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MECHANISM OF SILOXANE VAPOR INDUCED EXCESSIVE BRUSH WEAR IN TOTALLY ENCLOSED DC MOTORS

SF 013-12-09 TASK 4643

Lab. Project 9400-7, Final Report

Rainer J. Katzenstein

31 August 1966

# TECHNICAL REPORT

U.S. NAVAL APPLIED SCIENCE LABORATORY
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BROOKLYN, NEW YORK 11251



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3ND USNASL-9800-P-1A (REV. 7-63)

# MECHANISM OF SILOXANE VAPOR INDUCED EXCESSIVE BRUSH WEAR IN TOTALLY ENCLOSED DC MOTORS

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## ABSTRACT

Surface chemistry studies on the interfaces of components of class H totally enclosed DC motors indicate that siloxane vapors containing the Si-H moiety as an original contamination and as a result of thermal degradation of the vapor, interact with both the carbon brush and the copper commutator segments. Based on these interactions, a mechanism for the excessive brush wear in siloxane vapor contaminated atmospheres in totally enclosed DC motors is postulated. Recommendations are made for further studies to minimize or eliminate this wear.

Lab. Project 9400-7
Final Report


SUMMARY

Surface chemistry studies of thermally induced surface interactions and autoradiographic studies were carried out using both inert and $C^{14}$ tagged hexamethyldisiloxane. Results indicate that the Si-H moiety, present originally as an impurity in the vapor or produced by thermal degradation of the siloxane vapors, reacts with both the carbon brush and copper commutator of the totally enclosed DC motor. A mechanism for the siloxane vapor induced excessive brush wear is postulated by which excessive carbon brush wear is attributed to a combination of siloxane catalyzed oxidation of the brush carbon and a rapid, continuous formation, build-up, and stripping of a high strength dielectric film deposited by the carbon brush on the commutator segements. Recommendations are made for significant reduction and eventual elimination of brush wear by impregnation of conventional brushes with non-volatile reactive additives.

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## ADMINISTRATIVE INFORMATION

Ref: (a) NASL Program Summary dated 1 May 1966, SF 013-12-09, Task 4643
(b) NASL Program Summary dated 1 May 1965, SF 013-12-09, Task 4643
(c) NAVSHIPYD NYK MATLAB Project 5332-15 Part 2, Progress Report 2 of 4 Jun 1963
(d) NASL Project 5332-15 Part 2, Final Tech. Memo of 7 Jul 1964
(e) NASL Project 9400-7, Technical Memorandum 2 of 30 Nov 1964
(f) NASL Project 9400-7, Technical Memorandum 4 of 11 Aug 1965
(g) NASL Project 9400-7, Technical Memorandum 10 of 8 Aug 1966

In accordance with the objectives set forth in references (a) and (b), the U.S. Naval Applied Science Laboratory has conducted a research and development investigation of the fundamental nature of siloxane vapor-induced excessive brush wear in totally enclosed DC motors. Reported herein are the results of surface chemistry studies of the interaction of siloxane vapors with brush carbon and commutator copper components. A mechanism is postulated, based on all findings to date, to account for the excessive carbon brush wear noted in siloxane vapor-contaminated totally enclosed DC motors. Recommendations are made which will provide for immediate and interim use, significant reduction in brush wear; long range recommendations are advanced which could lead, eventually, to its complete elimination.

## ACKNOWLEDGMENTS

This study was conducted by R.J. Katzenstein, E. Eilen, and L. Lihach under the supervision of B.B. Simms, Head, Organic Chemistry Branch. The cooperation and efforts of J. Erikson in the design of a new carbon brush-commutator chamber for use with a $C^{14}$ radioactively tagged siloxane vapor are acknowledged. The Naval Ship Systems Command and Naval Ship Engineering Center Program Manager and Project Engineer are A. Chaiken (03414) and G.B. Gustafson (6660E), respectively.

## OBJECT

To investigate the mechanism of siloxane vapor induced excessive wear of standard carbon contact brushes in totally enclosed polysiloxane insulated "Class H" DC motors. To develop a practical chemical treatment for conventional brushes to permit their use in siloxane vapor-contaminated motor atmospheres.

## INTRODUCTION

The use of siloxane derivatives in Class H totally enclosed shipboard DC motors is currently prohibited due to excessive wear of carbon brushes associated with their use. Future naval operational requirements and design concepts show a trend towards miniaturization of shipboard devices, with resultant increase in operating temperature for peak efficiency. Fundamental knowledge of the role of siloxane vapors in the excessive wear of carbon brushes is necessary to develop effective brush treatments which will minimize excessive wear while not significantly altering desirable commutation characteristics.

Initial efforts were devoted to the development of a reliable method for the detection of minimum concentrations of siloxane vapors. A device was then developed for generating known and controlled siloxane vapor contaminations in air for use in brush wear studies in rotating machinery. This information was described previously in reference (c). Actual siloxane vapor concentrations of 10 ppm were found in operating totally enclosed "Class H" polysiloxane insulated motors. These results were reported to NAVSEC in reference (d). Mechanism studies were conducted in a static arcing device which was designed to eliminate frictional effects. Brush wear measurements in siloxane vapor contaminated atmospheres were made as described in reference (e). Results indicated that during arcing, the expected oxidation of the carbon brush occurred. However, the studies showed that the oxidation was accelerated by the presence of the siloxane vapors. Based on these results, feasibility studies were conducted which indicated, as reported in reference (f), that brush wear could be appreciably reduced by impregnating the brushes with antiozonants and other stabilizing chemicals without significantly affecting the commutation characteristics.

Brush contact voltage and coefficient of friction studies, previously described in reference (e) suggested that carbon brush wear occurs by a repetitive cycle of building-up and a stripping of a dielectric lubricating film on the commutator segments. The build-up phase manifests itself in a gradual increase in the brush contact voltage, while the stripping phase produces a characteristic sharp IR drop, accompanied by a simultaneous momentary frictional extreme. This cyclic behavior further suggested that an interaction occurs between the surfaces of the copper commutator segments and the brush carbon which involved the siloxane vapor, and which produces the observed IR drop. To verify this postulated mechanism, surface chemistry studies were carried out using radioactive $C^{14}$ labelled siloxanes to investigate the nature of this interaction of the siloxane vapor. In addition, investigations were carried out to determine the presence of siloxanes on the surfaces of these motor components, and their distribution pattern.

## EXPERIMENTAL

### Thermal Interaction Studies

Interaction of siloxane vapors with carbon and copper surfaces were carried out in a novel manner using specially prepared sample columns containing ground brush carbon (60-80 mesh) or copper powder (100 mesh). These columns were used in an Aerograph Model 350 dual column gas chromatograph equipped with a thermal conductivity detector. Changes in composition of the effluent siloxane vapors were observed by separately introducing 5 µl samples of hexamethyldisiloxane into the columns containing the carbon and copper. These packed columns were maintained at temperatures ranging from 25 to 350°C; measurements of concentration and nature of the effluent siloxanes were then made. Confirmation of carbon and copper interactions with siloxane vapors was undertaken with the same instrumentation assembly using radioactive $C^{14}$ tagged hexamethylsiloxane in lieu of the inert material and a column temperature of 250°C. To insure sufficient isotopic pick-up for precise quantitative measurements, the experiment was repeated approx. 200 times using the same column substrates, after which the column was cut open. The amount of radioactive siloxane reacted with the substrates was determined by scintillation counting on a weighed fraction of the column material.

Autoradiographic Studies

Radioactive $C^{14}$ tagged hexamethyldisiloxane vapors at concentrations of about 10 ppm in air were passed for 72 hours into the carbon brush-commutator chamber shown in Figure 1. The chamber had been specially designed to permit radioisotope studies. At the completion of the experiment the commutator strip and the surface of the brush in contact with it, were each held in contact with no-screen x-ray film for 14 days. Enlarged prints were then examined for isotope pick-up and distribution patterns.

Study of Siloxane Vapor Changes at Elevated Temperatures

Hexamethyldisiloxane vapors were passed over substrates of powdered brush carbon and powdered copper maintained at different temperatures over a 25°-650°C range. Samples of the effluent gases were collected in a 40 meter gas cell of a Perkin-Elmer Model 21 Double Beam Infrared Spectrophotometer. The physical arrangement of this equipment is shown in Figure 2. Qualitative and quantitative differences in the infrared spectra in the 2-15 μ range were evaluated in terms of chemical rearrangement or other significant changes in the spectrum of the siloxane vapor.

## RESULTS

Thermal Interaction Studies

The data for the thermal interaction studies of hexamethyldisiloxane with carbon brush surfaces are shown in Figure 3. Results indicate that up to 200°C no interaction with the brush carbon is observed. At 250°C a loss of 15% of the siloxane vapor was obtained. The absence of new retention peaks in the fractogram of each of the samples indicates that a surface adsorption had occurred rather than a molecular rearrangement or decomposition. Results from the siloxane vapor-copper interaction study, shown in Figure 4, indicate that no apparent interaction occurs up to 350°C. Surface interaction studies at 250°C using radioactively tagged siloxanes showed the presence of siloxanes on both surfaces, as indicated in Table 1. The apparent discrepancy in results obtained from thermal conductivity measurements which shows no siloxane vapor absorbed on copper, and the data from the scintillation counting which does, is attributed to the much lower sensitivity of the former technique. The maximmum sensitivity of thermal conductivity detectors are approximately 0.01%; the adsorbed siloxanes on the copper surfaces, as determined by scintillation counting, were of the order of 0.004% and 0.0007%, both substantially below the minimum detectable limit of the gas chromatograph.

Autoradiographic Studies

Autoradiographs of the surfaces of a carbon brush and a copper commutator strip, after operating for 72 hours under load conditions, are shown in Figures 5 and 6, respectively. These autoradiographs demonstrate the generally uniform distribution of the tagged siloxane over the entire area of both surfaces. On repeating this experiment under no-load conditions, no radioactive material was detected on either component.

Study of Siloxane Vapor Composition at Elevated Temperatures

Results of the interaction of siloxane vapor with the surfaces of brush carbon and copper powder are shown in Tables 2 and 3, respectively. These data show that no interaction occurs at room temperature. Over the range of 250-550°C, however, a decrease in the Si-H band at 4.7 μ is noted in the vapor samples after passing over the heated beds. A more pronounced decrease in Si-H was noted for a sample of powdered carbon obtained by crushing a carbon brush which had been impregnated as described in reference (f).

## DISCUSSION

Specially designed experimental studies were conducted to elucidate the mechanism of siloxane vapor induced excessive carbon brush wear in totally enclosed DC motors. Compilation of the data and critical examination of the results provides a better understanding of the role of siloxane vapors in the chemical reactions shown to occur on the surfaces of the carbon brush and commutator strips which result in excessive losses of carbon. Generally, investigations conducted indicate conclusively that in the presence of siloxane vapors excessive wear of carbon brushes in totally enclosed DC motors is attributable to a combination of (a) catalytic oxidation of brush carbon and (b) a repetitive momentary deposition and subsequent stripping of a high strength dielectric carbon film on the commutator strips. Dramatic confirmation of a siloxane vapor-catalysed carbon oxidation was indicated by results of surface reaction reaction kinetic studies which showed a first order reaction for the carbon dioxide formation in siloxane vapor contaminated atmospheres, as compared to an apparent zero order reaction for $CO_2$ formation under siloxane vapor-free conditions. Support for postulating brush wear by alternately laying down and stripping a dielectric film from the commutator is derived from measurements of IR drop and coefficient of friction in an operating service-simulated motor set. In these studies more frequent, more pronounced IR drops and coincident extremely high coefficient of friction peaks were obtained in siloxane vapor contaminated atmospheres than were encountered under uncontaminated test conditions. The greater frequency of deposition and stripping of carbon from the commutator is in fact the major cause of carbon brush loss - or wear. The rate of voltage build-up is significantly greater under siloxane vapor contaminated conditions than under siloxane free atmospheres. Autoradiographic studies of surfaces of carbon brushes and commutator strips, using radioactive $C^{14}$ tagged siloxane vapors in a simulated rotating motor set showed siloxane vapor adsorption only under load conditions indicating occurrence of an irreversible chemical reaction as against a physical surface adsorption. Studies by infrared spectrophotometry to determine the nature of compositional changes in the siloxane vapors under elevated temperatures in an operating electric motor showed that the only significant change involved the Si-H (silane) group. This moiety, present in small concentrations in the siloxane vapors, is reduced by interaction with carbon and copper surfaces at temperatures for 250 to 550°C from its normal concentrations as measured in the absence of copper and carbon over the same temperatures range. At temperatures in excess of 650°C, which approaches local hot spot temperatures on brush and commutator surfaces of operating motors, formation of free Si-H fragments is accelerated.

On the basis of this information, the use of Si-H scavengers, reagents which react more effectively with the Si-H than do copper and carbon, were considered for use as brush impregnants to reduce brush wear encountered in totally enclosed DC motors. Selection of appropriate reactive additives was based on accepted practice of using aromatic primary and secondary amines in elastomer formulation to minimize oxidative deterioration and on observations of Earborn(1) who reported that silicon hydrides containing Si-H configurations react with aromatic primary and secondary amines. Use of non-volatile species of such additives as brush impregnants produced dramatic reductions in actual brush wear from 40 to 10 times that normally encountered in siloxane vapor-free motors. Interrelationship of brush wear and free Si-H was confirmed by infrared spectrophotometric measurements at elevated temperatures; substantial decreases in free Si-H concentrations were observed when these stabilizing agents were added to brush carbon particles.

## CONCLUSIONS

On the basis of the foregoing, it is concluded that:

a. Excessive carbon brush wear in Class H, totally enclosed, siloxane insulated DC motors is induced by a combination of a siloxane vapor catalyzed oxidation of carbon at the brush face and a rapid, continuous formation, build-up, and stripping of a high strength dielectric film deposited by the carbon brush on the commutator segements.

b. An appreciable reduction in excessive brush wear in totally enclosed service-simulated DC motors is attainable by use of selective reactive additives as non-volatile anti-wear impregnants in conventional carbon brushes.

## RECOMMENDATIONS

In view of the indicated brush wear mechanism, and of the significant reductions therein obtained by judicious selection of appropriate brush additives, a two-fold investigation is recommended to develop as soon as practicable, an interim brush treatment by increasing concentration of the most effective additives studied to-date, to provide, immediately, some tolerable level of brush wear, while, simultaneously undertaking a longer range study to develop more effective additives to obtain maximum wear reduction. This Laboratory considers this approach as the most feasible inasmuch as the polysiloxanes are the only currently available elastomer suitable for use as high temperature insulations in electric motors and the brush impregnations suggested, and will require no extensive alterations in conventional brush manufacturing. While much polymer research is currently being pursued to develop new superior thermally resistant materials, their availability in the near future is not immediately foreseen.

## FUTURE WORK

This completes work under Task 4643 as reported in reference (g).

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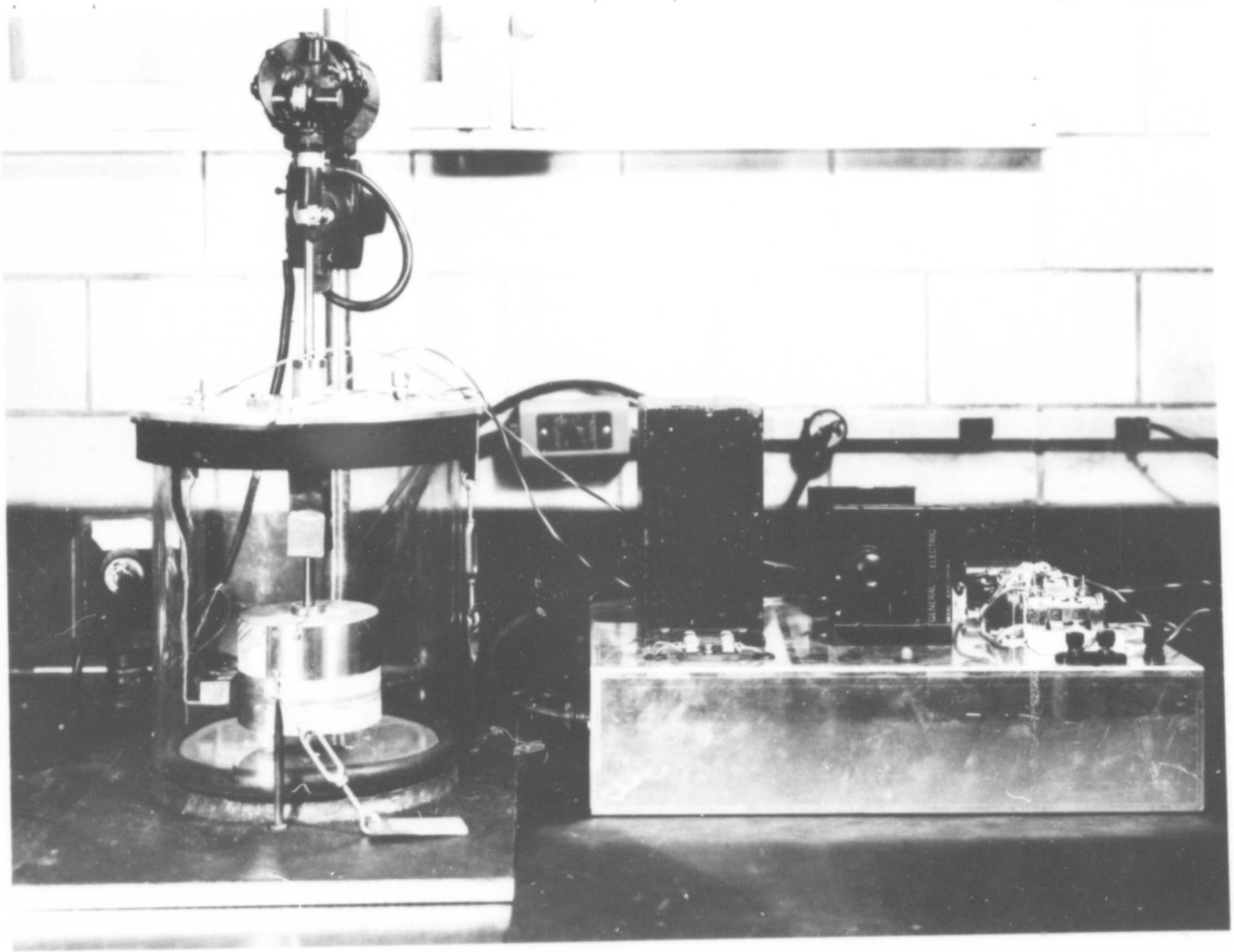

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Figure 1 - Carbon Brush Commutator Test Chamber for Autoradiographic Measurements

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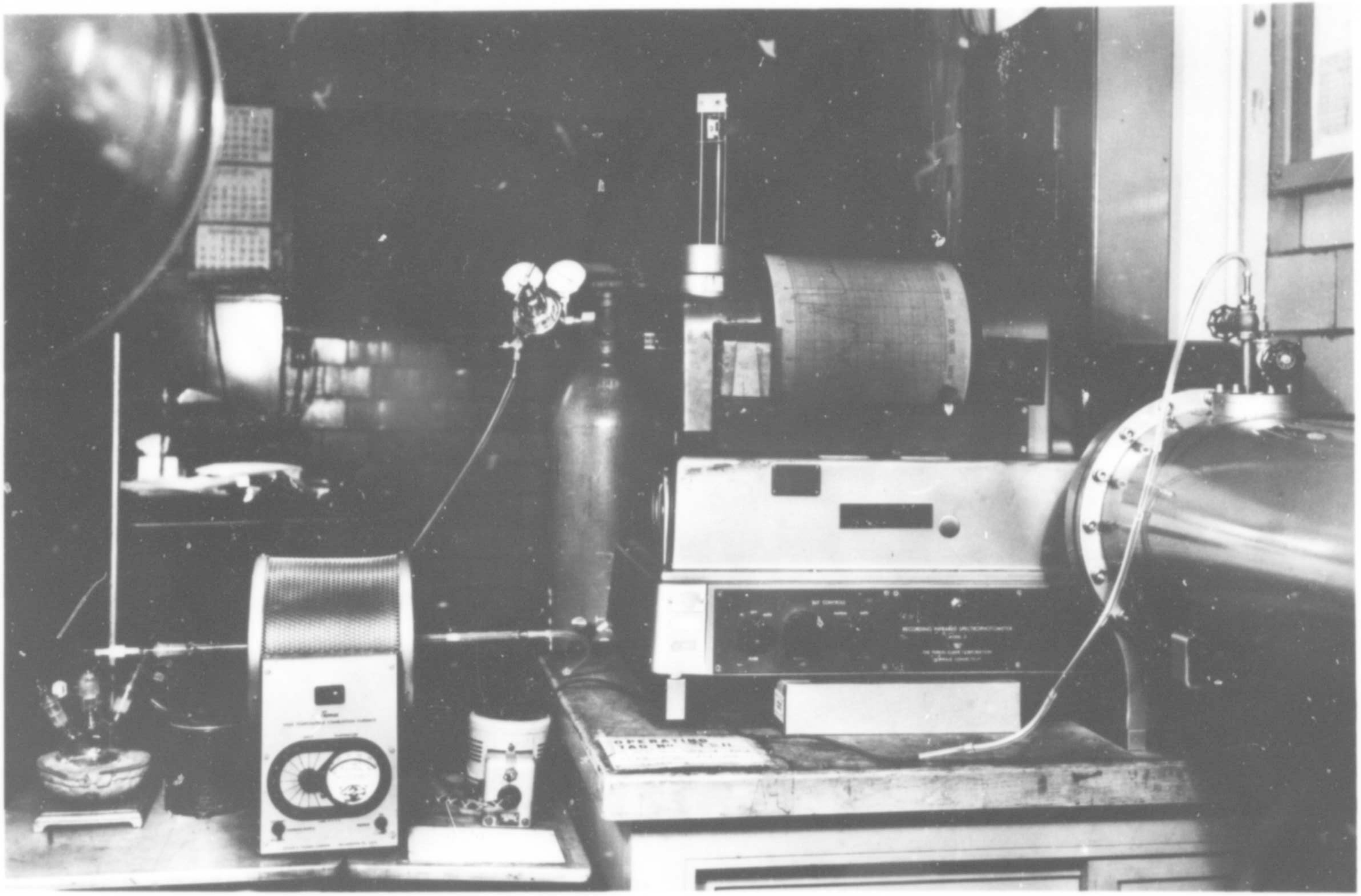

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Figure 2 - Instrumentation Used to Follow Changes in Siloxane Vapor Composition

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FIGURE 3

INTERACTION OF HEXAMETHYLDISILOXANE WITH BRUSH CARBON AT ELEVATED TEMPERATURES

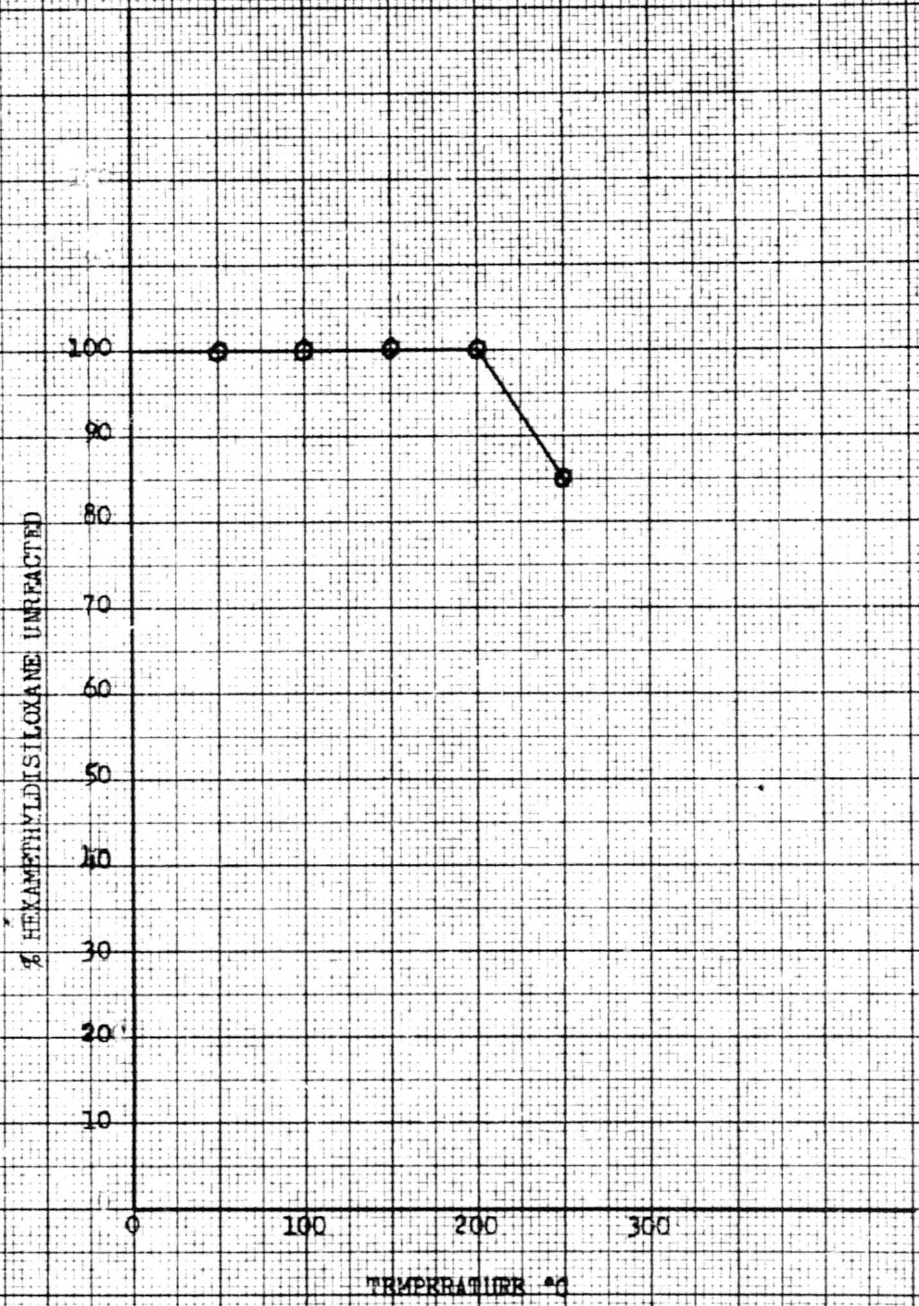

Fig 4

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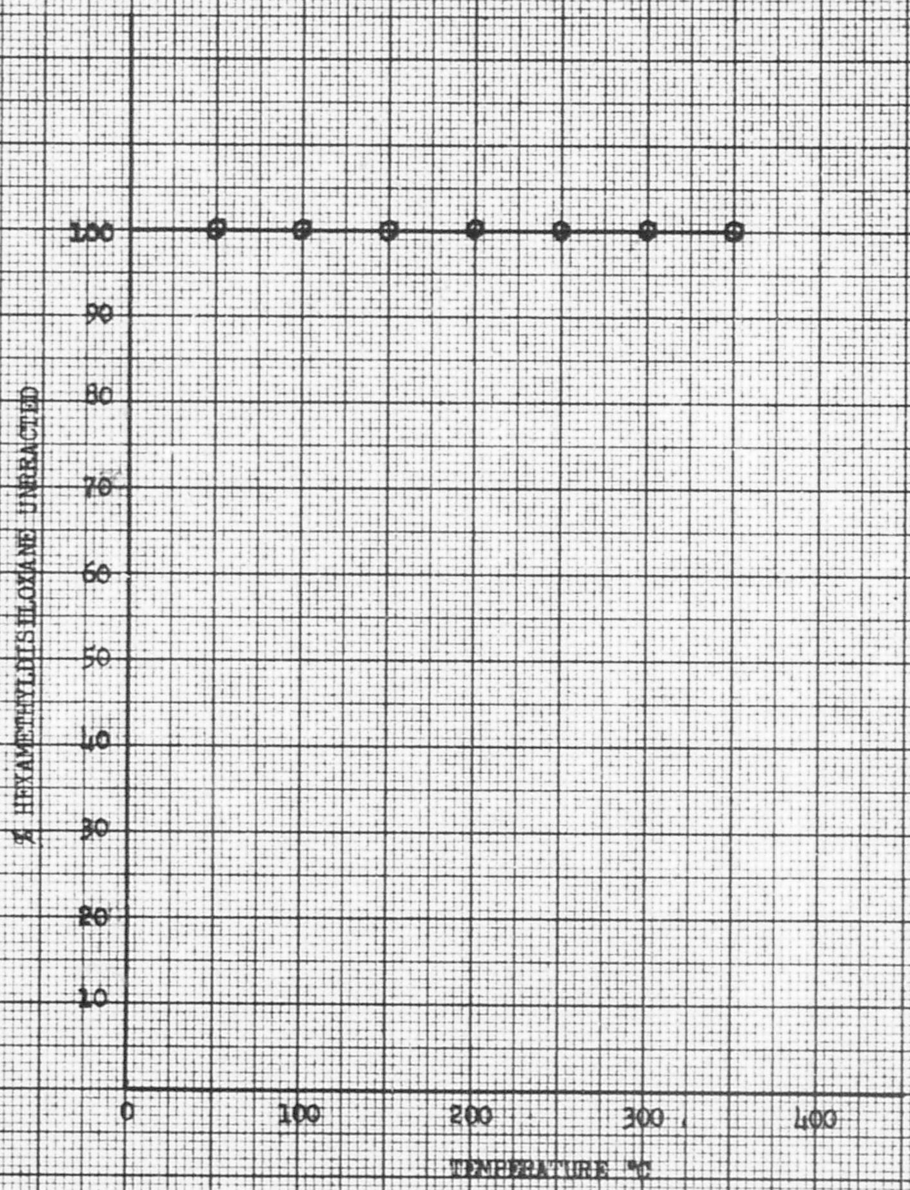
FIGURE 4

INTERACTION OF HEXAMETHYLDISILOXANE
WITH COPPER AT ELEVATED TEMPERATURES



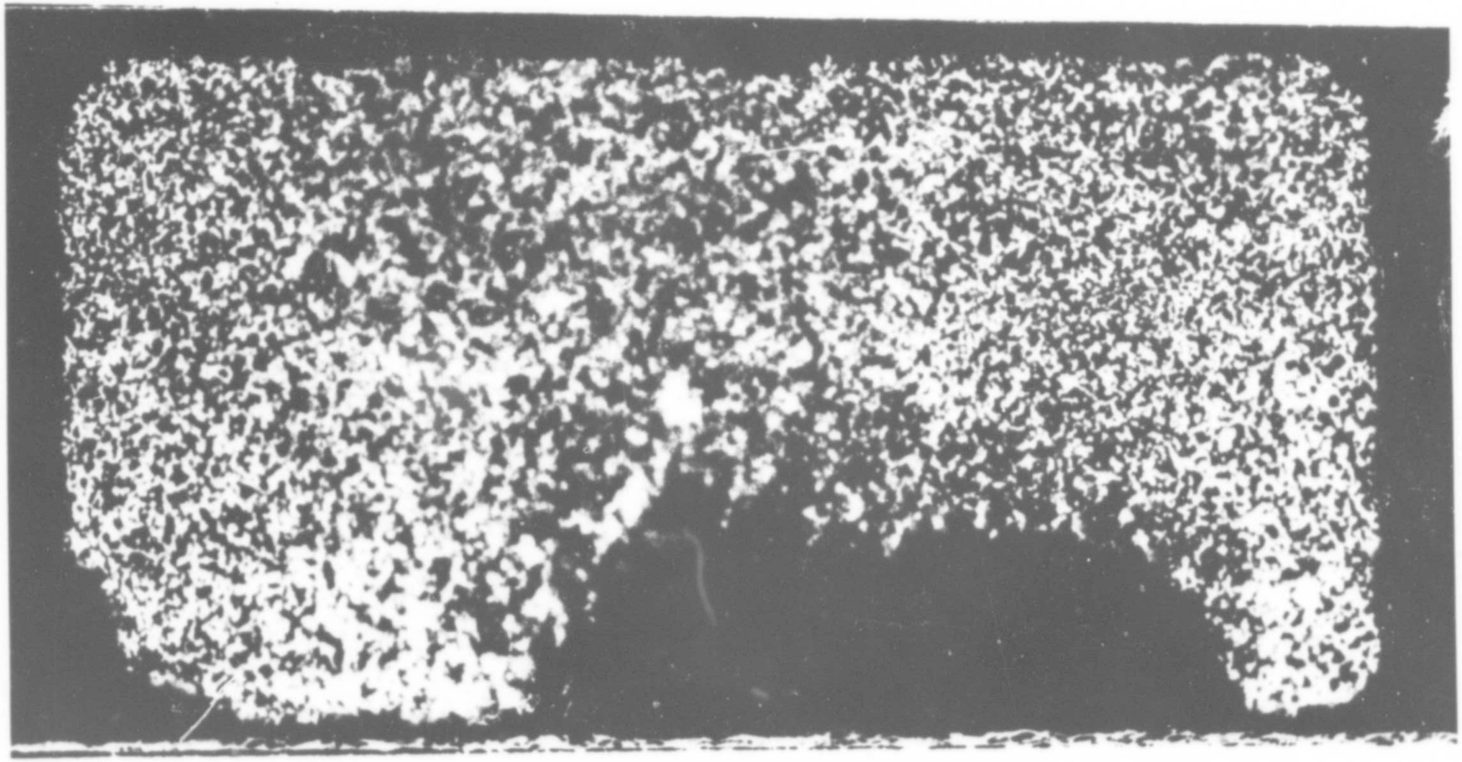


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Figure 5 - Autoradiograph of Carbon Brush After Interaction With Siloxane Vapors (Under Load Conditions)

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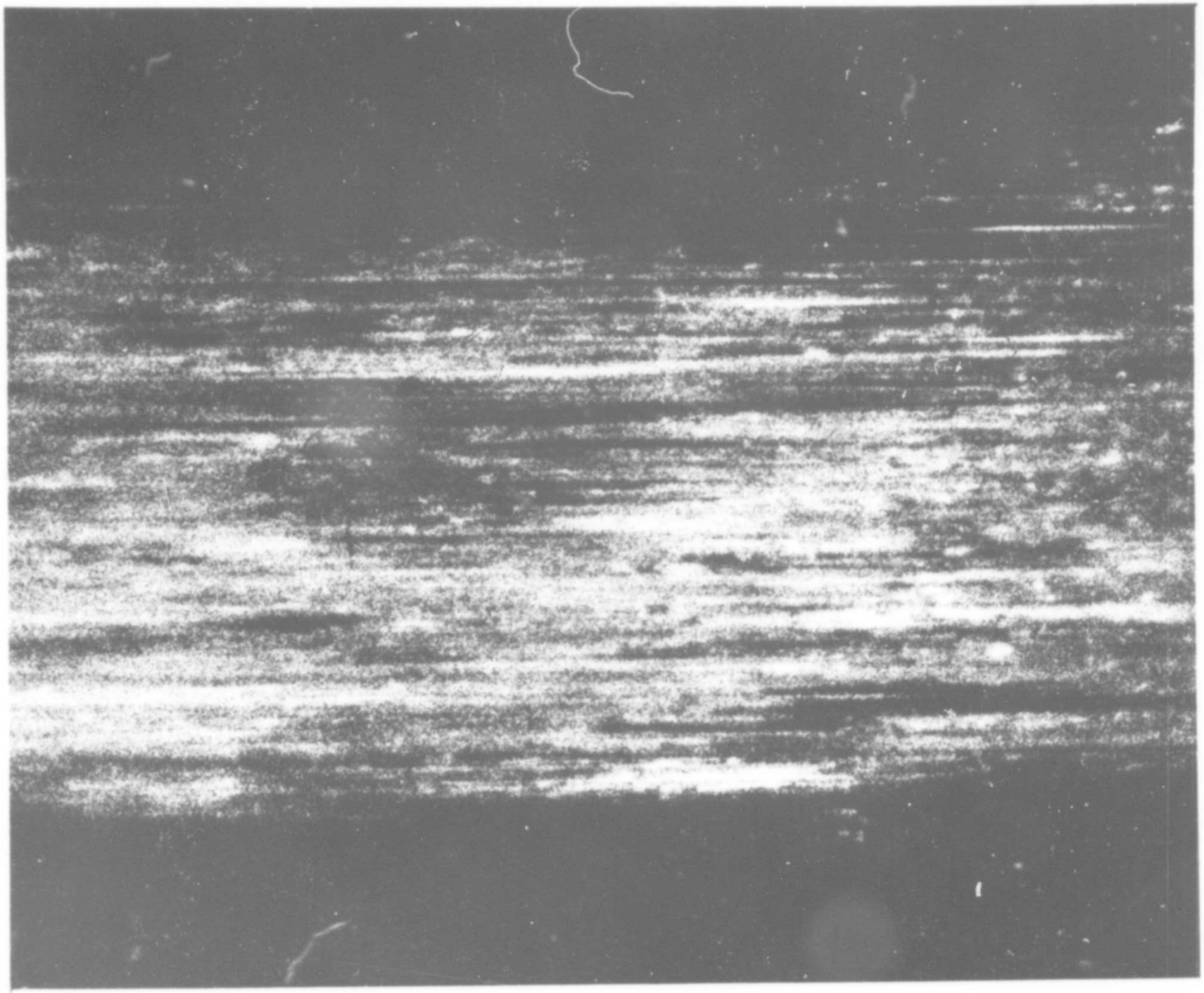

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Figure 6 - Autoradiograph of Copper Commutator After Interaction With Siloxane Vapors (Under Load Conditions)

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TABLE 1

SURFACE INTERACTION OF $C^{14}$ TAGGED HEXAMETHYLDISILOXANE (HMDS) WITH BRUSH CARBON AND COMMUTATOR COPPER

| Activity of HMDS μc/g | Total Activity Used μc | Activity of HMDS Found on Carbon μc | Activity of HMDS Found on Copper μc |
|---|---|---|---|
| 30 | 22.8 | None | $9 \times 10^{-4}$ |
| 750 | 570 | $6 \times 10^{-4}$ | $4 \times 10^{-3}$ |

Temperature of System 250°C

TABLE 2

INTERACTION OF (Si-H) WITH BRUSH CARBON AT ELEVATED TEMPERATURE

| Temperature of Substrate °C | Intensity of 4.7μ Si-H Bond Concentration mm: Before Surface Interaction | Intensity of 4.7μ Si-H Bond Concentration mm: After Surface Interaction |
|---|---|---|
| 25 | 15 | 15 |
| 250 | 15 | 12, 6* |
| 350 | 15 | 12 |
| 450 | 15 | 12 |
| 550 | 15 | 12 |
| 650 | 15 | 24 |

*For brush carbon impregnated with p-diphenyl phenylenediamine

TABLE 3

INTERACTION OF Si-H BONDS WITH COPPER SURFACES AT ELEVATED TEMPERATURE

| Temperature of Substrate °C | Intensity of 4.7μ Si-H Bond Concentration mm | |
|---|---|---|
| | Before Surface Interaction | After Surface Interaction |
| 25 | 15 | 15 |
| 250 | 15 | 12 |
| 350 | 15 | 10 |
| 450 | 15 | 10 |
| 550 | 15 | 10 |
| 650 | 15 | 28 |

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Mechanism of Siloxane Vapor Induced Excessive Brush Wear in Totally Enclosed DC Motors

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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5. AUTHOR(S) (Last name, first name, initial)

Katzenstein, Rainer J.

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13. ABSTRACT

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