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# INVESTIGATION OF THE PERFORMANCE OF TUNGSTEN-COBALT PLATED SLIP RINGS AND COMMUTATORS

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Miss E. F. Harmon of the Naval Research Laboratory furnished and analyzed data on the performance of various brushes on copper in the dummy commutator apparatus and assisted in performing the dummy commutator tests on the apparatus developed by her.

Dr. William Blum and Dr. Abner Brenner of the National Bureau of Standards prepared all of the tungsten-cobalt surfaces used in these experiments, using their new process for plating with this alloy.



## CONTENTS

Abstract	vi
Problem Status	vi
Authorization	vi
CONTENTS	
BACKGROUND	1
Film	1
High-Altitude Problem	1
Substitute for Copper	2
Tungsten	3
Tungsten-Cobalt Alloy	3
EXPERIMENTAL	3
Types of Investigations	3
Slip-Ring Apparatus	4
Slip-Ring Tests	4
Dummy Commutator Apparatus	6
Dummy Commutator Tests	6
Aircraft Generator Apparatus and Tests	8
CONCLUSIONS	10

### ABSTRACT

An electroplated alloy of tungsten and cobalt on copper has been given limited tests under sea level and simulated high-altitude conditions. The first series of tests, made with a slip ring and a dummy commutator under conditions of low temperature, humidity, and pressure, gave results which were favorable when compared to results on copper. Further tests of an actual aircraft generator at sea level have given unsatisfactory results to date. Mechanical difficulties may have contributed to this poor operation.

### PROBLEM STATUS

This is a second interim report.

### AUTHORIZATION

The problem on high-altitude carbon-brush wear was established at the request of the Aircraft Electrical Division of the Naval Research Laboratory and funds were allocated July 26, 1945 (Problem NRL-E3, later changed to 33E02-20).

## INVESTIGATION OF THE PERFORMANCE OF TUNGSTEN-COBALT PLATED SLIP RINGS AND COMMUTATORS

### BACKGROUND

#### Film

It has long been recognized<sup>1</sup> that the type of film on the commutator of an electrical machine greatly affects the operation of the brushes. Analyses of the normal film found on a copper commutator have shown<sup>2</sup> it to consist of copper oxides, carbon, various residues, and, under normal operating conditions, a certain amount of adsorbed water. It is fairly well agreed that the nature of the film is complex, but the exact role and the relative importance of each of the various components remain controversial topics.<sup>2,3,4</sup> Separating the influences of the water vapor and the oxide and carbon components of the film is difficult. Absolute humidity can be reduced by chemical drying and refrigeration, and many investigations have shown that it is possible in the laboratory to reduce the water-vapor concentration to such values that further reductions seem to have no effect. Elimination of the oxide film is more difficult<sup>5,6</sup> and is rarely obtained except by vigorous treatments which leave the surface in poor mechanical condition. A carbon-free surface can probably be obtained by cleaning with great care, but has been shown<sup>2</sup> that the single passage of a graphite brush lays down an invisible film of carbon on a metallic surface. Thus, a technique for isolating the effects of the various contributors to brush performance is virtually impossible of achievement.

#### High-Altitude Problem

The combination of copper commutator and carbon brushes has been found not to operate satisfactorily in aircraft flying at high altitudes. Many types of treatments of the brushes

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<sup>1</sup> Baker, R. M., "Sliding Contacts - Electrical Characteristics," Elec. Eng. 55, 94 (1936).

<sup>2</sup> Van Brunt, C., and Savage, R. H., "Carbon Brush Contact Films: Part I," Gen. Elec. Rev. 47, 16 (July 1944).

<sup>3</sup> Savage, R. H., "Carbon Brush Contact Films," Gen. Elec. Rev. 48, 13 (Oct. 1945).

<sup>4</sup> Elsey, H. M., "Treatment of High-Altitude Brushes by Application of Metallic Halides," Elec. Eng. 64, 576 (1945).

<sup>5</sup> Pilling, N. B., and Bedworth, R. E., "The Oxidation of Metals at High Temperatures," Am. Inst. of Met. Advance Paper No. 17 (1923).

<sup>6</sup> Lustman, B., "Dissociation Pressures of Metal Oxides Formed on Various Solid Metals," Abstract of Paper in Iron Age 158, 61 (Sept. 26, 1946).

have been tried in the attempt to get longer life out of the carbon brushes, but these treatments are only partially satisfactory. The problem of finding a substitute for carbon has been considered, but here the outlook does not seem promising.

Many investigators have tried materials other than copper for commutators and slip rings. Brass, iron, bronze, steel, and silver are commonly used. Published results of such tests, however, are scanty, and one is left with the impression that some of the trials may not have been fully exploited.

### Substitute for Copper

In order to make a choice of a metal to take the place of copper, its chemical, mechanical, physical, and electrical properties and their relation to the sliding contact environment must be considered. Chemically, the metal may combine with the constituents of the atmosphere, principally with oxygen, and with the brush materials to form on the metal a film which where it covers the metal, is the sliding contact surface. Water vapor and contaminants in the atmosphere, electric current, and arcing may have important effects on these chemical processes. The differences in behavior of positive and negative brushes, for example "copper picking," indicate that a sort of electrolysis<sup>7</sup> takes place at the surface. Any adsorbed film of gases or vapors on the surface is almost certain to affect the wear rate of a brush and its ability to handle current,<sup>8</sup> although it is believed by some not to be an essential<sup>9</sup> to good performance. Obviously, surface geometry can affect the rate of wear of a brush. Plasticity of the metal will determine its ability to smooth out any unevenness which might, for example be due to electrolytic action. Electrical conductivity of a metal must be considered, but the bulk conductivity of the metal may be of secondary importance when compared to the conductivity and thickness of its surface layers, particularly in those cases where insulating films are formed.<sup>10</sup> In the case of copper such a film can easily be broken down either mechanically or electrically. Film breakdown on some other metals like chromium<sup>11</sup> requires higher voltages, and may be accompanied by excessive sparking and roughening of the surface. It has been suggested that the mutual solubility of the two contact materials effects their tendency to seize and gall each other when in frictional contact. Studies in friction have, in general, indicated that a nonabrasive film on the surface of a metal serves to reduce "dry" friction by separation of the surfaces, thus lessening the interlocking of the irregularities of the base material and reducing the attractive surface forces.

After a consideration of the above factors, it is possible to specify some of the characteristics of a metal which it is believed, would make it suitable for the surface of a commutator or slip ring to be used at high altitude. There should be a continuous film over the surface under the adverse conditions of low oxygen and water vapor concentrations. This film should be maintained by rapid reformation rather than by mechanical strength

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<sup>7</sup> Hunter-Brown, P., "Carbon Brushes and Electrical Machines," London, The Morgan Crucible Co., Ltd., 1939, Second Edition, p. 129.

<sup>8</sup> Cf. Footnotes 1 and 2.

<sup>9</sup> Cf. Footnote 4.

<sup>10</sup> Hessler, V. P., "Probe Studies of Collector-Ring Films," Gen. Elec. Rev. 40, 358 (Aug. 1937).

<sup>11</sup> Neukirchen, J., "Carbon Brushes," St. Marys, Pa. Stackpole Carbon Company, 1937, p. 55 (Trans. from the German by E. I. Schobert).

alone. In fact, it would be desirable to have this film flow plastically, thus giving a sort of lubrication to the surface. (Obviously any abrasive film is to be avoided.) The film may consist of various adsorbed layers, oxides, carbon, and traces of other substances. A metal is needed which can provide a nonabrasive combination of these films, give satisfactory frictional properties, and still not seriously affect the voltage drop at the surface.

### Tungsten

In the literature is much information on the surface properties of many of the common metals, but very little can be directly applied to the sliding electrical-contact problem. Two of the reasons for this are: the important mechanical characteristics of these films are not well known; and, although the temperature characteristics of a film may have been determined, we can make only a crude estimate of the maximum temperature at which the metal may operate. The literature on the surface properties of tungsten at high temperatures is abundant because of the wide use of tungsten as a filament material. There has been great interest in the effect of oxygen on a tungsten surface at high temperatures. Morrison and Roberts<sup>12</sup> showed that the adsorbed film of oxygen on tungsten is stable at temperatures as high as 1100° K. Bowden and Hughes<sup>13</sup> found that, when a slight trace of oxygen was admitted to their vacuum chamber, the friction of nickel sliding on tungsten decreased by a factor of 4 to 1, a much greater reduction in friction than was observed on any of the other pairs of metals they used. Tungsten has an oxide dissociation pressure<sup>14</sup> which is lower than that for copper, nickel, cobalt, iron, or molybdenum, but higher than that for zinc or chromium. Thus, from several standpoints, it would seem that tungsten has a better than average chance of maintaining a covering film at high temperatures and low oxygen concentrations. This film, whether it be an oxide or an adsorbed layer, would reduce attractive surface forces and might be of practical value in reducing friction and wear. These are the reasons for the interest in tungsten as a surface material for slip rings and commutators.

### Tungsten-Cobalt Alloy

It was realized that there would be many difficulties in producing whole commutators or slip rings from tungsten; so interest turned to electroplating. Thus far it has not been possible to electroplate with pure tungsten, but a process has been developed by Dr. Abner Brenner of the National Bureau of Standards for a plating with an alloy of 80 percent cobalt and 20 percent tungsten, and this alloy was chosen for the tests described in this report.

## EXPERIMENTAL

### Types of Investigations

The first investigations of the tungsten-cobalt plating were made on slip rings which could be operated in room atmosphere or at simulated high altitude in a cold chamber.

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<sup>12</sup> Morrison, J. L., and Roberts, J. K., "A New Method for Studying the Adsorption of Gases at Very Low Pressures and the Properties of Adsorbed Films of Oxygen on Tungsten," Proc. Roy. Soc. 173, 1 (1939).

<sup>13</sup> Bowden, F. P., "The Friction of Clean Metals and the Influence of Adsorbed Gases. The Temperature Coefficient of Friction," Proc. Roy. Soc. 172, 263 (1939).

<sup>14</sup> Cf. Footnote 6.

The encouraging results obtained led to further work on a dummy commutator which could be operated at room temperature in an atmosphere of low pressure and low dew point. Under a set of conditions which would produce rapid wear on copper there was negligible wear on the alloy, although extremely high currents did produce rapid wear. In the last series of experiments a standard Aircraft Generator Type N75-2SB Eclipse Pioneer, Type 1273 was used. During these runs, rapid wear occurred with electric current and, on one occasion, with no current.

#### Slip-Ring Apparatus

For the slip-ring experiments, copper slip rings three inches in diameter were mounted on both ends of a 1/8-horsepower induction motor. One slip ring was plated with the tungsten-cobalt alloy and the other was left unplated. On each ring were two brushes 5/8 inch wide and 9/32 inch thick, with an initial length of 1-1/4 inches. Changes in brush pressure with wear were too small to measure with the spring balance used for brush-pressure measurements. The test rings were insulated from the motor shaft by a bakelite sleeve. This turned out to be a source of trouble, since the high expansion coefficient of bakelite caused cracking of the bakelite and eccentricity of the ring surface. The circuit was arranged so that the same current flowed through both sets of brushes. The total voltage drop across both positive and negative brushes was recorded for each of the rings. Temperatures near the face of each of the four brushes, and in two places in the chamber, were recorded.

#### Slip-Ring Tests

Sea-level tests showed that the voltage drop on the W-Co (tungsten-cobalt) alloy using a copper-graphite brush, Morganite CM-5H, was as much as twice that for the same grade on the copper ring. Average values for these voltages at sea level are shown in the left two columns of Table I.

TABLE I  
Voltage Drop on Tungsten-Cobalt and Copper-Surfaced  
Slip Rings, Copper Graphite Grade CM5H

Test No.	Total Voltages* from + to - Brush			
	<u>Sea Level</u> (freshly sanded surfaces)		<u>Simulated High Altitude</u> (with some film)	
	Copper	W-Co	Copper	W-Co
1. Brush Pressure 5 lbs/in <sup>2</sup> Speed 1370 ft/min	.30	.75	.46	.73
2. Brush Pressure 8.5 lbs/in <sup>2</sup> Speed (avg) 2500 ft/min	.27	.65	.45	.68
3. Brush Pressure 4.25 lbs/in <sup>2</sup> Speed (avg) 2500 ft/min	.55	.79	.70	.90

\*Voltage at sea level is averaged over first hour after sanding. Voltage at simulated high altitude is averaged over first 15 minutes of operation in chamber, the short time being due to dusting of brushes on copper rings.

The first simulated high altitude test was made at pressures in the range 5 to 6 cm Hg, at a speed of 1370 ft/min and at an initial ambient temperature of  $-57^{\circ}$  C. Previous tests in the same chamber had shown that the dew point in the chamber was within about  $1^{\circ}$  C of the ambient temperature. The current density at the beginning of the test was 114 amp/in<sup>2</sup>, later raised to 228 amp/in<sup>2</sup>. The film which had been formed by five hours of operation with current at sea level was left on both rings since the primary interest was in observing the effects of reduced temperature and pressure on a somewhat normal film. At the start of the "high-altitude" test there was an appreciable light brown film on the copper ring but no visible film on the W-Co. Operation at sea level had burnished the surface of the W-Co to a mirror polish. The W-Co ring had an eccentricity of .002 inch plus a gap 1/2 inch wide in the direction of rotation and .0015 inch deep, across which the brushes jumped each revolution. The overall eccentricity of the ring prevented machining out this gap. The copper ring had a simple eccentricity of .001 inch.

Both the copper and the W-Co rings operated satisfactorily for an hour and forty minutes with a current density of 114 amp/in<sup>2</sup>. Then the current was doubled. Within 40 minutes the brushes on the copper ring began to dust and wear rapidly. The same type of brush on the W-Co ring continued operating satisfactorily for an additional hour with only small changes in voltage drop. Dust collectors had been placed in such a position that any dust coming off the brushes would strike a white card. At the end of the test the cards for the copper ring were covered with black dust, while there was no dust whatsoever on the cards for the W-Co ring.

It was next decided to give the plating a more accelerated test; so the speed was increased from 1370 to 2500 ft/min and brush pressure was changed from 5 to 8.5 lbs/in<sup>2</sup>. The combined increase in speed and pressure gave a voltage drop at sea level very nearly the same as before. Operation under simulated high-altitude conditions ( $-55^{\circ}$  C and air pressure of 5 to 6 cm Hg) with a current density of 228 amperes per square inch, caused dusting on the copper ring within 15 minutes. The W-Co ring operated satisfactorily for two hours with a very small amount of wear which was believed to be due primarily to the very uneven surface, i.e., the gap 1/2 inch wide and .0015 inch deep.

It was decided that an attempt to machine the surface of the plated ring was worth the risk of grinding through the plating. The result was an elliptical surface with two minima .0018 inch and .001 inch below the highest point. The bakelite insulating sleeves on both rings had given considerable trouble with alternate expansion and contraction and it was found necessary to fasten the outer ring and hub to the bakelite with sheet metal screws. The copper ring had a simple eccentricity of .002 inch which is a slightly greater maximum deviation than on the plated ring. There were, however, two dips on the W-Co; hence the maximum angle of inclination and maximum brush acceleration were still considerably larger on the W-Co than on the copper ring.

The third sea-level test lasted four hours. The observed voltage across the brushes on the W-Co ring was approximately 50 percent higher than the voltage across the same brush grade on the copper ring.

The third and last simulated high-altitude test produced rapid dusting-wear on the copper ring in 25 minutes and satisfactory operation on the W-Co for 6 hours under the following conditions: speed 2450 to 2650 ft/min (except for 1/2 hour at half speed because of power difficulties); current density of 185 to 200 amp/in<sup>2</sup>; air pressures of 5 to 6 cm Hg; and ambient temperatures of  $-57^{\circ}$  C up to  $-46^{\circ}$  C. Each brush on the W-Co surface wore .002 inch in 6 hours, which is equivalent to 1/4-inch wear in 750 hours. Voltage drops on W-Co and copper surfaces at simulated high altitude are compared in the right hand columns of Table I.

A few observations were made with the slip ring motor apparatus under variable ambient conditions to see what rapid changes in operating characteristics might accompany such changes in environment. Unfortunately it is difficult to observe the same quantitative variations twice in succession. One appropriate procedure would be to adapt a regularly repeated cycle with a piece of apparatus and to repeat that cycle a large number of times so that the effects of previous operation are obscured. Such a procedure was not used in the tests about to be described; hence these tests are only an indication of trends.

After three hours operation in room atmosphere, the air pressure was reduced to 2 cm Hg, and both rings were subjected to sudden drying of the air in the chamber. This was accomplished by operating the refrigerant-circulating pump and the ventilating fan for a few minutes, precipitating enough moisture out of the air in the chamber to cover the coils with frost. The dew point obtained in the chamber was not known, but the refrigerant temperature in the copper cooling coils was below  $-65^{\circ}\text{C}$  and circulation of air in the chamber was rapid. As shown in Figure 1, the copper surface was much more sensitive to these rapid changes in humidity than was the W-Co surface. This seems to indicate a greater stability of the tungsten-cobalt film under conditions of low humidity.

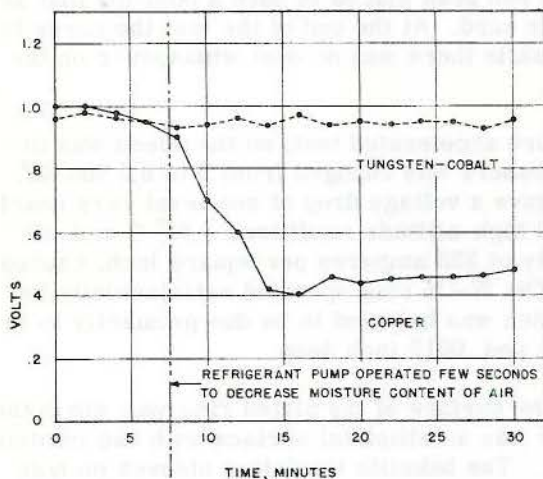


Fig. 1 - Voltage Drop Across Slip Rings; Effect of Drying Air. Air Pressure 2 cm Hg; Brush Pressure 4.25 lbs/in<sup>2</sup>, Current Density 228 amp/in<sup>2</sup>; Speed 1370 ft/min

### Dummy Commutator Apparatus

The second series of measurements were made on a conventional commutator, the bars of which had been shorted together, and which had been plated with the tungsten-cobalt alloy. The chamber in which this "dummy" commutator operated was covered with a plexiglas bell jar. By circulating dry air, the dew point could be lowered to values below  $-50^{\circ}\text{C}$ . Peripheral speeds of 2100 and 3400 ft/min and current densities of 114 to 285 amp/in<sup>2</sup> were used. Brushes were set at a  $15^{\circ}$  trailing angle. This apparatus is fully described elsewhere.<sup>15</sup>

### Dummy Commutator Tests

Under conditions which had been found by others to produce dusting on copper commutators, there was no rapid wear on the W-Co dummy commutator. As a check against

<sup>15</sup> Harmon, E. F., "Sliding Contacts at High Altitudes--Experimental System for Carbon Brush Investigations," NRL Report No. E-3176.

trends in the apparatus, the W-Co experiments were interspersed with similar ones on a copper dummy commutator in order to insure that "dusting" conditions were being produced in the chamber.

Two runs were made with Morganite HM-6, a natural graphite grade, with no dusting of the brushes on the W-Co. Previous work using this same apparatus had indicated that the HM-6 was one of the brush grades most difficult (among the untreated brushes) to get to dust. For this reason it was decided to use Morganite grade CM-6, which contains a sensible amount of metal, in the next W-Co test and thereby encourage rapid wear.

Initial speed in the third test was 2100 ft/min, current density was 200 amp/in<sup>2</sup>, air pressure was 6 cm Hg, and dew point was -55° C. After three hours of satisfactory operation the speed was increased to 3400 ft/min, and good operation continued for another hour. Previous tests with the same apparatus under the same conditions, but with a copper surface, had produced dusting in less than one hour at the lower speed. It was then decided to accelerate the test by increasing the current density to 285 amp/in<sup>2</sup>, and within 18 minutes after the current had been raised to this high value rapid wear of both the anodic and cathodic brushes<sup>16</sup> did begin and continued even though the current was reduced within 15 minutes to 200 amp/in<sup>2</sup> and reduced again one hour and ten minutes later to 114 amp/in<sup>2</sup>. The brush temperature as measured at approximately 1/8 inch from the face of the brush was 140° C when the rapid wear started.

The electrolytic action of the high current used had deposited a copper-colored film on the commutator under the anodic brush, and the face of this brush was shiny black, indicating that there had been removal of copper from its face. The face of the cathodic brush, on the other hand, had retained its original copper color and there was no visible copper color in the film on the commutator under the cathodic brush. The anodic brush wear rate was slightly more than twice that of the cathodic brush.

The last test of the dummy commutator was made using Morganite EG3, an electro-graphitic grade. Operation was satisfactory for the first hour at a speed of 2100 ft/min and a current of 114 amp/in<sup>2</sup> the first half hour and 200 amp/in<sup>2</sup> the second half hour. When the current was further increased (at the end of the first hour) to 285 amp/in<sup>2</sup>, rapid wear started. The temperature of the commutator at about the time rapid wear started was over 200° C, high enough to melt some ordinary solder which had been used to hold a thermocouple in the commutator.

In none of these W-Co dummy-commutator tests was there rapid wear under the set of conditions known to produce rapid wear of the same grades of brushes on a copper surface. The rapid wear occurred only at current densities two and one half times as great as that used on copper.

The voltage drops obtained in the W-Co tests are compared in Table II with those for the same grades of brushes on a copper surface. Again, as in the slip-ring tests, the voltages from positive to negative brush on the W-Co surface were higher than for the same grades of brushes on copper. This higher voltage contributed to higher brush temperatures for two of the grades. Comparative brush temperatures for the dummy commutator tests are given in Figure 2.

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<sup>16</sup> Anodic and cathodic, as used in this report, refer to brushes which are positive and negative respectively, with respect to the slip ring, or commutator surface on which they ride. Thus the positive brush of a motor is anodic and the positive brush of a generator is cathodic.

TABLE II

Voltage Drops Using Dummy Commutator  
In Dry Air at Low Pressure<sup>17</sup>

(Voltages averaged over first 30 minutes of test or until dusting started)

Air Pressure: 6 to 10 cm Hg  
 Brush Pressure: 3.5 lb/in.<sup>2</sup>  
 Current Density: 114 amp/in.<sup>2</sup>  
 Speed: 2100 ft/min.  
 Surfaces Freshly Sanded

Brush Material	SURFACE MATERIAL	
	Copper (Volts)	Tungsten-Cobalt (Volts)
Natural Graphite (HM-6)		
+ Brush (Anodic)	.34*	.91
- Brush (Cathodic)	<u>.55*</u>	<u>1.02</u>
Total Drop	.89*	1.93
Copper Graphite (CM-6)		
+ Brush (Anodic)	.22 ‡	.49
- Brush (Cathodic)	<u>.10 ‡</u>	<u>.33</u>
Total Drop	.32 ‡	.82
Electrographitic (EG-3)		
+ Brush (Anodic)	.86 ‡	.45
- Brush (Cathodic)	<u>.60 ‡</u>	<u>1.08</u>
Total Drop	1.46 ‡	1.53

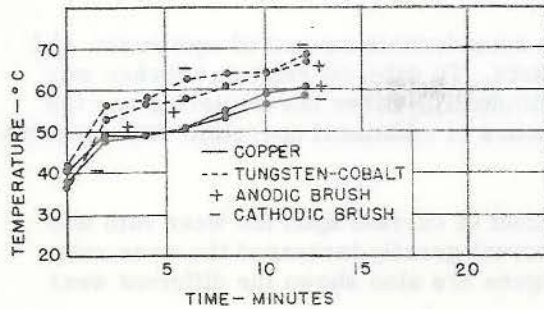
\* Dusted in 12 minutes on copper

‡ Dusted in 25 minutes on copper

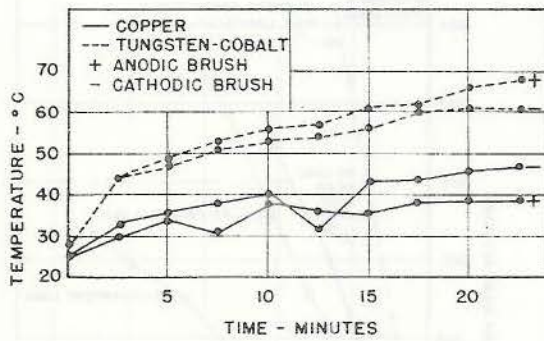
## Aircraft Generator Apparatus and Experiments

The final and most lengthy series of experiments with the tungsten-cobalt plating were made on a standard aircraft generator Type N75-2SB (Eclipse Pioneer Type 1273), a four-pole, 75-ampere machine with four radial brush holders 3/8 inch by 5/8 inch. Full load current density in this machine is approximately 165 amperes per square inch. The commutator of this machine is 2-27/32 inches in diameter and was turned at 5500 rev/min.

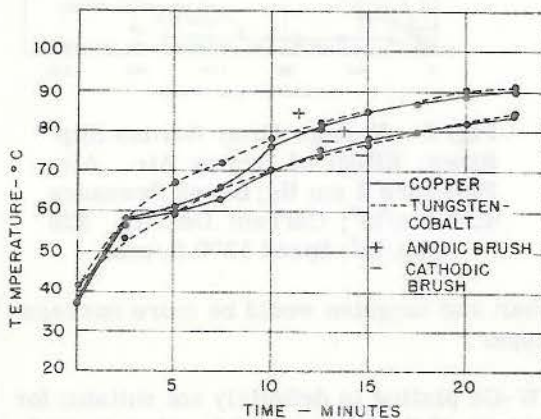
<sup>17</sup> Unpublished data for copper furnished by E. F. Harmon, Naval Research Laboratory, 1947.



(a) Natural graphite, HM 6



(b) Copper graphite, CM 6



(c) Electrographitic, EG3

Fig. 2 - Comparative Brush Temperatures on Dummy Commutators with Freshly Sanded Tungsten-Cobalt and Copper Surfaces. Air Pressure 6 to 10 cm Hg; Brush Pressure 3.5 lb/in<sup>2</sup>; Current Density 114 amp/in<sup>2</sup>; Speed 2100 ft/min.

The linear speed was 4100 feet per minute which was 20 percent higher than in any of the previous tests. All measurements were made under sea-level atmospheric conditions. Initial eccentricity of the commutator was approximately 0.0002 inch.

In the first 100 hours of operation no current was used and the greatest amount of wear of any brush was .005 inch--which is satisfactory. When lightly loaded with 20 amperes of current there was very rapid dusting wear of the original equipment brushes, a high-altitude-treated electrographitic type, Stackpole LHH. The average wear rate of the two cathodic brushes in the first test was over twelve times that of the anodic brushes even though all four were operating on the same track. Here the most rapid wear occurred on the brush which was cathodic with respect to the commutator. The order here is just the reverse of the observed with the copper graphite brushes operating on the dummy commutator. Since this rapid wear continued even after the current was reduced to zero, it was decided to smooth the surface by polishing at high speed in a lathe with fine aluminum oxide cloth and 4/0 sandpaper.

After smoothing the commutator, the machine was put in operation without current with several different types of brushes, one natural graphite and two electrographitic grades. In each case there was severe chattering which chipped the edges of the brushes and broke off some of the current leads. An attempt was made to reduce chattering by cutting down clearance in the brush holders but the chattering and rapid wear continued. No measurements of commutator unevenness were made at this point.

Finally, the original brushes were re-installed in the generator and operated satisfactorily without current for 88 hours; then the chattering started again. This continued, along with rapid wear, for some 80 hours and then suddenly stopped while the machine was operating. For the next 162 hours of operation without current, wear was low and there was no noticeable chattering. The reasons for the above mentioned changes are not understood. No effort was made to change the operating conditions of the test. The laboratory room

in which the tests were made is large, contains a considerable amount of equipment, and there are many conceivable sources of contaminants. To date, no relation between any contaminants and the test results have been established. Neither the chattering nor the rapid wear without current has recurred in 634 hours of additional operation with currents ranging from 0 to 75 amperes.

After the 162 hours of quiet operation, the effect of current upon the wear rate was examined; and it was found that an increase in current greatly increased the wear rate. This effect is shown in Figure 3. In this same figure are also shown the different wear rates with and without chattering, with no intentional changes in the operation conditions. Only the average wear for the four brushes is shown because in this series of tests there is small dispersion about the mean. For comparison, the dotted curve shows the maximum permissible amount of wear of brushes operating under full load on a copper commutator at sea level. This shows that the actual full load wear rate was one hundred times the maximum rate expected from brushes operating satisfactorily on a copper surface.

#### CONCLUSIONS

The tests discussed in this report indicate that there are noteworthy differences between the tungsten-cobalt surface and a copper surface in sliding electrical contact applications. The comparison is sometimes favorable and sometimes not, but the differences are great enough to indicate the need for further work.

The W-Co alloy operated satisfactorily as a slip-ring surface under conditions of low air pressure and very low water-vapor concentration. Under the same conditions copper surfaces gave rapid wear. These results are in agreement with the theory that the oxide film is important in preventing rapid wear and that the oxides of cobalt and tungsten would be more successful in this function than the less stable oxide of copper.

The generator tests were inconclusive. The W-Co plating is definitely not suitable for the particular machine used in these tests and, because of the tendency of brushes to chatter, may not be suitable for any machine having radial brushes. This type of surface may not be suitable for any commutating machine, but this can be determined only by further investigation using machines with different types of brush holders.

These experiments illustrate the often-encountered differences between the operation of brushes on slip rings in an experimental set-up and operation on a commutating machine. These differences emphasize the need for further understanding of the mechanism involved in sliding electrical contacts.

It is believed that further studies of this material and other materials with properties quite different from copper would be helpful to a more general understanding of sliding contacts and might lead to commutator materials which would reduce rapid brush wear at high altitudes.

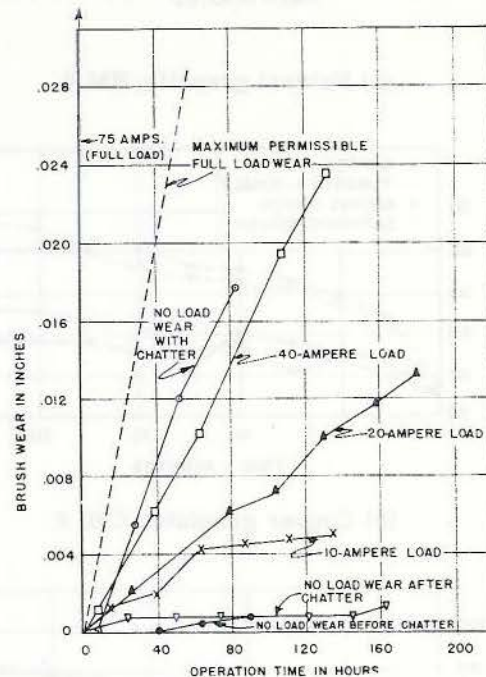


Fig. 3 - Voltage Drop Across Slip Rings; Effect of Drying Air. Air Pressure 2 cm Hg; Brush Pressure 4.25 lbs/in<sup>2</sup>; Current Density 228 amp/in<sup>2</sup>; Speed 1370 ft/min