Report No. E6000-29
Quarterly Report No. 10

ENVIRONMENTAL STUDY OF MINIATURE SLIP RINGS

George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Report No. E6000-29

Quarterly Report No. 10

ENVIRONMENTAL STUDY OF MINIATURE SLIP RINGS

1 October 1965 to 1 January 1966

Contract No. NAS8-5251
Control No. TP3-83367 (IF)
IITRI Project E6000

Prepared by

IIT Research Institute
Technology Center
Chicago, Illinois 60616

for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama 35812

Attn: PR-RDC

TABLE OF CONTENTS

ENVIRONMENTAL STUDY OF MINIATURE SLIP RINGS

I. INTRODUCTION

This is the tenth quarterly progress report on IITRI Project E6000, "Environmental Study of Miniature Slip Rings." This report covers the activities during the period 1 October 1965 to 1 January 1966 and is the second quarterly report on the twelve month continuation authorized by Modification No. 6 of Contract NAS8-5251. The objectives of the new effort are to evaluate slip ring materials and design techniques suitable for operation in high vacuum.

During the period reported herein, the following activities were performed:

A. Run-in tests in high vacuum were continued.

B. Investigations of different brush designs have been started.

C. Mass spectrographic analyses of off-gassing products from component materials used in experimental capsules have been completed.

D. Study of friction, wear, and lubrication of different materials in high vacuum has been initiated.

E. Performance of two types of hard gold overlays was studied.

F. Electroplating studies have been continued.

II. REPORTING PERIOD ACTIVITY

A. High Vacuum Run-in Tests

The first run-in of a brush-ring assembly using materials with good off-gassing properties was carried out in high vacuum for 250 hours of continuous rotation. The analysis of wear debris collected during this run-in was performed using the emission spectrograph technique. The analysis showed that hydrocarbons typical of diffusion pump oil were present in the debris. It became apparent that some backstreaming of oil had taken place during the test. This was traced to improper operation of the cold trap. Corrective measures were taken and subsequently, two run-in tests were completed. Each test was run continuously at 200 rpm for approximately 280 hours in a vacuum of 1 to 2 x 10^{-7} torr. Two of the four brush-ring circuits were run-in with a current of 25 ma while the remaining two were open circuited throughout the test except for periodic readings. After only a few hours of testing, the noise reached a level of one millivolt and after approximately 60 hours, the noise increased to one volt. The final readings were between 1.5 to 2.0 volts. The wear debris has been collected and is being analyzed by the emission spectrograph to determine if materials other than gold are present.

B. New Brush Designs

Study of different brush designs has been started. A test was conducted in a nitrogen atmosphere with a capsule using a new design in which two brushes were cemented to the brush block to increase brush stiffness. The remaining two brushes were not modified so as to enable a direct comparison of noise performance of the two designs. After over 400 hours of run-in, no significant difference in noise performance was evident. Visual examination after the completion of the test showed about the same amount of debris present on all brush-ring surfaces.

A new brush design conceived by a slip ring manufacturer will be evaluated. This design uses a brush wire truncated along the axis with the resulting cord of the wire sitting in the groove. Superior noise performance is claimed for this design. The Nye-Oro 7 mil brush wire used in all previous tests is now being modified to give the truncated shape and will be tested in capsules.

C. Mass Spectrographic Analysis of Off-Gassing Products

The analysis of off-gas products from three different electrical component materials used in experimental capsules (Mycalex used in brush blocks, and teflon used in lead wire insulation and in ring sleeves) was performed at room temperature using the mass spectrograph technique. As a result of the experience obtained from performing the analysis at elevated temperatures, the previously used technique was modified. A special sample collection vessel was constructed to allow cold-trapping of gases from samples in a vacuum of 10^{-6} torr over prolonged periods of time. Liquid nitrogen was used and cold-trapping was allowed to proceed for seven hours. The results showed that no detectable quantity of off-gassing materials was obtained for either sample in the mass range of m/e from 12 to 260. This indicates that organic component materials with good off-gassing properties have been selected for the experimental capsules.

D. Lubrication Studies

Apparatus has been designed to study friction, wear, electrical noise, and lubrication of different materials in high vacuum. The fabrication of this apparatus is scheduled to be completed by the end of January, 1966. The apparatus consists of a grooved shaft rotated in a vacuum chamber by a magnetic drive coupling. A weighed piece of 7 mil brush wire will be placed in the groove and attached to a microforce transducer. The brush wire will be adjusted to give a total weight of 2-1/2 grams, which is the load used in experimental capsules. The lubricant will be deposited on to the shaft by evaporation while the shaft is rotating to give a uniform deposition. Shielding will be provided to stop the lubricant from contaminating the system. The lateral force on the brush wire will be measured with the microforce transducer.

Knowing this force and the weight of the wire, the coefficient of friction can be calculated. Electrical noise will be measured during the experiments.

The lubricant materials that have been chosen for testing are soft metals. Using Rabinowicz's Concept of surface energy as a guide, the following hypothesis is developed. A low ratio of the cohesion force of a lubricant film to the adhesion force between the lubricant and the bearing surface tends to minimize friction between the bearing surfaces.

Desired parameters:

1. High adhesion to slip ring by film.
2. High adhesion to rider wire by film.
3. Low film cohesion.
4. (1) and (2) imply good wettability by film and also that wetting does not go to completion and then start to "not" wet by alloying, intergranular penetration, etc.
5. Table 1 lists further desirable properties.
6. Table 2 lists some relevant constants for various metals from which candidates could be chosen.

TABLE 1

DESIRABLE PROPERTIES OF SYSTEM

I LUBRICANT	II SLIP RING	III RIDER
1. Soft-weak in shear	Hard	Hard
2. Forms film easily	Takes high finish	Takes high finsih
3. Atomic lattice different from II & III	(If possible II & III differ from one another)	
4. Low surface tension	Must wet	Possibly not wet
	or	
	(Lubricant forms different alloys on II & III so that work of adhesion between II & III is minimized)	
5. Low modulus of elasticity	High modulus	High modulus
6. Low melting point for both film application and film shear	Relatively high melting point	Reliatively high melting point
7. Low vapor pressure if one shot application		
8. High vapor pressure if supplied by continuous or specified time application		

TABLE 2

PHYSICAL PROPERTIES OF MATERIALS

LUBRICANT	E MODULUS ELASTICITY psi (x 10^{-6})	HARDNESS	LATTICE TYPE	SURFACE TENSION DYNES/cm	VAPOR PRESSURE @600°C TORR	MELTING POINT °C	ATOM VOLUME cm^3/g-atom	COEF. EXPANSION (°C) x 10^{-6}	DENSITY g/cc	VISCOSITY CENTIPOISE	PRICE $
Barium			BCC(1)	195(1)	10^{-2} 617°C(2)	710(1)	39(1)	18(1)(3)	3.5		
Calcium	4(1)	2 Moh(1)	FCC(1)	255(1)	10^{-1} 683°C(2)	851(1)	25.9(1)	22 x (li) 717 x (cu)	1.54		
Strontium			FCC(1)	165(1)	10^{-1} 623°C(2)	770(1)	34(1)				
Cadmium	10	2 Moh(1)	Hex.(1)	≈550(1)	1000 μ(2)	321(1)		38(3)(li)	8.65	2.37 @ 350°C 1.63 @ 600°C	
Bismuth	4.6(1)		Rhombo Hedral	≈350(1)	10^{-2} 661(2)	271(1)	21.3(1)	13.3(li)(1)	9.8	1.63 @ 300°C 1.00 @ 600°C	
Gallium		1.5-2.5 Moh(1)	Ortho-rhombic	≈700(1)	10^{-5} 757(2)	29.75(1)	9.8	18(li)(1)	5.91	2.04 @ 30°C 0.592 @ 1000°C	3.00/g(1)
Indium	1.57(1)		FC Tet(1)	600(1)	10^{-5} 670(2)	156(1)	24.8(1)	24.8(li)(1)	7.3	1.69 @ 200°C 1.32 @ 300°C	2.25/Troy oz (1)
Lithium			BBC(1)	≈400(1)	10^{-1} 623(2)	179(1)		56(li)(1)	0.5	0.6 @ 180°C 0.44 @ 300°C	1.50/lb(1)
Lead	2.3(3)		Cubic like Cu(3)	460(3)	10^{-3} 627°C(3)	327(3)		30(li)(3)	11.34	2.32 @ 400°C 1.54 @ 600°C	
Tin	6.8(3)		Tetrag(3)	560(3)	10^{-5} 882(2)	232(3)		24(li)(3)	7.3	2.71 @ 300°C 0.81 @ 800°C	
Selenium			Hex.(1)		760 685°C(2)	217					7.00/lb(1)
Thallium(Tl)			Cubic(3)	400(1)	10^{-2} 615(2)	303	17.24(1)	28(li)(1)	11.85		7.50/lb(1)
Zinc	14(3)		Hex.(3)		1 mm at 485°C(3)			34(li)(1)	7.14	3.67 @ 500°C 3.29 @ 600°C	
Tungsten	59	37C(rock)	BCC				9.53(1)	4.98(li)	19.3 @20°C(1)		
Gold	11.5	58 Ban(4)	FCC	130(5)	10^{-2} 987	1063	10.2	14	19.3		
Silver	11	25 Vick (4)	FCC	120(5)	10^{-2} 757°C	961	10.3	21	10.5		

(1) Rare Metals Handbook (3) Smithells Structure (5) Guy, Elements of Physical Metallurgy
(2) Dushman (4) Metals Handbook (li) Linear (cu) Cubic

There are several c ndidate metals which could be used. For example, indium satisfies various requirements in the hypothesis. It has an FC lattice while gold has an FCC, its atomic volume is nearly 2-1/2 times that of gold, thus effectively preventing alloying, and its melting point is over 900°C less than that of gold. Other candidate materials are rhodium, chromium, and gold.

Inorganic compounds such as MoS_2 and $MoSi_2$, among others, will also be investigated. These compounds, of course, cannot be sublimed and deposited on the slip ring due to chemical breakdown. However, a flash technique can be used to deposit these compounds.

If time permits, additional consideration might be given to oils, such as P-38, diffusion pump oils, and others if some evaporative lubrication can be tolerated.

A preliminary investigation of the stress in the brush and the contact between the brush and the slip-ring has been initiated. The maximum bending stress in the 7 mil wire brush with 2.5 g preload and 90° groove is approximately 20,000 psi. The maximum contact stress is on the order of 60,000 psi. The maximum bending stress will be investigated further, particularly considering the fatigue limit of gold alloys.

E. Hard Gold Overlay Studies

Two sets of duplex gold plated slip rings were prepared for use in noise studies. The Orotemp 24 gold plated brass rings were overlaid with 100 microinches of hard gold deposits by a second electroplating step. Two different hard gold bath formulations were employed. A summary of the plating conditions is given in Table 3.

TABLE 3

SUMMARY OF PLATING CONDITIONS USED IN PREPARING DUPLEX GOLD-PLATED SLIP RINGS

GOLD BATH	TYPE OF DEPOSIT	CURRENT DENSITY ($amps/ft^2$)	TEMP. (°C)	pH
Orotemp 24*	24k, soft	5	50-55°	5.5-6.0
Orotherm HT*	24k, hard, acid bright gold	5	31°	4.3
Autronex NI**	hard, acid gold	5	31°	3.8

* Technic, Inc. proprietary formulation

** Sel-Rex Corporation proprietary formulation

Two rings of each of the Orotherm and Autronex deposits were prepared. The rings were run-in in a nitrogen atmosphere for 290 to 330 hours of continuous rotation at 200 rpm. A d-c current of 25 ma was applied to each brush-ring pair for approximately half of the time and the direction of rotation was periodically reversed. In all four cases, the noise level remained in the 100 to 150 microvolt range except for short periods following the reversals of the direction of rotation. After the completion of the tests, the rings and brushes were examined macrographically up to the 30x power. The grooves of all rings were remarkably free of all wear patterns although there was a quantity of fluffy, black debris in the bottom of the grooves and on the brush wires. There appeared to be considerably more debris on both rings overlaid with Autronex type of deposits. A qualitative spectrographic analysis was performed with the collected debris. The characteristic emission lines were negative with respect to gold, platinum, silver and copper. One each of the two types of rings was cross-sectioned for metallurgical examination. Photomicrographs of such a cross-section is shown in Figure 1. The light colored coating on the outside of the ring surface is nickel that was electroplated after the test to hold the corners during grinding and polishing. No significant wear was found in either type of overlay which agrees with the finding that the debris contained no gold. In order to

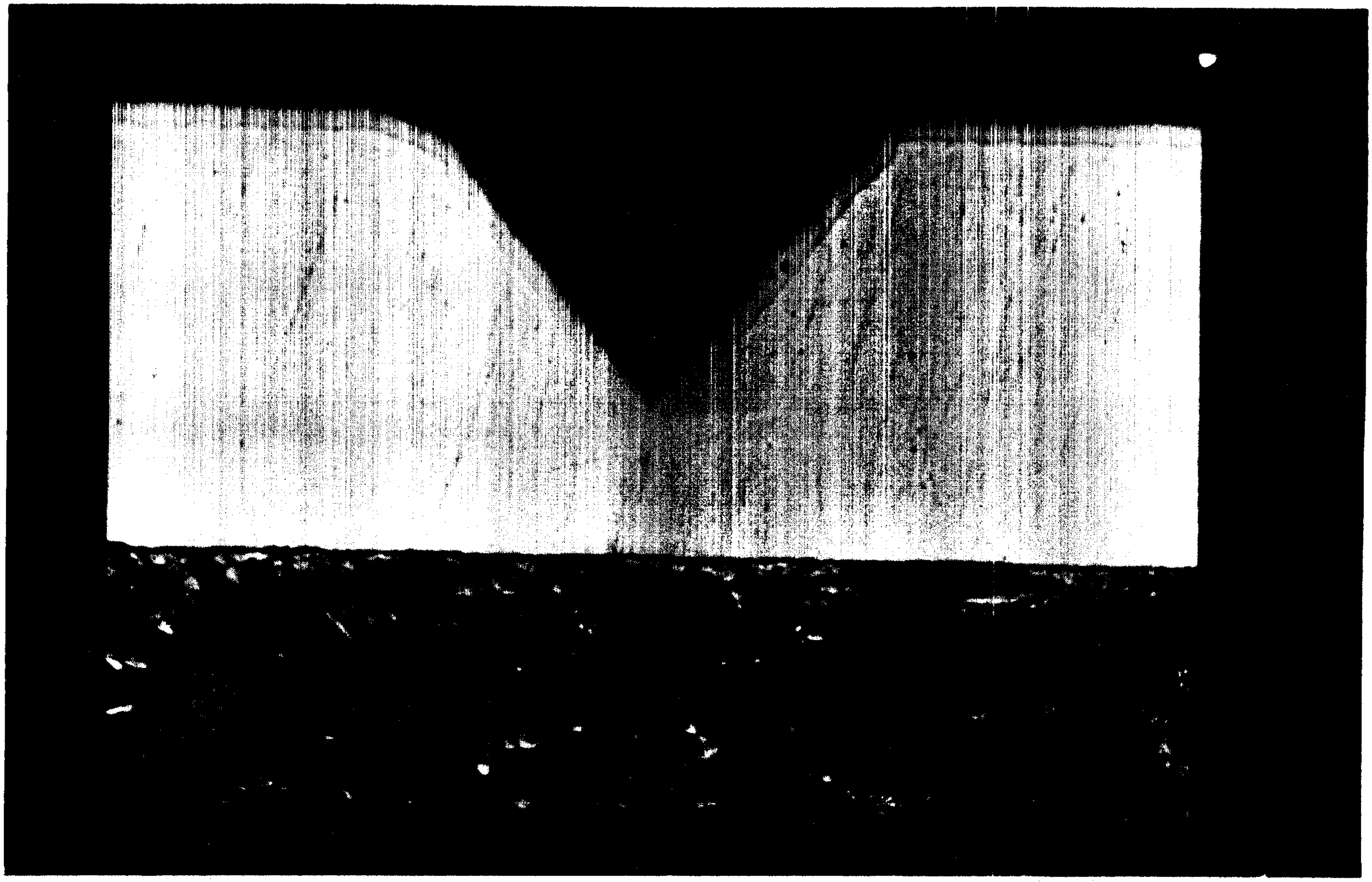

FIGURE 1

PHOTOMICROGRAPH OF THE CROSS-SECTION OF AUTRONEX NI GOLD PLATED RING

determine the origin of the debris, an attempt will be made to perform a qualitative analysis of its organic constituents. Further investigations of hard gold overlays will be carried out in high vacuum.

F. Electroplating Studies

An electroplating facility was assembled for conducting gold plating experiments in the presence of ultrasonic energy. A 75-watt Sonogen Z ultrasonic unit operating at a frequency of 25 kc was used to agitate an Orotemp 24 gold bath operating at a current density of 25 ampere per square inch. After four hours of operation, two types of plate roughness were exhibited: a fine, pebbled, uniform type of surface, and a gross type of swirled trenching about the bottom areas. In the fine pebbled areas, the smoothness was better than in corresponding specimens plated without ultrasonic agitation. The swirled pattern is unacceptable, but some of the roughness could be eliminated by the proper combination of specimen location and rotation.

The concept of using precious metal addition agents in gold electroplating baths for the purpose of obtaining harder deposits is basically sound. Although experimental work to date on this approach to electroplating more wear-resistant gold has shown negative results, it is recommended that the work be continued to higher addition agent levels than hitherto investigated. The maximum level of addition agents in past work was 1%; levels of 10% or higher should be investigated.

III. SUMMARY

The results of the activities performed during the reported period can be summarized as follows:

A. Run-in tests of brush-ring assemblies in high vacuum showed that unacceptable noise levels were developed in a very short time.

B. New brush-ring designs are being evaluated.

C. Mass spectrographic analyses of off-gassing products from three different organic components used in experimental capsules indicated that the selected materials had very good off-gassing properties.

D. Apparatus has been designed and is being fabricated for the study of friction, wear, electrical noise, and lubrication of different materials in high vacuum. Several promising candidate lubricants have been selected.

E. Run-in tests of two types of hard gold overlays in nitrogen atmosphere produced a type of debris which was not encountered in previous tests. Qualitative analysis of this debris is being conducted.

F. Studies of effects of electroplating were carried out in presence of ultrasonic energy. No definite improvement in plating quality was obtained.

IV. FUTURE ACTIVITIES

During the next quarterly report period of this program, the following activities will be performed:

A. Run-in tests of new brush-ring designs will be continued in high vaccum.

B. Spectral analysis of wear debris will be completed.

C. Lubrication studies will be started in high vacuum.

D. Hard gold overlay studies will be completed.

E. Electroplating studies will be continued.

V. PERSONNEL AND LOGBOOKS

IITRI staff members who have contributed to the research effort described in this report are J. L. Radnik, W. H. Graft, R. G. Scholz, W. J. Courtney, M. Lerner, M. Holzer, and O. M. Kuritza.

The data on this project are recorded in logbooks C15698, C14223, and C14942.

Respectfully submitted,
IIT RESEARCH INSTITUTE

O. M. Kuritza

O. M. Kuritza
Research Engineer
Reliability and Components

Approved:

J. L. Radnik

J. L. Radnik
Assistant Manager
Reliability and Components