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THE SYNERGISTIC EFFECTS OF SLIP RING-BRUSH DESIGN AND MATERIALS

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16. Abstract

This program has involved the design, fabrication and subsequent testing of four power slip rings for synchronous orbit application. Environmental and instrumentation systems necessary for monitoring electrical noise, friction and brush wear in air and at less than 5×10^{-8} torr have been developed.

Composite brushes consisting of silver-molybdenum disulfide-graphite and silver-niobium diselenide-graphite have been employed on rings of coin silver and rhodium plate.

These four contact combinations have been tested during an ambient condition run-in at 150 RPM and a humidity sequence at 0.1 RPM. At this time the first nine months of a two year vacuum test being performed at 0.1 RPM have been completed.

17. Key Words Friction, Wear, Electrical Noise Composite Lubricants	18. Distribution Statement

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PREFACE

This program involves the design, fabrication and subsequent testing of four power slip rings for synchronous orbit application. Frequent and simultaneous recording of friction, wear and electrical noise enable the synergistic effects of contact materials and slip ring-brush design to be studied.

The four ring and brush material combinations under evaluation are as follows:

- (A) Poly-Scientific ES383 brushes vs rings of rhodium plate over nickel plate on a brass substrate (Combination A)
- (B) Poly-Scientific ES383 brushes vs coin silver (silver - 10% copper) rings (Combination B)
- (C) Poly-Scientific ES384 brushes vs rings of rhodium plate over nickel plate on a brass substrate (Combination C)
- (D) Poly-Scientific ES384 brushes vs coin silver rings (Combination D)

These four contact combination have been tested under the following conditions:

1. Run-in at 150 RPM for 10 hours.
2. A five day humidity sequence at 0.1 RPM.
3. Nine months of vacuum operation ($<5 \times 10^{-8}$ torr) at 0.1 RPM.

The results of the run-in, humidity and first six months of vacuum operation have been previously reported.[19-20] Portions of these reports have been repeated here to maintain continuity. Conclusions based on the last three months of vacuum data are not being drawn in this report. The conclusions previously drawn after six months of vacuum operation were as follows:

Electrical Noise

1. A significant difference between inductive vs resistive loading does not appear to exist.

2. Noise levels across the positive brushes were found to be significantly lower than those across the negative brushes.
3. Coin silver ring material gave better results than rhodium plate.
4. Brushes lubricated with MoS_2 gave lower noise values than those lubricated with $NbSe_2$.
5. The Ag-MoS_2C/Ag combination gave the better performance than the other three combinations.

Friction

1. All combinations showed a significant decrease in friction in going from air operation to vacuum operation.
2. Those brushes lubricated with MoS_2 gave lower coefficients of friction in vacuum than those lubricated with $NbSe_2$.

Wear

1. The Ag-$NbSe_2$-C/Ag combination has yielded the lowest total wear and wear rate throughout vacuum operation to date.
2. Based on total wear, the Ag-MoS_2-C/Rh, Ag-MoS_2-C/Ag and Ag-$NbSe_2$-C/Rh combinations have yielded equivalent wear rates.
3. After 1000 hours of vacuum operation the Ag-MoS_2-C/Ag and Ag-$NbSe_2$-C/Rh combinations appear to be wearing at the highest rates.
4. Projecting from the 1000-4300 hours vacuum data, it would appear that low rate is the result of combination performance rather than a particular ring or brush material.

It is recommended that the two year vacuum test continue and data be collected at a frequency of twice per week.

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THE SYNERGISTIC EFFECTS OF SLIP RING-BRUSH DESIGN AND MATERIALS

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I. INTRODUCTION

Increasing satellite complexity, power usage and long life requirements are demanding more precise knowledge of sliding contact performance in the vacuum of outer space. Applications of slip rings for exceptionally long life have traditionally been dependent upon the use of contacts with solid lubricants of lamellar structure. With space missions now being projected to 10 years and longer and with more complex optical systems the selection of this type construction is nearly mandatory. This type of contact is being considered for transmission of high power levels from the solar array to the vehicle of future satellites and space stations in synchronous orbit. Such arrays rotate at the average speed of one revolution per day to maintain relative alignment to the sun and to earth stations. Such slow speeds might, it was thought, severely limit the performance of sliding contact power transfer devices.

Previous studies[1-18] have explored the performance of various contact materials in the vacuum environment. Most of these have been in relative high pressure $\approx 10^{-6}$ torr or were operated with high surface speeds to accelerate performance patterns of the contact materials.

This paper presents the results of four contact material combinations operated with a current density of 100 A/in^2 at speeds simulating earth rate rotation and low pressure similar to synchronous orbit vacuum. Silver graphite composite brushes utilizing equal volume fractions of MoS_2 or $NbSe_2$ lubricants were employed with rings of coin silver and rhodium plate. Emphasis has been placed on instrumentation and systems design to permit periodic monitoring of friction, wear and electrical noise. Data from brief air tests and nine months of vacuum operation have been presented.

II. Experimental

The equipment, instrumentation, techniques and materials analysis employed to date have been previously reported.[19] There have been no changes since that reporting.

III. Data Collection

Friction, electrical noise and wear measurements were taken from the four materials combinations during the following three periods:

1. Ten hours of run-in with a ring speed of 150 RPM.
2. Five days at controlled humidity, changing from 30-40% RH to 70-80% RH every 24 hours with a ring speed of 0.1 RPM.
3. Nine months at a pressure of $<5\times10^{-8}$ torr with a speed of 0.1 RPM.

Table I gives the number of data recordings for each of the three parameters during the three test periods.

Each time data was collected during the run-in period, the measurements were recorded over a time interval representing 15-20 ring revolution, under conditions of controlled humidity and vacuum.

The electrical noise data represent the maximum peak to peak (P-P) value recorded during each data collection interval (Tables 2 and 3 and Figure 1). The friction coefficients were determined using the maximum tangential force recorded during each interval (Table 4 and Figure 1). The variation in brush displacement with time under vacuum has been shown in Figure 1.

Future reference to the four brush and ring combinations will be as follows:

(A) Ag-MoS_2-C brushes on Rh rings (Combination A)
(B) Ag-MoS_2-C brushes on Ag rings (Combination B)
(C) Ag-$NbSe_2$-C brushes on Rh rings (Combination C)
(D) Ag-$NbSe_2$-C brushes on Ag rings (Combination D).

TABLE 1

DATA COLLECTION FREQUENCY

Test Period	Number of Recordings Materials Combinations			
Run-In Ambient	A Ag-MoS_2-Rh	B Ag-MoS_2-C/Ag	C Ag-$NbSe_2$-C/Rh	D Ag-$NbSe_2$-C/Ag
Condition 0-10 Hrs.	8	3	2	2
Relative Humidity 30-40% 70-80%				
0-24 Hrs.	3	3	3	3
24-48 Hrs.	3	3	3	3
48-72 Hrs.	3	3	3	3
72-96 Hrs.	3	3	3	3
96-120 Hrs.	3	3	3	3
Vacuum 0-10 Hrs.	7	7	7	7
10-32 Hrs.	6	6	6	6
32-100 Hrs.	8	8	8	8
100-1000 Hrs.	38	38	38*	38
1000-4300 Hrs.	26	26	26	26
4300-7700 Hrs.	21	21	21	17**

*After 1000 Hours 4 of 6 circuits were not operational.

**Feedthrough bearings failed after 7056 hours.

IV. Discussion

The run-in, humidity and first six months of vacuum data were treated in a previous report[20]. Only the Tables and Figures necessary to maintain continuity of the vacuum data are being repeated in this report.

A. Electrical Noise

A statistical analysis of the data was conducted after six months of vacuum operation. The results of that study have been repeated in Table 2. A similar statistical analysis will not be repeated until more data have been generated. It was concluded from that analysis that a significant difference between inductive and resistive loading for all combination did not exist. For this reason and for sake of clarity the inductive and resistive electrical noise data have been averaged in Figure 1. The additional three months of vacuum data do not appear to have made any significant difference from the first six months of data (Figure 1 and Table 3).

B. Friction

After the completion of six months of vacuum operation, the MoS_2 lubricated brushes were yielding lower coefficients of friction (0.12) than those lubricated with $NbSe_2$ (0.29). During the last three months of vacuum operation the MoS_2 lubricated brushes have moved up to a level of 0.25 while the $NbSe_2$ lubricated ones have remained nearly constant at 0.31.

C. Wear

The last three months of vacuum data have confirmed the projections made after six months of operation. At that point it appeared that the Ag-MoS_2-C/Ag and Ag-$NbSe_2$-C/Rh combinations were weaving at the highest rates. The wear data in Figure 1 indicates these combinations are wearing at a higher rate than the Ag-MoS_2-C/Rh and Ag-$NbSe_2$-C/Ag combinations. As previously concluded, it appears that wear performance is a result of materials combination rather than a single ring or brush material.

C

TABLE 2

STATISTICAL ANALYSIS OF THE MEANS OF THE ELECTRICAL NOISE DATA

Parameter Analyzed	TEST CONDITION							
	Run-In 0-10 Hrs.		Humidity 0-120 Hrs.		0-100 Hrs.		100-4300 Hrs.	
	TEST	CL*	TEST	CL*	TEST	CL*	TEST	CL*
Electrical Load Differences	$A_L = A_R$		$A_L < A_R$	83.5	$A_L < A_R$	99.9+	$A_L < A_R$	99.3
	$B_L = B_R$		$B_L < B_R$	99.9+	$B_L = B_R$		$B_L < B_R$	99.9+
	$C_L = C_R$		$C_L < C_R$	99.9+	$C_R < C_L$	96.7	$C_R < C_L$	99.9+
	$D_L < D_R$	60	$D_L = D_R$		$D_R < D_L$	97.6	$D_L < D_R$	99.9+
Polarity Differences	$A_R^+ < A_R^-$	99.9	$A_R^+ < A_R^-$	99.9+	$A_R^+ < A_R^-$	99.9+	$A_R^+ < A_R^-$	99.9+
	$B_R^+ = B_R^-$		$B_R^- < B_R^+$	99.9+	$B_R^+ < B_R^-$	99.9	$B_R^- < B_R^+$	99.9+
	$C_R^+ < C_R^-$**		$C_R^+ < C_R^-$	99.9+	$C_R^+ < C_R^-$	99.9	$C_R^+ < C_R^-$	99.9+
	$D_R^+ < D_R^-$**		$D_R^+ < D_R^-$	82.7	$D_R^+ < D_R^-$	99.9	$D_R^+ < D_R^-$	99.9+
Ring Material Differences	$B_R < A_R$	99.9+	$B_R < A_R$	99.9+	$B_R < A_R$	99.9+	$A_R < B_R$	98
	$B_L < A_L$	99.9+	$B_L < A_L$	99.9+	$B_L < A_L$	77.8	$B_L < A_L$	99.8+
	$C_R < D_R$	80	$D_R < C_R$	99.9+	$D_R < C_R$	99.9+	$D_R < C_R$	99.9+
	$C_L \doteq D_L$		$D_L < C_L$	99.9+	$D_L < C_L$	99.9+	$D_L < C_L$	99.9+
Brush Material Differences	$C_R < A_R$	99.9+	$A_R < C_R$	99.9+	$A_R < C_R$	99.9+	$A_R < C_R$	99.9+
	$C_L < A_L$	99	$A_L < C_L$	99.9+	$A_L < C_L$	99.9+	$A_L < C_L$	99.9+
	$B_R < D_R$	97	$B_R < D_R$	88.9	$D_R < B_R$	99.9+	$B_R < D_R$	99.9+
	$B_L < D_L$	76	$B_L < D_L$	99.9+	$B_L = D_L$		$B_L < D_L$	99.9+
Material Combination Differences	$D_R < A_R$	92.6	$D_R < A_R$	99.9+	$D_R < A_R$	99.9+	$A_R < D_R$	99.9+
	$B_R = C_R$		$B_R < C_R$	99.9+	$B_R < C_R$	99.9+	$B_R < C_R$	99.9+
	$D_L < A_L$	99	$D_L < A_L$	99.9+	$D_L < A_L$	97.6	$A_L < D_L$	99.9+
	$B_L < C_L$	60	$B_L < C_L$	99.9+	$B_L < C_L$	99.9+	$B_L < C_L$	99.9+

A - $Ag\text{-}MoS_2\text{-}C/Rh$

B - $Ag\text{-}MoS_2\text{-}C/Ag$

C - $Ag\text{-}NbSe_2\text{-}C/Rh$

D - $Ag\text{-}NbSe_2\text{-}C/Ag$

$\pm$ denote brush polarity.

L and R denote inductive or resistive load respectively

*Confidence limits are for two tailed testing

H_o: $X = Y$ H_a: $X \pm Y$

**Two observations only.

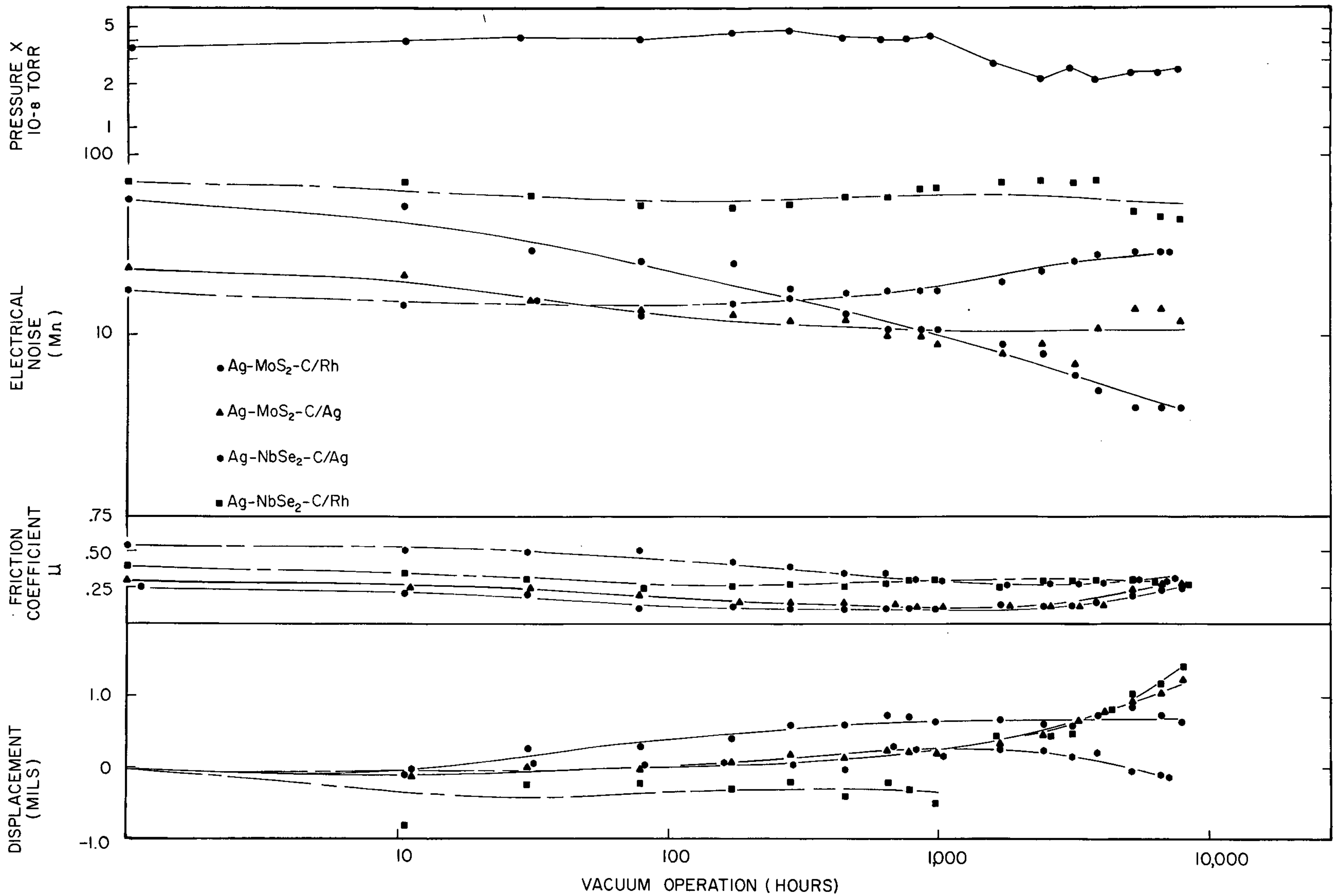

FIGURE 1. ELECTRICAL NOISE, FRICTION AND WEAR DURING VACUUM OPERATION AT 0.1 RPM

TABLE 3

AVERAGE ELECTRICAL NOISE LEVELS

Test Period	Run-In 0 Hrs.	Run-In 10 Hrs.	Humidity 0 Hrs.	Humidity 120 Hrs.	Vacuum 0 Hrs.	Vacuum 100 Hrs.	Vacuum 7700 Hrs.
(A) $Ag-MoS_2-C/Rh$	21.8	35.8	33.7	45.3	57.8	28.5	4.5
(B) $Ag-MoS_2-C/Ag$	6.6	9.5	12.8	15.7	23.5	13.5	12.7
(C) $Ag-NbSe_2-C/Rh$	5.3	15.2	31.0	100.8	71.5	50.2	61.0
(D) $Ag-NbSe_2-C/Ag$	19.8	10.8	13.8	21.0	18.2	13.3	31.5

*Average includes both resistive and inductive circuits.

TABLE 4

FRICTION COEFFICIENTS

Test Period	Run-In Initial	Run-In Final	Humidity Initial	Humidity Final	Vacuum Initial	Vacuum Final
(A) Ag-Mos_2-C/Rh	0.43	0.32	0.17	0.25	0.26	0.22
(B) Ag-MoS_2-C/Ag	0.41	.55*	0.44	0.46	0.30	0.30
(C) Ag-$NbSe_2$-C/Rh	0.33	0.57	0.48	0.37	0.40	0.25
(D) Ag-$NbSe_2$-C/Ag	0.41	0.38	0.33	0.48	0.54	0.36

*Average of three brushes.

As a result of feedthrough bearing failure after approximately 7000 hours of vacuum operation, rotation on combination D has ceased. Power is being kept on the fixture so cold welding tests can be performed at a later date.

V. NEW TECHNOLOGY

The system, experimental techniques and results reported to date do not directly represent a form of new technology.

VI. PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period the vacuum test will continue. Data will be taken on a twice per week basis.

VII. CONCLUSIONS

At this point, nine months of vacuum operation have been concluded. The results generated during the last three months of operation have not significantly altered the conclusions drawn after six months of operation. The conclusions drawn at that time were as follows:

A. Electrical Noise

1. A significant difference between inductive vs. resistive loading did not appear to exist.

2. Noise levels across the positive brushes were found to be significantly lower than those across the negative brushes.

3. Coin silver ring material gave better results than rhodium plate.

4. Brushes lubricated with MoS_2 gave lower noise values than those lubricated with $NbSe_2$.

5. The Ag-MoS_2-C/Ag combination gave better performance than the other three combinations.

B. Friction

1. All combinations showed a significant decrease in friction in going from air operation to vacuum operation.

2. Those brushes lubricated with MoS_2 gave lower coefficients of friction in vacuum than those lubricated with $NbSe_2$.

C. Wear

1. The Ag-$NbSe_2$-C/Ag combination yielded the lowest total wear and wear rate throughout vacuum operation to date.

2. Based on total wear, the Ag-MoS_2-C/Rh, Ag-MoS_2-C/Ag and Ag-$NbSe_2$-C/Rh combinations have yielded equivalent wear rates.

3. After 1000 hours of vacuum operation the Ag-MoS_2-C/Ag and Ag-$NbSe_2$-C/Rh combinations appear to be wearing at the highest rates.

4. Projecting from the 1000-4300 hours vacuum data, low wear rate is the result of combination performance rather than a particular ring or brush material.

VIII. RECOMMENDATIONS

This program should continue with the data collection frequency of twice per week until the completion of two years at less than $5X10^{-8}$ torr. At that time a post test analysis should be performed, the parts refurbished and the four-month test at speeds of 0.1 and 4 RPM should be completed.

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