NASA
Technical
Memorandum

NASA TM-103524

AN EVALUATION OF BEARINGS OPERATING IN A CRYOGENIC ENVIRONMENT WITH SILICON NITRIDE ROLLING ELEMENTS

By H.G. Gibson

Materials and Processes Laboratory
Science and Engineering Directorate

January 1991

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

AN EVALUATION OF BEARINGS OPERATING IN A CRYOGENIC ENVIRONMENT WITH SILICON NITRIDE ROLLING ELEMENTS

INTRODUCTION

The space shuttle main engine (SSME) 57-mm turbopump bearings currently used are made of 440C stainless steel. This includes the outer and inner races and the rolling elements, which are 0.5-inch diameter balls. The separator is a fiberglass/Teflon composite material called Armalon, used for strength and lubrication. The bearings fall short of their expected life, basically due to wear of the races and balls. These bearings operate in a liquid oxygen environment where they experience cryogenic temperatures (<-200 °F) and, during operation, they experience elevated temperatures (>500 °F).

Silicon nitride has become a viable bearing material for elevated temperature applications as well as having excellent wear resistant properties. In order to investigate the cryogenic behavior of silicon nitride, 0.5-inch diameter balls were used to replace the standard 440C balls in the 57-mm high pressure oxidizer turbopump (HPOTP) bearings. The bearings were then installed in Marshall Space Flight Center's (MSFC) bearing and seal material tester (BSMT), and full-scale tests were conducted. At the end of the test series, the bearings were removed from the tester, examined, photographed, and cataloged. The initial results from this test series have been positive and encouraging. A second test series has been planned to further document the results of silicon nitride balls in steel bearings operating at cryogenic conditions.

TEST EQUIPMENT

To conduct bearing tests, a device was designed and built in 1980 using similar materials and some of the same hardware as the SSME HPOTP. This test rig is known as the BSMT (fig. 1). This device houses four test bearings and uses liquid oxygen as a coolant flowing through the bearings. The shaft is rotated at 30,000 rpm for a predetermined amount of time depending on the test objectives. The flow rate, degree of subcooling, and internal pressures can be varied to set up different operating conditions for the bearings.

Instrumentation of the tester includes temperature, pressure, displacement, horsepower, and torque. These parameters are monitored at many locations throughout the tester and also at several test facility locations. Many of these measurements are used for safety as well as performance indicators.

The bearings are flight type, phase II, 57-mm bore bearings. Normally they are made of 440C stainless steel, but for this test, two of the bearings, Nos. 1 and 2, were CRB-7 material. The 13 balls were replaced with silicon nitride (Si_3N_4) balls in all bearings. Reports have been written expounding on the benefits of using Si_3N_4 as a bearing material [1–3]. However, very little information exists on using Si_3N_4 in cryogenic applications. It is known that silicon nitride is a powdered ceramic material, is very brittle, and is not capable of sustaining high mechanical over-loading. Typical comparisons of silicon nitride versus other bearing steels are given in table 1.

The four bearings used in this test were modified to account for the differing properties of the silicon nitride balls. Internal clearances were increased from the normal 0.0061 in to 0.0076 in and inner and outer race curvatures were 53 percent. Based on these changes, the contact stresses were modeled by "SHABERTH" to be 325,000 psi for the inner and outer races during operation. Liquid oxygen was used for the coolant flowing through each bearing pair at 6.5 lb/s with 40° subcooling.

TEST RESULTS

The BSMT was rotated for eight tests at 15,000-, 25,000-, 26,000-, 28,000-rpm, and four 30,000-rpm runs. The total test time accumulated on the tester was 1,630 seconds or 27 minutes. Total time at 30,000 rpm was 19 minutes. One of the 30,000-rpm tests ran for a continuous 10 minutes with stable bearing temperatures (fig. 2). This run had not been possible in any other bearing configuration using this tester.

Upon inspection of the bearings after the testing was complete, it was discovered that a ball from bearings No. 1 and No. 2 had a large spall on them (fig. 3). It is not known at this time if they were caused by a material flaw or high rolling contact stresses. Very short, hairline striations were observed circling around balls from bearings No. 1 and No. 2 also. Bearing No. 2 had a ball with minor spalling within the path of the striations. Bearing 3 had some balls with square areas of deformed ball material, and the balls from bearing 4 had signs of scuffing and possible unloading streaks.

Ball wear was uniform and very slight. Because of this, the ball track on the inner races was kept in the active surface region, not moving upwards toward the high shoulder. Cage pocket wear was also very benign. In past tests using 440C balls, major ball wear has occurred, cage pockets have been elongated, and a burr has been developed on the inner race high shoulder in a shorter amount of time. The appendix is a visual reference to the condition of the bearings. Figure 4 is a comparison of a 440C bearing from a previous test and a Si_3N_4 bearing from this test series. Unit 3 was run in liquid oxygen using the normal 440C material bearings, and unit 2 was the Si_3N_4 bearing test.

CONCLUSIONS

The use of silicon nitride balls has shown promising results. The BSMT ran in a thermally stable condition, with less heat generation than has been observed in the past. Silicon nitride has shown that it is a better wear resistant material than 440C steel in this bearing application. The spalling of the balls is still an issue to be studied and resolved. Testing by others [4] has shown that a hybrid bearing combination could be beneficial to wear life and will be investigated in this tester. The next test series will involve four 440C bearings with silicon nitride balls to expand the data base on the cryogenic use of Si_3N_4 materials.

REFERENCES

1. Baumgartner, H.R.: "Evaluation of Roller Bearings Containing Hot Pressed Silicon Nitride Rolling Elements." Norton Company.

2. DeYoung, H.G.: "Pitting Ceramic Bearings Against Steel." High Technology, July 1986.

3. Bhushan, B., and Sibley, L.: "Silicon Nitride Rolling Bearings for Extreme Operating Conditions." ASLE, vol. 25, No. 4, pp. 417–428.

4. Wedeven, L.D., and Miller, N.C.: "Development of New Materials for Turbopump Bearings." Final report, NASA-MSFC, November 1989.

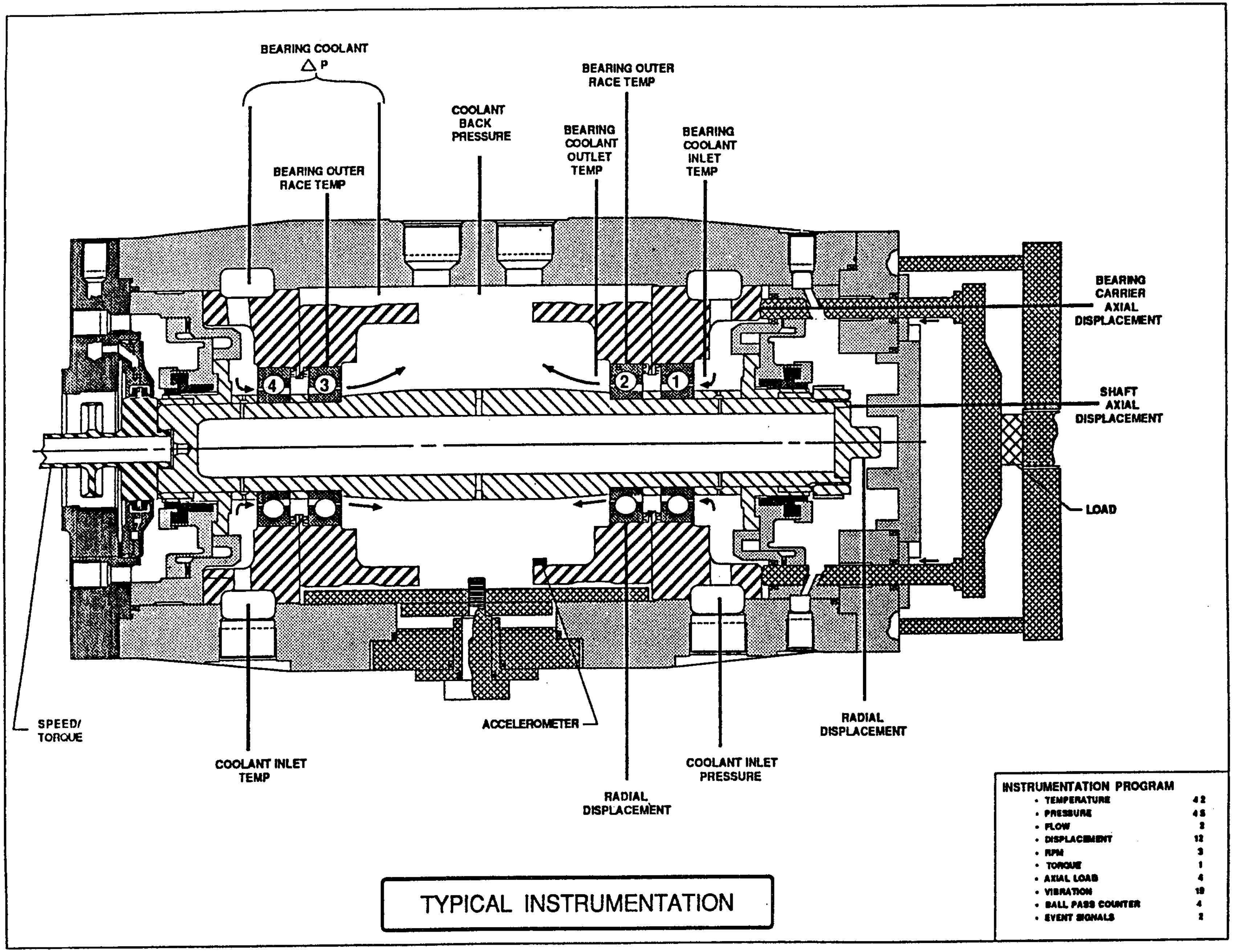


Figure 1. Bearing and seal material tester.

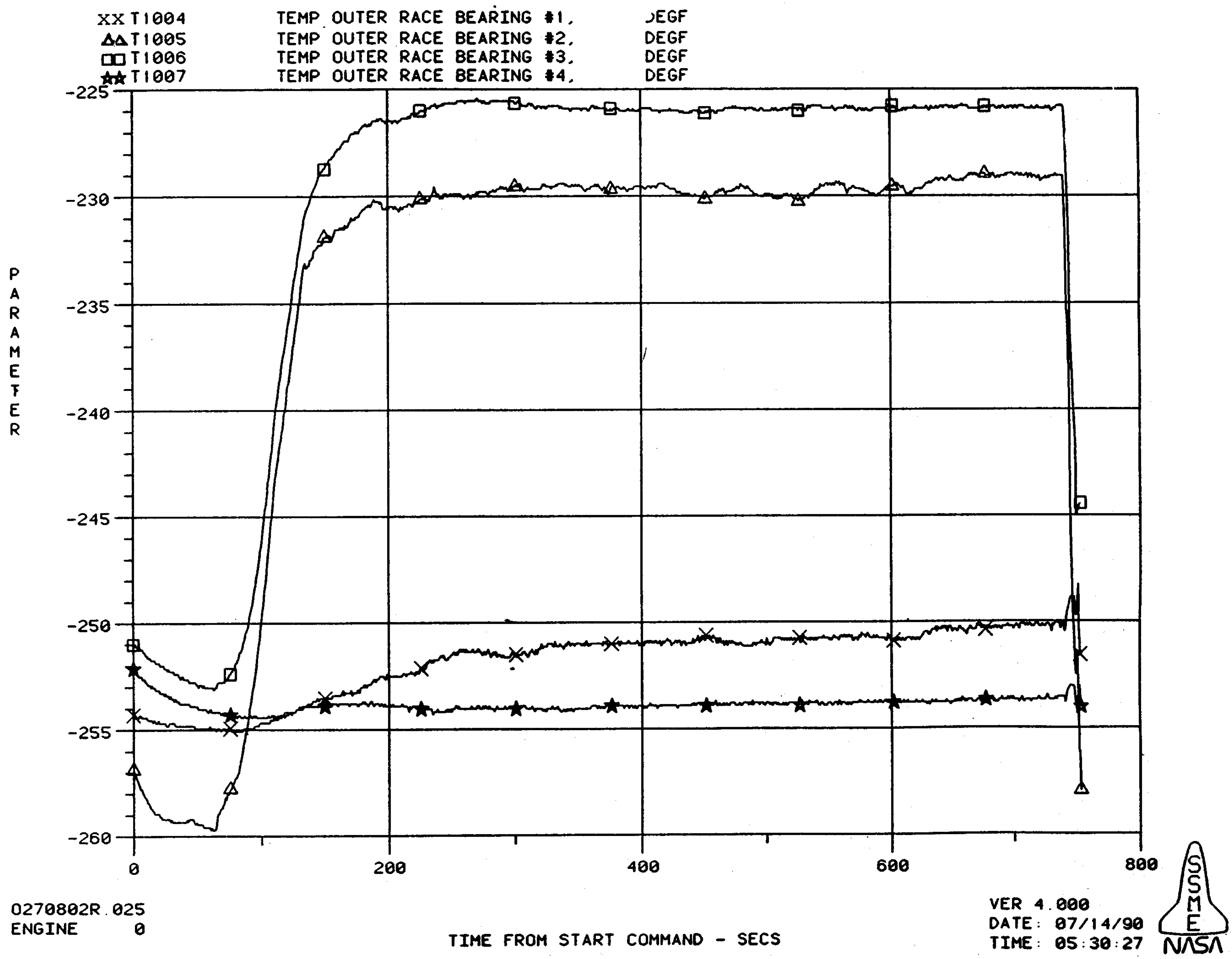
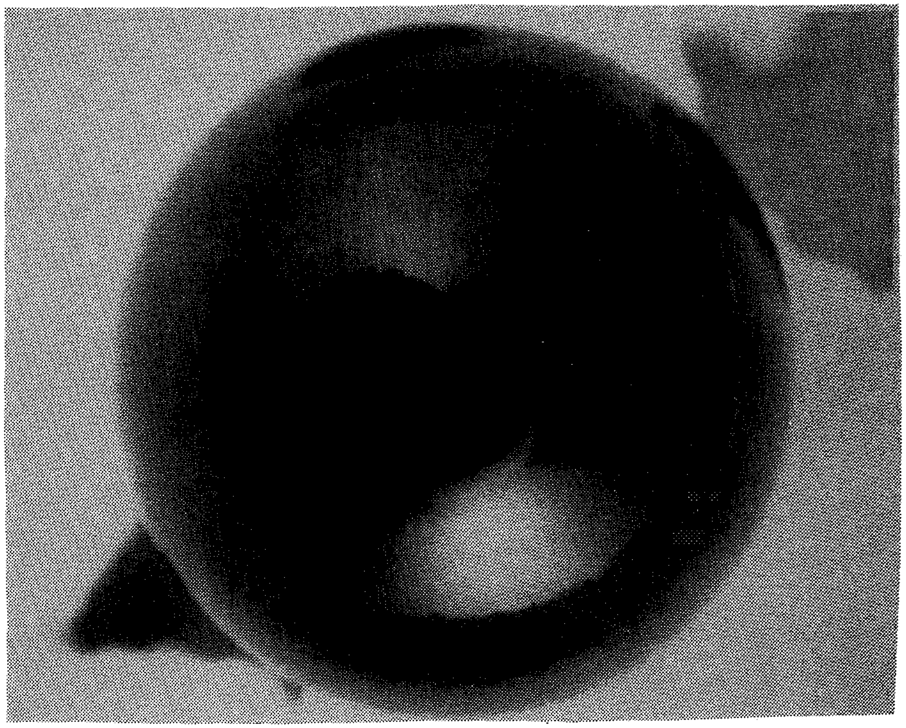
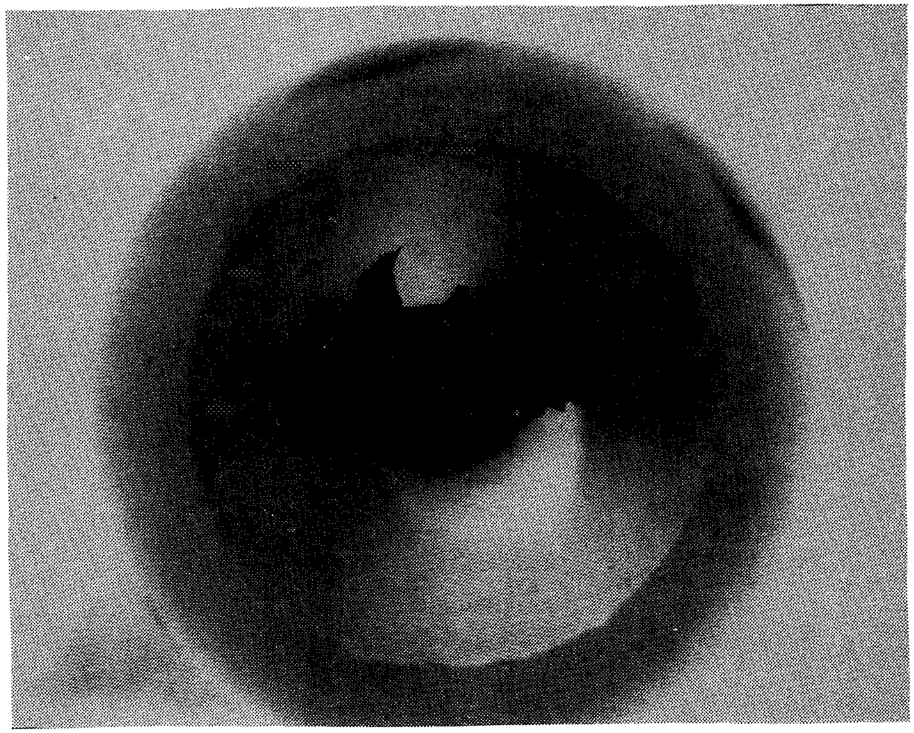


Figure 2. 30,000 rpm test.



BEARING NO. 1



BEARING NO. 2

Figure 3. Bearings No. 1 and No. 2 spall.

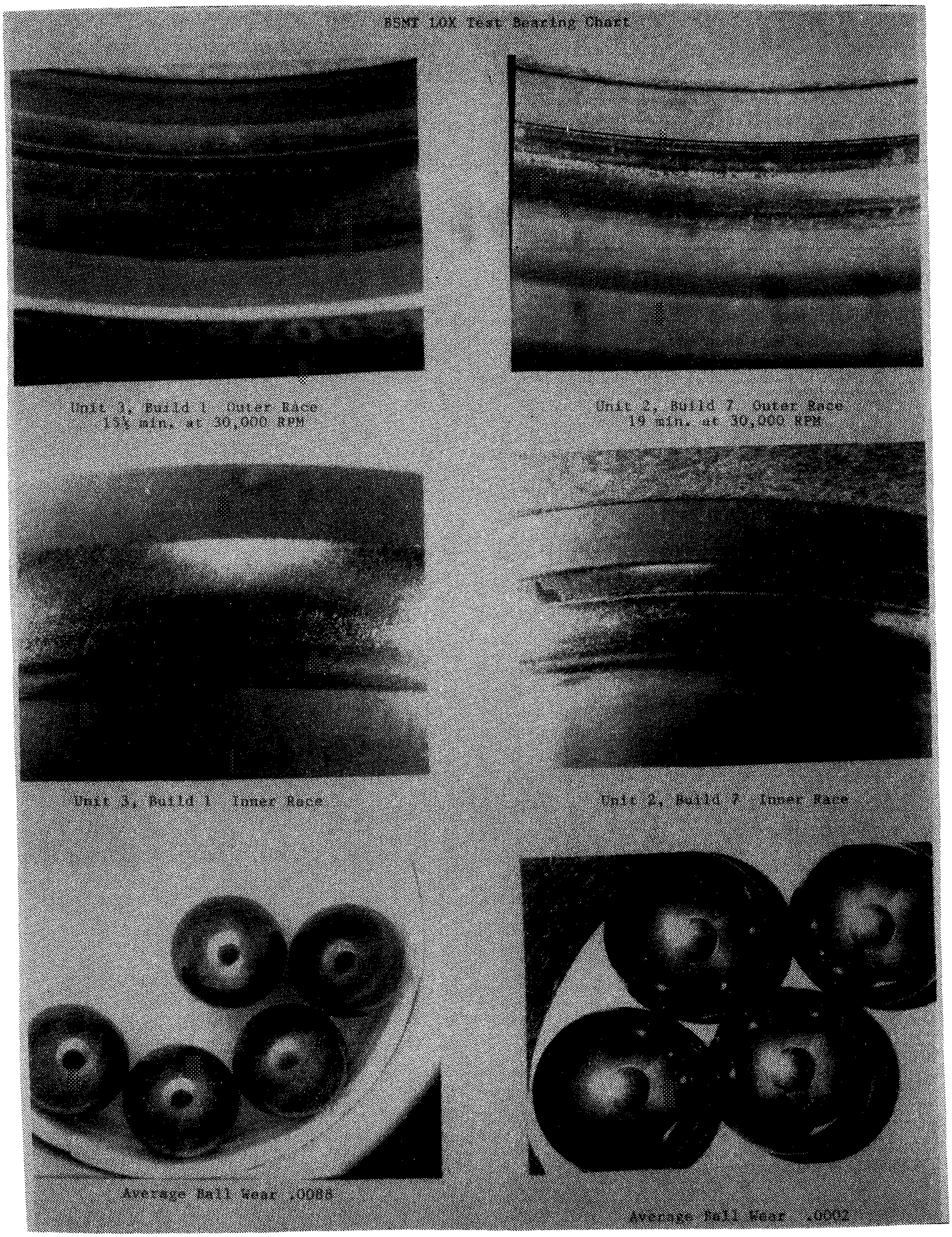


Figure 4. BSMT lox test bearing chart.

ORIGINAL PAGE

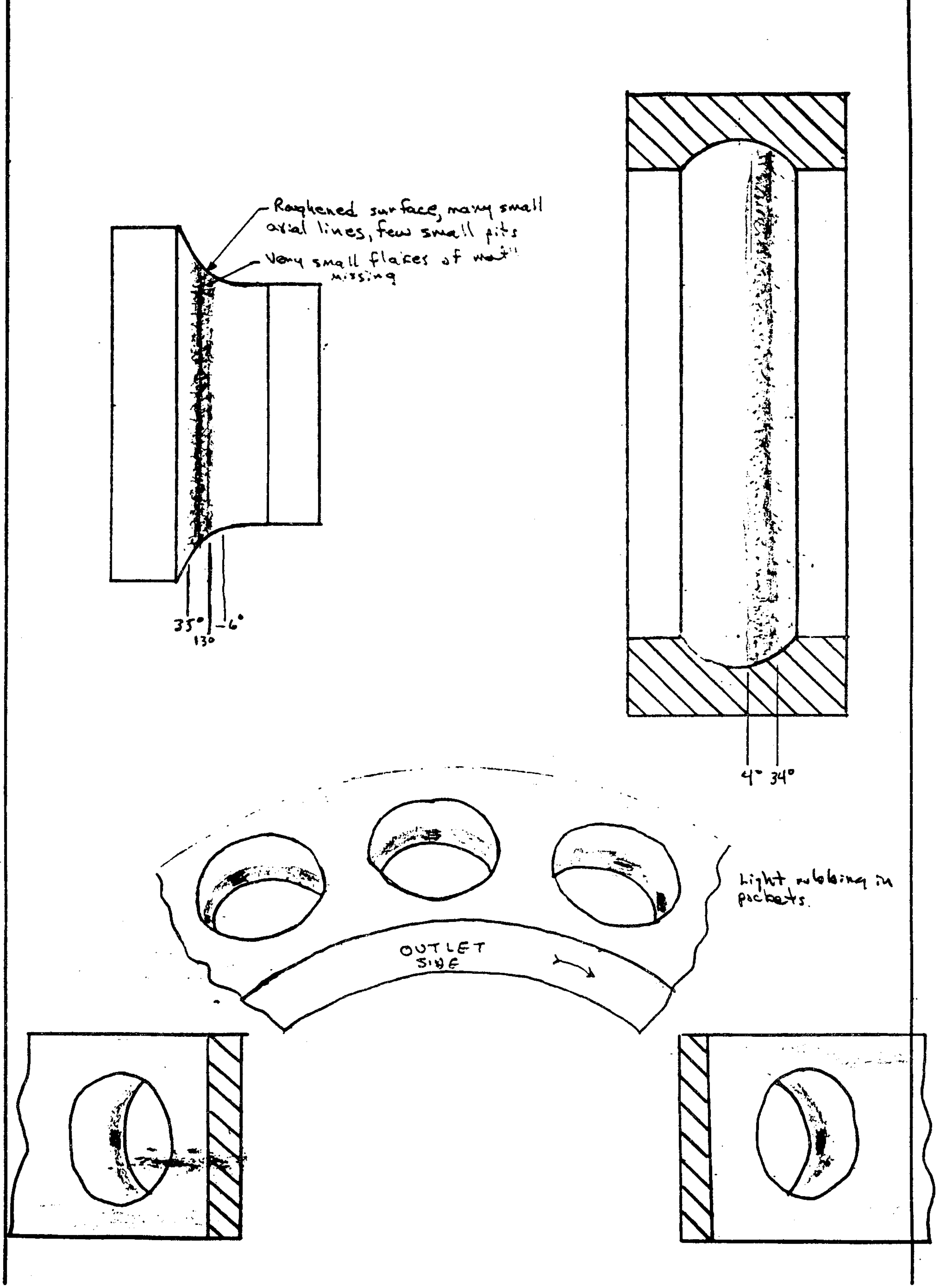
Table 1. Selected physical and thermal properties of rolling bearing materials.*

Material	NORALIDE Si_3N_4	52100 steel	440C st steel	M-50 steel	BeCu
Hardness R_C at 20°C	78	62	60	64	42
Maximum Useful Temperature °C (F)	1200 (2200)	180 (360)	260 (500)	320 (600)	200 (400)
Density g/cc	3.2	7.8	7.8	7.6	8.2
Elastic Modulus GPa (10^6 psi) at 20°C	310 (45)	210 (30)	200 (29)	190 (28)	128 (18)
Poisson's Ratio	0.26	0.28	0.28	0.28	0.30
Coefficient of Thermal Expansion 10^{-6}/°C 0-800°C	2.9	10.9	10.1	12.3	17.0

*Taken from: "Norton Company/High Performance Ceramics.

APPENDIX

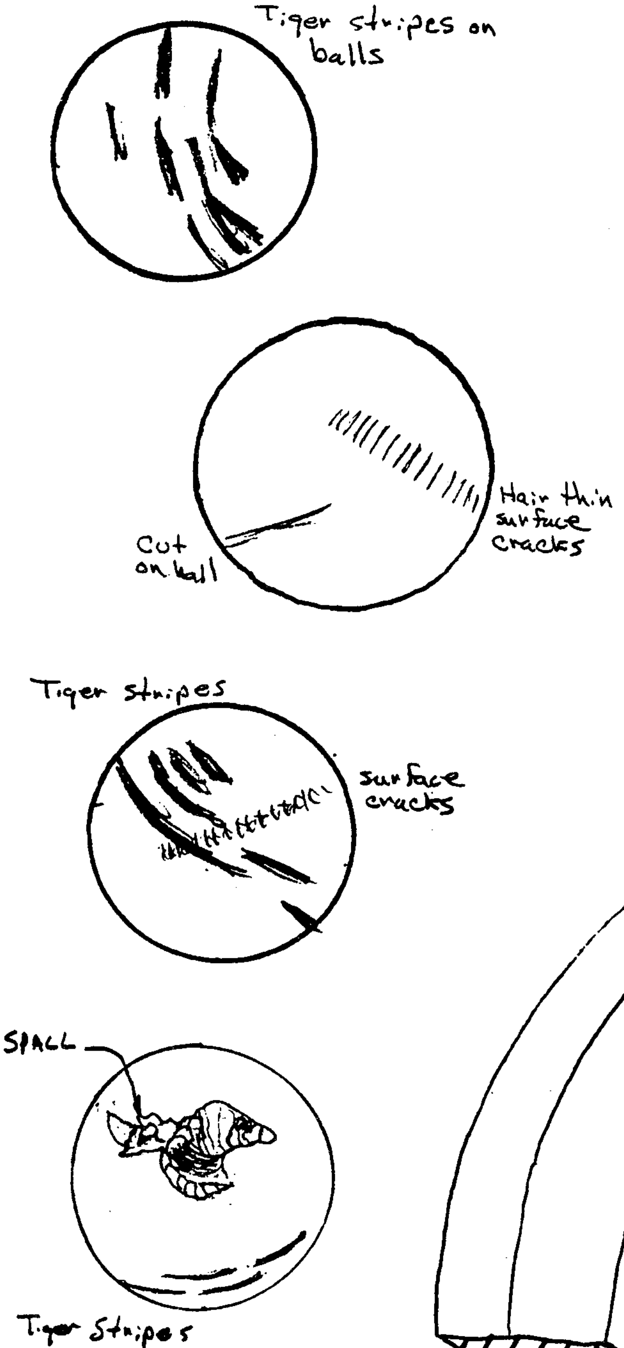
BSMT 217 B#1	S.N BALLS CRA-7	8-6-90



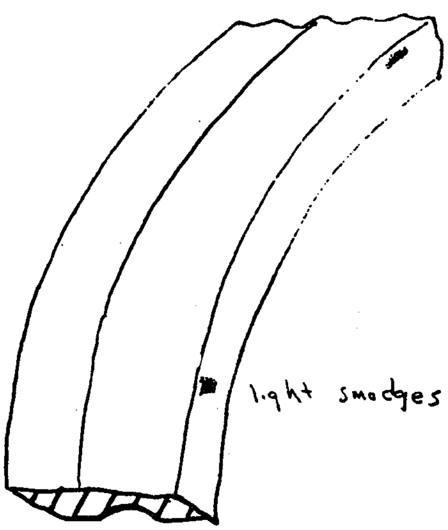
BSMT | 2/7 | BRG#1 | S.N BALLS CRB7 | MATL | 8-6-90

BALL #	DIA	WEAR *	
1	.499896	.000102	(ITI)
2	.499892	.000108	(ITI)
3	.4999	.0001	
4	.4999	.0001	
5	⋮	⋮	
6	⋮	⋮	
7	↓	↓	
8			
9			
10			
11			
12			
13			

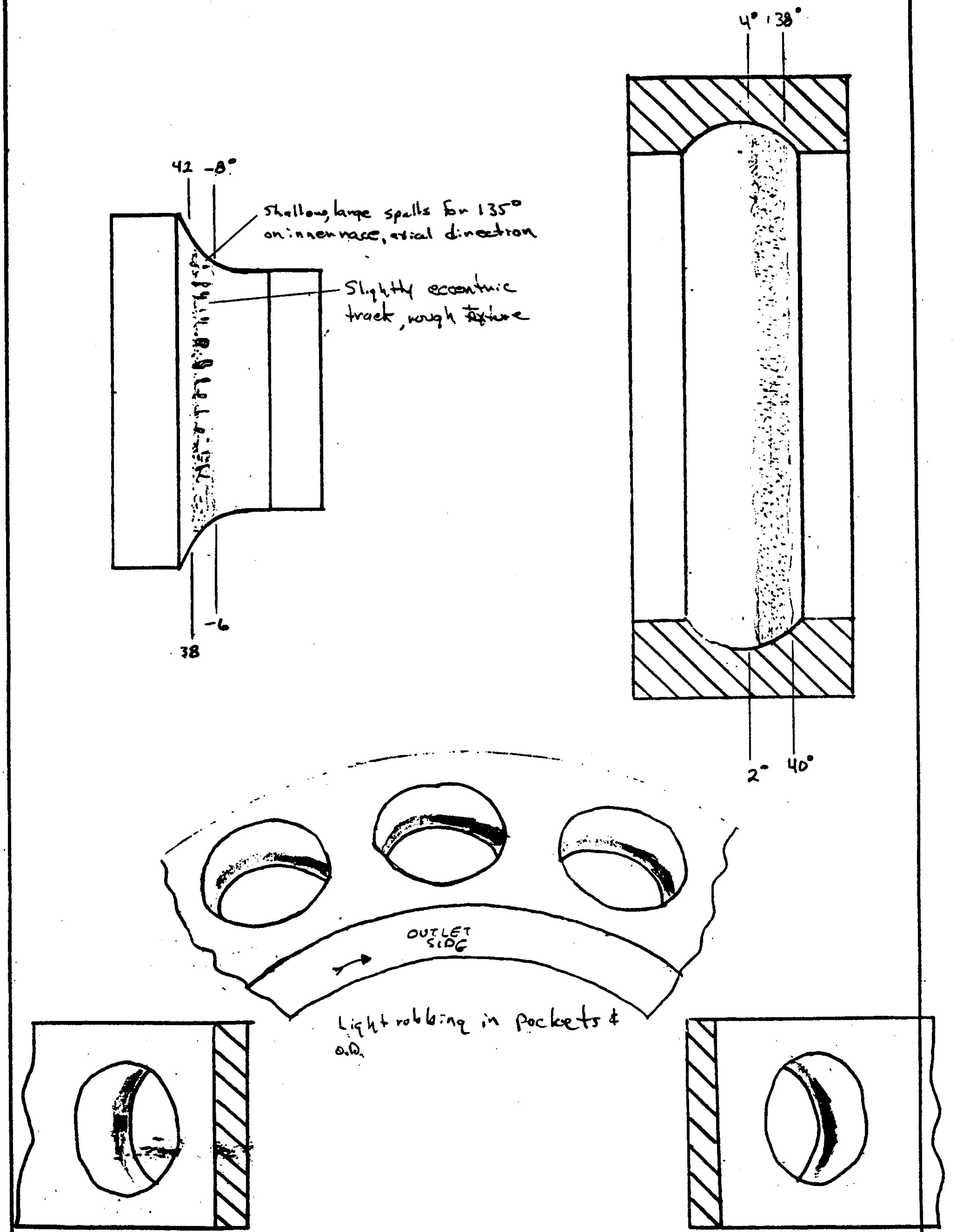
*NEW ø @ .5000"
ITI MADE MEASUREMENTS WHERE NOTED



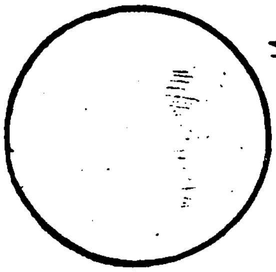
OUTER RACE HAS ROTATED 355°

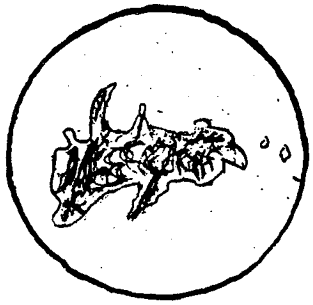


BSMT 217 B#2 | SiN BALLS SER. 7 | MATL 8-6-90



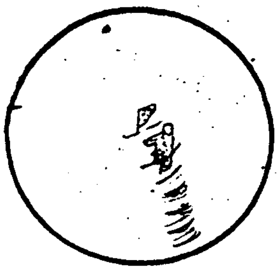
2/7 BRG 2 | S,N BALLS

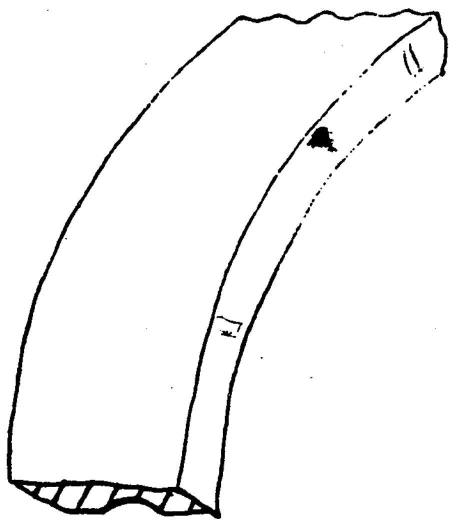




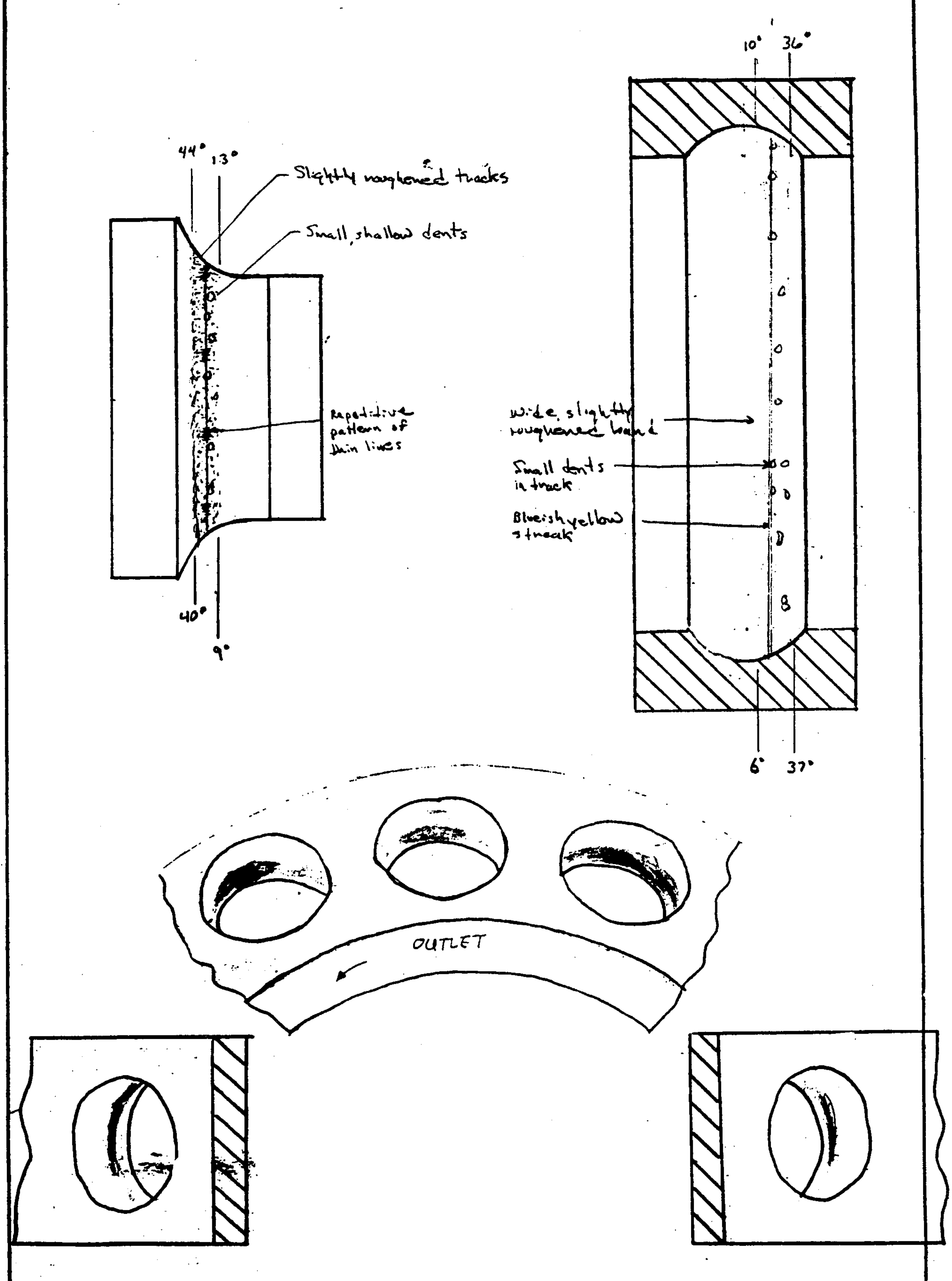
BALL #	DIA	
1	.499855	.000145 (ITI)
2	.499828	.000172 (ITI)
3	.4998	.0002
4	.4998	.0002
5	⋮ ↓	⋮ ↓
6		
7		
8		
9		
10		
11		
12		
13		

NEW ⌀ OF .5000"



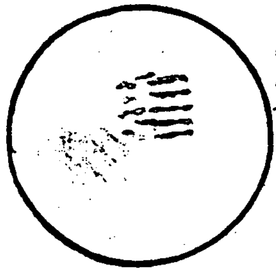


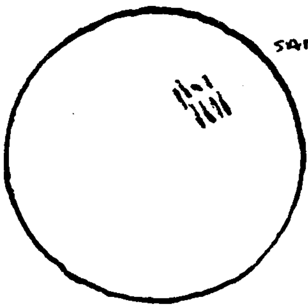
BSMZ 2/7 B#3	S.N BALLS 440C	MAZL 86-80

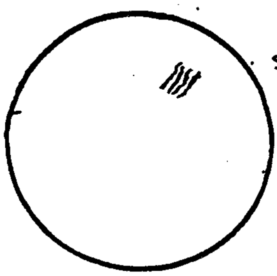


ORIGINAL PAGE IS
OF POOR QUALITY

BRG#3

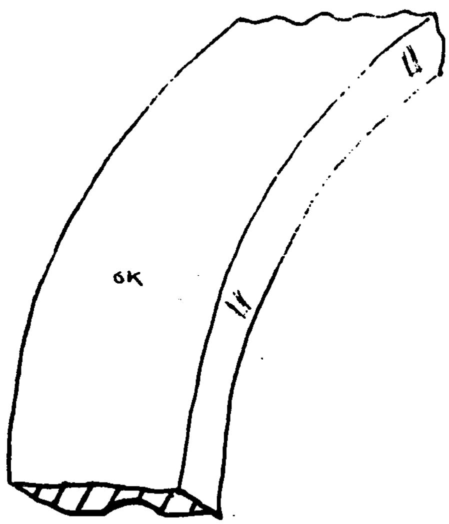






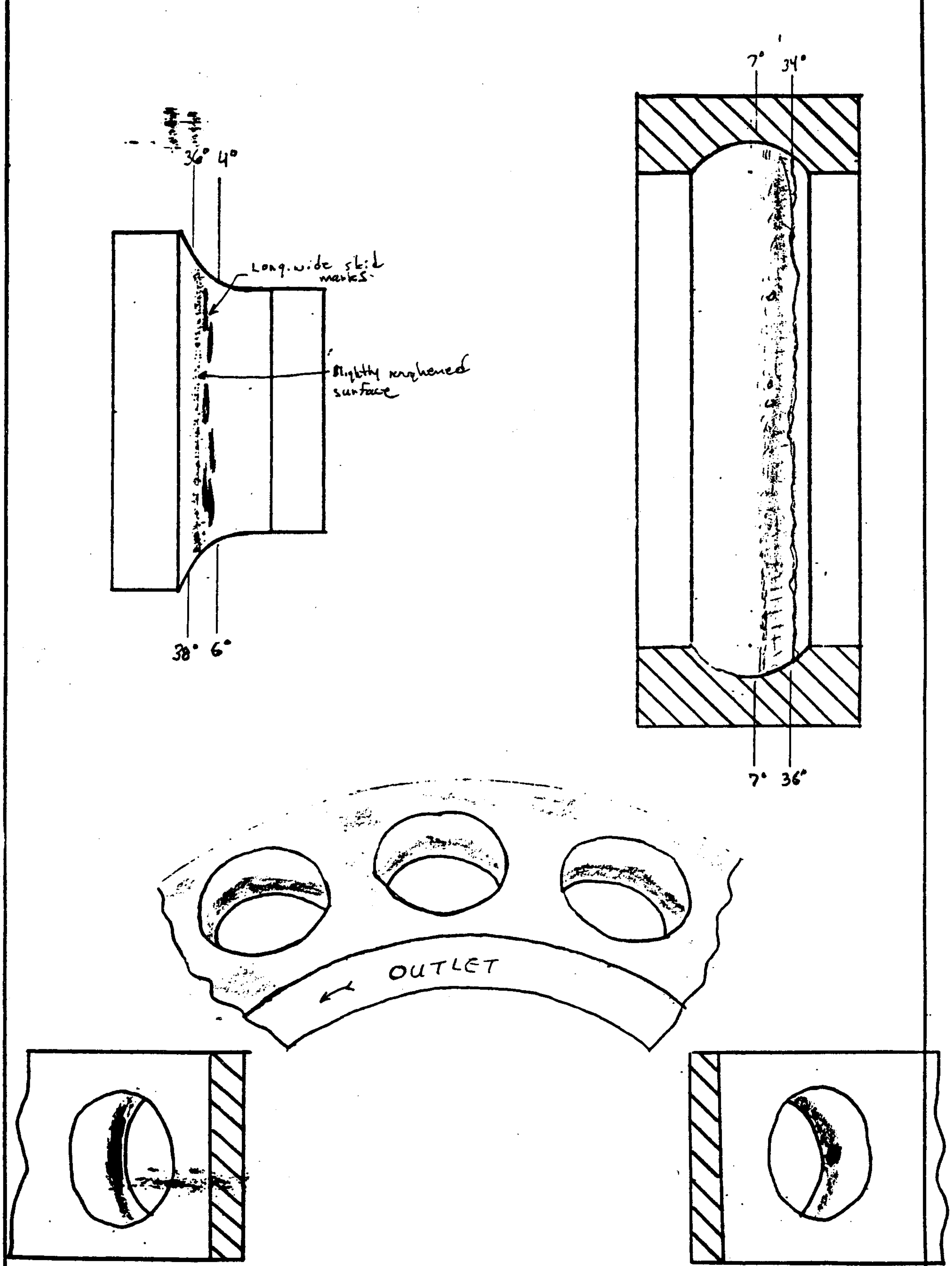
BALL #	DIA	WEAR	
1	.49984	.000158	(ITI)
2	.49985	.000141	(ITI)
3	.4998	.0002	
4	.4998	.0002	
5	⋮ ↓	⋮ ↓	
6			
7			
8			
9			
10			
11			
12			
13			

NEW ϕ OF .5000"

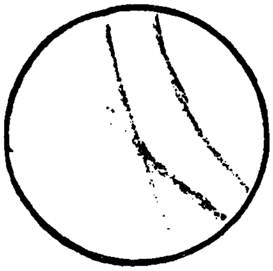


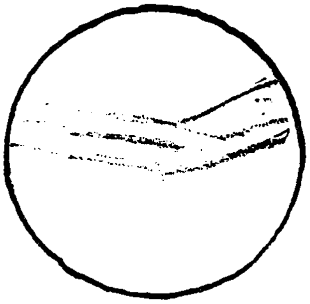
ORIGINAL PAGE IS

BSMT 217	B#4	S.N BALLS	440C MATL	8-6-90



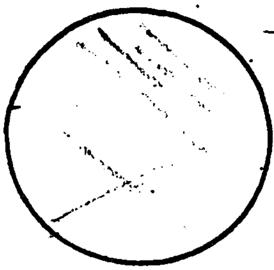
BSMT 217 | BRG 4 | S.N BALLS 440C | MATL | 8-6-90



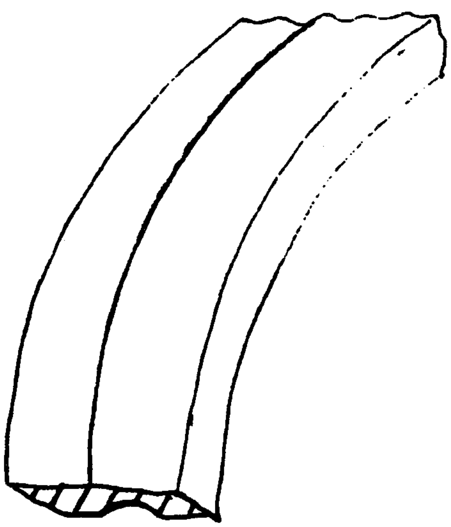


BALL #	DIA	WEAR	
1	.499892	.000108	(ITI)
2	.499889	.000111	(ITI)
3	.4999	.0001	
4	.4999	.0001	
5	.	.	
6	.	.	
7	↓	↓	
8			
9			
10			
11			
12			
13			

NEW ø OF .5000"



O.R. ROTATED 360°



APPROVAL

AN EVALUATION OF BEARINGS OPERATING IN A CRYOGENIC ENVIRONMENT WITH SILICON NITRIDE ROLLING ELEMENTS

By H.G.Gibson

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

PAUL H. SCHUERER
Director, Materials and Processes Laboratory

☆U. S. GOVERNMENT PRINTING OFFICE 1991 — 531—081/40013

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM- 103524		

4. Title and Subtitle

An Evaluation of Bearings Operating in a Cryogenic Environment With Silicon Nitride Rolling Elements

5. Report Date

January 1991

6. Performing Organization Code

7. Author(s)

H.G. Gibson

8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, DC 20546

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by Lubrication and Surface Physics Branch, Materials and Processes Laboratory, Science and Engineering Directorate.

16. Abstract

The bearings used in the space shuttle main engine (SSME) high pressure oxidizer turbopump (HPOTP) do not meet the expected life goals that were set for them. In an effort to improve their performance, many solutions are being studied. New bearing materials are being developed, better manufacturing techniques are being investigated, and improved cage materials for better lubrication are being tested. This report focuses on the replacement of steel balls with ones made of silicon nitride in 57-mm HPOTP bearings. The bearings were then installed in a test rig and run at near turbopump operating conditions. The results from this test series have been encouraging, with silicon nitride showing good wear resistance and thermal stability.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Bearing and Seal Material Tester Silicon Nitride	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	20	NTIS

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, VA 22161-2171