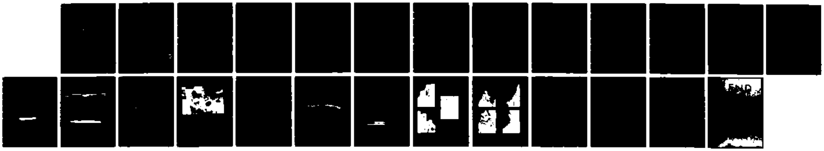
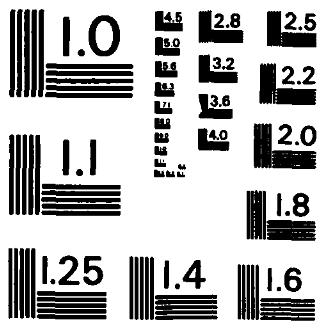
AD-A147 634 INVESTIGATION OF ELECTRIC AND WEAR PHENOMENA OF LIQUID METAL WETTED COPPE..(U) DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER ANN.. 1/1

UNCLASSIFIED N SONDERGAARD ET AL. OCT 84 F/G 13/9 NL





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

INVESTIGATION OF ELECTRIC AND WEAR PHENOMENA OF LIQUID METAL WETTED COPPER FIBER BRUSHES UNDER CONDITIONS OF HIGH SLIP RING ECCENTRICITY

by

Neal Sondergaard and Patrick Reilly

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

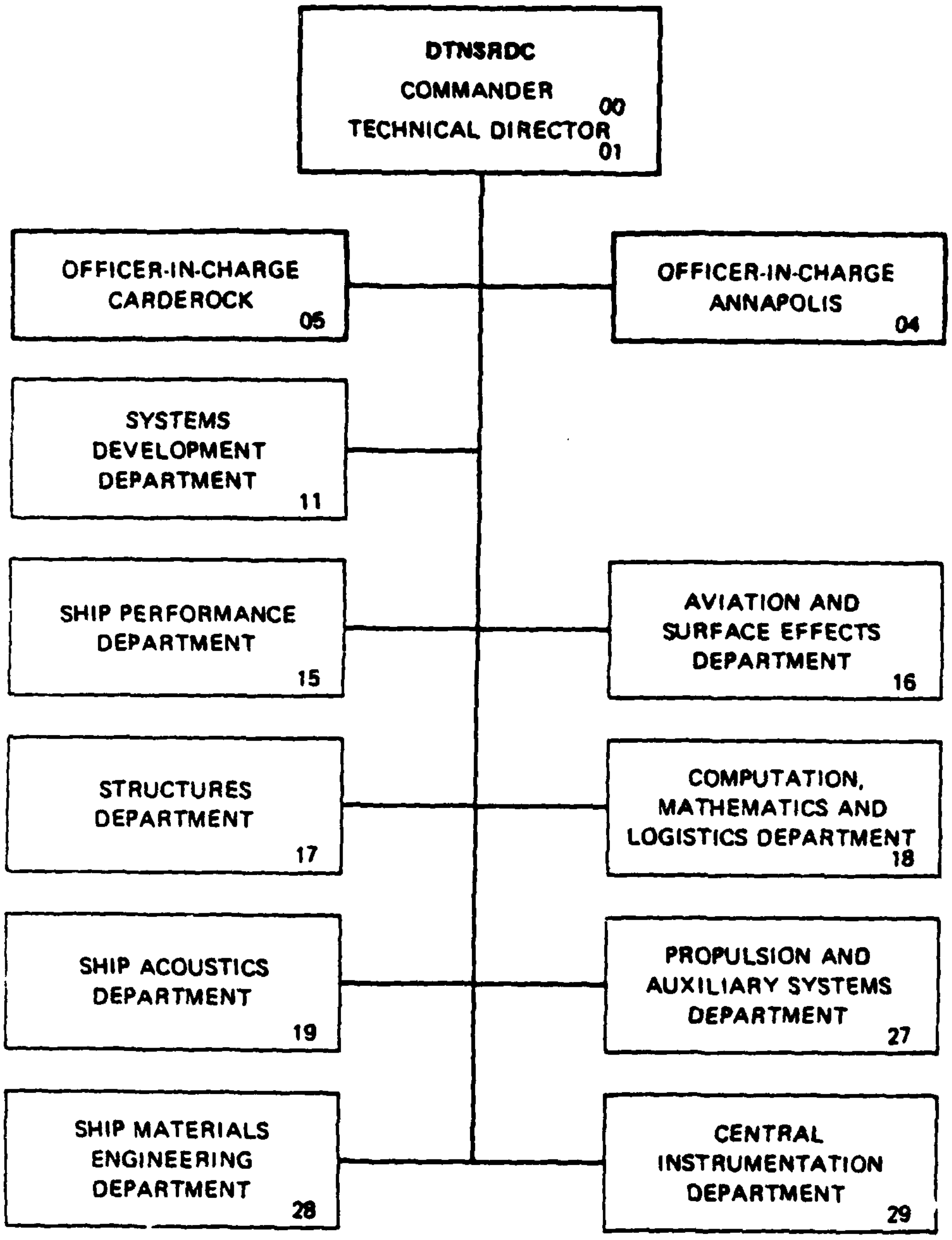
PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT

RESEARCH AND DEVELOPMENT REPORT

OCTOBER 1984

DTNSRDC/PAS-84-20

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER PAS-84-20	2. GOVT ACCESSION NO. AD-A147 634	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INVESTIGATION OF ELECTRIC AND WEAR PHENOMENA OF LIQUID METAL WETTED COPPER FIBER BRUSHES UNDER CONDITIONS OF HIGH SLIP RING ECCENTRICITY		5. TYPE OF REPORT & PERIOD COVERED Research and Development
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Neal A. Sondergaard and Patrick Reilly		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David Taylor Naval Ship R&D Center Annapolis, Maryland 21402		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 61152N Program No. ZR00001 Task Area ZR0240101 Work Unit 1-2712-121
11. CONTROLLING OFFICE NAME AND ADDRESS David Taylor Naval Ship R&D Center (Code 012.3) Bethesda, Maryland 20084		12. REPORT DATE October 1984
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Current Collectors
Liquid Metals
Homopolar Machines
Fiber Brushes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Metallic fiber brushes wetted with a liquid metal could potentially provide a current collector for large scale homopolar machinery. This study investigates brushes composed of copper fibers swaged together at one end and wetted with the liquid metal, Nak78. The brushes are forced to carry current while an eccentric slip ring compresses and releases the fibers, modeling the effect of rotor runout in a full scale collector. Preliminary studies indicate that these brushes are not transferring noise free steady current nor maintaining low levels of wear.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Amps
cc	Cubic Centimeters
cm	Centimeter
CO_2	Carbon Dioxide
CU	Copper
DEG C	Degrees in Centigrade
kW	Kilowatt
MA/m^2	Mega Amps/Square Meter
mg	Milligram
mm	Millimeter
mV	Millivolt
MW	Megawatts
μm	Micrometer
Nak_{78}	Eutectic mixture of sodium (22%) and potassium (78%)
PPM	Parts per million
rev/sec	Revolution per second
sec	Second
TEMP	Temperature

ABSTRACT

Metallic fiber brushes wetted with a liquid metal could potentially provide a current collector for large scale homopolar machinery. This study investigates brushes composed of copper fibers swaged together at one end and wetted with the liquid metal, Nak_{78}. The brushes are forced to carry current while an eccentric slip ring compresses and releases the fibers, modeling the effect of rotor runnout in a full scale collector. Preliminary studies indicate that these brushes are not transfering noise free steady current nor maintaining low levels of wear.

ADMINISTRATIVE INFORMATION

This work was performed under the Fiber Brush Current Collector Program, Task Area ZF66-512-001 sponsored by DTNSRDC Independent Research Program, under the direction of Dr. David Moran, Code 0120. This work was accomplished under Work Unit Number 1-2710-121-10 in the Electrical Machinery Technology Branch, Electrical Systems Division of the Propulsion and Auxiliary Systems Department of the Center.

INTRODUCTION

The development of advanced electric propulsion machinery offers tremendous benefits to the Navy in fuel efficiency and flexibility of ship design and component layout.[1] A critical area of technology development for direct current homopolar motors and generators intended for electric propulsion is the current collector which is the electrical interface between the rotating and stationary members of the machine. Laboratory scale (300 kW) machinery, utilizing liquid metal braid current collectors has been successfully demonstrated.[2,3,4] In these machines, a copper braid was assembled as an interference fit between the rotor and stator in the current collector which the rotor would wear to a minimum clearance of approximately 25 to 50 μm. The 300 kW motor and generator have rotor diameters of 30 and 12.9 cm, respectively.

When projecting to full scale (30 MW) machinery, this scheme of achieving close clearance may not be feasible because the combined effects of rotor sag, bearing runout and centrifugal and thermal growth are expected to lead to variations of the gap size of up to 1 mm. Metallic fiber brushes wetted with a liquid metal may potentially overcome this variable gap problem. Because of their inherent flexibility, the brushes should follow the surface of the rotor regardless of runout while maintaining a thin film of liquid metal at the rotor surface.

The purpose of the present study was to investigate the electrical and wear phenomena associated with current carrying, liquid metal wetted, copper fiber brushes under conditions of high runout.

DISCUSSION OF EXPERIMENTS

The brushes used in this investigation were provided by Westinghouse Corporation and have been extensively discussed in the literature[5,6,7] when run under the experimental conditions of wet CO_2 cover gas and no liquid metal. They consist of 168 fibers, 2.54 cm long and 127 µm in diameter swaged together at one end. A diagram of the brush with other dimensions and a photo of a typical brush is shown in Figure 1.

The brushes were assembled into a captive, screw type holder so they could be easily removed after the experiment. The clamping nuts of the holder were instrumented with thermocouples and voltage taps. A photograph of the brush holder is shown in Figure 2. The face of the brush is worn to the desired radius of curvature by lightly loading it against a non-eccentric rotor whose face was covered with #600 diamond impregnated paper and turning the rotor slowly by hand. The brush was considered worn in when its face was visibly observed to coincide with the contour of the rotor. The wear-in time was approximately two minutes.

The rotor used during the experiments was made of beryllium-copper with a nominal diameter of 6.35 cm and the runout was achieved by locating the drive shaft mounting center of the rotor off the axis of the true center of the disk. The runout was ±0.90 mm, a value well above predicted full scale runouts. A drawing of the rotor geometry is shown in Figure 3a. To provide additional flexibility, the brush is run at an angle relative to the rotor surface. In previous studies, these brushes were mounted in a trailing configuration, 45° with respect to rotor slip ring surface and in the same plane as the rotor face (see Figure 3b).

This is adequate if the rotor is to go in one direction only, as in a generator. In anticipation of using these brushes in a motor, a configuration was chosen which still maintains an angle of 45° with respect to the rotor face but now the brush is in a plane perpendicular to the rotor face. In addition to the two copper fiber brushes which are the subject of this study, a third fiber brush, made from niobium-titanium superconducting wire was used as a center tip for voltage measurements.

The slip ring face was silver plated to aid Nak wetting and the rest of the rotor disk was epoxy painted to prevent unwanted current conduction in those regions. The stator housing that the brushes were mounted in was made of lexan which allowed electrical isolation of the brush holders, visible observation of the liquid metal flow patterns and maintenance of a low moisture (< 3 PPM), low oxygen (< 5 PPM) nitrogen atmosphere necessary for operation with Nak_{78}. A photograph of the assembled rig is shown in Figure 4.

The brushes were loaded against the rotor with a normal load of 0.14 Newton This value was chosen to allow comparison with data taken when the brush was run with no liquid metal. Five cc's of Nak were loaded into the rig. The rotor was then turned by hand for several minutes to distribute Nak to the brushes. At this point, 5 amps was applied to the brushes and the rotor was again turned by hand. Several arcs were seen at the A brush but not the B brush. The drive motor was turned on and the Nak appeared fully distributed. The 5 amps were again turned on with no visibly apparent arcing. It was decided to proceed with the experiments, keeping in mind that one of the brushes may have been damaged by the arcing.

Data was then taken for the following experimental conditions. The top velocity for the brush surface was a constant 12 m/sec, a value which is typical for projected full scale motors, while currents of varying amounts up to 30A were passed through the brushes. The time for temperature stabilization of the brushes at each value of current was approximately 5000 sec.

The values of the voltage drop across each brush and the rotor, which was monitored by a third pick-up brush located on the rotor drive shaft were continually monitored but only the stabilized value (average value for the last 750 sec) was used as the voltage drop for a run. Values for the voltage drop across each brush is shown in Figure 5. The majority of the data were taken with brush A the anode and brush B the cathode. The leads were switched for one run and this is shown as the triangle on the above figure. Figure 6 shows typical data for the run where the brushes conducted 23A, which represents a current density in the fiber body of 10.8 MA/m^2 or about 130% of a full scale homopolar motor required current density.

The brushes were weighed before and after all the runs were completed which represented a total run time of around 16 hours.

DISCUSSION OF RESULTS

The results of the variation of brush voltage drop with increasing current for each of the copper fiber brushes investigated is shown in Figure 5. Each data point is a result of an experiment such as shown in Figure 6. Previous studies with liquid metal collectors suggest that wetting sometimes improves with increased current density, presumably due to temperature effects, and manifests itself with non linear voltage-current plots as well as improvement in voltage drop performance after a high current density is achieved. Neither of these phenomena is in evidence here. Data taken after the 30 amp run was not significantly different from those taken before the run and the slope of the voltage current curve is linear. The value of the voltage drops are a factor of two better than literature[6] values of the same brush running with wet CO_2 cover gas and no liquid metal. Although any reduction in contact drop is a beneficial finding, this is far from what one would expect (one to two orders of magnitude) using liquid metals. This higher than anticipated drop is probably due to the severe brush distortion discussed below.

A well known phenomenon in solid brush and dry fiber brush technology[5], the anode-cathode effect, that is, voltage drops of different magnitude (as well as direction) in a brush depending on the direction of the current, is also absent. The triangles on Figure 5 are the values of the voltage drops with the leads reversed. These results were expected, when using liquid metals to wet the interface.

Figure 6 shows data taken for the 23 amp run, where the current in the fiber body corresponds to full scale motor current density. It is noticed immediately that the voltage drop (6c and 6d) is somewhat noisy. The sampling rate of the data acquisition system used in this study was not sufficiently high enough to allow meaningful Fourier analysis or to obtain detailed measurements of the brush parameters as a function of the position of the rotor. However, the trend is clear that the brushes are not following the rotor and carrying current in a smooth manner.

Figure 6c and 6d show variations of the brush voltage drop with time (and implicitly temperature). The brushes are behaving complementary, maintaining a constant total voltage drop across the rig. This behavior was repeated in several of the other runs and is not explained, since one would predict increasing brush drop (increasing rig resistance) for both brushes as the temperature increases due to increasing copper resistivity.

Figure 7 is a sketch of the rotor showing the general characteristics of the rotor condition after the experiment. When one considers the runout condition, the area of the rotor where compression is the highest forms the maximum of a lobe. As the rotor turns, the area before the lobe is clean and silver plated. Light grooving starts as the lobe comes in contact with a brush. Light followed by heavy pitting is evident, suggesting some arcing may be occurring. In the area of the lobe maximum, silver plating was completely worn away and very pronounced grooving occurred. At the trailing edge of the lobe, the grooving and silver plating deterioration became less pronounced. The opposite side of the lobe showed no wear.

Figures 8 and 9 show the copper fiber brushes after the experiments. Both brushes show severe distortion from their pre-run condition. There was considerable loss of flexibility and evidence of welding of fibers together. The weights of each brush changed by only fractions of a gram (A brush 6.1 mg, B brush 21.1 mg, less than 1% and 3% of the brush weights, respectively) but it is clear from from the photographs that elevated temperatures were reached during the operation and taken in concert with the pitting marks and noisy voltage and current measurements, some arcing or intermittent contact was likely although none was visibly observable. As mentioned previously, there were several visible arcs on Brush A when current was applied immediately after Nak addition and several hand rotor rotations. This may explain some of the distortion and welding on one brush but not on B brush which showed no visible signs of arcing. Nak depletion near the brush seems unlikely, considering the flow (see next paragraph). Further experimentation is required to identify the cause of a possible correction of this severe brush distortion.

Previous experiments[8] in this laboratory with liquid metal wetted Niobium brushes raised the question of distortion of the fluid velocity profile by a single brush in the Nak flow field. It was observed that the flow pattern was severely distorted by the brushes, the deflected Nak dipping down along the rotor face by about one centimeter. Therefore, depletion of Nak near the brushes should not be a problem. However, one should be aware of this phenomenon when interpreting data with a single brush in the liquid metal flow field. As the slip ring surface becomes more populated with brushes, this flow distortion should become less pronounced.

When one compares the capabilities of these brushes with reported literature values, a considerable discrepancy exists. There are several areas that are different in the present experiment which may explain the differences.

First, the brushes in the literature were run on copper rotors whereas these experiments employ beryllium-copper rotors. Hardness, electrical conduction and heat transfer characteristics of the two materials are considerably different. Higher voltage drops, interface temperatures, and wear may result.

Secondly, the brushes are being run in the perpendicular rather than the trailing configuration. Previous studies in this laboratory[9] have shown these brushes incapable of literature[5,6], performance figures when run in the perpendicular configuration in a wet CO_2 atmosphere and no liquid metal. Furthermore, when grouped together into a continuous slip ring also in the perpendicular configuration and assembled into a 37 kW homopolar motor, these brushes again showed excessive wear after limited operation.[7]

Finally, these experiments represent rather severe conditions of runout while previous studies were done on rotors running as true as possible. Not only is the brush forced to travel ±0.90 mm, a number 80% higher than expected for a full scale rotor, but with the small motor of this experiment, it is doing it at high frequency (60 rev/sec rather than 3 rev/sec) and over a much smaller radius of curvature (3 cm vs 90 cm). Brushes that demonstrate stable operation under the present experimental conditions would most assuredly operate under the less stressful motor conditions while pessimism concerning negative results may be unwarranted.

CONCLUSIONS AND FUTURE WORK

Copper fiber brushes wetted with Nak_{78} have been studied under stringent current-runout conditions. Voltage current plots were linear under the conditions studied but the brushes were found to have difficulty transferring noisefree current and maintaining minimum wear. Voltage plots showed spikiness and rotor wear patterns showed pitting, both indicative of arcing. This was further confirmed with the observation of large areas of welding of fibers in the brushes themselves.

Efforts are underway to further investigate these brushes. First, one experiment will try to reproduce literature conditions, that is, concentric slip ring, trailing configuration of the brush and pure copper rotor. The same configuration will then be investigated with Nak added to the brushes. Following these studies the perpendicular configuration will be reinvestigated beginning at slower speeds and reduced slip ring eccentricity. The range of investigation should proceed to include larger diameter slip rings with lower frequencies of revolution for a given tip velocity. Variations of brush load and better Nak supply in the brush area will be investigated. Finally, considerable improvement in interpretation would result with faster data acquisition. For example, if the acquisition can be triggered to begin as the lobe approaches the brushes, better understanding the effects of the eccentricity will result. Efforts are underway to implement this scheme.

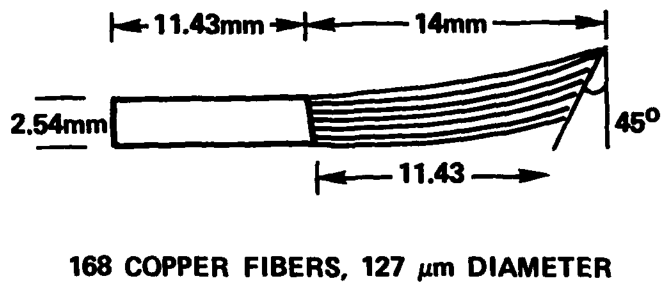
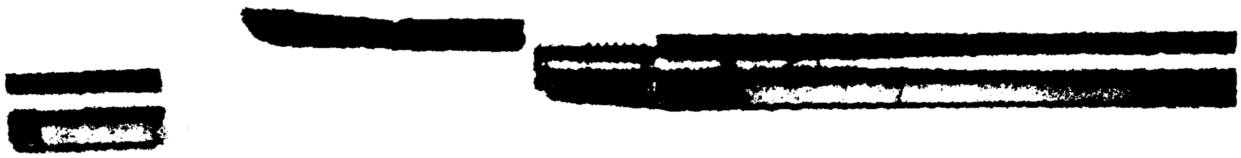


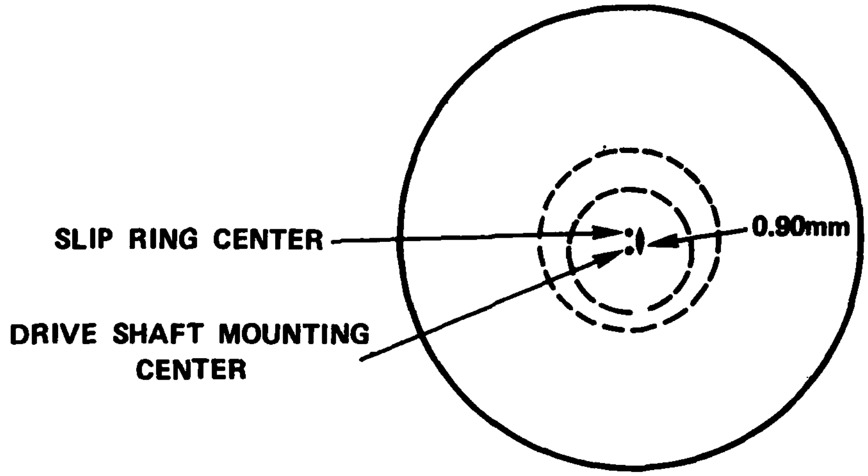
Figure 1 - Sketch and Photo of Copper Fiber Brushes of this Investigation



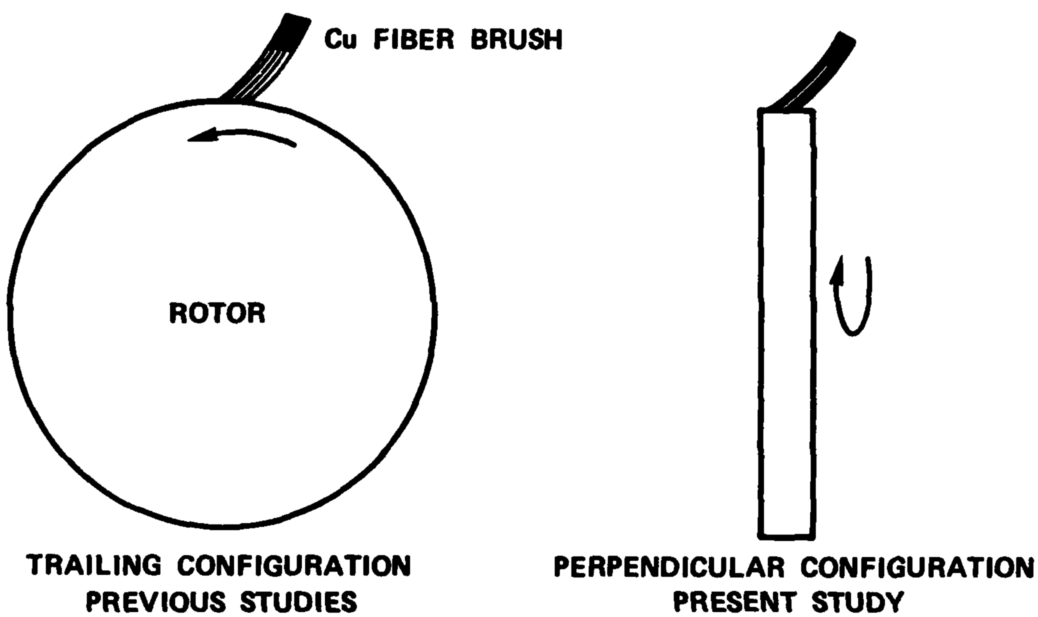
(a) Unassembled

(b) Assembled

Figure 2 - Photos of Brush Holder



a) Achievement of Runout by Offsetting Drive Center from Slip Ring Center



b) Two Possible Configurations for Contacting Fiber Brush to Slip Ring

Figure 3 - Brush-Slip Ring Geometries in Present Experiments

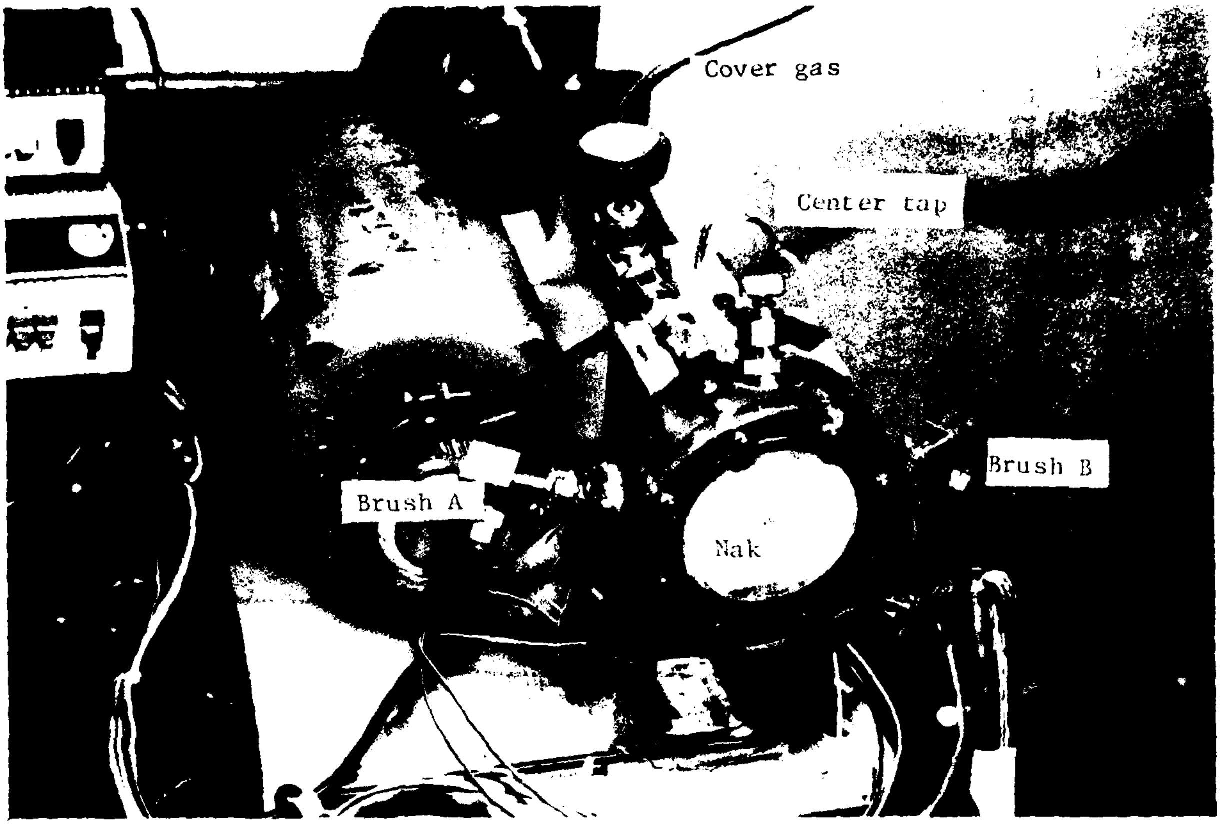


Figure 4. Brushes Assembled in Eccentric Rotor Apparatus

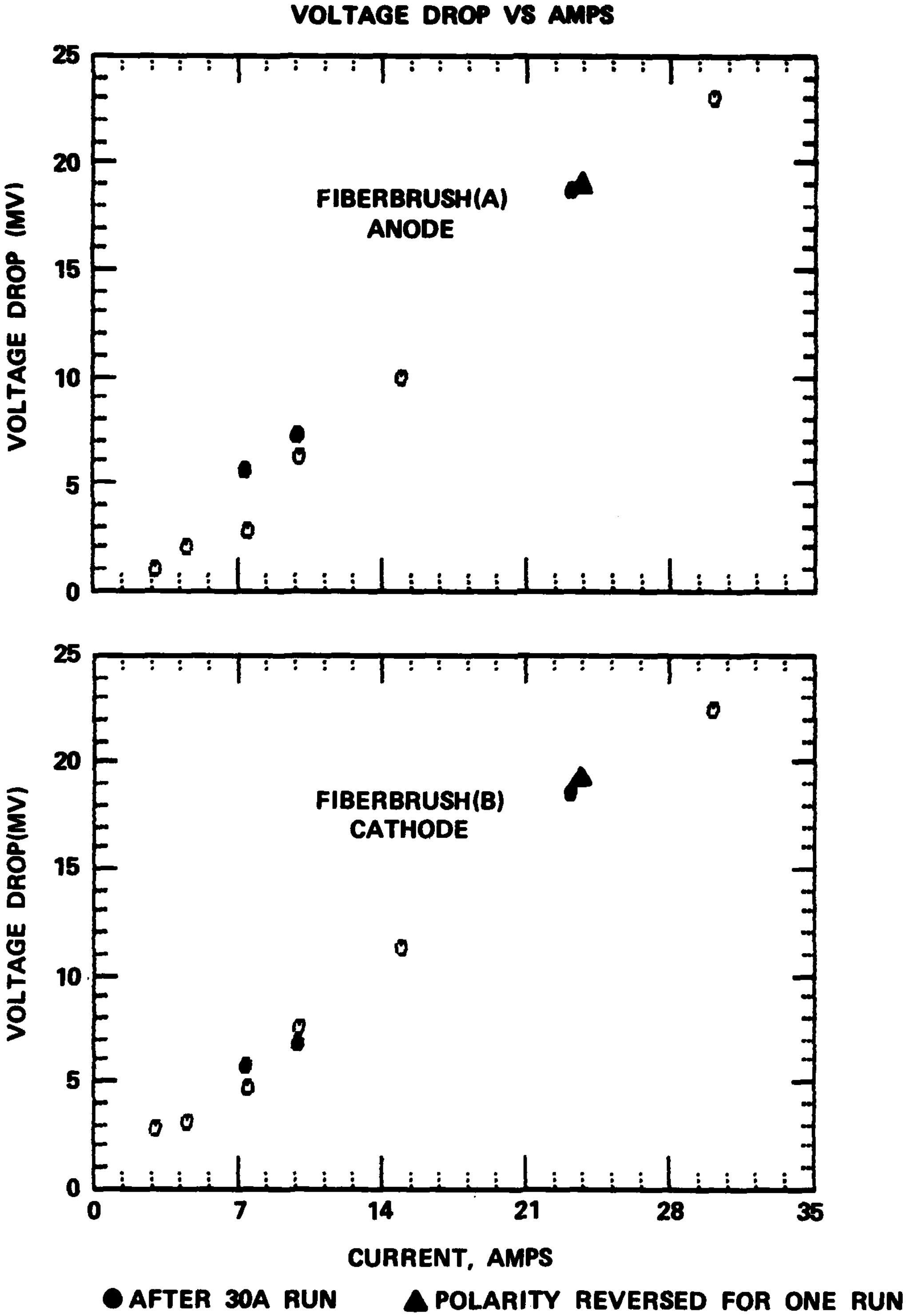


Figure 5 - Voltage Drop-Current Relationship for Copper Fiber Brush Experiments

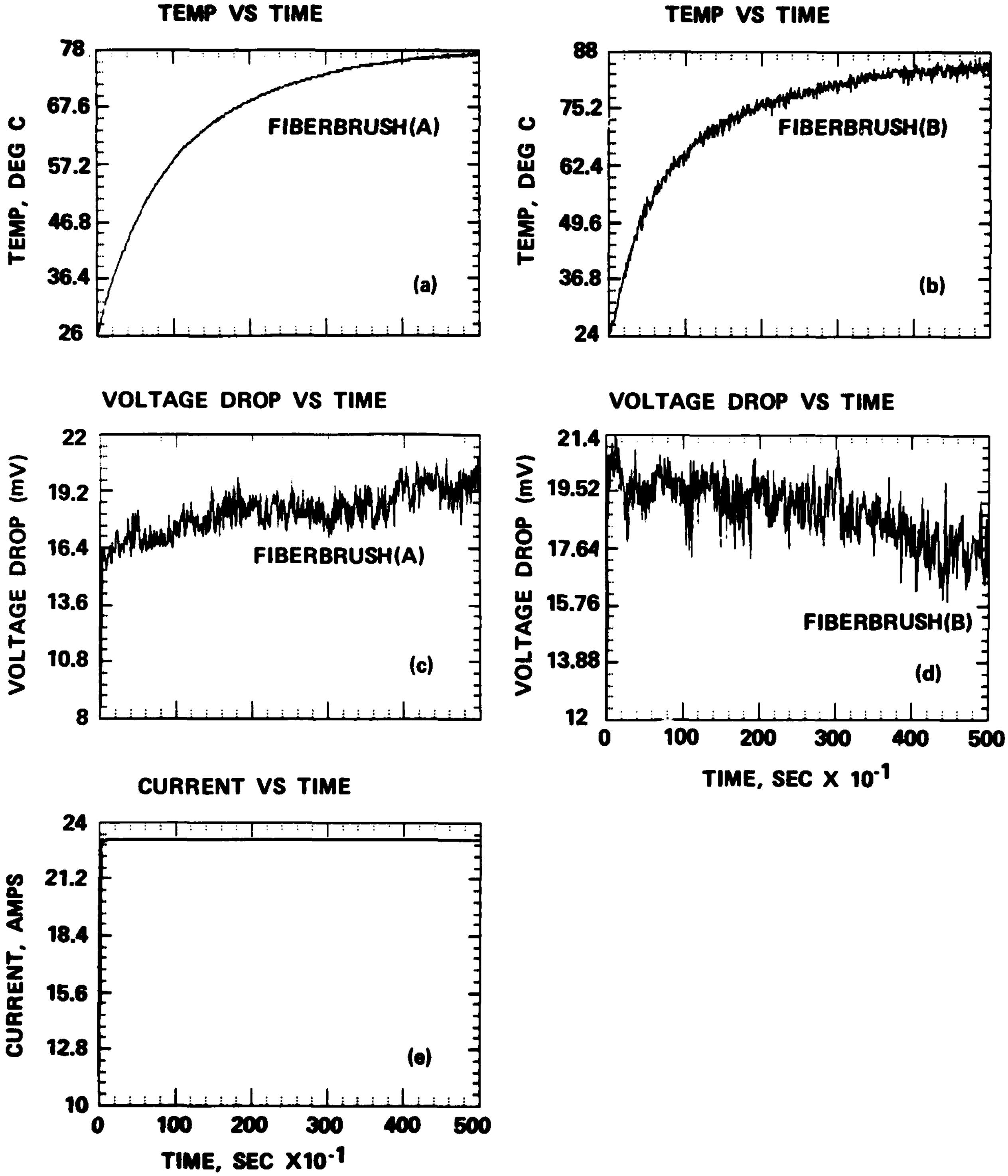


Figure 6 - Data for 23 Amp Copper Fiber Brush Experiment

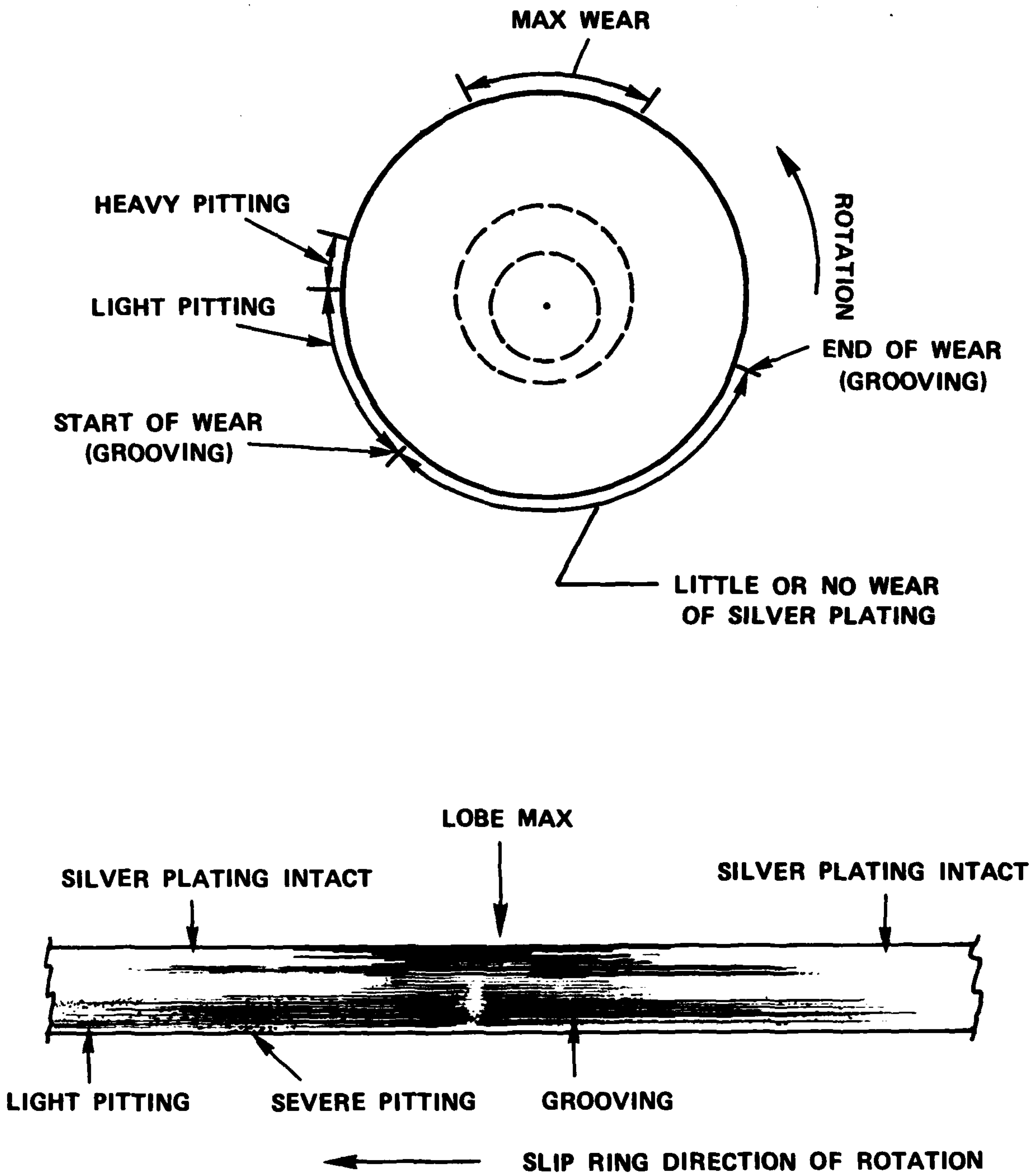
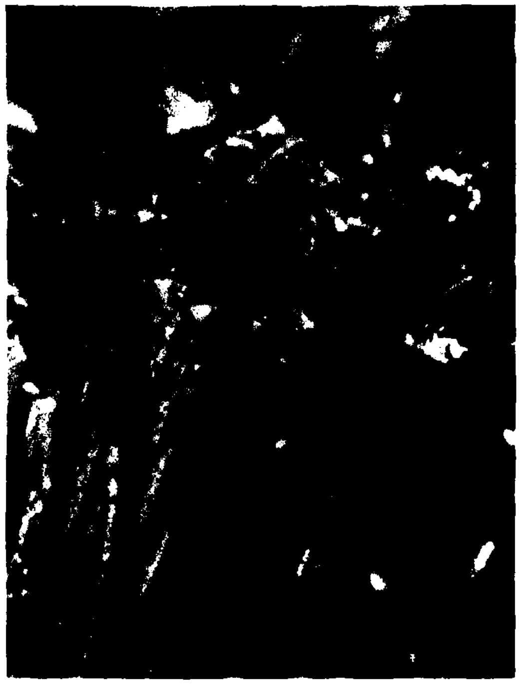


Figure 7 - Wear Pattern on Eccentric Rotor for Copper Fiber Brush Experiment

X 10



X 40

X 40

Figure 8. A Brush After Experiment

X 10

X 20

X 40

X 70

Figure 9. B Brush After Experiments

REFERENCES

1. "Superconducting Machinery for Naval Propulsion", H. O. Stevens, M. J. Superczynski, T. J. Doyle, J. H. Harrison, and H. Messinger, IEEE Transactions on Magnetics, Vol. Mag. 13, No. 1, Jan 1977.

2. "Development of Shaped Field Superconducting Motor", T. J. Doyle and M. J. Cannell, DTNSRDC Report No. 4178, 1974.

3. "No Lead Testing of the Shaped Field Superconductive Motor", H. N. Robey, M. J. Cannell, and L. T. Dunnington, DTNSRDC Report 79/076.

4. "Acyclic Superconducting Generator Development, 400 Horsepower Generator Design", M. J. Cannell and H. O. Stevens, DTNSRDC Report No. PAS 81/14 1982.

5. "Metallic Brushes for Extreme High Current Applications", P. Reichner, PWC 25th Anniversary Meeting, Holm Conference on Electrical Contacts, pp. 191-197, Sept 1979.

6. "High Current Tests of Metal Fiber Brushes", P. Reichner, Proceedings of 6th Annual Meeting, Holm Conference on Electrical Contacts, pp. 73-76, Sept 1980.

7. "Advanced Electric Drive Motor Test and Evaluation", O. S. Taylor and S. J. Scuro, Proceedings of 1983 International Current Collector Conference, pp. 156-176, Oct 1983.

8. "Studies of Liquid Metal wetted Metallic Fiber Brush Current Collector", Neal Sondergaard, Proceeding of 1983 International Current Collector Conference, pp. 217-245.

9. "Electrical Studies of Non-Liquid Metal Wetted Copper Fiber Brushes", Carol Cowan and Neal Sondergaard, DTNSRDC TM-27-84-59.

INITIAL DISTRIBUTION

Copies

2 NAVSEA
- 1 SEA 05R31
- 1 SEA 06R

2 ONR
- 1 Code 430
- 1 Code 431

2 DTIC

CENTER DISTRIBUTION

Copies	Code
2	271
1	2710
3	2711
15	2712
1	2702
1	012
1	522.1
2	5231

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.