N72-30429

NASA TECHNICAL NOTE

NASA TN D-6969

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EFFECT OF POLARITY OF ELECTRIC CURRENT ON FRICTION BEHAVIOR OF TWO GALLIUM-LUBRICATED TANTALUM SLIPRING ASSEMBLIES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-6969		

4. Title and Subtitle	5. Report Date
EFFECT OF POLARITY OF ELECTRIC CURRENT ON FRICTION BEHAVIOR OF TWO GALLIUM-LUBRICATED TANTALUM SLIPRING ASSEMBLIES	September 1972
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
John Przybyszewski	E-6974
	10. Work Unit No.
9. Performing Organization Name and Address	502-01
Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Note
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Computer-processed data from low-speed (10 rpm) slipring experiments with two similar (but of opposite polarity) gallium-lubricated tantalum slipring assemblies (hemisphere against disk) carrying 50 amperes dc in vacuum (10^{-9} torr) showed that the slipring assembly with the anodic hemisphere had significantly lower peak-to-peak values and standard deviations of coefficient-of-friction samples (a measure of smoothness of operation) than the slipring assembly with the cathodic hemisphere. Similar data from an experiment with the same slipring assemblies running currentless showed more random differences in the frictional behavior between the two assemblies.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Slipring assemblies Gallium-lubricated sliprings Polarity effects in sliprings Effect of polarity on friction	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	26	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

Three 8-hour electrical slipring experiments were conducted to evaluate the possible effect of a polarizing electrical current (dc) on the frictional behavior of a slipring assembly. Two similar gallium-lubricated slipring assemblies (hemisphere on disk), running simultaneously and connected in electrical series (opposed polarity), were used for these experiments. One experiment was conducted for each direction of electrical current input (two experiments) with a 50-ampere dc current. The third experiment was done without current. All experiments were conducted in vacuum (10^{-9} torr) at 10 rpm (sliding speed, 132 cm/min) with deadweight loads of 100 grams. A computer-controlled, asynchoronous, data-acquisition system was used to sample and process friction-force and contact-voltage-drop data from each assembly, successively, approximately every 3 minutes. The highest peak-to-peak value of the coefficient of friction and the standard deviation of each sample of coefficient-of-friction data (a measure of the smoothness of operation) were computed. Plots were made to show the differences between the computed values for one assembly and the computed values for the other assembly that occurred at approximately the same point in time. The data show that the assembly that had the anodic hemisphere had significantly lower peak-to-peak values of the coefficient of friction and lower standard deviations of the coefficient-of-friction data samples than the assembly that had the cathodic hemisphere. In the currentless experiment, differences in the peak-to-peak and standard-deviation values between the assemblies tended to be random.

INTRODUCTION

In the absence of an electrical current, the fundamental properties of materials and intervening surface films dictate the friction and wear behavior of two materials in sliding contact. If an electrical current is passed through two conductive materials in sliding contact, some alteration of the currentless friction and wear process can reasonably be expected to occur, since additional electrical energy is being added to the sliding system. One obvious effect of an electrical current is resistive heating. Resistive heating added to frictional heating can cause an increase in oxidation rates in atmosphere and softening of the sliding materials, with consequent changes in the friction and wear behavior of the sliding contact. Furthermore, if a direct current is used, the direction of current flow (polarity) can influence the wear of a sliding contact (ref. 1). In the case of a graphite brush in sliding contact with a copper slipring, wear of a cathodic (electron source) brush is greater than the wear of an anodic (electron sink) brush. It was also observed that an anodic brush, carrying current, wears less than the same type of brush running currentless.

The wear behavior of metal-graphite brushes running against copper sliprings is similar except that the wear of the anodic brush is not decreased. Nevertheless, the wear of the anodic brush remains less than that of the cathodic brush.

The effect of current polarity, as explained by reference 1, results from different conduction mechanisms under the anodic and cathodic brushes and copper ion transport by electrolysis (water vapor required) under the influence of the electric field.

Polarity effects on wear of materials other than graphite and copper running in vacuum have also been observed (ref. 2). Results from gallium-lubricated copper slipring assembly experiments with 20-ampere dc currents of opposite polarities showed that the friction data were rougher (more frequent and greater variations in amplitude of the data) and that wear was increased threefold when the hemisphere (brush) was cathodic. Larger variations in contact resistance and greater corrosion of the hemisphere were also observed when the hemisphere was cathodic.

A comparison of wear results from a 10-hour experiment with a gallium-lubricated tungsten slipring assembly that used a small milliampere alternating current (essentially no polarity) and results from a 500-hour experiment that used a 20-ampere direct current (hemisphere anodic, same materials) also gives evidence of the polarity effect on wear (refs. 3 and 4). The 500-hour wear of the anodic hemisphere was greater than the 10-hour wear of the nonpolarized hemisphere by a factor of only 29, although running times differ by a factor of 50. This fact suggests that wear was reduced when the hemisphere was made anodic. The difference in wear acquires additional significance when the ratio of contact currents in the two experiments (approximately 600 to 1) is considered.

Although there is some evidence for the effect of polarity on sliding-contact wear, there are no data concerning possible effects of electrical contact polarity on the frictional behavior of a sliding contact. The only reference to a possible relation between contact polarity and frictional behavior occurs in reference 2. It was noted that the friction data were rougher when the hemisphere was cathodic.

An evaluation of any differences in frictional behavior between two similar slipring assemblies having opposite polarities is difficult because the friction data generally consists of rapidly varying analog values. Furthermore, significant physical or mechanical differences between any two given slipring assemblies might mask any polarity effects on frictional behavior, since the magnitude of the effect is unknown.

It is the objective of this report to present and discuss computer-processed peak-to-peak and standard-deviation data from two similar gallium-lubricated tantalum slipring assemblies. Both assemblies were run simultaneously in vacuum (10^{-9} torr), each under a deadweight load of 100 grams, at a speed of 10 rpm (sliding speed, 132 cm/min). Two experiments were conducted with 50-ampere direct currents of opposite polarities. A third experiment was a currentless control experiment.

APPARATUS

Vacuum System

The vacuum system used for these experiments consists of a bakeable, circular, stainless-steel chamber that is pumped by two 400-liter-per-second and one 125-liter-per-second ion pumps. A liquid nitrogen cooled titanium sublimation pump assists the ion pumps. Rough pumping is accomplished by a set of three sorption pumps. Chamber pressure is measured by a hot cathode ionization gage.

Dual Slipring Test Assembly

The apparatus used in the experiments is shown in figure 1. Both slipring assemblies (herein designated 1 and 2), the rotary magnetic drive, and all electrical feedthroughs are mounted on a single vacuum flange.

All nonrotating components of each slipring assembly are mounted on individual, 1.6-centimeter-thick, 23-centimeter-diameter, stainless-steel plates. Each plate has three removable ball bushings located 120° apart near the rim. The bushings enable the plates to slide on three, 2.5-centimeter-outside-diameter, hardened, stainless-steel, support rods welded normal to the inside face of the vacuum flange. The lateral position of the plate nearest the vacuum flange (i.e., the plate for slipring assembly 2) is fixed by a removable tapered pin through a ball bushing housing and a support rod. The lateral position of the remaining mounting plate (for slipring assembly 1) is located by a shoulder on the drive shaft that acts as a stop for the shaft support bearing in the center of the plate. Movement of the bearing (and, consequently, of the plate) away from the shoulder is restrained by a small spring connected between the two plates. The spring

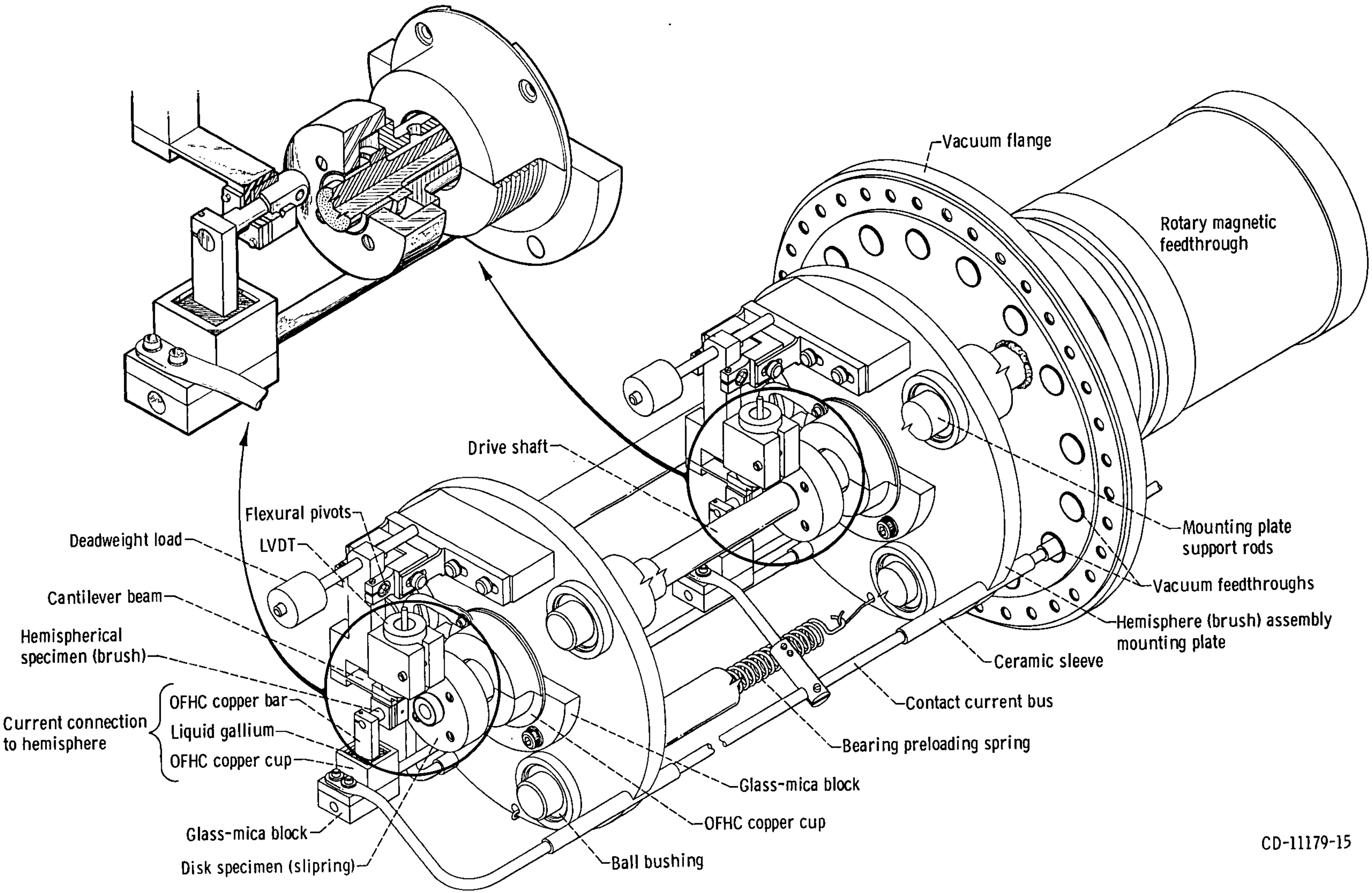


Figure 1. - Dual slipring test assembly.

also serves to apply a 2.3-kilogram axial preload on the bearings in addition to permitting axial expansion of the drive shaft.

A helically cut, all-metal, flexible coupling joins the shaft of the magnetic drive to the slipring-assembly drive shaft. The flexible coupling compensates for misalignment and thermal expansions of both shafts.

Each hemispherical specimen (brush) support arm (one on each plate) is hinged on two flexural pivots. The support arm constitutes a first-class lever, with an adjustable deadweight load on one end and a cantilever-beam-supported hemispherical specimen at the opposite end. Each hemispherical specimen can be adjusted radially in relation to its disk specimen.

Drive power is supplied by a mechanical, variable-speed drive unit (output speed, 0 to 50 rpm) coupled to a 1/4-horsepower, 1750-rpm; ac electric motor. A timing belt transmits power from the drive assembly to the magnetic drive (modified for use with timing belt) at a 1-to-1 ratio. Slipring speed is measured by a photoelectric tachometer that is chain driven from the output shaft of the variable-speed drive assembly.

Friction-Force Measurement System

The hemisphere is mounted in a small, electrically insulated, oxygen-free, high-conductivity (OFHC) copper block that is attached to one end of a cantilever beam. The frictional force developed between the hemisphere and the disk bends the beam. A linear variable differential transformer (LVDT) converts the cantilever-beam displacement to an electrical signal. Since the large wire size required to supply 50 amperes to the hemisphere would have an undesirable effect on the friction measurements, a different approach had to be used. It consisted of an OFHC bar clamped to a 6.3-millimeter-diameter rear extension of the hemisphere and partially submerged in liquid gallium contained in a small OFHC copper cup. Since this type of electrical connection has a very high compliance, its effect on friction force measurements would be minimal.

Electrical Connections

A schematic of the electrical circuit is shown in figure 2. Each two-part disk specimen (a 3.2-mm-thick tantalum disk backed by an OFHC copper disk) is mounted on an OFHC copper spindle that is completely insulated from the drive shaft. A ring machined into the opposite end of each spindle is immersed in liquid gallium contained in individual, circular, OFHC copper cups. One lead from the current supply is connected by means of a 6.3-millimeter-diameter copper rod to the circular copper cup of slipring assembly 1. The other current-supply lead is similarly connected to the circular copper cup of

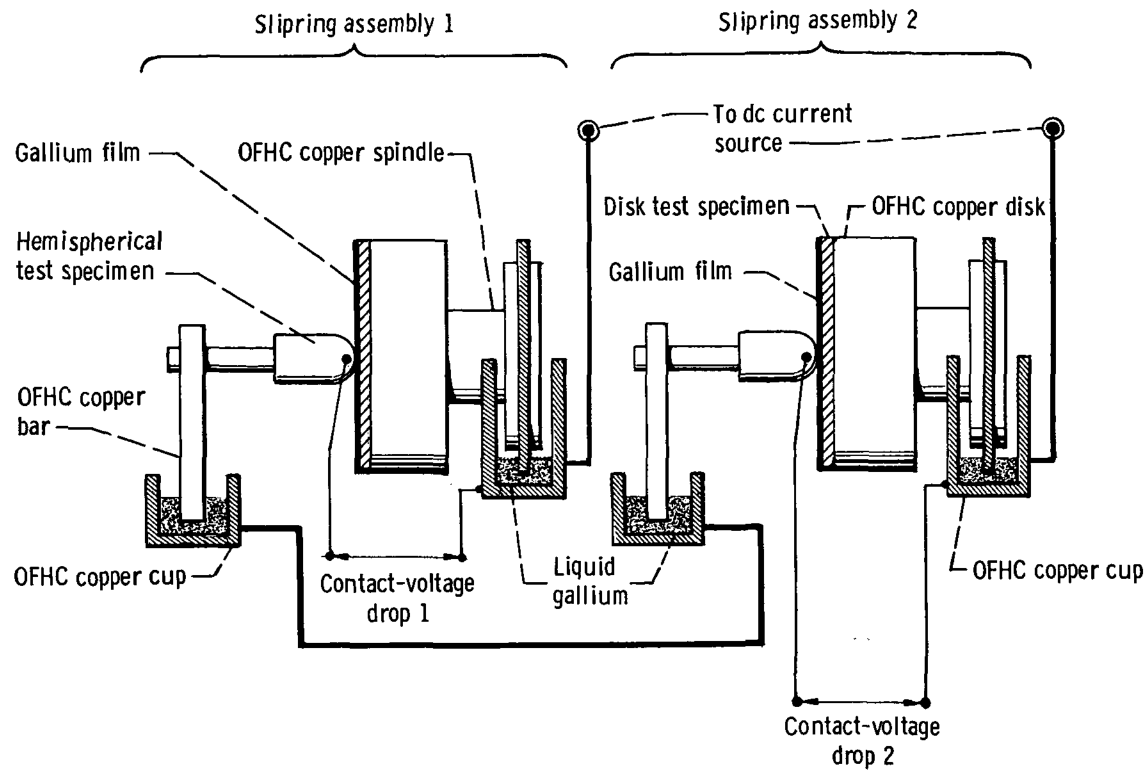


Figure 2. - Schematic diagram of current path through the two slipring assemblies and method of measuring contact-voltage drops.

slipring assembly 2. A series electrical curcuit is completed by joining the small gallium cups that feed electrical current to the hemispheres by means of a section of 6.3-millimeter-diameter copper rod. The entire electrical circuit is insulated from ground.

Two separate gold leads are used for each contact voltage drop measurement. One lead is connected directly to a hemisphere near its tip. The remaining lead is connected to the associated circular copper cup.

SPECIMEN PREPARATION

Both hemispherical specimens were machined from a single unannealed tantalum rod. Impurities present in quantities greater than 50 parts per million (ppm) were columbium (480 ppm) and tungsten (170 ppm). The two disk specimens were machined from individual 5.08-centimeter-square by 0.159-centimeter-thick annealed tantalum sheets. Impurities present in quantities greater than 50 ppm in the sheet material were tungsten (100 ppm) and columbium (85 ppm). All contacting surface finishes were 8 microinches or less.

All specimens were washed thoroughly in a hot detergent solution and rinsed a number of times in absolute alcohol. Liquid gallium (starting purity >99.99 percent) was applied, in atmosphere, to one face of a warmed disk by means of a cotton swab. No great difficulty was experienced in forming a continuous film, although a small amount of rubbing was required. A smooth, bright film resulted on both disks. The final form of the gallium film was a 0.635-centimeter-wide annulus that straddled the anticipated wear-track area. No gallium was applied to the hemispherical specimens.

The amount of gallium applied to each disk was determined by weighing each disk before and after gallium application. The amount applied to disk 1 (farthest from the vacuum flange) was 124 milligrams, and the amount applied to disk 2 was 192 milligrams. If uniform distribution of gallium is assumed in the annular area, the calculated film thickness was 4.2×10^{-3} centimeter on disk 1 and 6.62×10^{-3} centimeter on disk 2. In actual use, the film thickness in the contact area would be less than the calculated values because a portion of the liquid gallium would migrate to the bottom of the disk (which is vertical during the experiments) under the influence of gravity. The actual contact area on each disk was displaced 90 degrees from the bottom of the disk.

PROCEDURE

Three experiments of 8 hours duration each were made. The same slipring assemblies and materials, kept continuously under vacuum, were used throughout the duration of the three experiments. Two experiments used contact currents of 50 amperes dc (opposite polarities), and 1800 watts was delivered to a resistive load through both slipring assemblies connected electrically in series. The third experiment was made with zero current. Before the series of experiments was begun, both slipring assemblies were run-in for approximately 200 hours to develop a semistable contact area.

A computer-controlled data-acquisition system was used to take periodic samples of friction-force and contact voltage-drop data throughout the course of each 50-amperes dc experiment. In the currentless experiment, only the friction-force data was sampled periodically. The data-acquisition system was programmed to take a sample of 60 readings of contact voltage drop and a sample of 30 readings of friction-force data from each slipring assembly. Data were taken from each assembly, successively, approximately every 3 minutes, throughout each experiment. Data readings were taken at a rate of 10 per second. Since the data-acquisition system was operating asynchronously, it can be reasonably assumed that data from the entire circumference of the wear track were sampled many times during the experiments.

All data samples were processed and converted to the units of interest, on line, and the results were printed out on a teleprinter shortly after the data samples were taken.

The data-acquisition system was programmed to retain the highest and lowest readings obtained in a sample and to calculate the difference between these readings. The result was expressed as a peak-to-peak value. The data-acquisition system was also programmed to calculate the standard deviation of each sample (a measure of the spread of readings in a sample). Both peak-to-peak and standard-deviation values are a measure of the smoothness of operation.

The data system was also programmed to supply a mean value of each sample of readings. In the case of the friction-force samples, the mean values were judged to be invalid because of a large amount of zero drift of the frictional force measurement assembly. This effect was probably due to heating of the assembly by the relatively large amount of contact current used. Therefore, all mean values of friction force were disregarded. However, the peak-to-peak values and standard deviations are not affected by moderate zero drift problems because they are insensitive to a dc component. However, it must be assumed that the zero drift remains constant during any one period of data sampling. Proofs are shown in the appendix. However, if the magnitudes of the zero shifts are such that they drive the measurement system into a region of gross nonlinearity, the peak-to-peak and standard-deviation values also become invalid. Since the magnitudes of the zero shifts were such that problems of nonlinearity were not encountered, the peak-to-peak and standard-deviation values were used as a basis for comparison of the frictional behavior of the two slipring assemblies.

It is important that the contact-area conditions be reasonably stable during the course of the three experiments in order that the friction data be comparable among the experiments. Hence, continuous contact resistance calculations, which reflect conditions in the contact area, were made during the entire duration of the two 50-ampere dc experiments. A small electrical current of 5 amperes dc was used to periodically examine the contact resistance during the currentless experiments. If either assembly showed any abrupt change in contact resistance during the experiments, it would indicate that conditions in the contact area had changed and the friction data would no longer be comparable for the purposes of this experiment.

RESULTS AND DISCUSSION

Initially, the peak-to-peak coefficient-of-friction data were plotted against time on the teleprinter. One graph, containing the peak-to-peak coefficient-of-friction data from both slipring assemblies, was made for each experiment. The large number of intermingled data points on these graphs obscured the effect of current polarity on the peak-to-peak coefficient-of-friction values. Consequently, differential graphs were constructed from these same data. The differential graphs show the effect of current polarity very clearly and are used to compare the frictional behavior of the two slipring assemblies among the experiments.

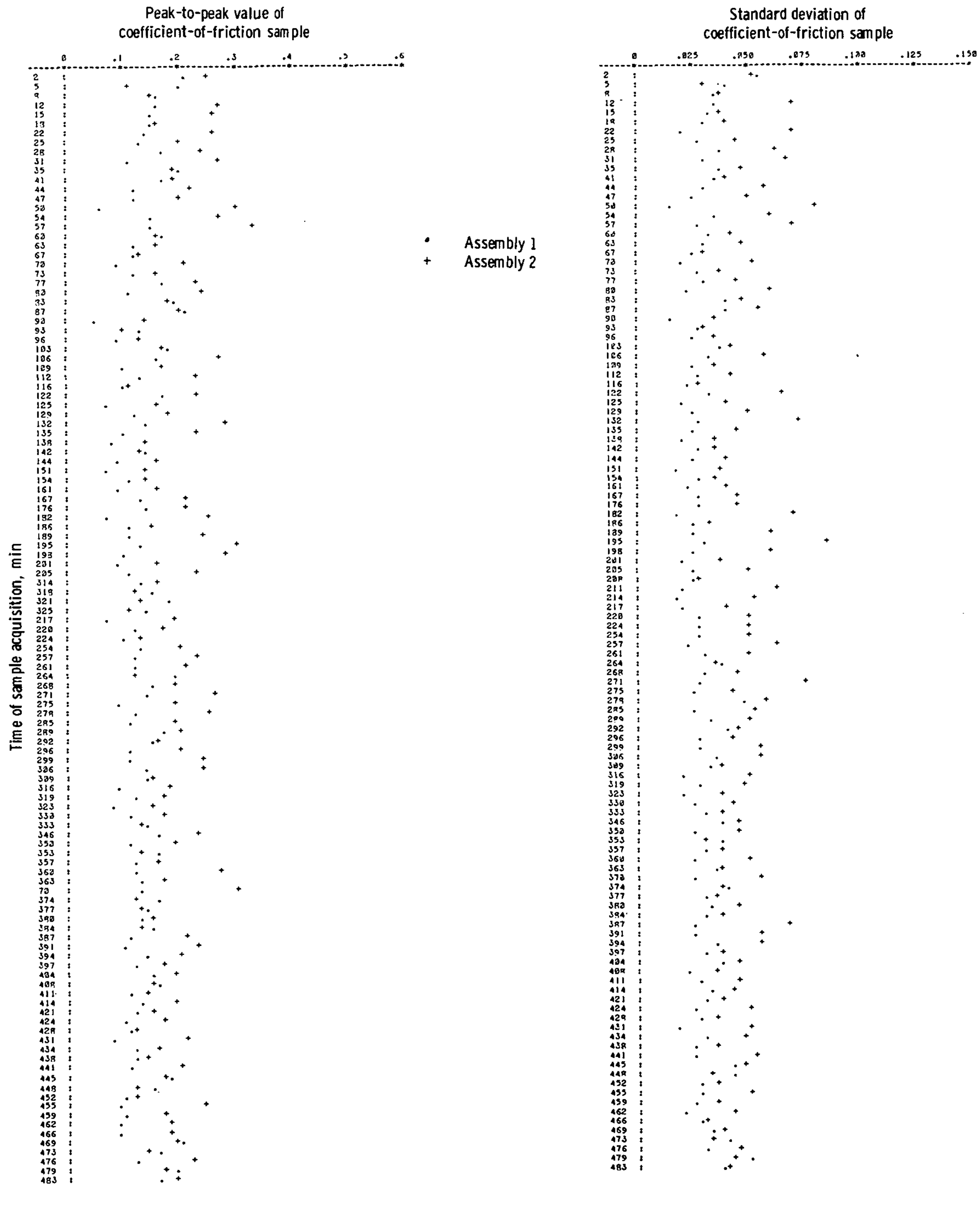
Differential graphs of the peak-to-peak and standard-deviation data from each experiment were plotted separately on the teleprinter. In all cases, the formula used to locate the ordinate of the points on the graphs was $D = X_1 - X_2$ (magnitude of the difference = magnitude of data from slipring assembly 1 minus the magnitude of coincident data from slipring assembly 2). If the difference was negative ($X_1 < X_2$), the result was plotted to the left of the zero centerline. If the difference was positive ($X_1 > X_2$), the difference was plotted to the right of the zero centerline. The differential graph quickly shows the two items of interest in these experiments - whether a data point from assembly 1 was numerically larger or smaller than a coincident data point from assembly 2, and the magnitude of the difference. Thus, the differential graphs can be used to clearly show the effect of slipring-assembly polarity on its frictional behavior. Comparisons are easily made by noting the density and displacement of the plotted points on each side of the zero centerline in the graphs. In the discussion, graphs of the actual peak-to-peak coefficient-of-friction data and the differential graphs derived from them are presented.

In addition, arithmetic means were calculated for all peak-to-peak and standard-deviation data. The arithmetic means are compared between the assemblies and among the experiments. Also, a comparison of arithmetic means between the currentless and current-carrying experiments are made and used in an effort to determine the magnitude and character of the polarity effect.

Hemisphere 1, Anodic; Hemisphere 2, Cathodic; Contact Current, 50 Amperes dc

The first 8-hour experiment was made with the polarity of the hemisphere of slipring assembly 1 anodic in relation to its disk. This choice of polarity automatically made hemisphere 2 cathodic in relation to its disk. The actual values of the peak-to-peak coefficient-of-friction data obtained from both assemblies during this experiment are shown plotted against time in figure 3(a). The differential graph derived from these data is presented in figure 4(a). The differential graph shows that the greatest density of plotted values lie on that side of the zero centerline labeled "assembly 1 < assembly 2."

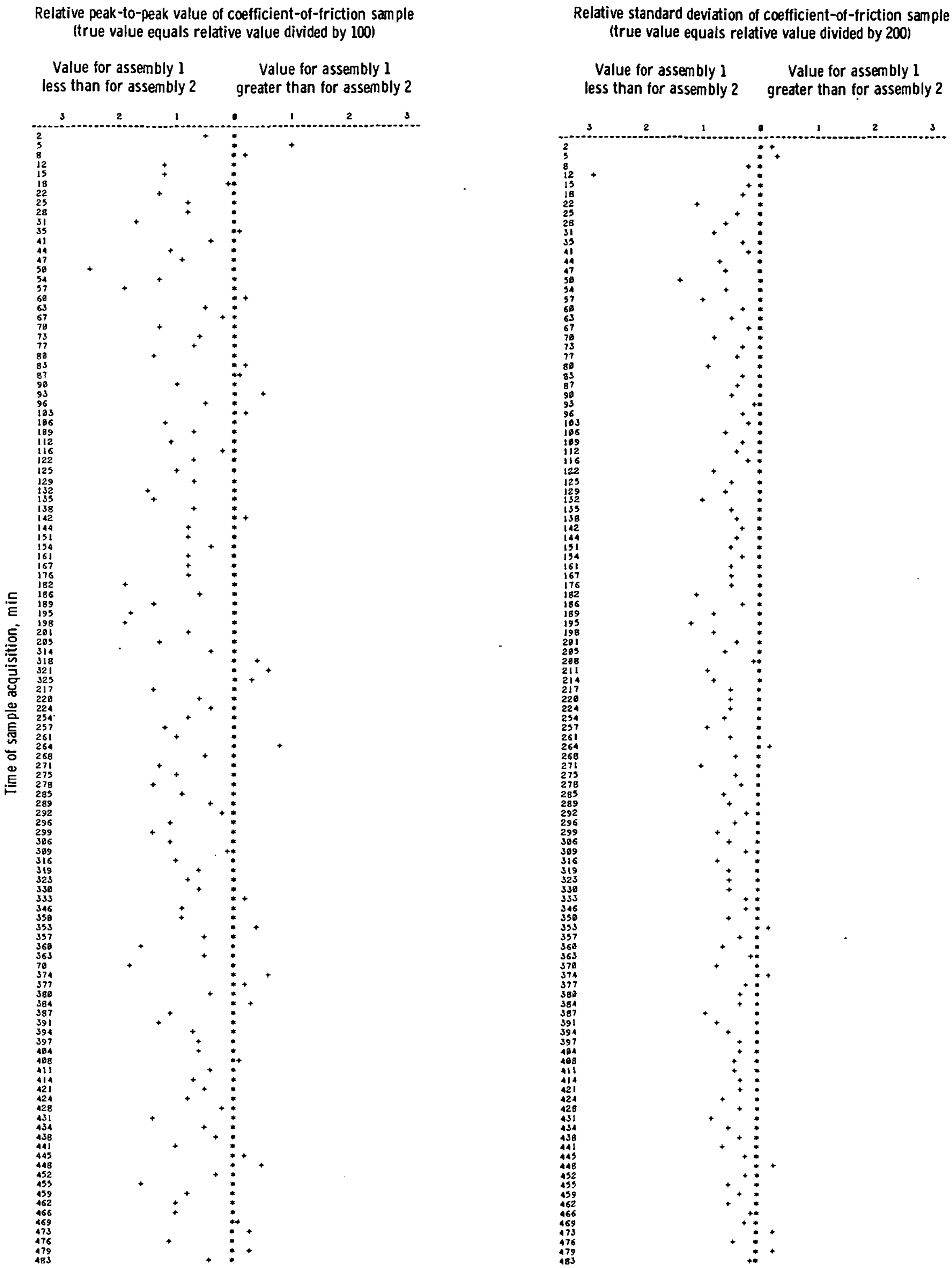
The actual standard deviations of the coefficient-of-friction data samples obtained from this experiment are shown plotted against time in figure 3(b). The differential graph derived from these data is shown in figure 4(b). The standard-deviation graph also shows a segregation of plotted values similar to the peak-to-peak differential graph. Calculations of the arithmetic mean values of both peak-to-peak coefficient-of-friction and standard-deviation data were made for each assembly. The results of the calculations are shown in table I. The data in the table show that the assembly with the anodic hemisphere (assembly 1 in this experiment) had a mean value of the peak-to-peak coefficient



(a) Peak-to-peak values.

(b) Standard deviations.

Figure 3. - Computer terminal plots of peak-to-peak values and standard deviations of coefficient-of-friction samples obtained from two similar slipring assemblies of opposite polarities. Hemisphere (brush) of assembly 1 anodic relative to its disk (slipring); hemisphere of assembly 2 cathodic relative to its disk; contact current, 50 amperes dc.



(a) Relative peak-to-peak values.

(b) Relative standard deviations.

Figure 4. - Computer terminal plots of relative peak-to-peak values and relative standard deviations of coefficient-of-friction samples obtained from two similar slipring assemblies of opposite polarities. Hemisphere (brush) of assembly 1 anodic relative to its disk (slipring); hemisphere of assembly 2 cathodic relative to its disk; contact current, 50 amperes dc.

TABLE I. - COMPARISON OF THE ARITHMETIC MEAN VALUES OF THE PEAK-TO-

COEFFICIENT OF FRICTION AND STANDARD-DEVIATION

DATA FOR THE THREE EXPERIMENTS

Contact current, A dc	Hemisphere 1			Hemisphere 2		
	Polarity	Peak-to-peak coefficient of friction	Standard deviation	Polarity	Peak-to-peak coefficient of friction	Standard deviation
50	Anodic	0.1499	0.029	Cathodic	0.1843	0.047
50	Cathodic	.2042	.050	Anodic	.1348	.033
0	-------	.201	.048	-------	.211	.054

of friction approximately 0.05 (or about 24 percent) lower than the mean value of similar data from the assembly with the cathodic hemisphere (assembly 2).

The data in table I also show that the mean value of the standard deviations of the coefficient of friction was approximately 0.02 (or about 62 percent) lower for the assembly that had the anodic hemisphere (assembly 1) than for the assembly that had the cathodic hemisphere (assembly 2).

Since the type of data used for a comparison is a measure of the scatter of data, and consequently, smoothness of operation, it can be concluded that the assembly that had the anodic hemisphere (assembly 1) ran more smoothly than the assembly that had the cathodic hemisphere (assembly 2) during this experiment.

Figure 4 also shows that a total segregation of the plotted values to one side of the zero center did not occur. The desegregation could be a result of the instantaneous mechanical differences between the slipring assemblies that occasionally overcame the polarity effect of the electrical current, although the contact resistance readings remained quite stable.

Hemisphere 1, Cathodic; Hemisphere 2, Anodic; Contact Current, 50 Amperes dc

The second 8-hour experiment was made with the polarity of hemisphere 1 negative in relation to its disk. The polarity reversal was accomplished by reversing the input-current leads on the vacuum feedthroughs. The slipring assemblies remained under vacuum and were undisturbed.

The actual values of the peak-to-peak coefficient of friction obtained from both assemblies during this experiment are shown in figure 5(a), and the differential graph developed from these data is shown in figure 6(a). The differential graph shows that the

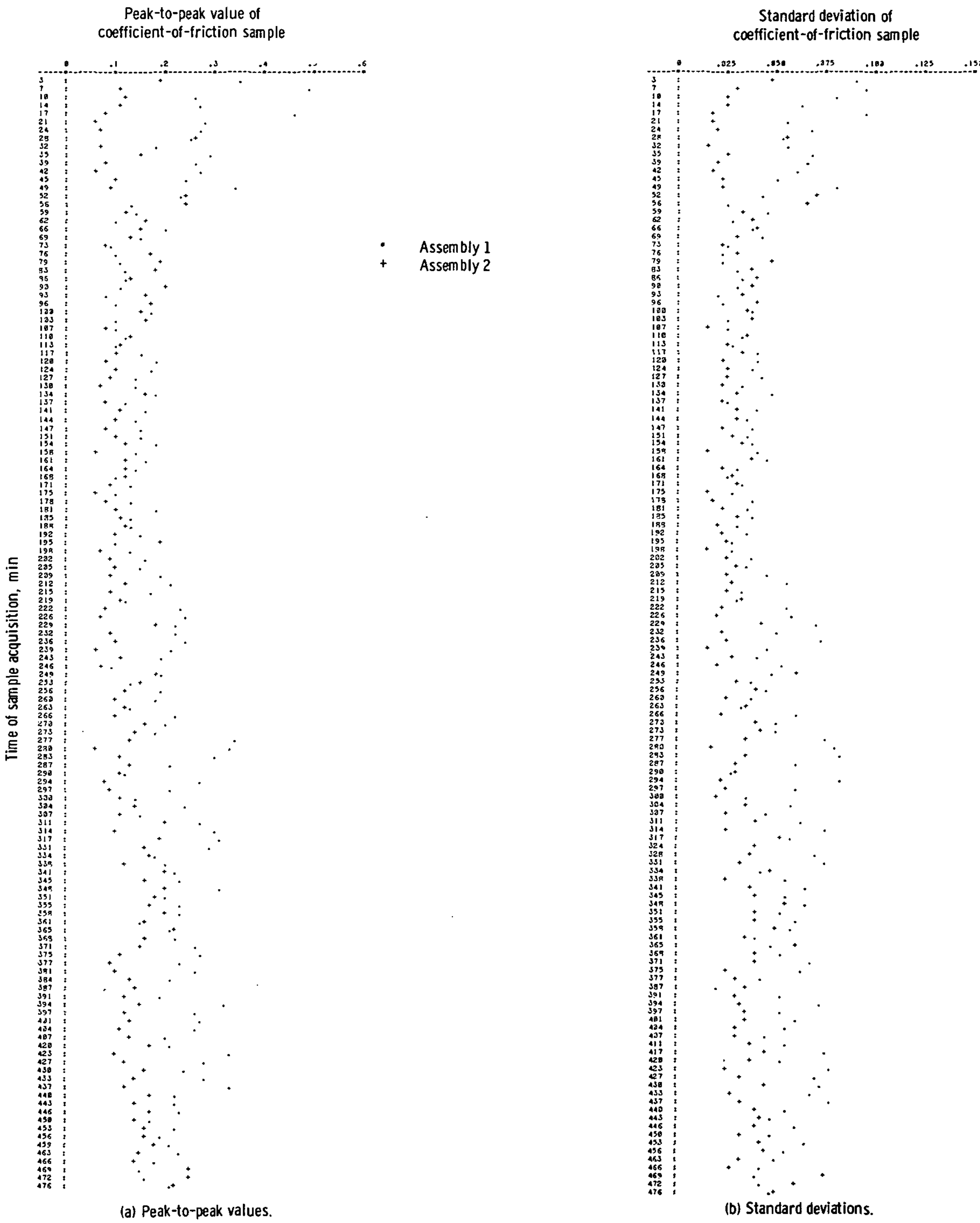
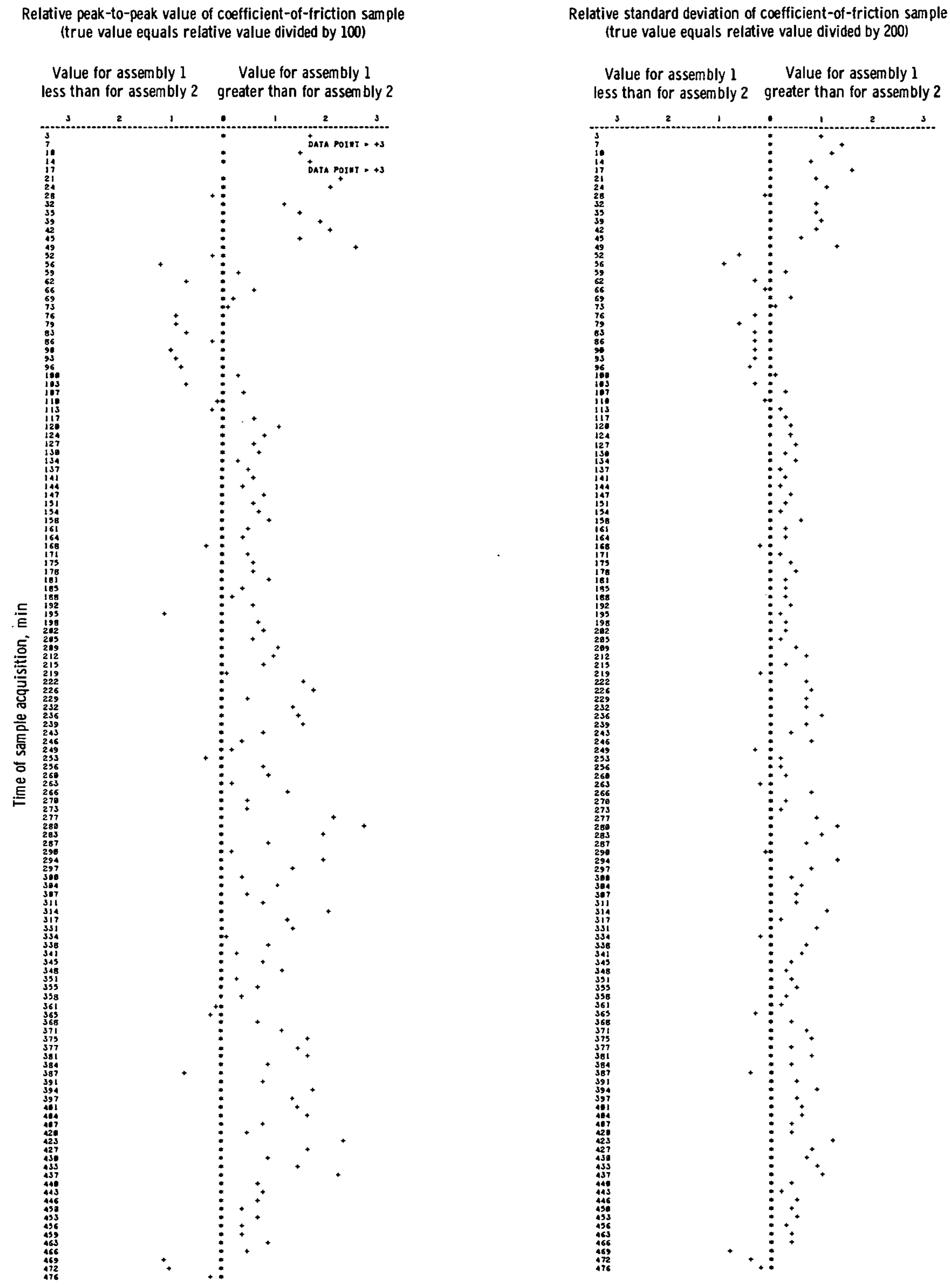


Figure 5. - Computer terminal plots of peak-to-peak values and standard deviations of coefficient-of-friction samples obtained from two slipring assemblies of opposite polarities. Hemisphere (brush) of assembly 1 cathodic relative to its disk (slipring); hemisphere of assembly 2 anodic relative to its disk; contact current, 50 amperes dc.



(a) Relative peak-to-peak values.

(b) Relative standard deviations.

Figure 6. - Computer terminal plots of relative peak-to-peak values and relative standard deviations of coefficient-of-friction samples obtained from two similar slipring assemblies of opposite polarities. Hemisphere (brush) of assembly 1 cathodic relative to its disk (slipring); hemisphere of assembly 2 anodic relative to its disk; contact current, 50 amperes dc.

greatest density of data points is on that side of the graph labeled "assembly 1 > assembly 2" which is equivalent to assembly 2 < assembly 1. The arithmetic mean of the peak-to-peak data from assembly 2 (0.1348, table I) was 34 percent lower than similar data from assembly 1 (0.2042).

The standard-deviation data from this experiment (fig. 5(b)) and the related differential graph (fig. 6(b)) show the same relation as the peak-to-peak data. The mean value of the standard deviation from assembly 2 (0.033, table I) was 34 percent lower than the mean value from assembly 1 (0.050).

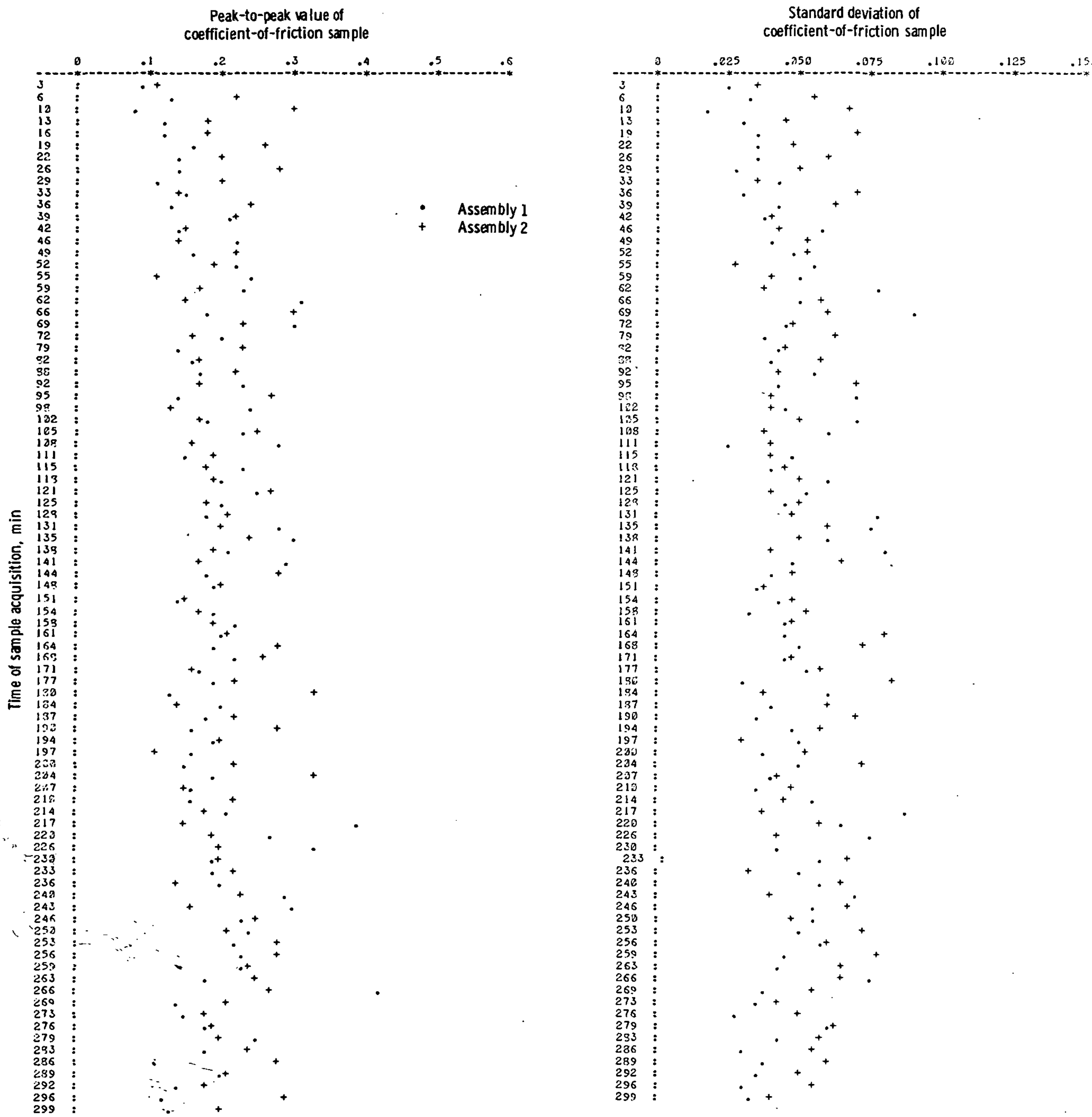
Again, the assembly with the anodic hemisphere (assembly 2 in this experiment) showed lower values of the peak-to-peak coefficients of friction and standard deviation.

Zero Contact Current

The data from the first two experiments show that the relative polarities of the slipring-assembly components do have an effect on the frictional behavior of a slipring assembly. In order to provide a basis for comparison of the data obtained in the first two experiments, and to further test the validity of the polarity effect, a third experiment was conducted with zero contact current. The same slipring assemblies used for the first two experiments were also used for the zero-current experiment. All other experimental parameters (except contact current) remained the same. The absence of an electrical current should negate any polarity effects, and the frictional behavior of the two slipring assemblies should be more nearly alike. In a currentless experiment, any differences in the frictional behavior should tend to be random (if contact area compositions are similar) and due to only the instantaneous differences in the contact area. This type of behavior would be manifested on a differential graph by a scattering of values on either side of the zero centerline.

The data from the currentless experiment were gathered and processed in the same manner as the data from the first two experiments. The actual peak-to-peak and standard-deviation data are shown in figure 7. The differential graphs are shown in figure 8. The differential graphs, as expected, show a scattering of data points on either side of the zero centerline. Although the number of data points is not evenly distributed (the percentages are shown in figures 9 and 10) on each side of the zero centerline, there is no strong segregation of values as there was in the differential graphs of the first two experiments.

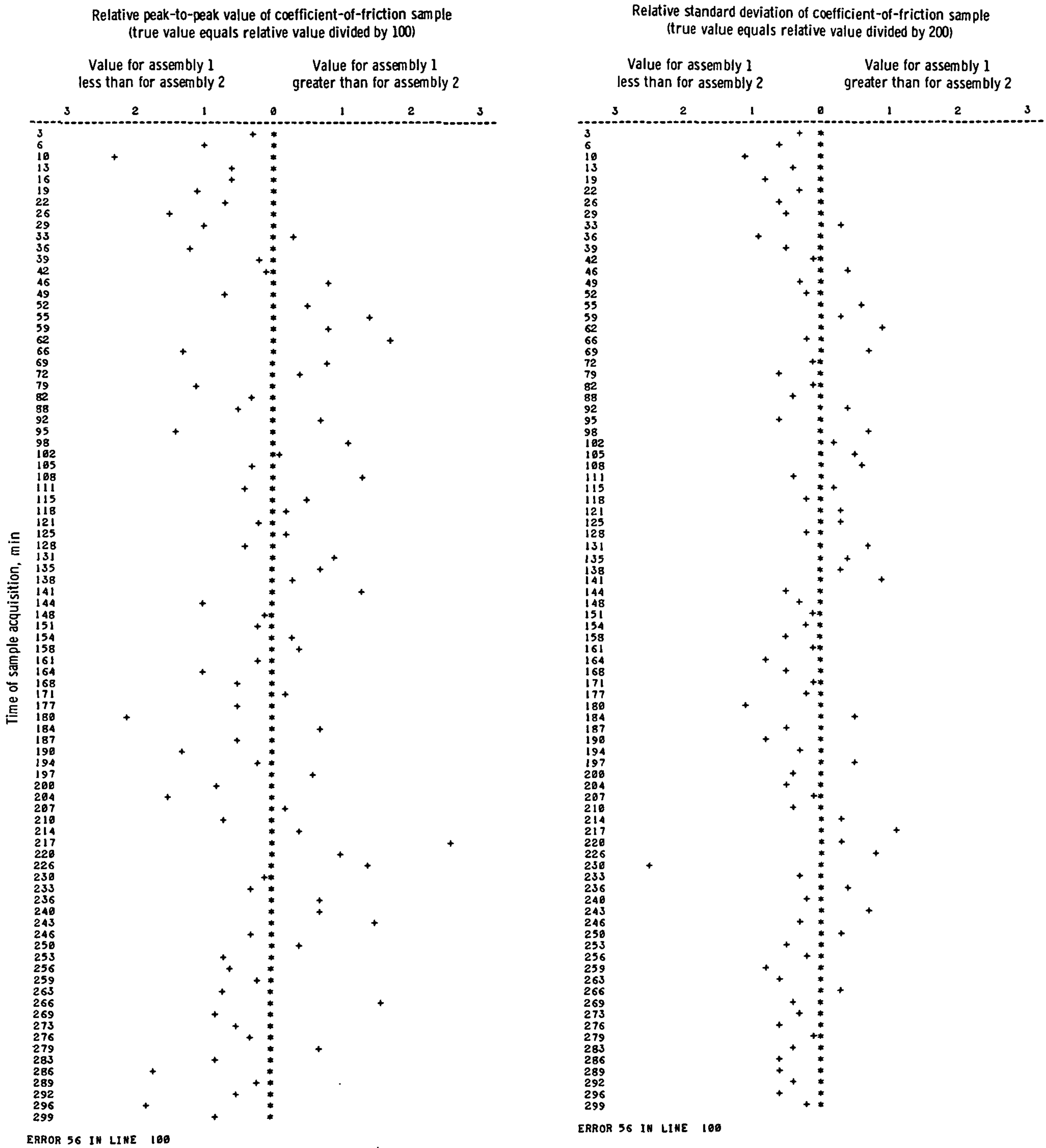
The actual percentages of values on each side of the zero centerline for both the peak-to-peak and standard deviations of the coefficient of friction do not indicate a true randomness. However, they do differ significantly from those calculated from the data of the first two experiments.



(a) Peak-to-peak values.

(b) Standard deviations.

Figure 7. - Computer terminal plots of peak-to-peak values and standard deviations of coefficient-of-friction samples obtained from two similar slipring assemblies with zero contact current.



(a) Relative peak-to-peak values.

(b) Relative standard deviations.

Figure 8. - Computer terminal plots of relative peak-to-peak values and relative standard deviations of coefficient-of-friction samples obtained from two similar slipring assemblies with zero contact current.

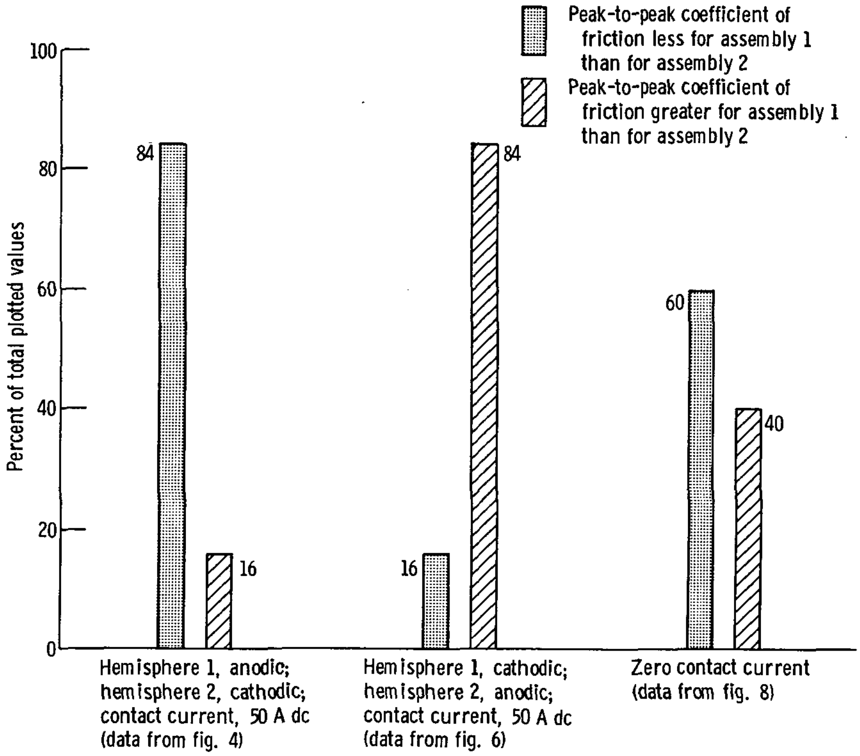


Figure 9. - Comparison of percentages of plotted values on each side of the zero centerline in the differential graphs (figs. 4, 6, and 8) of the peak-to-peak values of the coefficient-of-friction data samples.

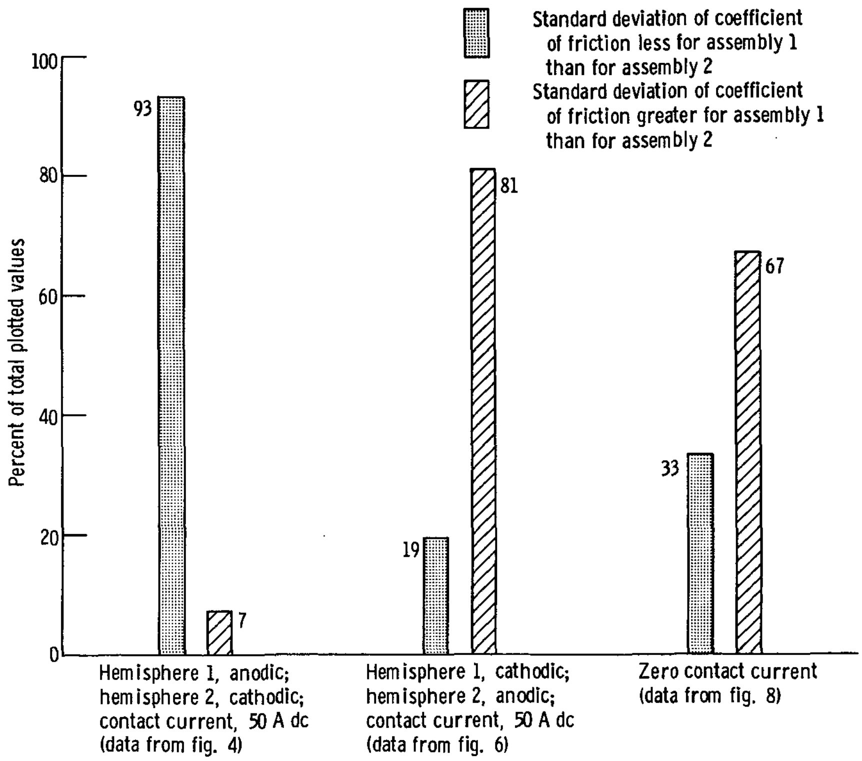


Figure 10. - Comparison of percentages of plotted values on each side of the zero centerline in the differential graphs (figs. 4, 6, and 8) of the standard-deviation values of the coefficient-of-friction data samples.

The arithmetic means for both the peak-to-peak and standard-deviation data show the least amount of difference between the assemblies among the experiments (table I). For the peak-to-peak data, the difference between the assemblies was only 0.01 (approximately 5 percent), and for the standard-deviation data, only 0.006 (approximately 12 percent).

Comparison of Results

The actual percentages of plotted values on each side of the zero centerline in figures 4, 6, and 8 are shown in figures 9 and 10.

Figure 9 shows that in the first experiment, 84 percent of the peak-to-peak values of the coefficient of friction from slipring assembly 1 (hemisphere anodic) were less than the peak-to-peak values of the coefficient of friction from assembly 2 (hemisphere cathodic). The standard-deviation values from the first experiment showed a similar segregation. Figure 10 shows that 93 percent of the standard deviations of the coefficient-of-friction data from assembly 1 were less than similar data from assembly 2. Thus, both types of data indicate that the assembly that had the anodic hemisphere ran smoother than the assembly that had the cathodic hemisphere.

For the second experiment, the polarities of the two slipring assemblies were reversed, which made hemisphere 1 cathodic and hemisphere 2 anodic in relation to their disks.

Figure 9 shows that in the second experiment, 84 percent of the peak-to-peak values from slipring assembly 2 (hemisphere anodic) were less than similar data from assembly 1 (hemisphere cathodic).

The standard deviations of the coefficient-of-friction data show a similar division of values on each side of the zero centerline. Figure 10 shows that 81 percent of the standard deviations from slipring assembly 2 were less than similar data from assembly 1. Once again, the assembly that had the anodic hemisphere ran smoother than the assembly that had the cathodic hemisphere.

A comparison of the differential graphs of figures 4 and 6 shows that the greatest density of plotted values shifted from one side of the zero centerline to the other as the polarities of the slipring assemblies were interchanged. The peak-to-peak data indicate that the assembly that had the anodic hemisphere (assembly 1 in the first experiment, assembly 2 in the second experiment) generally ran with lower peak-to-peak values of the coefficient of friction. Any conclusion based on the peak-to-peak data is necessarily weak because only two values of the coefficient of friction in a data sample were used to calculate the peak-to-peak value. However, the standard-deviation data, which utilize all of the data values in each sample, show the same general behavior as do the peak-to-peak data. Consequently, the polarity effect is well established on the basis of the standard-deviation data.

In an effort to define the character of the polarity effect, the arithmetic means calculated from the data obtained from the current-carrying experiments were compared with the arithmetic means calculated from the data obtained from the currentless experiment. The data are shown in table I.

The data in table I reveal two interesting facts: (1) a large decrease in arithmetic means occurred in all cases in which a slipring assembly had an anodic hemisphere; and (2) only small undirected differences in arithmetic means occurred in all cases in which a slipring assembly had a cathodic hemisphere.

These facts reveal that the polarity effect is limited to those cases in which the stationary component (hemisphere or brush) of the slipring assembly is anodic in relation to the rotating component (disk or slipring). The effect of an anodic hemisphere is one that results in a much smoother running slipring assembly, as evidenced by the approximately 38-percent reduction in the peak-to-peak coefficient-of-friction values and by the 25- to 35-percent reduction in the standard-deviation values in comparison with the values obtained with the same slipring assembly running currentless.

A cathodic hemisphere had little effect on the frictional behavior of the slipring assemblies. The data show only small differences in frictional behavior between a slipring assembly running with a cathodic hemisphere and the same assembly running currentless.

SUMMARY OF RESULTS

Three 8-hour experiments conducted with two similar gallium-lubricated slipring assemblies running in vacuum yielded the following results:

1. Peak-to-peak values of the coefficient of friction and standard deviations of coefficient-of-friction data samples (which reflect the smoothness of operation) show that a polarizing electrical current does have an effect on the frictional behavior of a slipring assembly.

2. A slipring assembly with an anodic hemisphere showed approximately a 38-percent decrease in the mean values of the peak-to-peak coefficient of friction and in the mean values of the standard deviations of the coefficient of friction when compared to similar mean values obtained from the same slipring assembly running currentless.

3. A slipring assembly with a cathodic hemisphere showed mean values of the peak-to-peak coefficient of friction and mean values of standard-deviations of coefficient of friction that differed little from similar mean values obtained from the same slipring assembly running currentless.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 10, 1972,
502-01.

APPENDIX - CALCULATIONS SHOWING THAT ZERO SHIFTS DO NOT INFLUENCE RESULTS

The addition of a dc zero shift (constant) to data used for calculating either a peak-to-peak value or a standard-deviation value of a sample of values does not affect the calculated values. This can be proven by the equations presented herein.

SYMBOLS

X_{p-p}	peak-to-peak value
X_h	highest reading obtained during sample period
X_l	lowest reading obtained during sample period
n	number of points obtained during sample period
s	standard deviation
X	value of a given data point
$\bar{X}$	mean value of a sample of data points
K	dc zero shift (assumed constant within a data sample)

PROOFS

The equation for peak-to-peak values is

$$X_{p-p} = X_h - X_l \tag{1}$$

Adding a dc zero shift (constant) to each data point yields

$$X_{p-p} = (X_h + K) - (X_l + K) \tag{2}$$

which reduces to

$$X_{p-p} = X_h - X_l \tag{3}$$

This equation is the same as equation (1).

The equation for standard-deviation values is

$$s = \left[\frac{\sum_{j=1}^{n} (X_j - \bar{X})^2}{(n - 1)}\right]^{0.5} \tag{4}$$

Adding a dc zero shift to each data point in a sample and to the sample mean yields

$$s = \frac{1}{(n - 1)^{0.5}} \left\{\sum_{j=1}^{n} [(X_j + K) - (\bar{X} + K)]^2\right\}^{0.5} \tag{5}$$

Expanding the equation gives

$$s = \frac{1}{(n - 1)^{0.5}} \left[(X_1 + K - \bar{X} - K)^2 + (X_2 + K - \bar{X} - K)^2 + \ldots . + (X_n + K - \bar{X} - K)^2\right]^{0.5} \tag{6}$$

Collecting the terms gives

$$s = \frac{1}{(n - 1)^{0.5}} \left[(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \ldots + (X_n - \bar{X})^2\right]^{0.5} \tag{7}$$

Using summation notation yields

$$s = \left[\frac{\sum_{j=1}^{n} (X_j - \bar{X})^2}{(n - 1)}\right]^{0.5} \tag{8}$$

This equation is the same as equation (4).

The following sample calculations, which use the same 20 arbitrarily chosen integer values for each computation, show that the peak-to-peak and standard-deviation values of the data obtained are not affected by any zero shift (dc value):

```
?0
D.C. VALUE IS  0     FOR THIS COMPUTATION

HI PK          LO PK          P-P          MEAN          STAN DEV

 10             1              9            5.65          2.49789


?.1
D.C. VALUE IS  .1          FOR THIS COMPUTATION

HI PK          LO PK          P-P          MEAN          STAN DEV

 10.1           1.1            9            5.75          2.49789


?10
D.C. VALUE IS  10    FOR THIS COMPUTATION

HI PK          LO PK          P-P          MEAN          STAN DEV

 20             11             9            15.65         2.49789


?100
D.C. VALUE IS  100   FOR THIS COMPUTATION

HI PK          LO PK          P-P          MEAN          STAN DEV

 110            101            9            105.65        2.49789


?1000
D.C. VALUE IS  1000     FOR THIS COMPUTATION

HI PK          LO PK          P-P          MEAN          STAN DEV

 1010           1001           9            1005.65       2.49789
```

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