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EVALUATION OF DIRECT CURRENT MOTORS IN VACUUM

By K. E. Demorest, and A. F. Whitaker
Propulsion and Vehicle Engineering Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

Special materials were selected for use on 1/6 horsepower motors which were tested in a simulated space environment. These materials were employed as the bearing retainers, brushes, and in the insulation system. Temperatures of the components were monitored as well as the power out and the torque required by the motor to turn the generator.

In general, it was concluded that motor materials are now available which will allow d.c. motors open to the space environment to operate reliably.

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PROPULSION & VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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EVALUATION OF DIRECT CURRENT MOTORS IN VACUUM

SUMMARY

Two 1/6 horsepower shunt wound, direct current motors were tested at 600 r.p.m. in a motor generator set at 70°F and 300°F ambient temperatures and at a pressure of 1×10^{-6} mm of Hg. Special materials employed in these motors included self-lubricating ball bearing retainers of polyimide-copper, polyimide-silver, and Rulon A, brush materials of molybdenum disulfide-silver, niobium diselenide, tantalum disulfide-graphite-niobium diselenide, niobium diselenide-molybdenum disulfide, and molybdenum disulfide-tantalum, and insulation system of polyimide enamel and H-Film. It was concluded that the materials used in the last reported tests were satisfactory, but that additional testing needs to be done at a wide range of speeds and torques.

INTRODUCTION

A primary concern in the development of space or lunar based equipment is to find the most reliable, least complex solution to the problem of conversion from electrical to mechanical energy. Batteries, solar cells, fuel cells, and other power generating devices being used, or considered, produce direct current. The use of direct current motors rather than alternating current motors precludes the use of inverters to produce the alternating current required for alternating current induction motors. Direct current motors offer the advantages of a lower speed and a higher torque with high loads. These features make them desirable for use in moon based equipment such as surface traction vehicles and lifting devices, or in spacecraft for deployment of booms or wings. Applications involving pumping drives for circulating fluids in space vehicles are being developed, currently.

The components of these motors must function under the extreme temperatures, low pressure and radiation of the space environment, and in the dust of the lunar surface. As a result of these requirements, a program has been initiated to evaluate direct current motors over a range of temperatures in a vacuum environment. Critical parts of the motors under these environmental conditions are bearings, brushes, and insulation. Lubrication of motor bearings presents a problem that requires considerable attention because even the most stable oils and greases volatilize in the vacuum and high temperature environment of space. The evaporation of liquid lubricants causes a further, interrelated problem with other materials because it increases the environmental pressure to the region of easy ionization (10^{-3} mm Hg to 10^{+2} mm Hg) and allows arcing of electrical contacts and corona attack on dielectric surfaces. Additionally, evaporated liquid lubricants often recondense on cooler surfaces, such as optical windows, lenses, and white, reflective surfaces, causing unwanted diffusion and absorption of light in optical systems, and increased absorptivity in thermal balance systems. Hence, liquid lubricants had to be discarded while available dry film lubricants at that time could not provide the wear life required of rolling element bearings (Ref. 1).

The standard dielectric materials used in motor insulation posed the problem of outgassing in the vacuum and high temperature environment, and of becoming embrittled at low temperatures. The outgassed material caused the same problems as the evaporated liquid lubricants. Additionally, the lack of convection cooling in the vacuum environment allows hot spots to occur which lead to thermal breakdown of the polymeric wire coating materials.

At low pressures, the carbon (graphite) brush-copper commutator interface abrades rapidly because the lubricity of graphite depends upon water vapor and/or oxygen in the environment rather than upon an inherent crystalline structure (Ref. 2). The problem had been encountered previously in high altitude aircraft and had been solved by adding metallic halides to the brushes. However, this solution was unacceptable at very low pressures.

In attacking these problems which confront the materials of direct current motors employed in the space environment, special materials have replaced the ordinary insulation system, bearing lubricants and brush materials used in these motors. Oil lubricated ball bearings have been replaced by ball bearings having self-lubricating, solid retainers. Brush materials with the required electrical and lubricating characteristics in vacuum (Ref. 3 and 4) have supplanted standard graphite brushes, and the motor insulation system now employs stable materials rather than those common insulation materials which outgas, degrade, and embrittle in the extreme environments of space.

TEST EQUIPMENT

A photograph of a typical test arrangement is shown in Figure 1 and a schematic is shown in Figure 2. The test system consists of two shunt-wound, 1/6 horsepower, direct current motors mounted on standard 1/4 horsepower frames. The windings are insulated with "ML" polyimide resin, and the slots are lined with H-Film. These enamels and resins are usable as insulations at sustained temperatures above 200°C (392°F). Tests were made at ambient room temperature and at a pressure of 1×10^{-6} mm of Hg. Additional tests were made at high temperatures (300°F) and at a pressure of 1×10^{-6} mm of Hg.

Torque Measurement

The motor which is mounted at the top of the system is connected to the generator through a torque-measuring coupling consisting of calibrated springs mounted between a pair of opposing discs. Torque and rotational velocity are determined by directing a light beam onto small mirrors mounted on the edges of the discs of the torque coupling. The reflected beams are chopped into one pulse for each rotation. The beam from the generator disc lags behind the beam from the motor disc by an angle proportional to the drag torque of the generator. The light beams are converted into electrical signals by photo diodes and fed into a digital counter (Ref. 5).

Temperature Measurements

Temperatures of the brushes, bearings, field coils, and armatures are monitored by the thermocouples placed as shown in Figure 2. An indirect method was employed to measure the temperature of the rotating armature. A stationary probe device which consists of a thermocouple and a heating element with attached thermocouple is inserted in the hollow shaft of the rotating armatures. The probe thermocouple receives heat radiated from the armature. The probe temperature is balanced by a heater at the end of the shaft to provide a minimum axial thermal gradient. Then the temperature of the heater represents the temperature of the rotating armature. Heat accumulated within the system produces thermal expansion of the armatures and case which places an axial load on the bearings. To alleviate excess axial loading of the bearing, a spring washer was designed to fit against the bearing outer race as shown in Figure 2.

Power Supplies and Electrical Measurements

The generator field of 1.5 amperes is provided from a direct current power supply. The power produced by the system is expended in a bank of external incandescent lamps. Power was applied to the motor from a second direct current power supply by setting the motor brush current at from 4.25 to 4.6 amperes, thereby, giving a brush current density of approximately 40 amperes/in.^{2}. Current and voltage readings of both the motor and generator were monitored as were the system input and output power. In the later tests the units were operated with separately excited fields. Temperatures of system components were recorded continuously, and torque and rotational velocity were recorded through the torque-counter system. At the completion of each test, brush wear was measured and visual examination was made of the other components.

TEST DATA

Average values of power-in efficiencies, torques and speeds for the motor-generator tests are summarized in Table I. The motor and generator were operated with separately excited fields after test twelve. The other tests were made with the motor and generator having shunt fields. Both input and output power varied widely for tests one and two because of problems connected with brush arcing while the input and output were quite constant for test three. Typical temperatures obtained in the motor and generator during continuous operation are shown in Figure 3. This test which ran for 80 hours appeared to provide sufficient time for the temperatures to stabilize. The maximum temperature appeared in the armature shaft which reached approximately 170°C (338°F). The field and outer portions of the motor and generator appeared to reach a maximum temperature of about 150°C (302°F). These temperatures were generally slightly lower than expected. Figure 4 shows temperatures obtained in the motor and generator with heat applied to the system prior to the beginning of the tests. A maximum temperature of 271°C (520°F) was recorded for the shaft of the generator while the highest temperature of the motor was 253°C (488°F) on the motor shaft.

Figures 5 and 6 show the performance curves of the motor and generator respectively. The motor characteristic curves were obtained with the armature voltage maintained at 50 volts and the field at 1.5 amperes. Generator performance curves are shown at two speeds with the generator field current set at 1.5 amperes. This graph shows values of output current and voltage for 630 r.p.m. and 880 r.p.m.

DISCUSSION

Special Materials

The following special materials listed in Table II were used in both the motor and generator:

TABLE I

Motor-Generator Test Data

Test Number	Average Motor Power-In, Watts	Motor Eff., %	Average Torque in./lb.	Generator Efficiency, %	Average Speed, r.p.m.	Test Duration (Hrs.)	Max. Temperature, °F	Comments
1*	180	56	15.0	58	600	72	352°, Motor Brush	Heavy Deposits on Commutator-Brush Wear
2*	160	48	12.2	75	575	52	338°, Generator Shaft	Heavy Deposits on Commutator
3*	175	45	12.0	84	600	80	338°, Generator Shaft	Commutator in Good Condition-Brushes Chipped on Trailing Edge
4*	180	44	12.2	83	580	80	357°, Generator Shaft	Commutator in Good Condition-Brushes Chipped on Trailing Edge
5*	187	48	13.4	77	570	80	385°, Generator Shaft	High Temperature Test-Commutator in Excellent Condition Brushes Chipped Badly
6*	Torque tests, variable speed					-	Did not monitor Temperature	
7*	220	62	19.2	62	600	18	398°, Generator Shaft	Commutator in Excellent Condition-Friction Moderate-Light Chipping on Trailing Edge of Brushes
8*	268	47	18.8	76	600	1/3	Did not monitor	Commutator Badly Scratched
9*	225	63	19.0	61	620	80	457°, Generator Shaft	High Temperature Test-Commutator in Good Condition-Slight Chipping on Brushes

TABLE I

Motor-Generator Test Data

Test Number	Average Motor Power-In, Watts	Motor Eff. %	Average Torque in/lb.	Generator Efficiency, %	Average Speed, r.p.m.	Test Duration (Hrs.)	Max. Temperature, °F	Comments
10.*	250	60	21.0	57	610	8	Did Not Monitor Temperature	Same Brushes as Test 9 (No Problems)
11.*	Torque tests, variable speed						Did Not Monitor Temperature	
12.*	120	75	11.6	83	650	14	Did Not Monitor Temperature	Chipping of Brushes
13.*	180	60	14.8	70	630	2	Did Not Monitor Temperature	Commutator Badly Worn
14.*						113	520°F, Generator Shaft	High temperature test-$NbSe_2$-TaS_2 brushes failed after 3 hours; glass-filled Teflon bearing retainer failed after 8 hours, chipping of $NbSe_2$-MoS_2 brushes.
15.*	150	-	12.8	-	650	1	320°F, Generator Shaft	Ring Fire on Commutator
16.* ** ***	160	77	15.8	72	680	21	382°F, Generator Shaft	Brushes wore badly in air-run at 70° and 300° ambient temperature and 2 hours in air.
17.*	168	74	15	70	680	23	735°, Motor Brush	Severe arcing, brush temperature went to 735°F.
18.*	168	78	16.5	70	680	315	450°, Generator Shaft	No problems.
19.**	176	84	18.5	64	680	62	578°, Generator Shaft	No problems.

TABLE I (Concl'd)

Motor-Generator Test Data

Test Number	Average Motor Power-In, Watts	Motor Eff. %	Average Torque in/lb.	Generator Efficiency, %	Average Speed, rpm	Test Duration (Hrs.)	Max. Temp. °F	Comments
20.***	184	67	17.5	67	600	6 1/2	-	No problems
21.*	287	78	10.7	76	1770	3 1/2	475°, Generator Shaft	Generator bearing seized

* Vacuum test
** Vacuum high temperature test
*** Air test

TABLE II

Special Materials Employed in Motor and Generator

TEST	BEARING RETAINERS	INSULATION	BRUSHES	TEST CONDITIONS
1.	Polyimide-Copper Reinforced	ML-Polyimide Enamel	MoS_2-Silver 80% / 20%	2×10^{-6} torr 70°F Ambient
2.	Polyimide-Copper Reinforced	ML-Polyimide Enamel	MoS_2-Silver 85% / 15%	2×10^{-6} torr 70°F Ambient
3.	Polyimide-Copper Reinforced	ML-Polyimide Enamel	$NbSe_2$	2×10^{-6} torr 70°F Ambient
4.	Polyimide-Silver	ML-Polyimide Enamel	$NbSe_2$	2×10^{-6} torr 70°F Ambient
5.	Polyimide-Silver	ML-Polyimide Enamel	$NbSe_2$	5×10^{-6} torr 320°F Ambient
6.	Polyimide-Silver	ML-Polyimide Enamel	$NbSe_2$	-
7.	Polyimide-Copper	ML-Polyimide Enamel	$NbSe_2$-MoS_2 80% / 20%	2×10^{-6} torr 70°F Ambient
8.	Polyimide-Copper	ML-Polyimide Enamel	TAS_2-Graphite-$NbSe_2$ 33 1/3% / 33 1/3% / 33 1/3%	2×10^{-6} torr 70°F Ambient
9.	Polyimide-Copper	ML-Polyimide Enamel	$NbSe_2$-MoS_2 80% / 20%	5×10^{-6} torr 320°F Ambient
10.	Polyimide-Copper	ML-Polyimide Enamel	$NbSe_2$-MoS_2 80% / 20%	2×10^{-6} torr 70°F Ambient
11.	Polyimide-Copper	ML-Polyimide Enamel	$NbSe_2$-MoS_2 80% / 20%	2×10^{-6} torr 70°F Ambient
12.	Rulon, Glass Reinforced Teflon	ML-Polyimide Enamel	$NbSe_2$-MoS_2 80% / 20%	2×10^{-6} torr 70°F Ambient
13.	Polyimide-Copper	ML-Polyimide Enamel	Iron MoS_2 Mixture	2×10^{-6} torr 70°F Ambient
14.	Rulon, Glass Reinforced Teflon	ML-Polyimide Enamel	$NbSe_2$-TaS_2 80% / 20%	2×10^{-6} torr 70°F Ambient
15.	Polyimide-Silver	ML-Polyimide Enamel	100% $NbSe_2$	1×10^{-6} torr 75°F Ambient
16.	Polyimide-Silver	ML-Polyimide Enamel	90% $NbSe_2$ 10% Ag	Operated in vacuum at 70°F and 323°F and in air at 70°F
17.	Polyimide-Silver	ML Polyimide Enamel	86% WSe_2 14% Ag	1×10^{-6} torr 70°F Ambient
18.	Salox M, Bronze Reinforced Teflon	ML Polyimide Enamel	MoS_2-Ta	1×10^{-6} torr 70°F Ambient
19.	Salox M, Bronze Reinforced Teflon	ML Polyimide Enamel	MoS_2-Ta	5×10^{-6} torr 300°F Ambient
20.	Salox M, Bronze Reinforced Teflon	ML Polyimide Enamel	MoS_2-Ta	Air 70°F Ambient
21.	Salox M, Bronze Reinforced Teflon	ML Polyimide Enamel	MoS_2-Ta	2×10^{-6} torr 70°F Ambient High Speed

The polyimide metal matrix retainer material was used for bearing lubrication in these tests in an effort to substitute a high temperature cage material for the more common "Teflon." Prior to these tests, it was feared that the stable motor temperatures might degrade Teflon cages. Later tests using both metal matrix and filled Teflon indicated that these latter materials were suitable for this application. Polyimide insulation was also used as a wire coating and insulation to obtain a stable motor insulation under high temperatures and low pressure. This insulation withstood the operating environment satisfactorily through all tests. Hot pressed molybdenum disulfide-silver brushes were tested in the first two runs to overcome the effect of vacuum on graphite brushes. The niobium diselenide brushes were used because of problems associated with arcing of the molybdenum disulfide silver combination. While fairly good results were achieved with the $NbSe_2$ brushes the extreme brittleness of the brush was a major drawback. Several additional brush materials were tested with optimum results being obtained with a MoS_2-tantalum compact. All other motor materials were standard.

Brushes

Test one was shut down at approximately 72 hours and test two was shut down at approximately 52 hours because of heavy arcing and wear on the brushes. Figure 7 shows the motor and generator armatures, brushes and bearings at the completion of test two. A typical example of the motor armature brush wear track is shown in Figure 8. Examination of these armatures indicated that the silver from the brushes had been deposited on the armature by arcing, thereby roughening the armature and increasing the arcing until failure occurred by an avalanche effect. For the third test, niobium diselenide brushes were used in an effort to obtain a conductive material without the addition of a metallic element. During the third test heavy arcing occurred at the start of the test; however, this arcing did not appear to damage the commutator, and the arcing ended as the brushes wore-in. The third, fourth, and fifth tests each operated for the planned eighty hours with no apparent brush problems. Examination of the motor at the completion of these tests showed that the armature was in excellent condition as shown in Figure 9. The brushes had chipped rather badly as shown in Figure 10; however, the chipping did not appear to affect the current carrying characteristics of the brushes. Actual brush wear was extremely low.

To overcome chipping of these brushes by reducing their brittleness, MoS_2 was added to the $NbSe_2$, and tests were made with brushes of 80% $NbSe_2$-20% MoS_2. There was slight chipping of the trailing edge of the brushes during the ambient temperature test but the chipping was severe during the high temperature tests. In addition, a brush material of 33 1/3% TaS_2 - 33 1/3% graphite - 33 1/3% $NbSe_2$ was tested. However, the test lasted only 1/3 hour after which the commutator was scratched badly. In test 17 a brush material consisting of 86% WSe_2 and 14% silver was tested. These brushes operated for 23 hours but wore badly during this time. Results of this test are shown in Figures 11 and 12.

For test 18 a proprietary brush material was obtained from The Boeing Company. This material is a compact formed of MoS_2 and tantalum and is designated 046-45. Brushes cut from this compact were used in a 315 hour vacuum test. Wear rates of this material appear to be in the 10^{-5} inches per hour range. These brushes were tested for an additional 62 hours at high temperature in test 19 and for 6 1/2 hours in air in test 20. In both cases the brush and commutator were in good condition at the completion of the run. Measurements at the conclusion of test 20 indicated that the brush wear in air is higher than in vacuum; running approximately 10^{-4} inches per hour. The condition of brush and commutator at the conclusion of these tests is shown in Figures 13 and 14.

Work is now underway to further characterize The Boeing Company 046-45 material.

Insulation

The motor and generator insulation was examined after each test. No indication of any problems was apparent from these examinations. The polyimide insulation should be stable to considerably higher temperatures than were encountered during these tests.

Bearings

The bearings were examined at the completion of each test. In each test using the polyimide copper retainer, heavy retainer wear occurred with the wear particles retained in the bearing. After stoppage, the bearings tended to jam because of these wear particles. After cleaning with high pressure air, the bearings were suitable for reuse. However, the retainer wear was excessive. The polyimide silver bearing retainers showed little wear after a high temperature test. Tests 4, 5, and 6 in which these retainers were used, were disregarded as bearings tests because of poor design of the bearings. The Rulon retainers ran well until loose brush material contaminated the bearings causing the torque to rise, and thus forcing replacement of the bearings. Tests 18 through 20 were made with Salox M bearing retainers. These tests indicated that the Teflon based materials were suitable for this application at speeds from 600 to 800 r.p.m. In test 21 the motor generator set was operated at 1,700 to 1,800 r.p.m. This test was concluded after 3 1/2 hours when the generator bearing seized. Temperature measurements on the generator bearing shaft indicated a constant rising temperature throughout the test with the final shaft temperature reaching 475°F.

It appears that seizure occurred by thermal expansion of the inner bearing race during this high speed run. Proper design of the bearing will require sufficient clearance to allow for high temperature differentials across the bearing during high speed operation.

CONCLUSIONS

These tests show that brush-type direct current motors will operate satisfactorily under highly loaded conditions in a vacuum environment.

The polyimide insulation employed in these motors withstood the low pressure (1×10^{-6} mm) and temperatures to 271°C (520°F) satisfactorily during continuous operation.

The deposition of a metallic brush material component on the commutator wear track as a result of heavy arcing can cause rapid wear of the brushes. The use of single phase niobium diselenide brushes corrected this problem. However, chipping of the niobium diselenide brushes was a major problem. The MoS_2-tantalum compacts appear to meet all of the requirements of a vacuum motor brush material. These brush materials are now being evaluated at pressures to 10^{-9} torr.

Excessive wear of the polyimide-copper bearing retainers makes them unsuitable for application in the space motors. However, reinforced Teflon retainers have proved satisfactory and will be used in future tests.

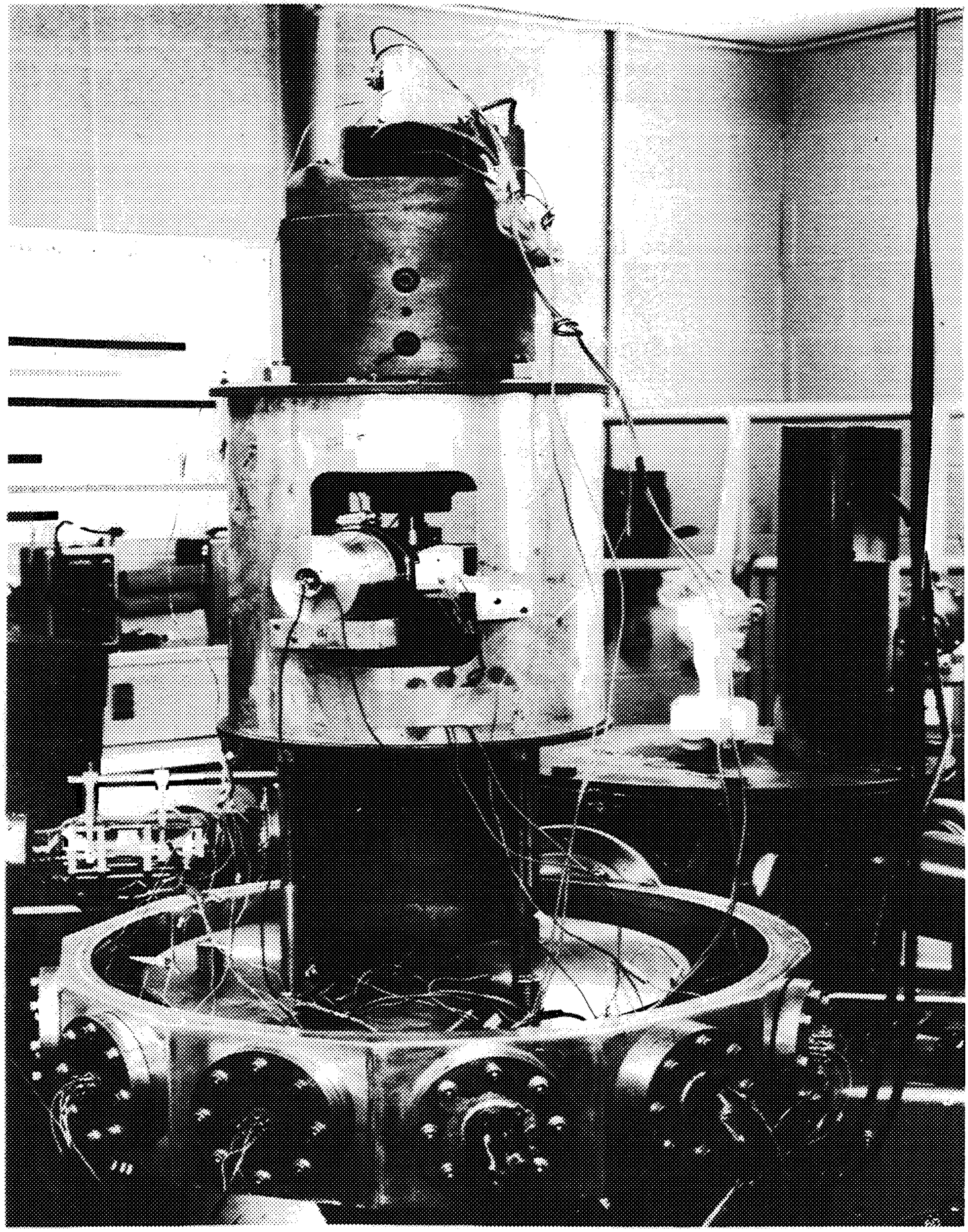


FIGURE 1. - PHOTOGRAPH OF MOTOR-GENERATOR TEST SET-UP

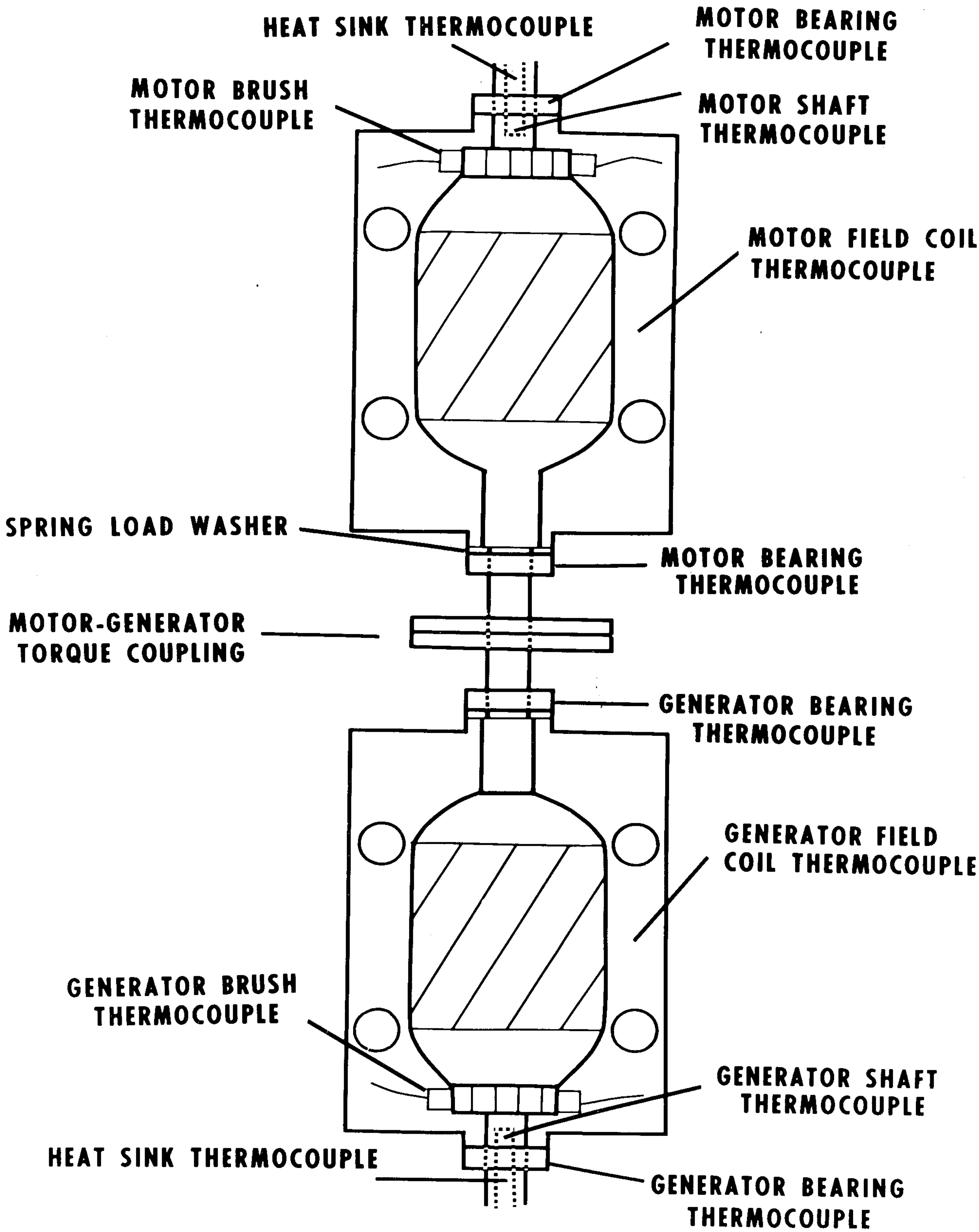
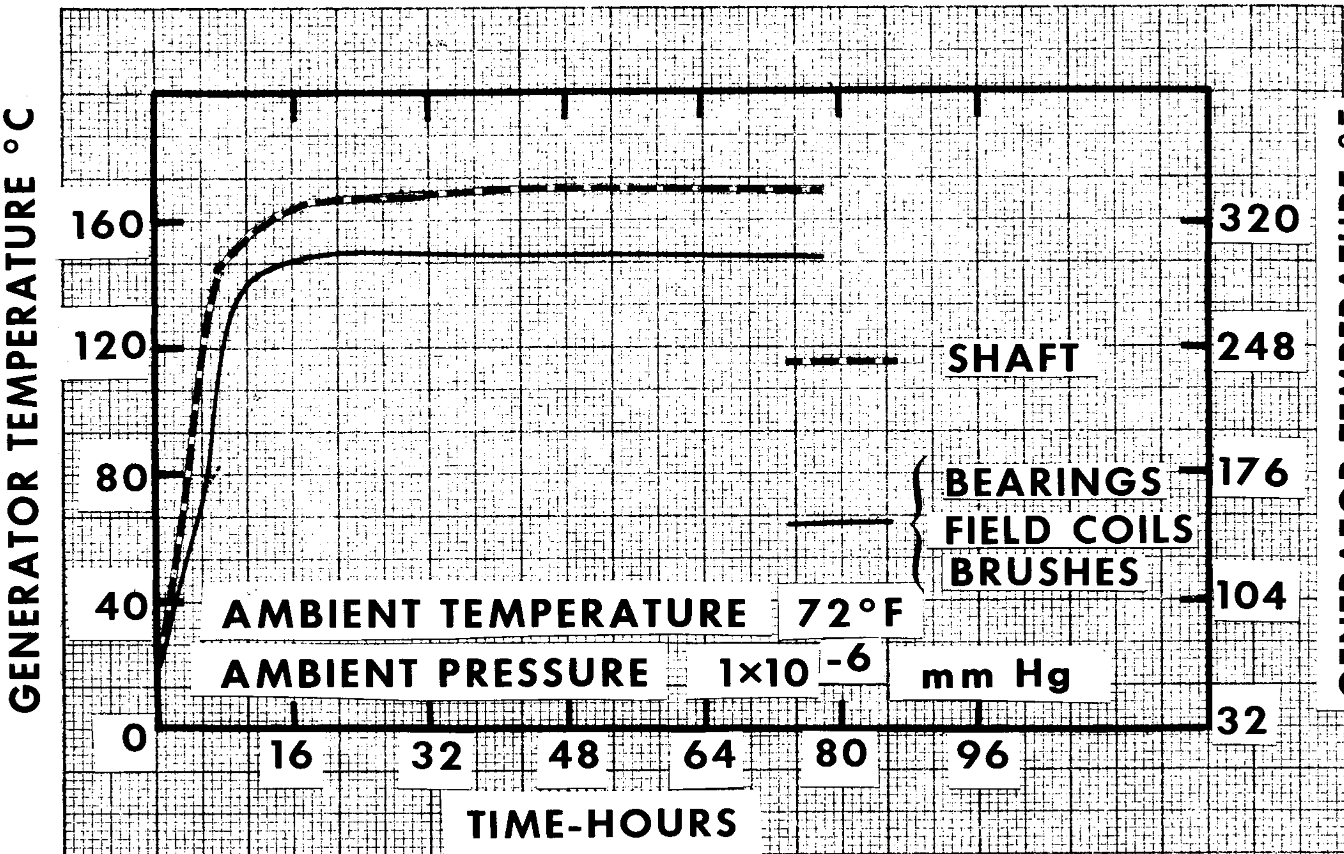


FIGURE 2.- SCHEMATIC OF MOTOR-GENERATOR TEST SETUP



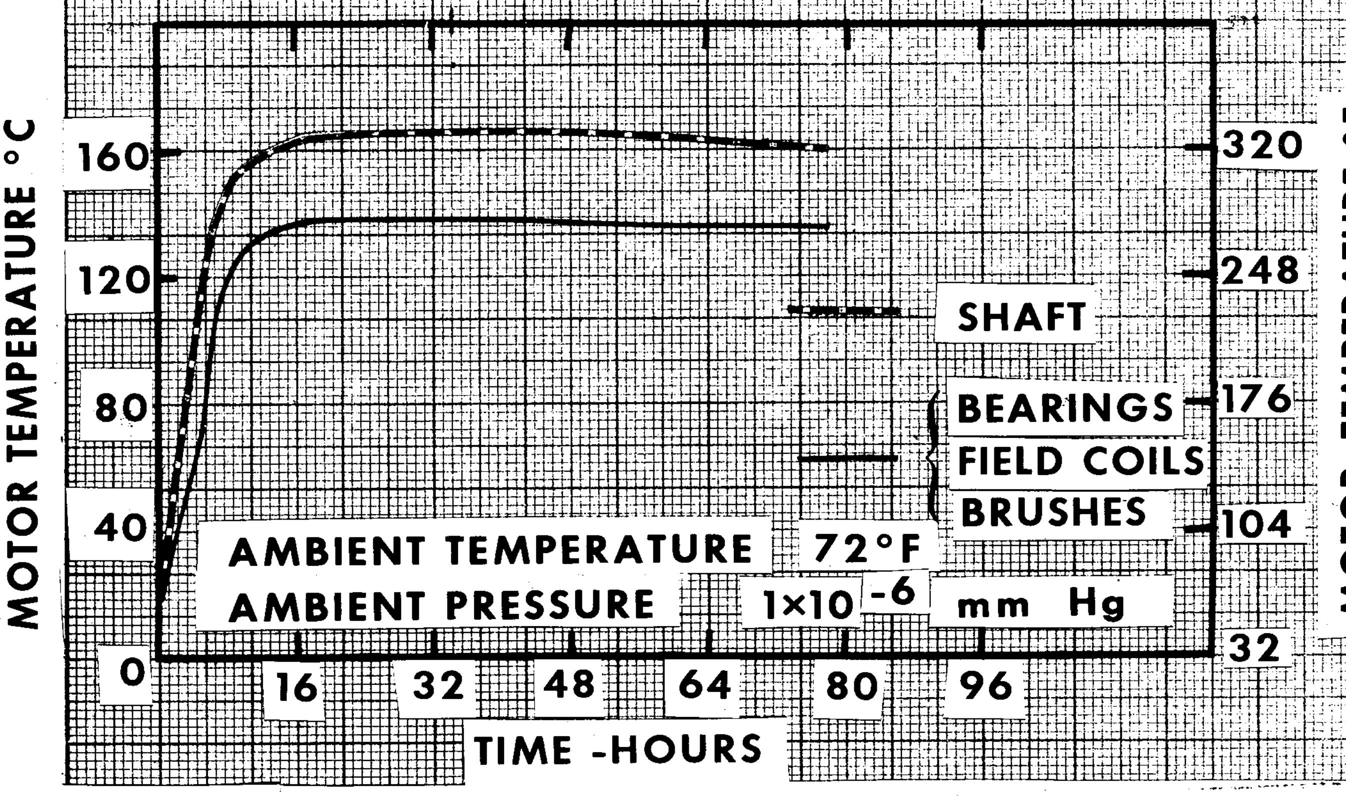


FIGURE 3. - MOTOR AND GENERATOR TEMPERATURES VS TIME

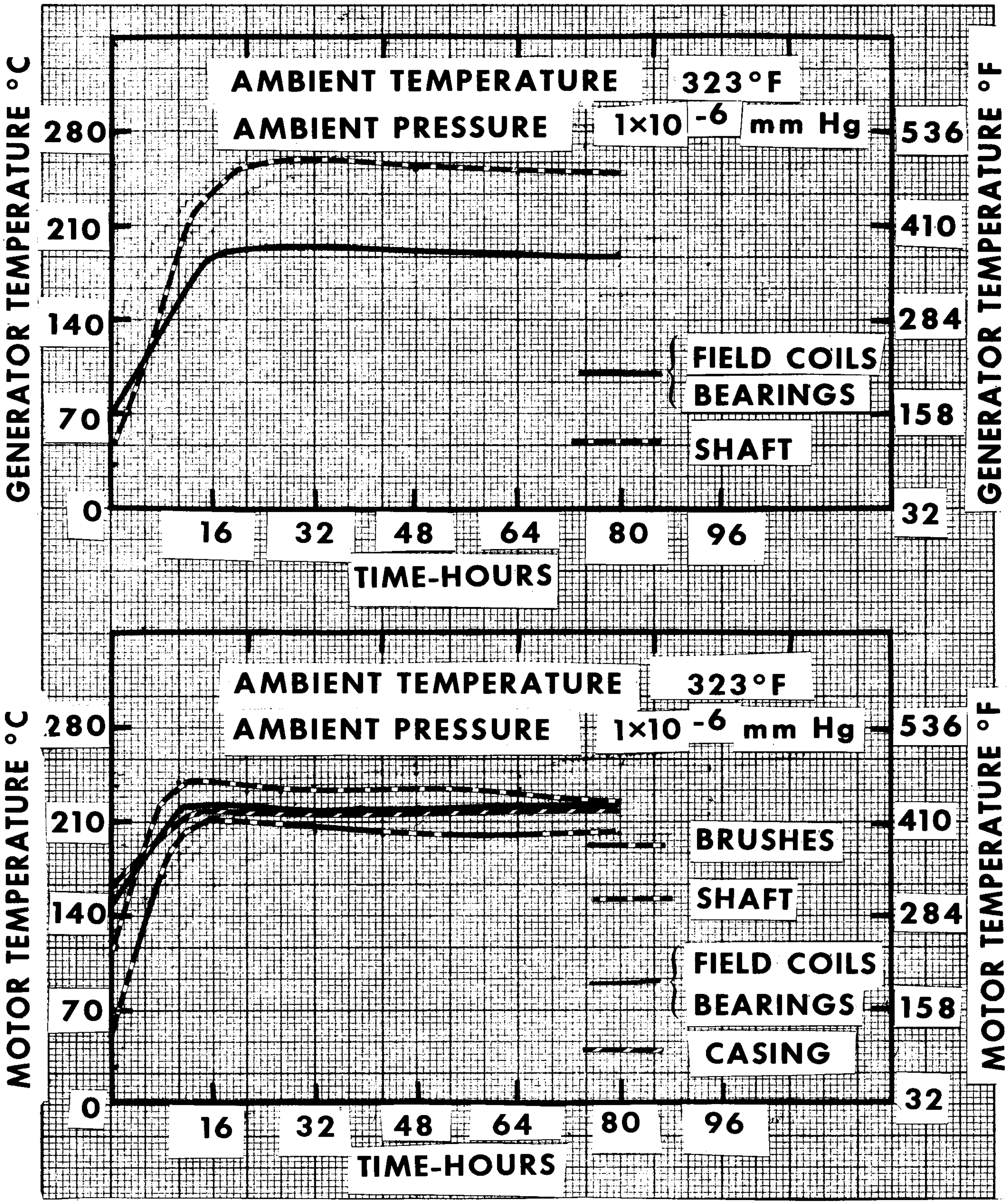


FIGURE 4. - MOTOR AND GENERATOR TEMPERATURES VS TIME

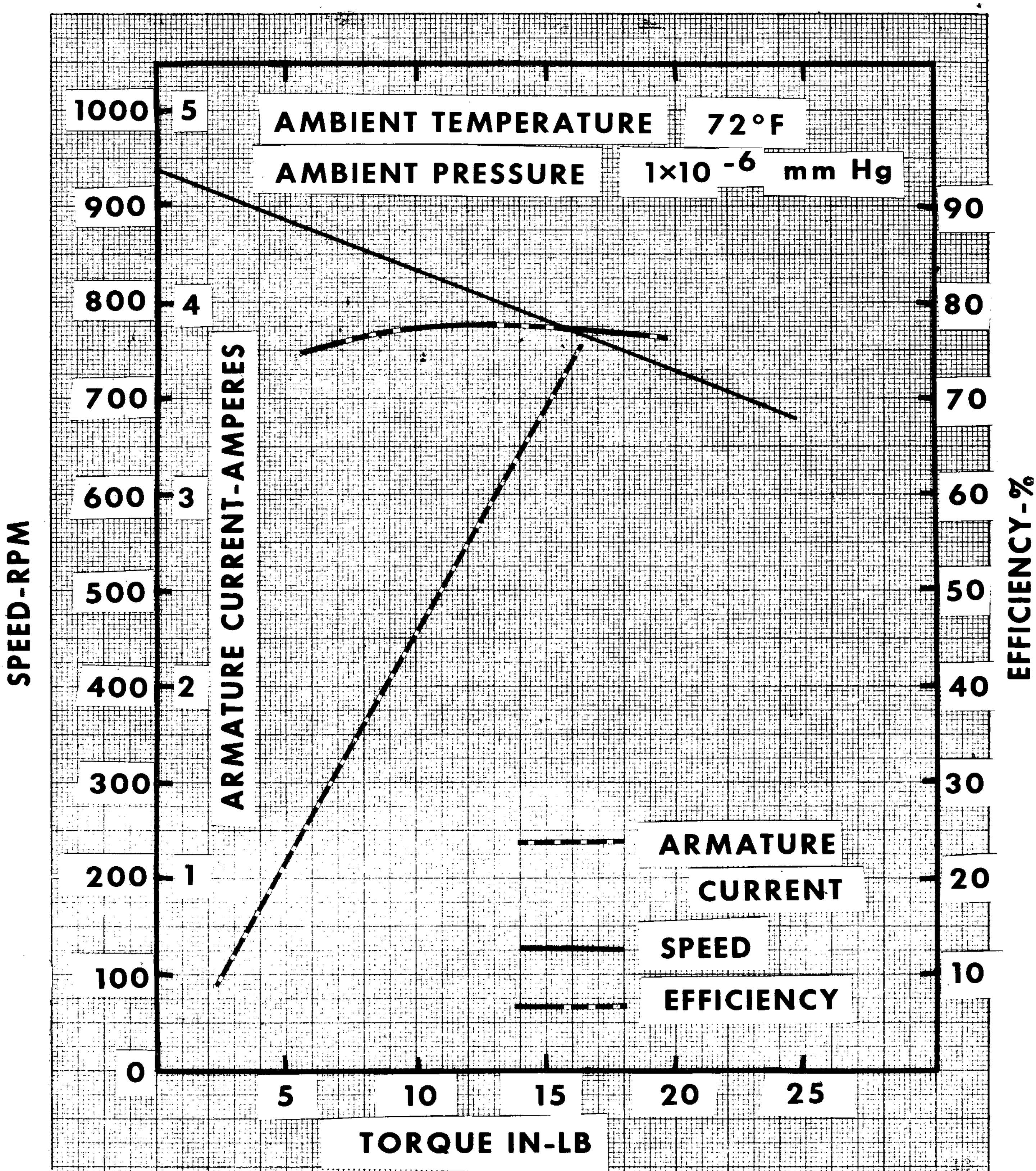


FIGURE 5. - MOTOR PERFORMANCE CURVES WITH ARMATURE VOLTAGE AND FIELD CURRENT CONSTANT

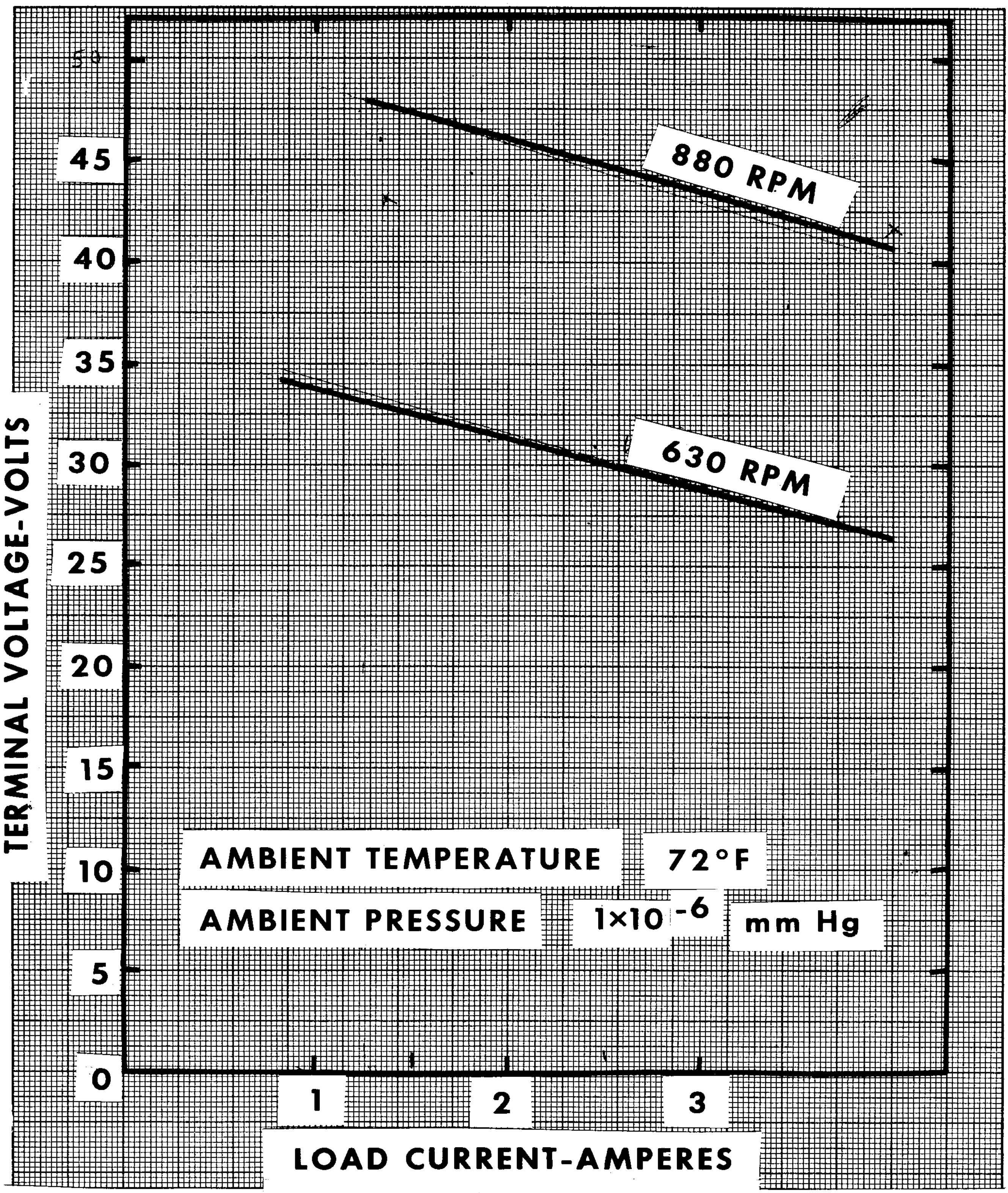


FIGURE 6. - GENERATOR PERFORMANCE CURVES AT TWO SPEEDS WITH CONSTANT FIELD CURRENT

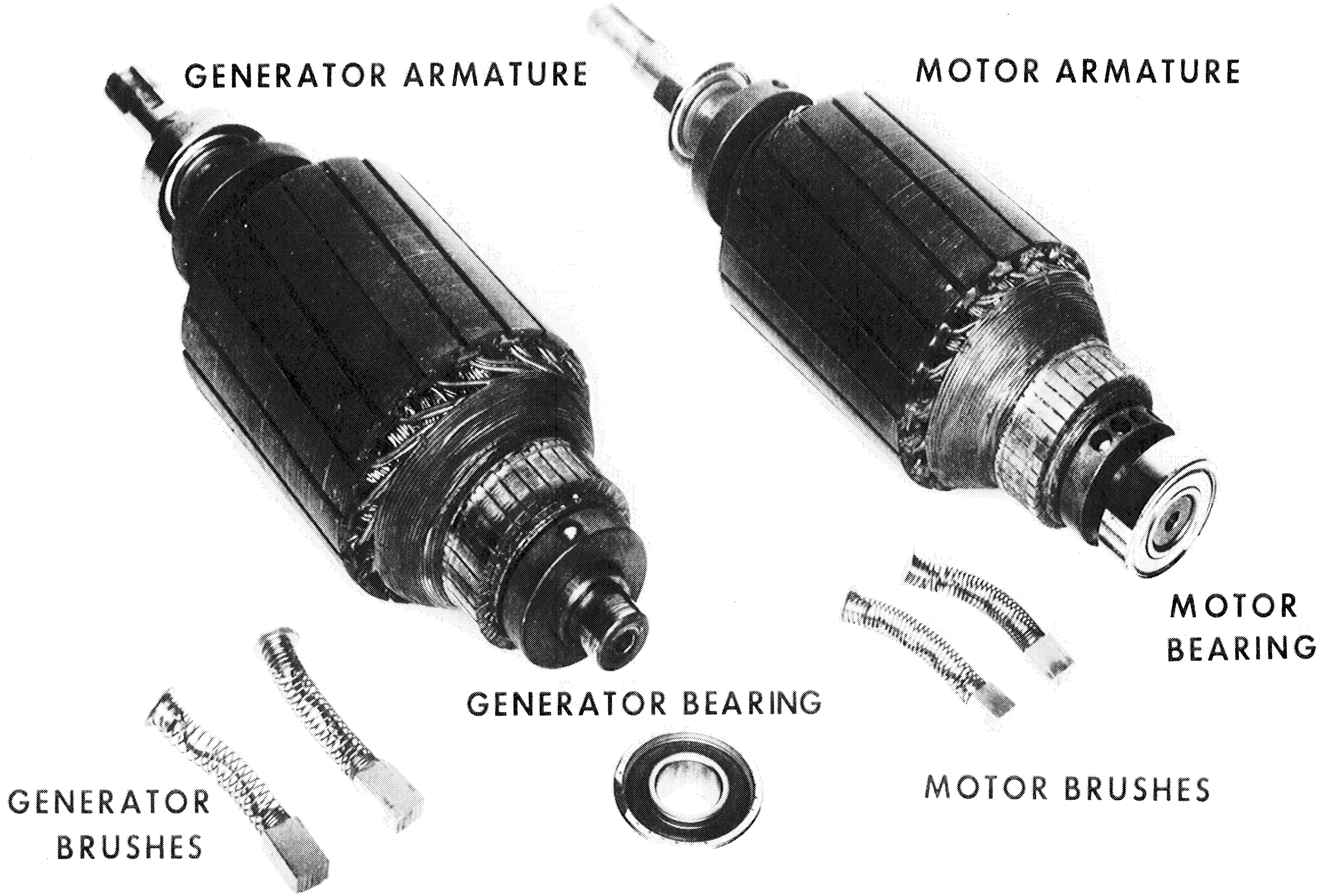


FIGURE 7. - MOTOR AND GENERATOR ARMATURES, BRUSHES, AND BEARINGS AT THE COMPLETION OF TEST TWO

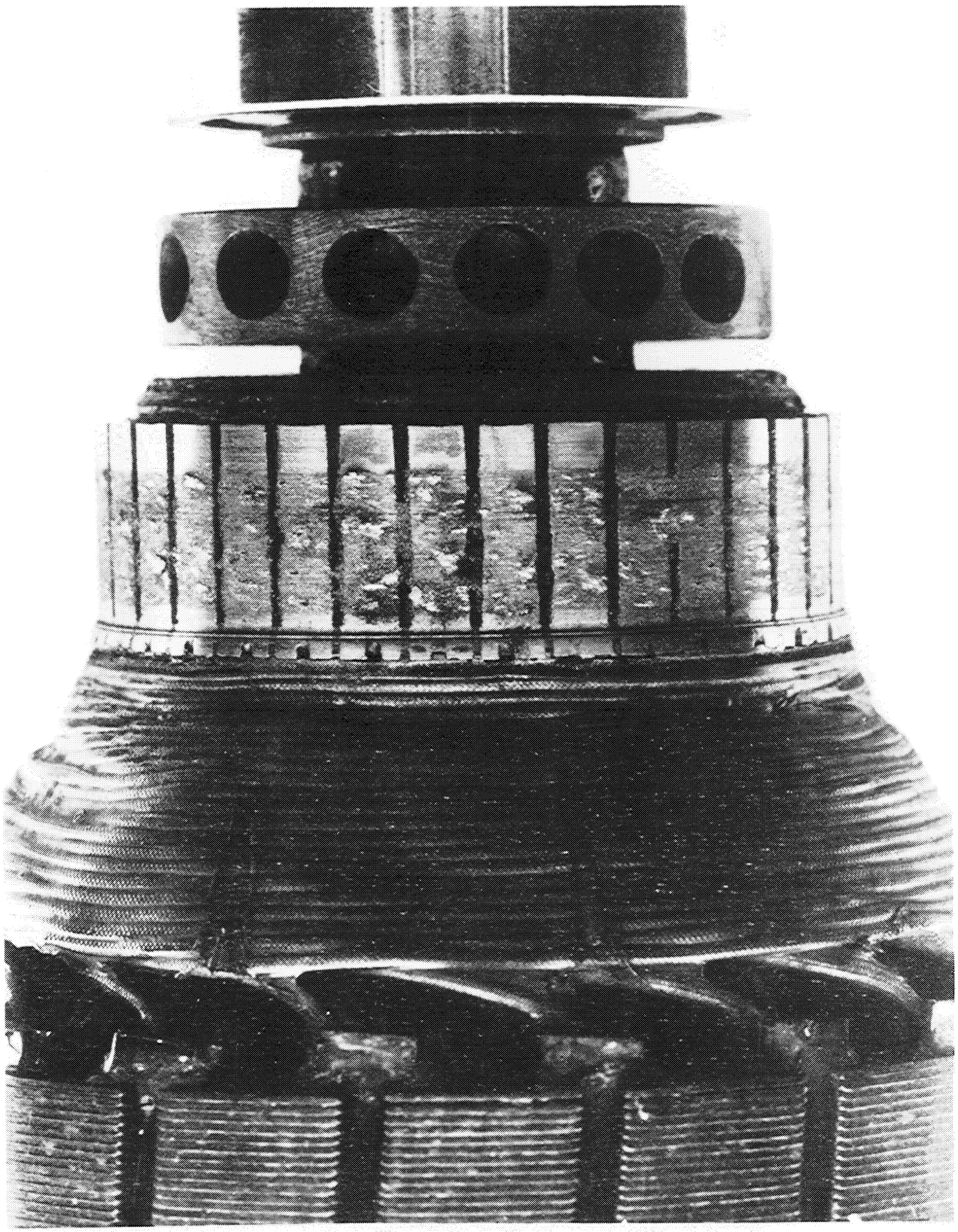


FIGURE 8. - MOTOR ARMATURE BRUSH WEAR TRACK AT COMPLETION OF TEST TWO

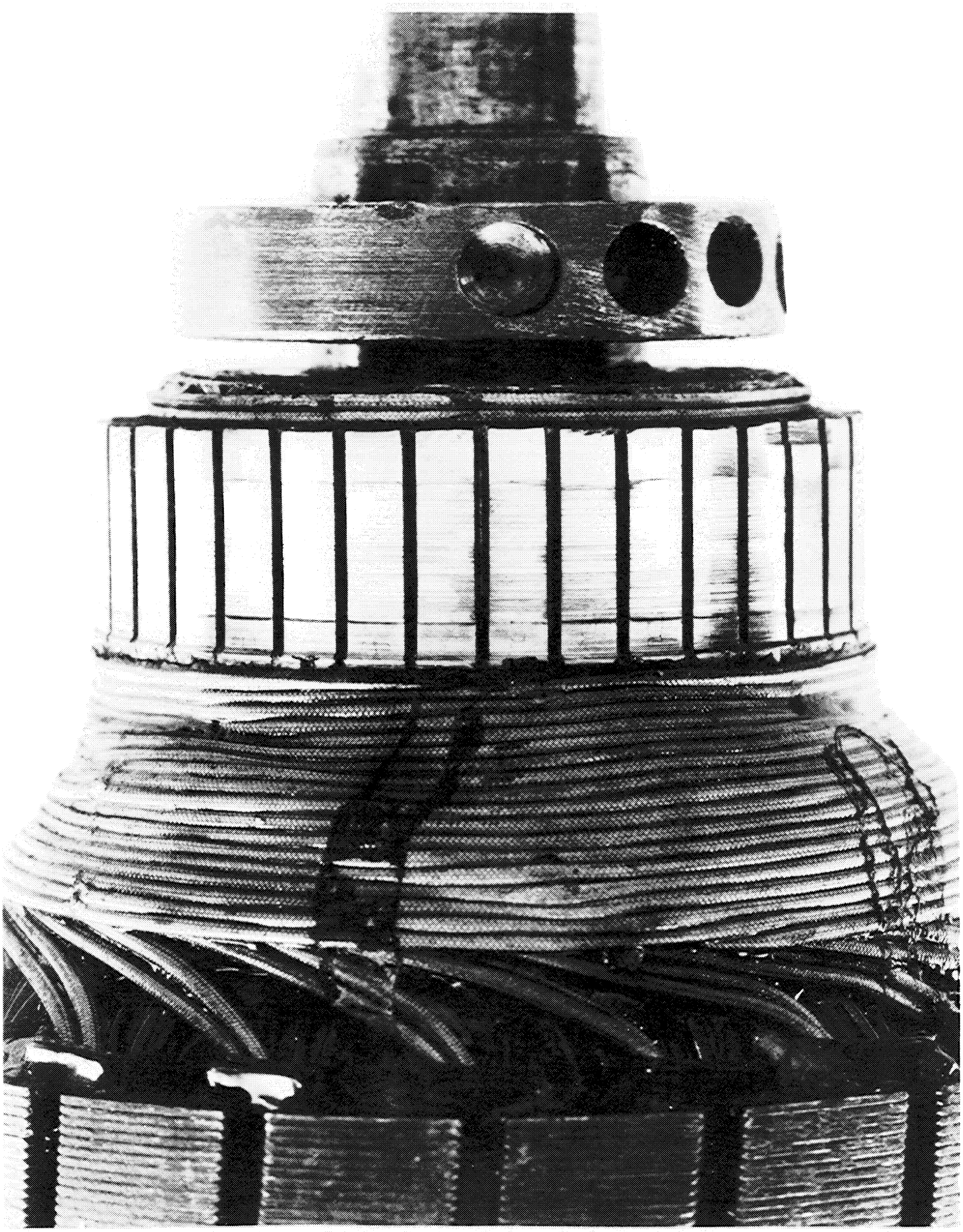


FIGURE 9. - MOTOR ARMATURE BRUSH WEAR TRACK AT COMPLETION OF TEST THREE

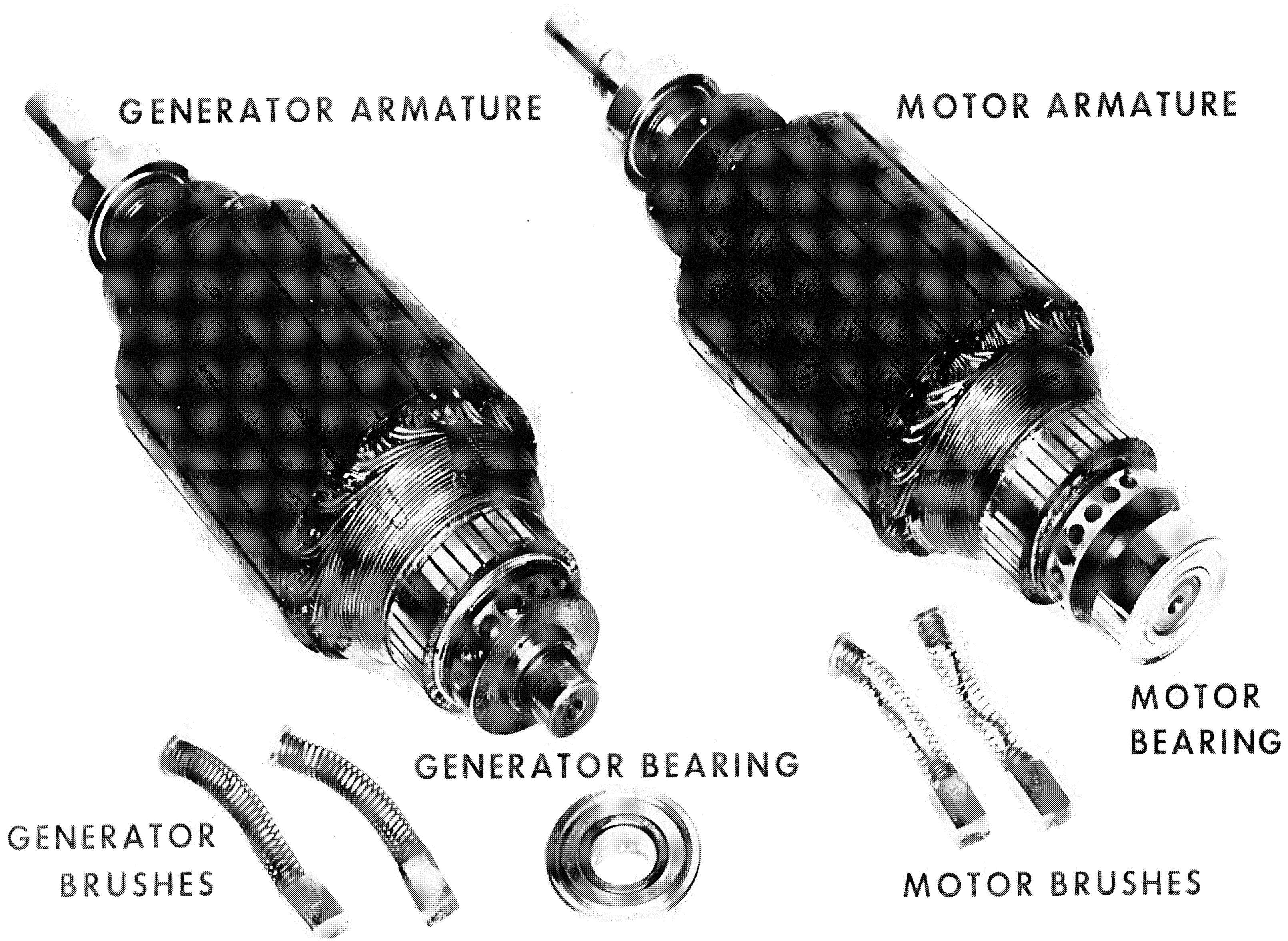


FIGURE 10. - MOTOR AND GENERATOR ARMATURES , BRUSHES, AND BEARINGS AT COMPLETION OF TEST THREE

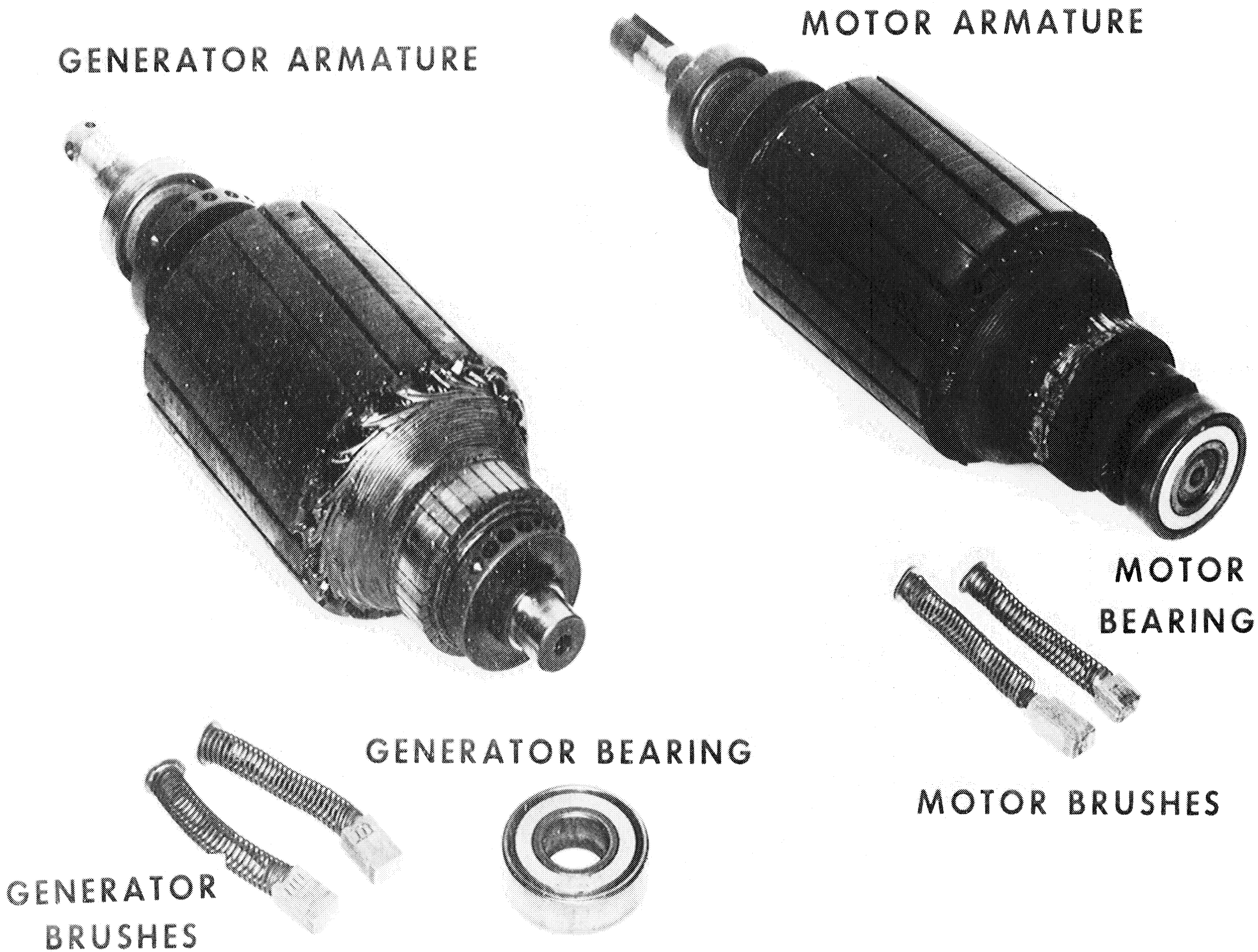


FIGURE 11. - MOTOR AND GENERATOR ARMATURES, BRUSHES AND BEARINGS AT THE COMPLETION OF TEST SEVENTEEN

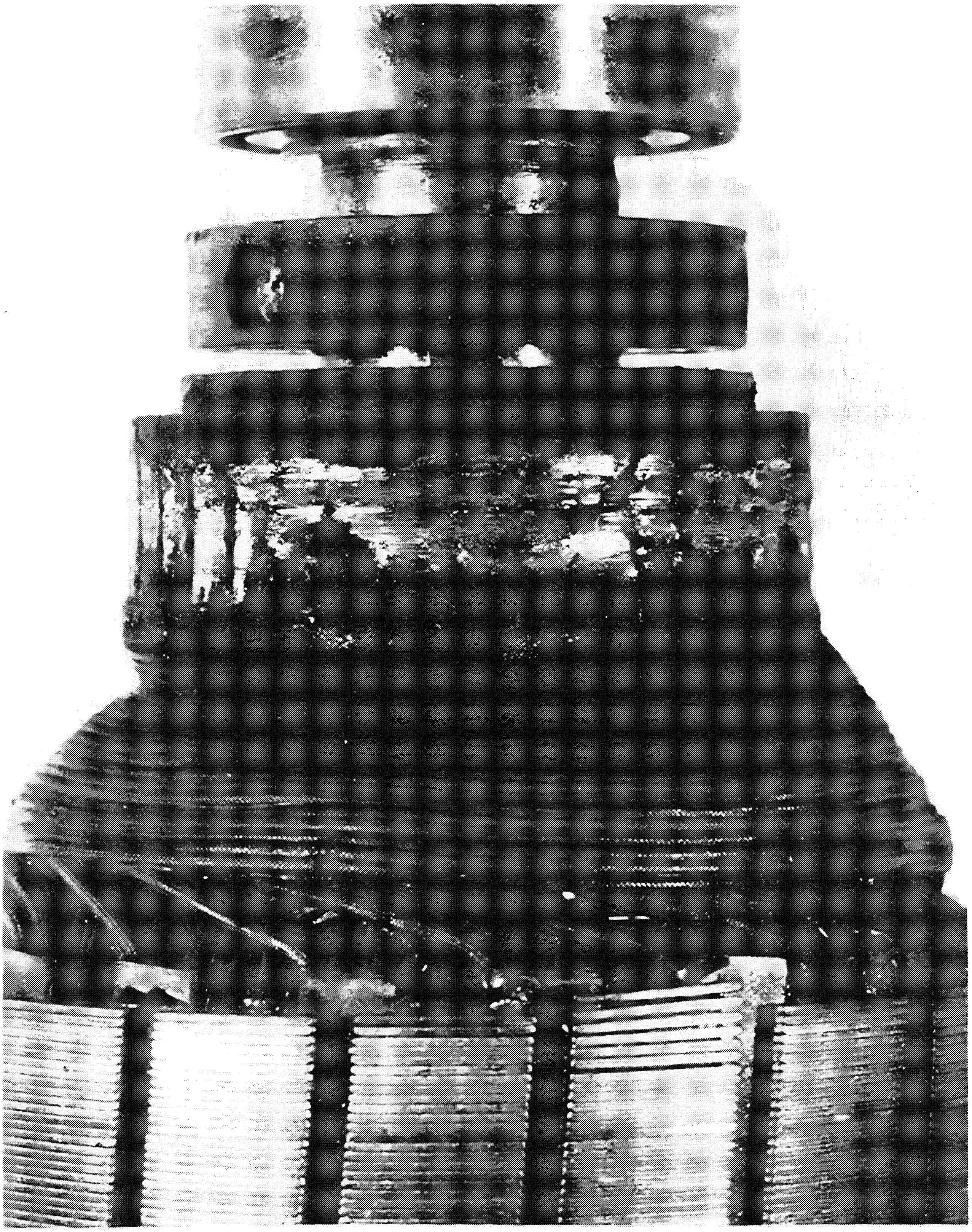


FIGURE 12. - MOTOR ARMATURE BRUSH WEAR TRACK AT COMPLETION OF TEST SEVENTEEN

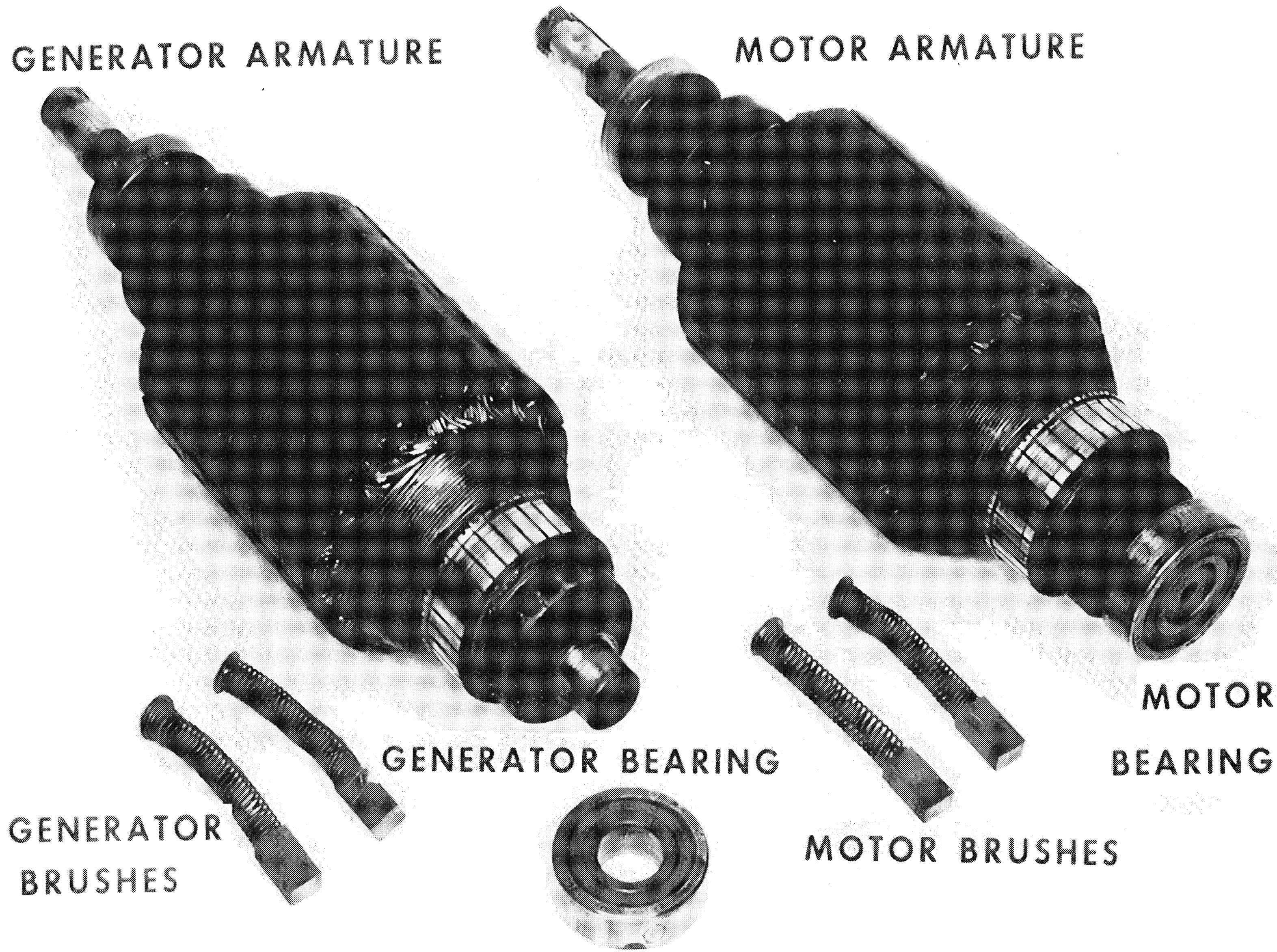


FIGURE 13. - MOTOR AND GENERATOR ARMATURES, BRUSHES AND BEARINGS AT THE COMPLETION OF TEST TWENTY

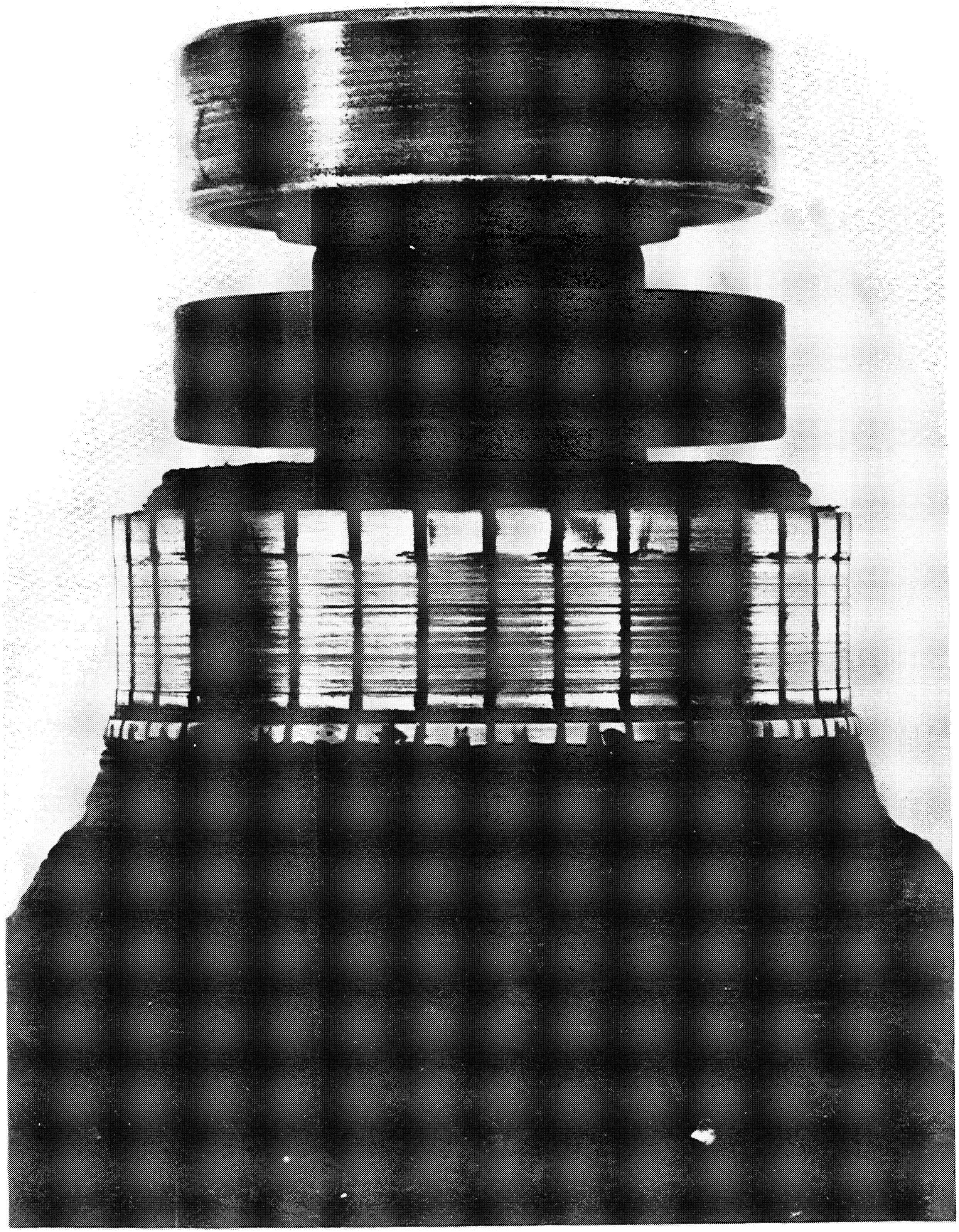


FIGURE 14. - MOTOR ARMATURE BRUSH WEAR TRACK AT THE COMPLETION OF TEST TWENTY

REFERENCES

1. McKannan, E. C. and Kingsbury, J. E., A Survey of Vacuum Lubrication Developments, MTP-P&VE-M-63-17, George C. Marshall Space Flight Center, December 7, 1963.

2. Horton, J. C., Electrical Contacts in Vacuum A. Brushes - Status Report Number 1, MTP-S&M-M-61-19, George C. Marshall Space Flight Center, July 1961.

3. Horton, J. C., Electrical Contacts in Vacuum (A) Brushes - Status Report No. 2, MTP-P&VE-M-62-17, George C. Marshall Space Flight Center, December 1962.

4. Horton, J. C., Wear and Noise Characteristics of Brushes in Vacuum, Proc. of the 1966 International Symposium on Research and Electrical Contact Phenomena, June 1966, University of Maine Press.

5. Demorest, K. E. and McKannan, E. C., Vibration of Journal Bearings Lubrication Engineering, Vol. 19, No. 2, February 1963, pp. 59-67.

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This document has also been reviewed and approved for technical accuracy.

E C McKannan

E. C. McKannan
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J. E. Kingsbury
Chief, Materials Division

W. R. Lucas

W. R. Lucas
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R-P&VE-A	Mr. Goerner
R-P&VE-M	Mr. Kingsbury (6)
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R-P&VE-RT	Mr. Hofues
R-P&VE-MEV	Mr. Horton
R-P&VE-MEV	Mr. Ruff
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R-P&VE-VNT	Mr. Hill
R-QUAL-DIR	Mr. Grau
R-QUAL-A	Mr. Henritze
R-ASTR-DIR	Dr. Haeussermann (2)
R-SSL-DIR	Dr. Stuhlinger
R-SSL-N	Dr. Shelton
R-QUAL-OC	Mr. Mordecai
MS-IP	Mr. Ziak
MS-IPL	Miss Robertson (8)
MS-H	Mr. Akens
CC-P	Mr. Rice
MS-T	Mr. Wiggins (5)
I-RM-M	
DEP-T	

Scientific and Technical Information Facility (25)
P.O. Box 33
College Park, Md. 20740