No. 1)

1. Standard nitrile per spec. MIL-B-17901, Class I (85-1338).
2. Item 1 with 5% migrating lubricant (incompatible oil) (85-1338 A).
3. Item 1 with 5% Dixon #2 medium-flake graphite powder (85-1338 B).
4. Item 1 with 10% Dixon #2 medium-flake graphite powder (85-1338 C).
5. Item 1 with 5% CdO-graphite-Ag\* (85-1338 D).
6. Item 1 with 10% CdO-graphite-Ag (85-1338 E).

Minnesota Rubber Company (Supplier No. 2)

7. Standard nitrile per spec MIL-B-17901, Class I, (IX876-BS).
8. Item 1 with 20 phr\*\* graphite (0.25 to 0.50 microns) (IX876-BP).
9. Item 1 with 5 phr "slippery stuff" (IX876-BQ).
10. Item 1 with 20 phr MoS<sub>2</sub> (Molykote Z - 4 to 10 microns) (IX876-BR).

Johnson Rubber Company (Supplier No. 3)

11. Standard nitrile per spec MIL-B-17901, Class I.
12. Item 1 with 10% graphite #87 superior (0.25-0.50 micron particle size).
13. Item 1 with 20% graphite #87 superior (0.25-0.50 micron particle size).
14. Item 1 with 10% CdO-graphite-Ag.
15. Item 1 with 20% CdO-graphite-Ag.
16. Item 1 with 10% Molykote Z powder (4-10 microns particle size).
17. Item 1 with 20% Molykote Z powder (4-10 microns particle size).

\* 20% CdO (99.9% commercially pure, particle size - 95-200), 65% synthetic graphite (99.9% pure KS-2, particle size - 2  $\mu$ m), and 15% Ag (99.99% pure, particle size - 1 to 5 microns).

\*\* Parts per hundred parts of base polymer (nitrile).

The exact composition and molding procedure of the test samples are given below, if the information was supplied by the manufacturers:

Astro Molding Inc. (Supplier No. 1)

No further details on the compositions or molding procedure were provided by Astro Molding Inc.

Minnesota Rubber Company (Supplier No. 2)

The composition of the materials which were sent by Minnesota Rubber Company was identical for all with the exception of the internal lubricant. The formulation was as follows:

| <u>INGREDIENT</u>                               | <u>DESCRIPTION</u>   | <u>TOTAL PARTS<br/>PER HUNDRED PARTS OF<br/>BASE POLYMER (PHR)</u> |
|-------------------------------------------------|----------------------|--------------------------------------------------------------------|
| Acrylonitrile<br>Butadiene Copolymer            | ACN 40.0%            | 100.0                                                              |
| Carbon Black                                    | N-774 Particle size  | 60.0                                                               |
| Carbon Black                                    | N-550 Particle size  | 40.0                                                               |
| Zinc Oxide                                      | ----                 | 5.0                                                                |
| Stearic Acid                                    | ----                 | 0.5                                                                |
| Sulfur                                          | ----                 | 0.5                                                                |
| Mixed Alkyl Thiram                              | ----                 | 2.0                                                                |
| N-Cyclohexyl-2-<br>benzothiazole<br>sulfenamide | ----                 | 2.0                                                                |
| Di(2-ethylhexy 1)<br>Phthalate                  | ----                 | 5.0                                                                |
| Polyethylene                                    | Low molecular weight | 2.0                                                                |

All compounds were mixed on a laboratory-size internal Banbury mixer. The ASTM test specimens were molded for 20 minutes @ 300°F at 5000 psi pressure. The ASTM test plugs were molded for 40 minutes @ 300°F at 2000 psi pressure.

Johnson Rubber Company (Supplier No. 3)

The following information was supplied by this supplier:

1. Composition of Buna "N" (per MIL-B-17901 A) nitrile compound to meet this spec. Composition - proprietary.
2. Molding procedures - tensile slabs cured in mold - 20 minutes @ 320°F; adhesion pins (rubber only) - cured in mold 30 minutes @ 320°F.

### 3.0 EXPERIMENTAL RESULTS AND DISCUSSIONS

#### 3.1 Description of the Tests

##### 3.1.1 Static Material Submersion Tests

These tests were designed to determine the geometric stability and compatibility of the elastomers with the operating fluids, synthetic seawater in operating temperature range. Shore hardness, tensile strength, and elongation were also measured to determine any strength degradation as a result of submersion tests.

Test Temperature: Elastomers, in general, are not good heat conductors. When these materials rub against other materials under load, the frictional heat generated at the interface builds up and, depending on the load, speed, and coefficient of friction, may increase the interface temperatures considerably. If the rubbing interface is submerged in a good heat-conducting environment, namely seawater, the heat buildup will be dissipated and interfacial temperatures will remain moderate. Since many elastomers have poor geometric stability and compatibility with seawater and result in strength degradation at relatively low temperatures (65-125°C) under continuous use, the effect of interface temperatures must be given serious consideration.

The ships and other sea transport vehicles sail from north arctic to tropical seas and must operate in seawater temperatures from close to the freezing point ( $\sim -2^{\circ}\text{C}$ ) to  $30^{\circ}\text{C}$  ( $85^{\circ}\text{F}$ ). Considering the frictional heat generated, the interface temperature, especially under misaligned conditions, could be higher than  $66^{\circ}\text{C}$  ( $150^{\circ}\text{F}$ ) for a short duration. A majority of the time, the ships are in the temperature range of  $15-27^{\circ}\text{C}$  ( $60-80^{\circ}\text{F}$ ). Therefore, three temperatures were selected for the submersion tests:  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ),  $22^{\circ}\text{C}$  ( $72^{\circ}\text{F}$ ), and  $66^{\circ}\text{C}$  ( $150^{\circ}\text{F}$ ).

Specimen Size: The test specimens for geometrical stability and hardness measurements were made per ASTM Spec. No. D471-75. The specimens were rectangular having dimensions of 25 by 50 by  $2.0 \pm 0.1$  mm (1 by 2 by

0.08 ± 0.005 in). Two specimens of each material were put in each test to get some indication of repeatability.

The ASTM tensile specimens were made for tensile strength and elongation tests. Three specimens of each material were put in each test to get some indication of repeatability.

Test Equipment: The test equipment consisted of a glass container with a cover. A rack was made of Inconel foils to set the specimens individually. For 66°C tests, a heater with temperature control system was used. For 0°C tests, the glass container was placed inside a freezer and the temperature was periodically checked.

The specimens were fully submerged in synthetic seawater\* (per ASTM D-1141-52). Synthetic seawater has to be aerated in order to keep salt dissolved in the water. The seawater during tests was aerated by a fish tank pump.

The tests were run for a period of two months.

Measurements: The shore hardness, weight, volume, tensile strength and elongation of the specimens were measured in the beginning and after two months. The specimens were periodically examined for any apparent deterioration. The shore hardness type A was measured. The volume of the specimens was calculated from weighing them in air ( $W_a$ ) and when submerged in water ( $W_w$ ).

$$\text{Volume} = \frac{W_a - W_w}{\rho_w}$$

where  $\rho_w$  is the density of water.

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\* Major constituents of sea salt are: NaCl - 58.49%,  $\text{MgCl}_2 \cdot 6 \text{H}_2\text{O}$  - 26.46%,  $\text{Na}_2\text{SO}_4$  - 9.75%,  $\text{CaCl}_2$  - 2.77%, KCl - 1.645%,  $\text{NaHCO}_3$  - 0.48% and KBr - 0.24%. The sea salt is mixed in water in the proportion of 41.92 mgs/liter.

The weight measurements were made with an electronic balance with an accuracy of  $\pm 0.1$  mg.

The tensile strength and elongation measurements were conducted using standard test machines.

### 3.1.2 Friction and Wear Tests

Test Apparatus: A unidirectional continuous sliding test rig was used to conduct friction and wear tests in synthetic seawater. In the test rig, the elastomer pin specimen rubbed against the circumference of a rotating cylinder. The pin was loaded by dead weights and the cylinder (disc) was rotated by a variable speed motor. The cylinder and the pin were surrounded by a container made of plexiglass which was filled with synthetic seawater. The frictional force was measured by a strain-gage load cell. The output of the load cell was fed to a Chart Recorder and a continuous trace of the frictional force versus time was obtained. The rate of wear was obtained by measuring the change in the length of the pin with a dial indicator.

Since the frictional heat dissipated at the rubbing interface heated up the water, a stainless steel coil was placed in the container and the cold water was circulated through it during the experiment to maintain the water temperature close to room temperature,  $22^{\circ}\text{C} - 27^{\circ}\text{C}$  ( $72^{\circ}\text{F} - 80^{\circ}\text{F}$ ). A photograph of the test rig is shown in Figure 3.1. A schematic of the apparatus is shown in Figure 3.2.

Test Specimens: The rotating member was a round cylinder (disc) with 50 mm O. D. and 25 mm wide (see Figure 3.3). The O. D. was ground to a typical surface roughness of a marine shaft ( $0.40 \mu\text{m}$ ). The cylinder was made of marine propeller shaft material - 70% Cu - 30% Ni per Mil-C-15345G, Alloy 24 (casted).

The tips of the test pins were made of the elastomers to be tested. The elastomers were molded in place on the pins. In some cases, the elastomer was glued to the metal backing with an epoxy. A dovetail was provided on

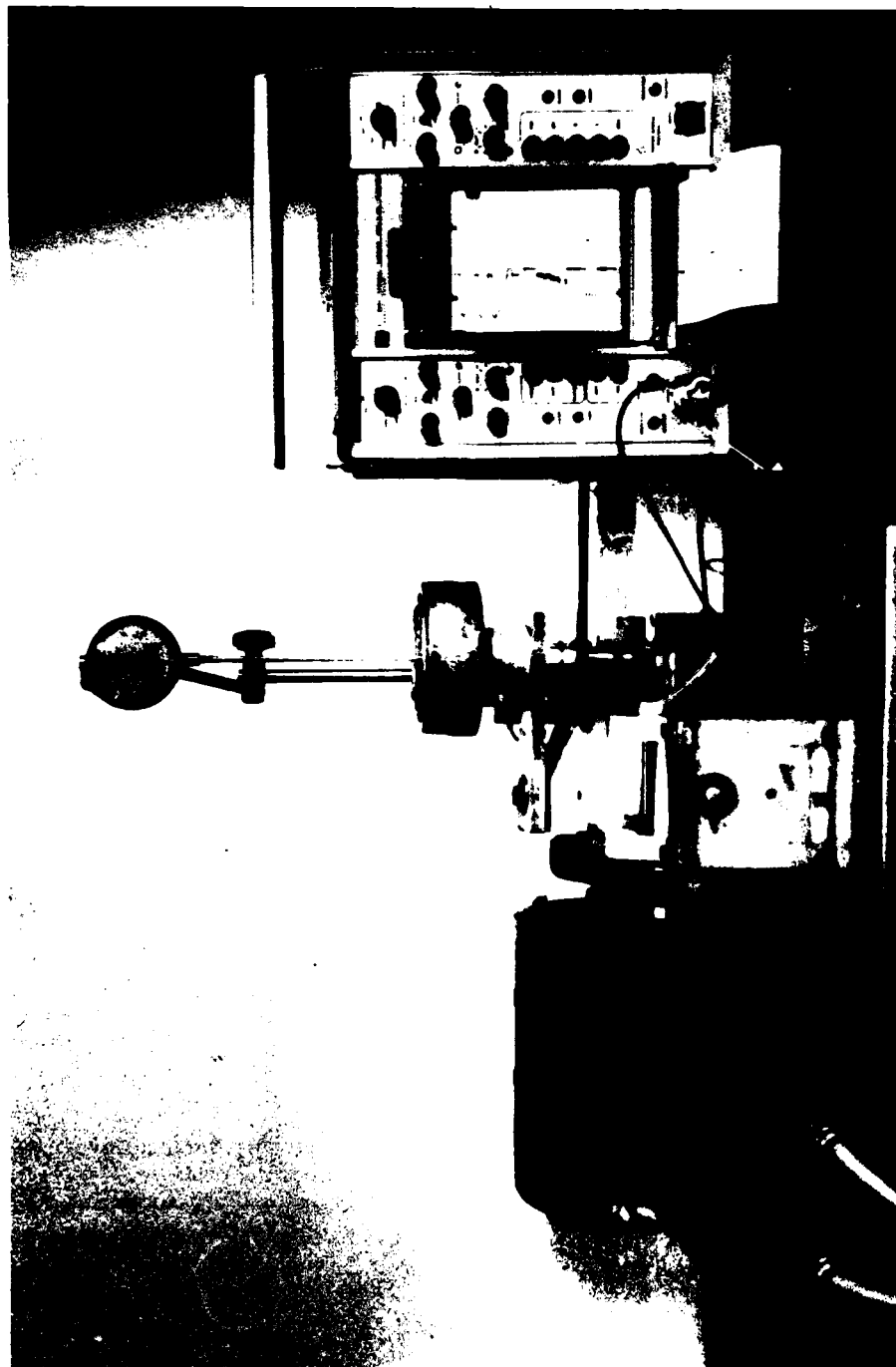


Fig. 3.1 Unidirectional Continuous Sliding Test Rig

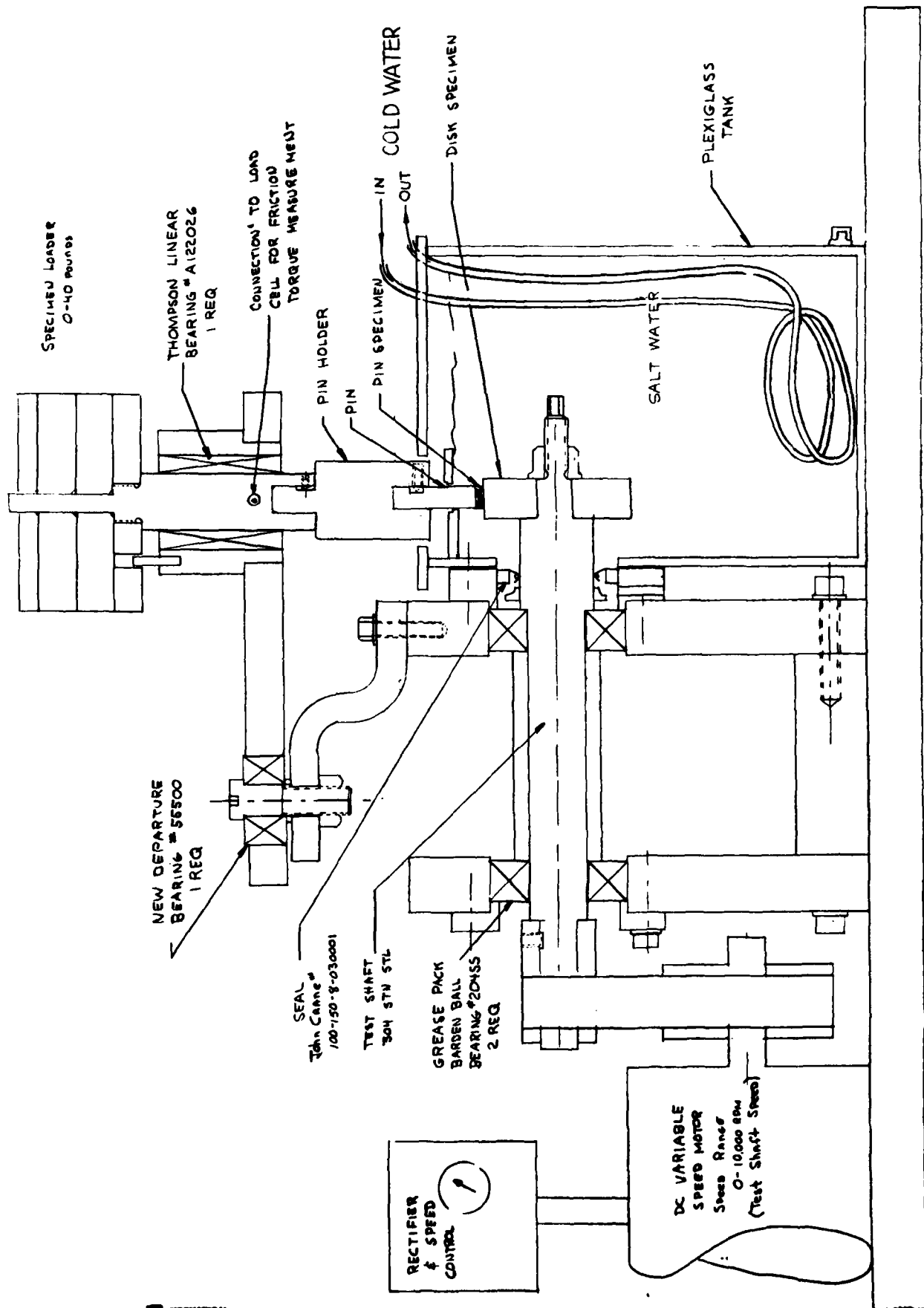


Fig. 3.2 Schematic Drawing of the Unidirectional Continuous Sliding Tester

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the pin to provide elastomer locking. The radius on the elastomer tip was conforming to the disc (see Figures 3.4 and 3.5). A radius was also given to the pin base in order to provide the uniform thickness of the elastomer. Photographs of the pin and cylinder are shown in Figure 3.6.

Test Procedure: The static and dynamic run-outs of the discs were controlled to  $7.5 \mu\text{m}$  (0.0003 in.). The stern-tube bearings are designed to a stress of 0.28-0.35 MPa (40-50 psi). Since the bearing-squeal typically occurs at 5 to 10 rpm on a 460 mm diameter shaft (Padden [3]), tests were conducted slightly above that speed. The conditions selected for the test were 0.35 MPa (50 psi) and 140 rpm ( $0.37 \text{ m.s}^{-1}$ ). The test duration was 24 hours. The selected materials were tested at the additional stresses of 0.18 and 0.7 MPa and speeds of 70 and 210 rpm ( $0.18$  and  $0.55 \text{ m.s}^{-1}$ ) to study their influence on the coefficient of friction.

The following measurements were made and data taken on the test samples in the experiments:

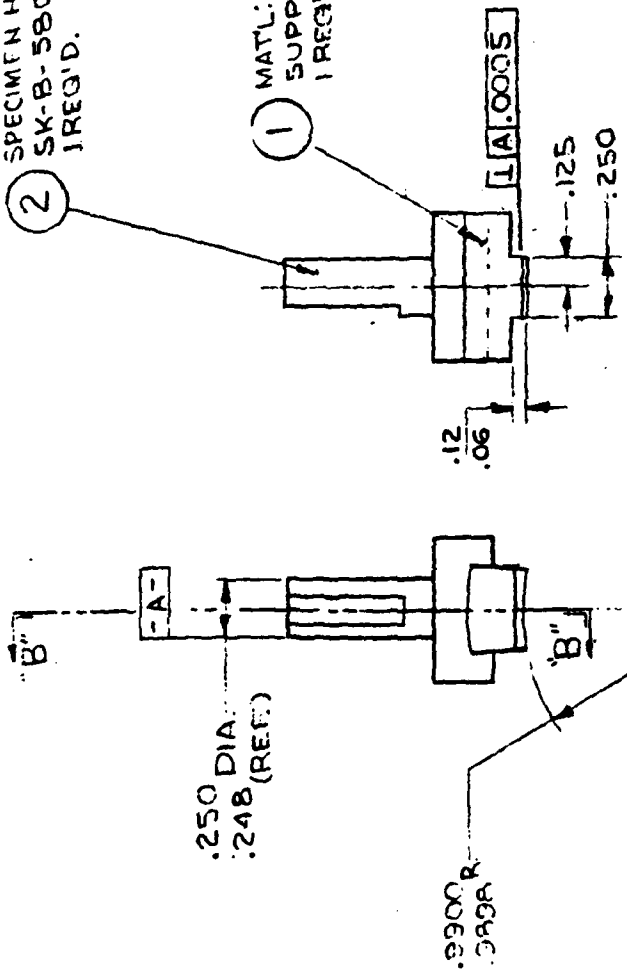
- Length of the pin before and after tests for calculating total wear of polymer
- Outer diameter of the cylinder before and after test for calculating total wear of disc
- Transverse surface roughness of the cylinder before and after tests
- Record of normal load and surface speed
- Static and dynamic run-out of the cylinder
- Change in length of the pin and radius of the cylinder during experiment with dial indicator every four hours for calculating wear rate
- Kinetic frictional force versus time during test at interval of every four hours
- Photographs of the worn surfaces for record wherever necessary.

| REV. | SIZE | DESCRIPTION | DATE     | APPROVAL |
|------|------|-------------|----------|----------|
| A    | B    | ISSUED      | 11/15/79 | 2/20/80  |

| REV. | SIZE | DESCRIPTION | DATE     | APPROVAL |
|------|------|-------------|----------|----------|
| A    | B    | SK-B-5803   | 11/15/79 | 2/20/80  |

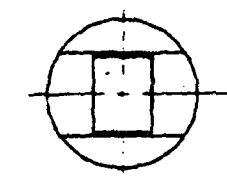
2 SPECIMEN HOLDER  
SK-B-5801 PI  
1 REQ'D.

1 MAT'L: ELASTOMER (MOLDED) - INFO.  
SUPPLIED BY ENGINEERING  
1 REQ'D.



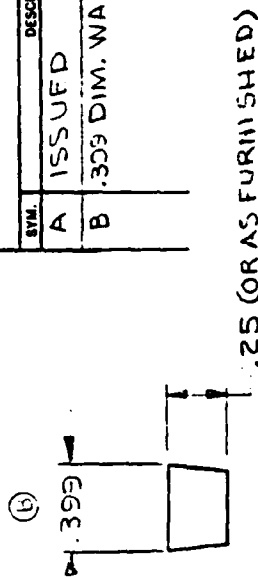
SECTION "B"-"B"

(G)



|                                                                          |                                                |                                             |                                          |
|--------------------------------------------------------------------------|------------------------------------------------|---------------------------------------------|------------------------------------------|
| UNLESS OTHERWISE SPECIFIED<br>DIMENSIONS ARE IN INCHES<br>TOLERANCES ON: | DECIMALS                                       | FRACTIONS                                   | ANGLES                                   |
|                                                                          | .010 ±                                         | 1/16 ±                                      | 2°                                       |
|                                                                          | .005 ±                                         | 1/32 ±                                      | 1/2°                                     |
|                                                                          | .002 ±                                         | 1/64 ±                                      | 1/4°                                     |
|                                                                          | .001 ±                                         | 1/128 ±                                     | 1/8°                                     |
|                                                                          | .0005 ±                                        | 1/256 ±                                     | 1/16°                                    |
|                                                                          | .0002 ±                                        | 1/512 ±                                     | 1/32°                                    |
|                                                                          | .0001 ±                                        | 1/1024 ±                                    | 1/64°                                    |
|                                                                          | .00005 ±                                       | 1/2048 ±                                    | 1/128°                                   |
|                                                                          | .00002 ±                                       | 1/4096 ±                                    | 1/256°                                   |
|                                                                          | .00001 ±                                       | 1/8192 ±                                    | 1/512°                                   |
|                                                                          | .000005 ±                                      | 1/16384 ±                                   | 1/1024°                                  |
|                                                                          | .000002 ±                                      | 1/32768 ±                                   | 1/2048°                                  |
|                                                                          | .000001 ±                                      | 1/65536 ±                                   | 1/4096°                                  |
|                                                                          | .0000005 ±                                     | 1/131072 ±                                  | 1/8192°                                  |
|                                                                          | .0000002 ±                                     | 1/262144 ±                                  | 1/16384°                                 |
|                                                                          | .0000001 ±                                     | 1/524288 ±                                  | 1/32768°                                 |
|                                                                          | .00000005 ±                                    | 1/1048576 ±                                 | 1/65536°                                 |
|                                                                          | .00000002 ±                                    | 1/2097152 ±                                 | 1/131072°                                |
|                                                                          | .00000001 ±                                    | 1/4194304 ±                                 | 1/262144°                                |
|                                                                          | .000000005 ±                                   | 1/8388608 ±                                 | 1/524288°                                |
|                                                                          | .000000002 ±                                   | 1/16777216 ±                                | 1/1048576°                               |
|                                                                          | .000000001 ±                                   | 1/33554432 ±                                | 1/2097152°                               |
|                                                                          | .0000000005 ±                                  | 1/67108864 ±                                | 1/4194304°                               |
|                                                                          | .0000000002 ±                                  | 1/134217728 ±                               | 1/8388608°                               |
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|                                                                          | .0000000000000000000000000000000000000002 ±    | 1/166153499473114484112975882535043072 ±    | 1/10384593717069655257060992658440192°   |
|                                                                          | .0000000000000000000000000000000000000001 ±    | 1/332306998946228968225951765070086144 ±    | 1/20769187434139310514121985316880384°   |
|                                                                          | .00000000000000000000000000000000000000005 ±   | 1/664613997892457936451903530140172288 ±    | 1/41538374868278621028243970633760768°   |
|                                                                          | .00000000000000000000000000000000000000002 ±   | 1/1329227995784915872903807060280344576 ±   | 1/83076749736557242056487941267521536°   |
|                                                                          | .00000000000000000000000000000000000000001 ±   | 1/2658455991569831745807614120560689152 ±   | 1/166153499473114484112975882535043072°  |
|                                                                          | .000000000000000000000000000000000000000005 ±  | 1/5316911983139663491615228241121378304 ±   | 1/332306998946228968225951765070086144°  |
|                                                                          | .000000000000000000000000000000000000000002 ±  | 1/10633823966279326983230456482242756608 ±  | 1/664613997892457936451903530140172288°  |
|                                                                          | .000000000000000000000000000000000000000001 ±  | 1/21267647932558653966460912964485513216 ±  | 1/1329227995784915872903807060280344576° |
|                                                                          | .0000000000000000000000000000000000000000005 ± | 1/42535295865117307932921825928971026432 ±  | 1/2658455991569831745807614120560689152° |
|                                                                          | .0000000000000000000000000000000000000000002 ± | 1/85070591730234615865843651857942052864 ±  | 1/5316911983139663491615228241121378304° |
|                                                                          | .0000000000000000000000000000000000000000001 ± | 1/170141183460469231731687303715884105728 ± | 1/10633823                               |

| REV.      |                    | SIZE               | REV.               |
|-----------|--------------------|--------------------|--------------------|
| B         |                    | SK-B-5802          | B                  |
| REVISIONS |                    | DATE               | APPROVAL           |
| SYM.      | DESCRIPTION        |                    |                    |
| A         | ISSUED             | 11/13/79<br>E.F.B. | 1/10/80<br>M.J.C.  |
| B         | .309 DIM. WAS .375 | 11/27/79<br>E.F.B. | 11-27-79<br>M.J.C. |

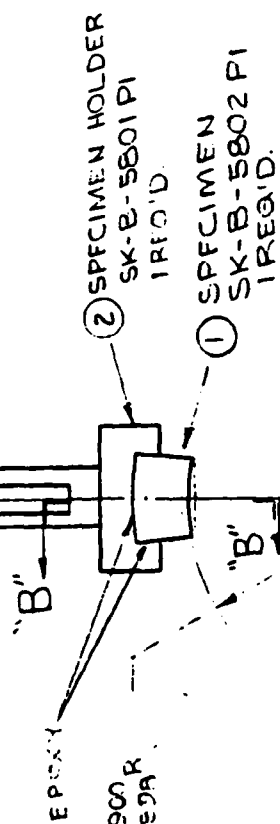


.25 (OR AS FURNISHED)

(PI) MAT'L: ELASTOMER  
SUPPLIED BY ENGINEERING



.250 DIA.  
(REF.)



SECTION "B"-"B"

|                                                                                                                                             |                                |                                                                 |                  |
|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------|------------------|
|  Mechanical Technology Incorporated<br>Lynch, Pa. U.S.A. |                                | TITLE<br>Figure 3.5<br>Schematic of Assembly<br>Specimen Holder |                  |
| DRAWN<br>J. J. J. 13 NOV. '79                                                                                                               | CHECKED<br>H. H. 11/13/79      | CODE IDENT NO.<br>26741                                         | SIZE<br>B        |
| DESIGN<br>ANALYTICAL<br>MATERIALS<br>MFG. ENGR.                                                                                             | PROJ. ENGR.<br>QUALITY CONTROL | SCALE<br>2X                                                     | ACT.<br>MT. ORG. |

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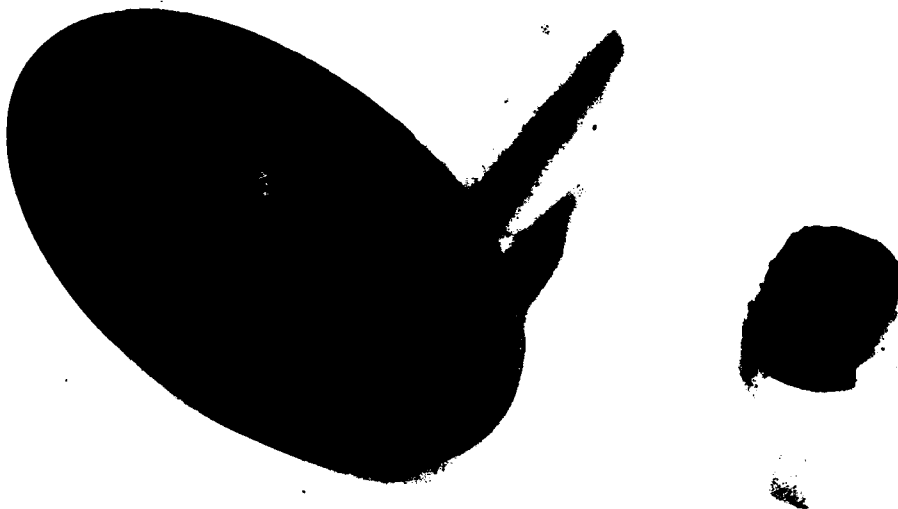


Fig. 3.6 Cylinder and Pin

### 3.2 Test Results and Discussions

#### 3.2.1 Static Material Submersion Tests

As mentioned earlier, the static soak tests were conducted at 0°C, 22°C, and 66°C submerged in synthetic seawater for two months. The properties measured were: weight, volume, hardness, tensile strength, and elongation changes.

The change in properties during tests are presented in Table 3.1. The samples after 0°C tests showed no significant weight and volume changes; in all cases it was less than 0.1% which is within the experimental error. The weight and volume changes at 66°C were higher than at 22°C as one would expect. The samples having migrating liquid lubricant (2 and 9 in Table 3.1) showed lower volume change but higher weight changes.

Hardness, tensile strength and elongation changes of lubricant-filled elastomers were comparable to unfilled elastomers. Scatter found in tensile strength and elongation data was responsible for the higher changes recorded. Samples with migrating lubricant (from Astro Molding) and with "slippery stuff" (Minnesota Rubber Company) had slightly more tensile strength loss and elongation change than others, probably because, with oil fillers, there is a poorer molecular bond between the polymer and oil than polymer and graphite, etc. Samples with CdO-graphite-Ag generally had higher strength than samples with other fillers.

Most samples were unchanged in their physical appearance after soak tests. Only samples numbered 11 to 17 (Table 3.1) after 66°C tests had some change; i.e., a white deposit film which could be scrapped off easily (Figure 3.7). No significance was attached to the film.

Test data showed that changes in the properties measured of lubricant-filled elastomers were statistically comparable to unfilled elastomers. Therefore, there is no apparent degradation of the elastomers due to lubricant fillers. All elastomers were recommended for friction and wear tests.

TABLE 3-1  
PHYSICAL TEST DATA OF MATERIAL SOAK TESTS  
Test Duration = 2 Months  
Test Specimens Per ASTM Spec #D471-75

| Item No.                             | Material Designation                       | Original Properties         |               |                   | Synthetic Seawater at 0°C |                  |                   |                            |                      | Synthetic Seawater at 22°C |                  |                   |                            |                      | Synthetic Seawater at 66°C |                  |                   |                            |                      |
|--------------------------------------|--------------------------------------------|-----------------------------|---------------|-------------------|---------------------------|------------------|-------------------|----------------------------|----------------------|----------------------------|------------------|-------------------|----------------------------|----------------------|----------------------------|------------------|-------------------|----------------------------|----------------------|
|                                      |                                            | Tensile Strength, MPa (ksi) | Elongation, % | Shore Hardness, A | Weight Change, %          | Volume Change, % | Hardness, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, %           | Volume Change, % | Hardness, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, %           | Volume Change, % | Hardness, Shore A | Tensile Strength Change, % | Elongation Change, % |
| ASTRO                                | HOLDING INC (Vendor #1)                    |                             |               |                   |                           |                  |                   |                            |                      |                            |                  |                   |                            |                      |                            |                  |                   |                            |                      |
| 1                                    | Standard Nitrile Rubber                    | 15.85 (2.30)                | 150           | 89                |                           |                  | 0                 | 6.52                       | -6.7                 | 1.16                       | 0.68             | -1                | 6.40                       | -10.0                | 5.68                       | 6.25             | +1                | 4.34                       | -3.3                 |
| 2                                    | Nitrile Rubber with 5% migrating lubricant | 16.67 (2.42)                | 135           | 80                |                           |                  | 0                 | -13.4                      | -7.4                 | 0.78                       | 0.069            | 0                 | -11.36                     | -14.8                | 5.13                       | 5.07             | +2                | -11.57                     | -22.2                |
| 3                                    | Nitrile Rubber with 5% graphite            | 17.43 (2.53)                | 150           | 88                |                           |                  | -2                | -5.30                      | -10.0                | 0.97                       | 0.64             | -1                | -3.10                      | -18.6                | 5.84                       | 6.71             | +1                | -6.13                      | -3.3                 |
| 4                                    | Nitrile Rubber with 10% graphite           | 16.26 (2.36)                | 155           | 90                |                           |                  | +2                | -4.02                      | -9.7                 | 0.86                       | 0.55             | -1                | -4.87                      | -8.4                 | 5.35                       | 6.22             | +1                | -5.72                      | -12.9                |
| 5                                    | Nitrile Rubber with 5% CdO-graphite-Ag     | 18.12 (2.63)                | 150           | 87                |                           |                  | +1                | -4.18                      | -6.7                 | 0.95                       | 0.60             | -1                | -5.06                      | -6.7                 | 5.05                       | 5.00             | +2                | -4.00                      | -12                  |
| 6                                    | Nitrile Rubber with 10% CdO-graphite-Ag    | 17.16 (2.49)                | 150           | 89                |                           |                  | 0                 | -3.61                      | 0                    | 0.92                       | 0.50             | -1                | -1.80                      | -2.0                 | 3.47                       | 3.27             | +2                | -1.80                      | -6.7                 |
| MINNESOTA RUBBER COMPANY (Vendor #2) |                                            |                             |               |                   |                           |                  |                   |                            |                      |                            |                  |                   |                            |                      |                            |                  |                   |                            |                      |
| 7                                    | Standard Nitrile Rubber                    | 18.19 (2.64)                | 210           | 87                |                           |                  | +1                | +7.59                      | 0                    | 0.71                       | 0.067            | -1                | +3.3                       | -14.3                | 2.25                       | 1.66             | 0                 | +3.56                      | -26.2                |

TABLE 3-1 (cont'd)

| Item No.                       | Material Designation                             | Original Properties         |               |                   | Synthetic Seawater at 0°C |                  |                              |                            |                      |                  | Synthetic Seawater at 22°C |                              |                            |                      |                  |                  | Synthetic Seawater at 66°C   |                            |                      |  |  |  |
|--------------------------------|--------------------------------------------------|-----------------------------|---------------|-------------------|---------------------------|------------------|------------------------------|----------------------------|----------------------|------------------|----------------------------|------------------------------|----------------------------|----------------------|------------------|------------------|------------------------------|----------------------------|----------------------|--|--|--|
|                                |                                                  | Tensile Strength, MPa (ksi) | Elongation, % | Shore Hardness, A | Weight Change, %          | Volume Change, % | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, % | Volume Change, %           | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, % | Volume Change, % | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % |  |  |  |
| 8                              | Nitrile Rubber with 20 phr <sup>†</sup> graphite | 16.61 (2.41)                | 215           | 88                |                           |                  | 0                            | -2.00                      | -11.6                | 0.81             | 0.35                       | 0                            | -1.08                      | -13.9                | 2.22             | 1.64             | 0                            | +3.60                      | -32.6                |  |  |  |
| 9                              | Nitrile Rubber with 5 phr "slippery stuff"       | 18.33 (2.66)                | 215           | 86                |                           |                  | -3                           | -11.69                     | +2.5                 | 0.22             | -0.54                      | -1                           | -9.58                      | 0                    | 1.66             | 0.94             | -1                           | -8.05                      | -9.3                 |  |  |  |
| 10                             | Nitrile Rubber with 20 phr molybdenum disulfide  | 18.53 (2.69)                | 200           | 87                |                           |                  | +1                           | -8.81                      | +10                  | 0.78             | 0.16                       | 0                            | -8.66                      | +2.5                 | 2.18             | 1.48             | +1                           | -4.23                      | -17.5                |  |  |  |
| JOHNSON RUBBER CO. (Vendor #3) |                                                  |                             |               |                   |                           |                  |                              |                            |                      |                  |                            |                              |                            |                      |                  |                  |                              |                            |                      |  |  |  |
| 11**                           | Standard Nitrile Rubber                          | 15.50 (2.25)                | 350           | 85                |                           |                  | -3                           | -8.84                      | -20                  | 1.30             | 0.81                       | -2                           | -5.77                      | -14.2                | 3.88             | 3.05             | 0                            | -8.22                      | -45.7                |  |  |  |
| 12**                           | Nitrile Rubber with 10% graphite                 | 13.78 (2.00)                | 290           | 89                |                           |                  | -1                           | -2.65                      | -24.1                | 1.41             | 1.11                       | 0                            | -6.65                      | -20.7                | 3.88             | 3.34             | 0                            | -10.4                      | -58.6                |  |  |  |
| 13**                           | Nitrile Rubber with 20% graphite                 | 12.13 (1.76)                | 180           | 90                |                           |                  | +1                           | -5.51                      | -27.7                | 1.30             | 1.04                       | 0                            | -4.94                      | -25                  | 4.21             | 3.72             | 0                            | -3.01                      | -55.5                |  |  |  |
| 14**                           | Nitrile Rubber with 10% CdO-graphite-Ag          | 14.61 (2.12)                | 320           | 86                |                           |                  | 0                            | -2.26                      | -15.6                | 1.35             | 1.03                       | 0                            | -11.46                     | -25                  | 3.86             | 3.70             | -1                           | -22.92                     | -59.3                |  |  |  |

\*Parts per hundred parts of nitrile (base polymer).

\*\*White deposit on the test specimens after tests at 66°C. The deposit could easily be scraped off.

TABLE 3-1 (cont'd)

| Item No. | Material Designation                     | Original Properties         |               |                   | Synthetic Seawater at 0°C |                  |                              |                            |                      | Synthetic Seawater at 22°C |                  |                              |                            |                      | Synthetic Seawater at 66°C |                  |                              |                            |                      |
|----------|------------------------------------------|-----------------------------|---------------|-------------------|---------------------------|------------------|------------------------------|----------------------------|----------------------|----------------------------|------------------|------------------------------|----------------------------|----------------------|----------------------------|------------------|------------------------------|----------------------------|----------------------|
|          |                                          | Tensile Strength, MPa (ksi) | Elongation, % | Shore Hardness, A | Weight Change, %          | Volume Change, % | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, %           | Volume Change, % | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % | Weight Change, %           | Volume Change, % | Hardness Pts Change, Shore A | Tensile Strength Change, % | Elongation Change, % |
| 15*      | Nitrile Rubber with 20% CdO-graphite-Ag  | 16.40 (2.38)                | 200           | 90                |                           |                  | +1                           | -9.66                      | -30.0                | 1.20                       | 1.07             | 0                            | -11.20                     | -35                  | 3.05                       | 2.52             | +2                           | -15.46                     | -65.0                |
| 16*      | Nitrile Rubber with 10% MoS <sub>2</sub> | 14.54 (2.11)                | 280           | 89                |                           |                  | -1                           | +4.17                      | -46.4                | 1.30                       | 1.08             | -1                           | -1.75                      | -46.4                | 3.60                       | 3.10             | +1                           | -1.32                      | -64.2                |
| 17*      | Nitrile Rubber with 20% MoS <sub>2</sub> | 13.78 (2.00)                | 260           | 86                |                           |                  | 0                            | -7.9                       | -7.7                 | 1.23                       | 1.00             | 0                            | -6.65                      | -26.9                | 4.14                       | 3.95             | +2                           | -14.90                     | -53.8                |

\*White deposit on the test specimens after tests at 66°C. The deposit could easily be scraped off.



Fig. 3.7 Test Samples After Submersion Test  
(Item 2, Table 3.1)

### 3.2.2 Friction and Wear Tests

All seventeen elastomer samples were tested against 70 Cu - 30 Ni cylinder in seawater at 0.35 MPa and  $0.37 \text{ m.s}^{-1}$  (140 rpm) for a test duration of 24 hours. The kinetic friction data are presented in Table 3.2. The measured total wear (25-35  $\mu\text{m}$  in 25 hours) of different pins was within the experimental error so no discrimination could be made of pin materials based on the wear. Tests for longer duration have to be conducted in order to determine wear. Primarily, the objective here was to develop a low-friction material.

The surface roughness of the cylinders after test did not change. In each case the pin surfaces were generally polished and shiny. In some cases the solid-lubricant particles could be seen on the pin surface (Table 3.2 and Figure 3.8). In tests of nitrile rubber with 5% migrating lubricant, the lubricant oozed to the surface after the pin was allowed to sit for a few hours (Item 2, Table 3.2). In tests with 5 phr "slippery stuff" a distinct white layer of the "slippery stuff" was formed after the specimen was allowed to sit overnight (Item 9, Table 3.2).

In each case there was a slight deposit on the cylinder surface of either elastomer constituent or from the cylinder's reaction with seawater (see Figure 3.9 for typical appearance). This was not considered significant.

Friction coefficients were found to start out high and, as they ran, went down steadily, reaching a plateau after about four to six hours (e.g., see Figure 3.10). The friction coefficients reported here were rather low ( $< 0.1$  in all cases) which is due to boundary lubrication effects. Kinetic friction with solid-lubricant impregnated with elastomers was noted to be lower than that of standard elastomers. The specimens having migrating lubricant (Item 2) supplied by Astro Molding, specimens having "slippery stuff" (Item 9) supplied by Minnesota Rubber Company, and also specimens having CdO-Graphite-Ag (Item 15) supplied by Johnson Rubber Company had lower friction than others supplied by these same companies. Increased addition of lubricant fillers resulted in slightly lower friction.

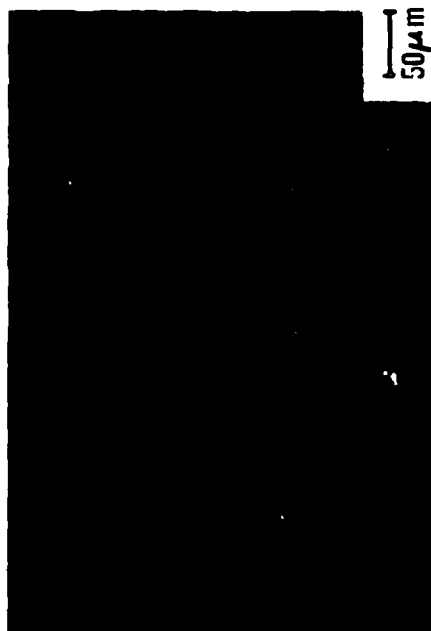
TABLE 3-2

## FRICTION TEST RESULTS FROM UNIDIRECTIONAL CONTINUOUS SLIDING TESTER

Lubricant: Synthetic Seawater      Sliding Speed =  $0.37 \text{ m} \cdot \text{s}^{-1}$  or 140 rpm      Normal Stress =  $0.35 \text{ MPa}$  (50 psi)  
 Test Duration = 24 hours      Temperature =  $22^\circ\text{C}$  ( $72^\circ\text{F}$ )  
 Surface Roughness of Cylinder =  $0.41 \pm 0.03 \mu\text{m}$  ( $16 \pm 1 \mu\text{in.}$ ) CLA

| Item No.                         | Elastomer Material                               | Kinetic Friction Coefficient |             | Comments                                                                                                                                                                                                                                                                       |
|----------------------------------|--------------------------------------------------|------------------------------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  |                                                  | Start of Test                | End of Test |                                                                                                                                                                                                                                                                                |
| ASTRO HOLDING INC. (Vendor #1)   |                                                  |                              |             |                                                                                                                                                                                                                                                                                |
| 1                                | Standard Nitrile Rubber                          | 0.21                         | 0.09        | Ran rough. Graphite particles clearly visible on the pin surface.<br><br>Ran rough. Graphite particles clearly visible on the pin surface.<br><br>Very few particles visible on the pin surface.<br><br>Very few particles visible on the pin surface.                         |
| 2                                | Nitrile Rubber with 5% Migrating Lubricant       | 0.11                         | 0.025       |                                                                                                                                                                                                                                                                                |
| 3                                | Nitrile Rubber with 5% Graphite                  | 0.15                         | 0.045       |                                                                                                                                                                                                                                                                                |
| 4                                | Nitrile Rubber with 10% Graphite                 | 0.17                         | 0.06        |                                                                                                                                                                                                                                                                                |
| 5                                | Nitrile Rubber with 5% CdO-Graphite-Ag           | 0.19                         | 0.04        |                                                                                                                                                                                                                                                                                |
| 6                                | Nitrile Rubber with 10% CdO-Graphite-Ag          | 0.17                         | 0.04        |                                                                                                                                                                                                                                                                                |
| MINNESOTA RUBBER CO. (Vendor #2) |                                                  |                              |             |                                                                                                                                                                                                                                                                                |
| 7                                | Standard Nitrile Rubber                          | 0.22                         | 0.07        | White layer of "slippery stuff" visible on the pin surface after sitting for few hours.                                                                                                                                                                                        |
| 8                                | Nitrile Rubber with 20 phr <sup>a</sup> Graphite | 0.29                         | 0.04        |                                                                                                                                                                                                                                                                                |
| 9                                | Nitrile Rubber with 5 phr "Slippery Stuff"       | 0.13                         | 0.04        |                                                                                                                                                                                                                                                                                |
| 10                               | Nitrile Rubber with 20 phr Molybdenum Disulfide  | 0.13                         | 0.05        |                                                                                                                                                                                                                                                                                |
| JOHNSON RUBBER CO. (Vendor #3)   |                                                  |                              |             |                                                                                                                                                                                                                                                                                |
| 11                               | Standard Nitrile Rubber                          | 0.18                         | 0.07        | Graphite particles visible on the pin surface.<br><br>Graphite particles visible on the pin surface.<br><br>Graphite particles visible on the pin surface.<br><br>Graphite particles visible on the pin surface.<br><br>MoS <sub>2</sub> particles visible on the pin surface. |
| 12                               | Nitrile Rubber with 10% Graphite                 | 0.17                         | 0.03        |                                                                                                                                                                                                                                                                                |
| 13                               | Nitrile Rubber with 20% Graphite                 | 0.07                         | 0.02        |                                                                                                                                                                                                                                                                                |
| 14                               | Nitrile Rubber with 10% CdO-Graphite-Ag          | 0.06                         | 0.03        |                                                                                                                                                                                                                                                                                |
| 15                               | Nitrile Rubber with 20% CdO-Graphite-Ag          | 0.07                         | 0.015       |                                                                                                                                                                                                                                                                                |
| 16                               | Nitrile Rubber with 10% MoS <sub>2</sub>         | 0.14                         | 0.03        |                                                                                                                                                                                                                                                                                |
| 17                               | Nitrile Rubber with 20% MoS <sub>2</sub>         | 0.06                         | 0.025       |                                                                                                                                                                                                                                                                                |

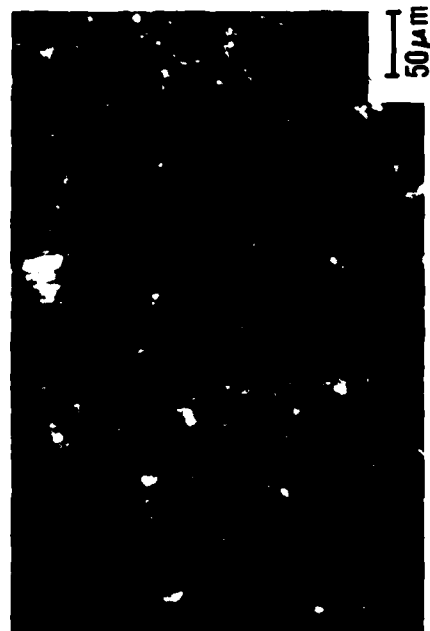
<sup>a</sup>Parts per hundred parts of Nitrile (base polymer)



Standard Nitrile Rubber



Standard Nitrile Rubber with 20% MoS<sub>2</sub> Powder



Standard Nitrile Rubber with 20% Graphite Powder

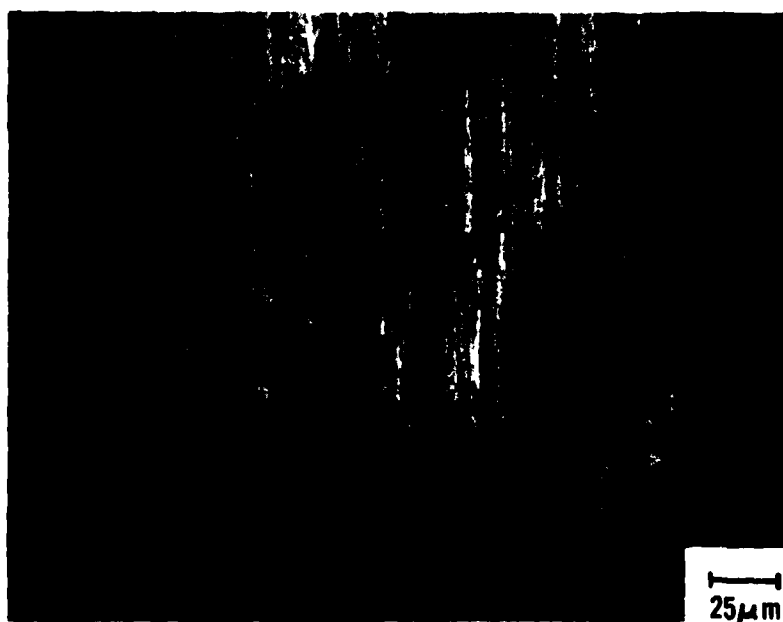


Standard Nitrile Rubber with 20% CdO-Graphite-Ag Powder

Fig. 3.8 Optical Micrographs of Elastomer Samples (Johnson Rubber Company)  
After Test



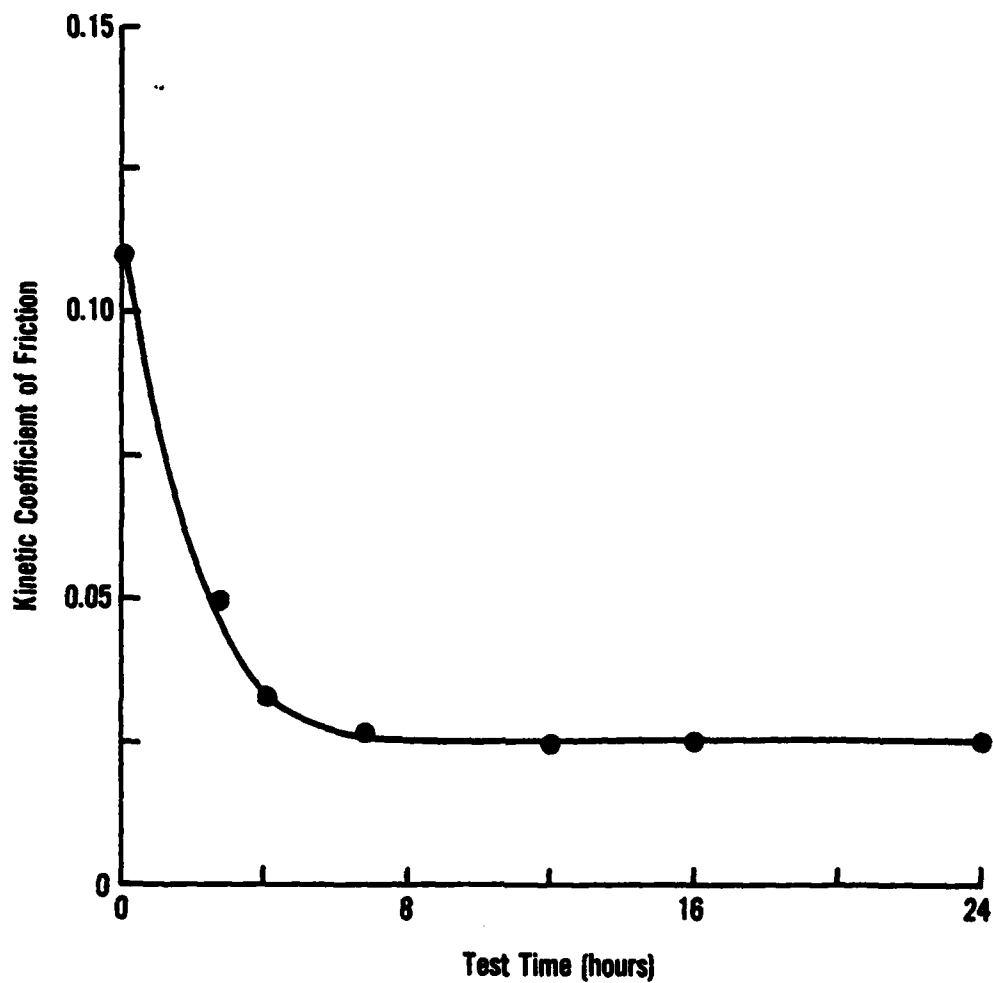
After Test Against Standard Nitrile Rubber



After Test Against Nitrile Rubber with 5% CdO-Graphite-Ag

Fig. 3.9 Optical Micrographs of Cylinder Surfaces  
After Tests Against Elastomers (Astro  
Molding) as Indicated

-31-



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Fig. 3.10 Kinetic Coefficient of Friction vs Time Curve  
for Nitrile Rubber with 5% Migrating Lubricant  
(Item 2, Table 3.2)

There is a potential disadvantage of using liquid lubricants because the lubricant due to surface migration may be used up after some period.

PV Tests: The additional tests were conducted at normal stresses of 0.18 and 0.70 MPa at a speed of 140 rpm and at 0.35 MPa at speeds of 70 and 210 rpm on selected specimens. These were: Standard nitrile rubber, Standard with 10% CdO-graphite-Ag, and Standard with 5% migrating lubricant supplied by Astro Molding. At the test conditions, the coefficient of friction was independent of both stress and speed.

#### 4.0 CONCLUSIONS AND RECOMMENDATIONS

##### 4.1 Conclusions

Static submersion tests showed that the weight, volume, hardness, tensile strength, and elongation changes of the lubricant-filled elastomers were comparable to unfilled elastomers after submersion tests of two months at 0°C, 22°C, and 66°C in synthetic seawater. Therefore, for at least that period of time, there is no material degradation in seawater submersion due to fillers in the elastomers. Friction tests indicate that the kinetic coefficient of friction of lubricant-filled elastomers (0.015-0.06, varying from one filler to another and from one supplier to another) was lower than that of unfilled elastomers (0.07-0.09). Elastomers with higher concentration of lubricant fillers generally had slightly lower friction than those with a lower concentration of fillers. Stress and speed had no influence on the coefficient of friction in the range tested.

It has, therefore, been demonstrated that the coefficient of friction of elastomers during sliding can be reduced by adding lubricants during compounding. The lubricant fillers have no adverse effect on the physical and mechanical properties during long-term seawater submersion.

##### 4.2 Recommendations

Preliminary work done in the program indicate that lubricant-filled elastomers lead to lower friction. This work should be continued. The concept of migrating lubricant should be further developed by using different types and percentages of incompatible oils. The supply of oil in the elastomer may be used up after some period. A study should be conducted to determine its useful life. Addition of different grades of MoS<sub>2</sub> and graphite mixtures should be further investigated. No study on PTFE powder, bronze powder, or graphite fiber could be done in this work due to the limited scope of this program; this study should be performed. Some thoughts on methods of improving the bond of PTFE powder with elastomers are given in this report.

The lubricant fillers should be added to elastomers other than nitrile which are used in bearing and seal applications.

The addition of lubricants may result in an elastomer-metal-backing bond problem in bearing systems. This can be prevented by a number of ways, e. g., by having dovetails on the metal surface to provide elastomer locking; by bolting the elastomer to the metal surface, or by bonding elastomer to nonmetallic (plastics or rubber) backing. The lubricant addition could also be graduated so there is more lubricant near the sliding surface and none near the elastomer-metal backing interface. This may minimize the bond problem.

The lubricant-filled elastomers developed here should be tested for noise generation in the squeal test rig (see Reference 4) for comparison with that of unfilled elastomers.

#### ACKNOWLEDGMENT

The author would like to thank the following companies for preparing the elastomer test specimens: Astro Molding Inc., Minnesota Rubber Company and the Johnson Rubber Company.

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APPENDIX A

Military Spec. MIL-B-17901  
Class I for Nitrile Rubber Bearings

DR. BHARAT BHUCHAN

DR. BHARAT BHUCHAN

QPL-17901-17  
6 August 1969  
SUPERSEDING  
QPL-17901-16  
30 April 1969

QUALIFIED PRODUCTS LIST  
OF  
PRODUCTS QUALIFIED UNDER MILITARY SPECIFICATION

PSC 3130

MIL-B-17901

Class I

BEARING COMPONENTS, BONDED SYNTHETIC RUBBER, WATER LUBRICATED

This list has been prepared for use by or for the Government in the procurement of products covered by the subject specification and such listing of a product is not intended to and does not connote endorsement of the product by the Department of Defense. All products listed herein have been qualified under the requirements for the product as specified in the latest effective issue of the applicable specification. This list is subject to change without notice; revision or amendment of this list will be issued as necessary. The listing of a product does not release the supplier from compliance with the specification requirements. Use of the information shown herein for advertising or publicity purposes is expressly forbidden.

The activity responsible for this Qualified Products List is Naval Ship Engineering Center

| GOVERNMENT DESIGNATION  | MANUFACTURER'S DESIGNATION                                                   | TEST OR QUALIFICATION REFERENCE                                  | MANUFACTURER'S NAME AND ADDRESS                                                                                                                                               |
|-------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class I                 | Byron-Jackson<br>Compound 7-6                                                | Byron-Jackson<br>Rpt. WDC3672,<br>dtd. 26 May 1961               | Byron-Jackson Tools, Inc.<br>Borg-Warner Corp.<br>P. O. Box 2709<br>Terminal Annex<br>Los Angeles, Calif. 90054<br>Plant: 1900 E. 65th Street<br>Los Angeles,<br>Calif. 90001 |
| Class I<br>(Stave type) | Johnson Rubber Co.                                                           | Johnson Rubber Co.<br>Lab. Rpt. dated<br>25 October 1963         | Johnson Rubber Co.<br>Marine Products Division<br>222 Vine Street<br>Middlefield, Ohio<br>Plant: Same address                                                                 |
| Class I                 | DKK-54 (Buns N)                                                              | EES-C-2719-B                                                     | L. Q. Moffitt, Inc.<br>P. O. Box 1415<br>Akron, Ohio 44309<br>Plant: B. F. Goodrich Co.<br>Akron, Ohio                                                                        |
| Class I                 | Stillman<br>Compound SR322-85                                                | Rubber Co.<br>Rpt. #1305, dtd<br>5 April 1962                    | Cresskill/Stillman Rubber Corp.<br>196-200 Forest Avenue<br>Englewood, N. J. 07631<br>Plant: Same address                                                                     |
| Class I                 | Waukesha Stave<br>Bearing #330-001,<br>utilizing Firestone<br>Compound 93129 | Firestone Industrial<br>Products Co.<br>Rpt. of<br>23 March 1959 | Waukesha Bearings Corp.<br>Commerce and Pearl Streets<br>Waukesha, Wisc. 53187<br>Plant: Firestone Industrial<br>Products Co.<br>Noblesville, Ind.                            |
| Class I                 | West American<br>Rubber Compound<br>90P148                                   | West American<br>Rubber Rpt.<br>191, 1/20/59                     | West American Rubber Co.<br>750 N. Main St.<br>Orange, Calif. 92667<br>Plant: Same address                                                                                    |

1 of 2

| GOVERNMENT DESIGNATION | MANUFACTURER'S DESIGNATION                                 | TEST OR QUALIFICATION REFERENCE                          | MANUFACTURER'S NAME AND ADDRESS                                                                                                                                          |
|------------------------|------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class II               | Byron Jackson Compound D60                                 | SPS 140027                                               | Byron-Jackson Tools, Inc.<br>Borg-Warner Corp.<br>P. O. Box 2709<br>Terminal Annex<br>Los Angeles, Calif. 90054<br>Plant: 1900 E. 65 Street<br>Los Angeles, Calif. 90001 |
| Class II               | Johnson Rubber Co. No. 2813                                | Johnson Rubber Co.<br>Rpt. of 27 Jan. 1961               | The Johnson Rubber Co.<br>Marine Products Division<br>222 Vine Street<br>Middlefield, Ohio<br>Plant: Same address                                                        |
| Class II               |                                                            | NYK Mat. Lab. 4921-1                                     | L. G. Moffitt, Inc.<br>P. O. Box 1415<br>Akron, Ohio 44309<br>Plant: B. F. Goodrich Co.<br>Akron, Ohio                                                                   |
| Class II               | Waukesha Full Molded Bearing with Firestone Compound 93242 | Firestone Industrial Products Co.<br>Rpt. of 4 Jan. 1960 | Waukesha Bearings Corp.<br>Commerce and Pearl Streets<br>Waukesha, Wisc. 53187<br>Plant: Firestone Industrial Products Co.<br>Noblesville, Ind.                          |
| Class II               | West American Rubber Compound 70P123                       | West American Rubber Rpt.<br>192 1/20/69                 | West American Rubber Co.<br>750 N. Main St.<br>Orange, Calif. 92667<br>Plant: Same address                                                                               |

MIL-B-17901A(SHIPS)  
AMENDMENT - 3  
3 June 1966  
SUPERSEDING 1/  
Amendment - 2  
28 October 1964

MILITARY SPECIFICATION  
BEARING COMPONENTS, BONDED SYNTHETIC  
RUBBER, WATER LUBRICATED

This amendment forms a part of Military Specification MIL-B-17901A(SHIPS), 3 April 1963.

# Page 1, paragraph 2.1: Under Military Specifications add:  
"MIL-I-45208 - Inspection System Requirements."

# Page 3: Add as paragraph 4.1.1:

"4.1.1 Inspection system requirements. - The supplier shall provide and maintain an inspection system acceptable to the Government. The inspection system requirements shall be in accordance with MIL-I-45208. The supplier is in no way relieved of the final responsibility to furnish bearing components meeting the requirements of this specification."

# Page 5: Add as paragraph 4.6:

"4.6 Qualification continuance tests. - Qualification continuance tests shall be conducted at a laboratory satisfactory to the Naval Ship Engineering Center (NAVSEC) and shall consist of the same tests and procedures specified for the qualification tests in 4.2. Three copies of the qualification continuance test reports shall be forwarded to NAVSEC. Action to maintain the approval of the material will be taken by NAVSEC on the basis of the test results. If qualification continuance test results are not received before the expiration of five years from the date of a qualification or prior qualification continuance test approval, such approval will be withdrawn, and the product removed from the Military Qualified Products List."

Preparing activity:  
Navy - SH  
(Project 3130-NODASH)

1/ CHANGES FROM PREVIOUS ISSUE. THE OUTSIDE MARGINS OF THIS DOCUMENT HAVE BEEN MARKED "#" TO INDICATE WHERE CHANGES (DELETIONS, ADDITIONS, ETC.) FROM THE PREVIOUS ISSUE HAVE BEEN MADE. THIS HAS BEEN DONE AS A CONVENIENCE ONLY AND THE GOVERNMENT ASSUMES NO LIABILITY WHATSOEVER FOR ANY INACCURACIES IN THESE NOTATIONS. BIDDERS AND CONTRACTORS ARE CAUTIONED TO EVALUATE THE REQUIREMENTS OF THIS DOCUMENT BASED ON THE ENTIRE CONTENT AS WRITTEN IRRESPECTIVE OF THE MARGINAL NOTATIONS AND RELATIONSHIP TO THE LAST PREVIOUS ISSUE.

FSC 3130

MILITARY SPECIFICATION  
BEARING COMPONENTS, BONDED SYNTHETIC RUBBER, WATER  
LUBRICATED

1. SCOPE

1.1 Scope. - This specification covers both stave and full molded type synthetic rubber faced metal backed bearings.

1.2 Classification. - Bearings shall be of the following classes, as specified (see 6.1):

Class I - Stave type.  
Class II - Full molded type.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

FEDERAL

QQ-B-621 - Brass; Castings, Leaded Yellow  
QQ-B-637 - Brass, Naval: Rod, Wire, Shapes, Forgings, and Flat Products With Finished Edges (Bar, Flat Wire, and Strip)  
QQ-B-639 - Brass, Naval: (Flat Products) Plate, Bar, Sheet and Strip

MILITARY

MIL-C-15345 - Castings, Non-Ferrous, Centrifugal  
MIL-B-16541 - Bronze, Valve: Castings  
MIL-M-16576 - Metal, Gun: Castings

STANDARDS

FEDERAL

Fed. Test Method Std. No. 601 - Rubber: Sampling and Testing  
Fed. Test Method Std. No. 791 - Lubricants, Liquid Fuels and Related Products: Methods of Testing

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. - The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

OFFICIAL CLASSIFICATION COMMITTEE

Uniform Freight Classification Rules.

(Application for copies should be addressed to the Official Classification Committee, 1 Park Avenue at 33rd Street, New York 16, New York.)

FSC 3130

## 3. REQUIREMENTS

3.1 Qualification. - Bearings furnished under this specification shall be a product which has passed the qualification tests specified herein and has been listed or approved for listing on the applicable qualified products list.

3.2 Bearing material. - Bearing material covered by this specification shall be a synthetic rubber compound.

3.2.1 Physical properties. - The material shall conform to the following physical requirements:

(a) Before aging:

Tensile strength, minimum, pounds per square inch . . . . . 1500  
Ultimate elongation, minimum, percent . . . . . 150

(b) Hardness. - Initial hardness shall be as follows:

Class I - 85 ± 5 points, durometer, instantaneous.

Class II - 70 ± 5 points, durometer, instantaneous.

(c) After aging. - After being subjected to the oven aging test specified in 4.5.6, the rubber material shall not vary more than 25 percent from the initial tensile strength and ultimate elongation.

FO  
DE

3.2.2 Metal parts. - Metal parts for class I bearings shall be Naval brass in accordance with QQ-B-637 or QQ-B-639. Metal parts for class II bearings shall be casting or tubing as specified in 3.2.2.1. and 3.2.2.2.

3.2.2.1 Casting. - Casting shall be one of those specified in table I.

Table I - Castings

| Material     | Centrifugal castings | Static castings |
|--------------|----------------------|-----------------|
| Gun metal    | MIL-C-15345          | MIL-M-16576     |
| Naval brass  | MIL-C-15345          | QQ-B-621        |
| Valve bronze | MIL-C-15345          | MIL-B-16541     |

3.3.2.2 Tubing. - Naval brass tubing shall conform to the chemical requirements of QQ-B-637 or QQ-B-639.

3.3 General requirements. - Type, form, style, design, and dimension tolerances shall be as specified (see 6.1).

3.4 Adhesion. -

FO

3.4.1 Before aging. - The adhesion of the rubber material to the metal backing shall be not less than 40 pounds when tested as specified in 4.5.3.

3.4.2 After aging. - The adhesion of the rubber material to the metal backing after oven aging specified in 4.5.6 shall be not less than 30 pounds when tested as specified in 4.5.3.

3.4.3 After oil immersion. - The adhesion of the rubber material to the metal backing after oil immersion as specified in 4.5.7 shall be not less than 20 pounds when tested as specified in 4.5.3.

3.4.4 Delamination. - Rubber material shall show no evidence of separation into distinct layers or laminations when tested as specified in 4.5.4.

3.4.5 Volume change. -

3.4.5.1 Water immersion. - When immersed in water, the volume of the rubber specimen shall not increase more than 5 percent when tested as specified in 4.5.5.1.

3.4.3.2 Oil immersion. - When immersed in oil as specified in 4.5.7, the volume of the rubber specimen shall not increase more than 5 percent when tested as specified in 4.5.5.2.

3.4.6 Performance. - The rubber material shall be capable of passing the performance test for wear, friction, and noise characteristics specified in 4.5.8.

#### 4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Qualification tests. - <sup>1/</sup> Qualification tests shall be conducted at a laboratory satisfactory to the Bureau of Ships. Qualification tests shall be conducted on each class and shall consist of the tests specified in 4.5.

#### 4.3 Quality conformance inspection. -

4.3.1 Lot. - All bearings of the same class and size, having metal parts conforming to the same specification and offered for delivery at one time shall be considered a lot.

4.3.2 Sampling for examination. - Sample bearings shall be selected at random from each lot in accordance with table II and subjected to the examination of 4.4.

Table II - Sampling for examination  
(AQL (approx.) = 1.5 percent defective.)

| Lot size number of bearings | Sample size number to be inspected | Acceptance number (defectives) | Rejection number (defectives) |
|-----------------------------|------------------------------------|--------------------------------|-------------------------------|
| 15 and under                | 7                                  | 0                              | 1                             |
| 16 to 40                    | 10                                 | 0                              | 1                             |
| 41 to 110                   | 15                                 | 0                              | 1                             |
| 111 to 300                  | 25                                 | 1                              | 2                             |
| 301 to 500                  | 35                                 | 1                              | 2                             |
| 501 to 800                  | 50                                 | 2                              | 3                             |
| 801 to 1300                 | 75                                 | 3                              | 4                             |
| 1301 and over               | 110                                | 4                              | 5                             |

#### 4.3.3 Sampling for tests. -

→ 4.3.3.1 Class I (stave type). - Two staves at least 24 inches long shall be made from samples selected from each lot and subjected to the test specified in 4.5.1 through 4.5.4, and 4.5.6.

4.3.3.2 Class II (full molder type). - One bearing at least 24 inches long shall be made from samples selected from each lot and subjected to the test specified in 4.5.1 through 4.5.4, and 4.5.6.

4.3.3.3 Sampling for performance test. - When required by the Bureau or agency concerned, a suitable bearing assembly or test specimen, or both, shall be selected and subjected to the test specified in 4.5.8.

4.4 Examination. - Each of the sample bearings shall be examined to determine conformance with the requirements of this specification not involving tests. Any bearing containing one or more defects shall not be offered for delivery and if the number of defective bearings in any sample exceeds the acceptance number for that sample, the lot represented by the sample shall not be offered for delivery.

<sup>1/</sup> Application for Qualified tests shall be made in accordance with "Provisions Governing Qualification" (see 6.2 and 6.2.1).

4.5 Tests. - <sup>2/</sup>

4.5.1 Tension and elongation. - <sup>3/</sup> Straight type test specimens shall be tested for tensile strength and elongation in accordance with methods 4111 and 4121 respectively of Federal Test Method Standard 601.

4.5.2 Hardness. - The instantaneous durometer hardness test shall be made with a Shore type A durometer in accordance with method 3021 of Federal Test Method Standard 601.

4.5.3 Adhesion. -

4.5.3.1 Class I specimens. - Two 6 inch long specimens shall be cut from the sample staves. Two parallel longitudinal cuts, 1 inch apart, shall be made in the central portion of the synthetic rubber face material cut or buffed to 1/4 inch in thickness. The excess rubber on the edges of the bearing shall be carefully removed leaving a 1-inch wide rubber strip approximately in the center of the bearing strip.

4.5.3.2 Class II specimens. - Two 6 inch long specimens shall be cut from the length of the full molded bearing. If lands are sufficiently wide, specimens 1 inch wide shall be prepared as specified in 4.5.3.1. If not, specimens shall be cut the width of the land and adhesion value corrected to allow for the difference in width. Width shall be measured as the area of contact of rubber material with the metal backing.

4.5.3.3 Two specimens shall be tested, and the value for adhesion shall be the average tension required to cause separation of the synthetic rubber material from the backing of each specimen at a jaw speed of 2 inches per minute. The machine method 8031 of Federal Test Method Standard No. 601 shall be used. The average adhesion shall be determined from the autographic chart omitting the initial load build-up portion, where the elastomer is elongated without being stripped from the backing. If, during the test, the synthetic rubber strip starts to tear instead of stripping from the backing, the strip shall be cut with a sharp knife to the interface and the test continued. If the strip persists in tearing instead of separating from the backing, the average load at which tearing occurs shall be reported with a notation with respect to the type of failure. If the tear strength of the strip is less than the specified minimum adhesive strength, the sample shall be considered to have failed specification requirements. In the event that the average adhesive strength of the specimens fails to meet the specification requirements by less than 20 percent, two additional specimens from the same sample shall be tested. If either of these two specimens fails, the sample shall be considered to have failed specification requirements.

4.5.4 Delamination. - The delamination test shall be in accordance with the method 6311 of Federal Test Method Standard 601 except for specimen size. Specimens shall be 3 inches by 1 inch by thickness of the rubber facing for class I. In class II, specimens shall be 3 inches by width of land by thickness of the rubber facing.

4.5.5 Volume change. -

4.5.5.1 Water immersion. - The volume change test shall be in accordance with the method 6211 of Federal Method Standard 601, except that the period of immersion shall be one week.

4.5.5.2 Oil immersion. -

4.5.5.2.1 Test specimens. - Three specimens shall be used, and the result averaged. The test specimens shall be 1 inch by 2 inches by 0.07 to 0.09 inch.

4.5.5.2.2 Procedure. - The volume of each test specimen shall be measured by the water displacement method, in which the specimen is accurately weighed to the nearest milligram in air ( $W_1$ ) and in

<sup>2/</sup> Unless otherwise indicated in the test method, no tests shall be conducted prior to a conditioning period of 4 hours at room temperature. Sample preparation may be undertaken without regard to this time interval.

<sup>3/</sup> Samples of the rubber material shall be furnished by the manufacturer for the tensile and elongation and before and after aging tests as specified in 4.5.6. Two specimens, 6 inches by 6 inches by 0.075 inch thick, identical in composition, and prepared at the same time from material used in bearings offered for delivery and subjected to equivalent cure, shall be tested.

distilled water ( $W_2$ ) at room temperature. When weighing in water, care shall be taken that the specimen is free from adhering air bubbles, and, if necessary, it may first be wetted by dipping into 95 percent ethyl alcohol and then thoroughly rinsed with distilled water. After weighing, the specimen shall be blotted dry with filter paper, completely immersed in 100 milliliter ( $m^l$ ) of oil, and conditioned for 46 hours,  $\pm 1/4$  hour, at room temperature ( $77^\circ$  to  $87^\circ$  Fahrenheit (F.)). At the termination of the immersion period, the specimen shall be removed from the oil dipped in 95 percent ethyl alcohol, bottled lightly with filter paper, and placed in a tared weighing bottle and weighed ( $W_3$ ). The specimen shall then be removed from the bottle and weighed in distilled water ( $W_4$ ) in immediate consecutive procedure to determine the displacement after test. The final weighing shall be completed within 3 minutes after removal from the oil.

4.3.5.2.3 Calculation. - The increase in volume shall be calculated as follows:

$$\text{Percentage increase in volume} = \frac{(W_3 - W_4) - (W_1 - W_2)}{(W_1 - W_2)} \times 100$$

4.3.6 Aging test. - Specimens for tension, elongation and adhesion tests shall be given an accelerated aging test by subjecting them to dry circulating air at a temperature of  $158^\circ \pm 2^\circ$  F. ( $70^\circ \pm 1.1^\circ$  Centigrade (C.)) for 96 hours. Final determination of aged tension-test specimens shall be made not less than 20 hours or more than 48 hours after removal from the oven. Tension tests on unaged specimens shall be made immediately prior to, and on the same type of machine as, the tension tests on the aged specimens.

4.3.7 Oil immersion. - Specimens for the adhesion and volume change tests shall be conditioned for 46 hours,  $\pm 1/4$  hour, at room temperature ( $77^\circ$  -  $87^\circ$  F.) in a petroleum base oil<sup>4</sup> with the following properties, as specified in Federal Test Method Standard 791.

- (a) Viscosity, Saybolt Universal:  $155 \pm 5$  seconds (measured at  $100^\circ$  F.).
- (b) Aniline point:  $157.1^\circ \pm 1.8^\circ$  F.
- (c) Flash point:  $330^\circ \pm 5^\circ$  F.

Adhesion measurements shall be made within 30 minutes after removal from the oil.

4.5.8 Performance test. -- When required by the bureau or agency concerned, a bearing assembly or test specimen, or both, selected in accordance with 4.3.3.3 shall be subjected to performance tests including tests of wear, dynamic and static coefficient of friction, noise generation characteristics and such other tests as may be necessary to determine the characteristic of the bearing material and design. Acceptability shall be based upon comparison with results of performance tests made on bearings currently used by the Navy.

## 5. PREPARATION FOR DELIVERY

### 5.1 Domestic shipment and early material installation. -

#### 5.1.1 Bearings. -

5.1.1.1 Preservation and packaging. - Preservation and packaging shall be sufficient to afford adequate protection against corrosion, deterioration and physical damage during shipment from the supply source to the using activity and until early installation and may conform to the suppliers commercial practice when such meets these requirements.

5.1.1.2 Packing. - Packing shall be accomplished in a manner which will insure acceptance by common carrier at the lowest rate and will afford protection against physical or mechanical damage during direct shipment from the supply source to the using activity for early installation. The shipping containers or method of packing shall conform to the Uniform Freight Classification Rules and Regulations or other carrier regulations as applicable to the mode of transportation and may conform to the suppliers commercial practice when such meets these requirements.

<sup>4</sup>ASTM oil No. 3 meets the requirements for this test fluid.

MIL-B-17901A(SHIPS)

5.1.1.3 Marking. - Shipment marking information shall be provided on interior packages and exterior shipping containers in accordance with the contractor's commercial practice. The information shall include nomenclature, Federal stock number or manufacturer's part number, class, contract or order number, contractor's name and destination.

5.2 Domestic shipment and storage or overseas shipment. - The requirements and levels of preservation, packaging, packing and marking for shipment shall be specified (see 6.1).

(5.2.1 The following provides various levels of protection during domestic shipment and storage or overseas shipment, which may be required when procurement is made.

5.2.1.1 Preservation and packaging. -

5.2.1.1.1 Level A. - Preservation and packaging of bearings shall be in accordance with the requirements of MIL-P-2845.

5.2.1.2 Packing. -

5.2.1.2.1 Level A. - Bearings shall be packed in accordance with the overseas shipment requirements of MIL-P-2845.

5.2.1.2.2 Level B. - Bearings shall be packed in accordance with the domestic shipment requirements of MIL-P-2845.

5.2.1.3 Marking. - Shipment marking information shall be in accordance with MIL-P-2845 and MIL-STD-129.)

6. NOTES

6.1 Ordering data. - Procurement documents should specify the following:

- (a) Title, number, and date of this specification.
- (b) Class required (see 1.2).
- (c) Type, form, style, design and dimensional tolerances required (see 3.3).
- (d) Selection of preservation, packaging, packing and marking required if other than as specified in 5.1 (see 5.2).

6.2 With respect to products requiring qualification, awards will be made only for such products as have, prior to the time set for opening of bids, been tested and approved for inclusion in Qualified Products List QPL 17901, whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification, in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the qualified products list is the Bureau of Ships, Department of the Navy, Washington 25, D. C., and information pertaining to qualification of products may be obtained from that activity. Application for Qualification tests shall be made in accordance with "Provisions Governing Qualification" (see 6.2.1).

6.2.1 Copies of "Provisions Governing Qualification" may be obtained upon application to Commanding Officer, Naval Supply Depot, 5801 Tabor Avenue, Philadelphia 20, Pennsylvania.

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 of permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Preparing activity  
Navy - Ships  
Project 3130-N002Sh

APPENDIX B

CORRESPONDENCE WITH DUPONT ON LUBRICANT FILLED VITON



**E. I. DU PONT DE NEMOURS & COMPANY**  
INCORPORATED

4330 ALLEN ROAD  
STOW, OHIO 44224

ELASTOMER CHEMICALS DEPARTMENT

February 27, 1980

Dr. B. Bhushan  
Mechanical Technology Incorporated  
968 Albany-Shaker Road  
Latham, NY 12110

Dear Dr. Bhushan:

Last week five ASTM test buttons and ten tensile bars were sent to you via UPS. The three compounds are all based on VITON® E-60 fluoro-elastomer and use the same cure system based on "VITON" Curative Masterbatch No. 20 and VITON Curative Masterbatch No. 40, especially formulated for a steam environment. Compound No. 328 incorporates a different filler system than the other two compounds. All compounds used N-770 Carbon black. The details of the filler and cure system is proprietary.

All three compounds were mixed in a "BR" lab Banbury. A standard up-side-down mix was used. The filler, release system, curatives, then polymer was added and mixed at slow speed and finally dumped at about 110° C. The time to dump was 1 1/4 minutes in each case. The stock was then passed through a two roll mill, allowed to relax overnight and then 10 passed through the mill. The stock was then sheeted out, die cut to the approximate slab size and press cured five minutes at 176° C.

The physical properties are:

|               | <u>328</u> | <u>329</u> | <u>330</u> | <u>Specification</u> |
|---------------|------------|------------|------------|----------------------|
| Tensile MPa,  | 10.4       | 12.5       | 12.0       | 10.3                 |
| Elongation, % | 330        | 430        | 390        | 150                  |
| DH, A         | 85         | 78         | 79         | 85±5                 |

Further testing to MIL-B-17901 is in progress. I'll send further results as they are received.

BETTER THINGS FOR BETTER LIVING . . . THROUGH CHEMISTRY

The recommendations for use of our products are based upon tests believed to be reliable. However, we do not guarantee the results to be obtained.

Dr. B. Bhushan  
February 27, 1980  
Page 2

As of this date, I have not received the metal pin that you noted in your letter of February 11, 1980. When it has arrived, what type of epoxy do you prefer? I did not see any specified in your letter.

I will be sending you two more samples of compounds that are under consideration for your testing. If you must limit your testing to two compounds, use #328 and #470.

If you have any questions, feel free to call me at 216/929-6903.

Sincerely,

*ANNE*

A. C. Zaragoza  
Akron Laboratory

ACZ/abk