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THE DESIGN AND DEVELOPMENT OF A DYNAMIC BRUSH WEAR MEASUREMENT APPARATUS

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ABSTRACT

An apparatus that permits the continual measurement of electrical brush wear in high vacuum is described. As the sensing element a linear voltage differential transformer is used, and its output is displayed on a potentiometric recorder. Resolution may be obtained from 0.0001 inch to 0.025 inch total wear, thus permitting wear rate measurements from 10^{-7} inches/hour to one inch per hour to be made. Calibration curves are shown, and the results from several tests are plotted and analyzed. Accuracy is shown to be better than ±0.5 percent.

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

An apparatus that permits the continual measurement of brush wear of electrical brushes operating in high vacuum is described. The apparatus does not interfere with normal operation of the brush and measurements may be made with the commutator rotating and electrical current flowing through the brushes. This allows wear measurements to be made while the parameters which affect brush wear are varied.

The sensing element is a linear voltage differential transformer, excited by a 1,600 cps signal. The output is demodulated and displayed on a potentiometric recorder which reads directly in thousandths of an inch. Resolution may be obtained from 0.0001 inch to 0.025 inch total wear, thus permitting wear rate measurements from 10^{-7} inches/hour to one inch per hour to be made. The wide range of measurements allows many different materials and applications to be considered.

The apparatus was calibrated by driving the LVDT armature with a precision micrometer with the recorder in operation. The calibration curves are shown, and the linearity is better than ± 0.5 percent. The results from several test runs are presented and discussed. The rotational speed and current to the brushes were varied, and the effects of these variables on the wear rate are given. The system is shown to be capable of following both sudden changes in a short time and gradual changes over extended time periods.

INTRODUCTION

In a program to develop electrical motor brushes for use in high vacuum (ref. 1), it became apparent that a means for continuous measurement of the brush wear was required. Brush wear rates determined from length measurements made before and after the test provided useful information for those tests which functioned satisfactorily, but these rates could provide little useful information for those tests which were erratic or which failed suddenly since an instantaneous wear rate could not be obtained.

A device was needed which would give a continuous reading of brush wear so that both instantaneous and average brush wear rates could be determined. This would permit the determination of the effects of rotational speed, current density, and arcing on the wear rate of a particular composition of materials and would allow the determination of the reasons for failure.

BACKGROUND

Instrumentation for measuring wear has been in general use for several decades in the electrical brush industry (ref. 2). However, most of the instruments are relatively bulky and intended for operation in large machinery. Some effort was expended on wear measurements during research on the high altitude brush problem (ref. 3 and 4), but even these solutions were too bulky and unsuitable for use in high vacuum. The majority of these systems was intended to measure wear rates of 10^{-3} to 10^{-4} inches per hour over extended periods of time and would not provide the resolution required for the brush development program of this division.

These devices generally employed a spring loaded lever or cam arrangement to gain a mechanical advantage and to provide rotation of a small potentiometer (ref. 5). The potentiometer was one arm of a voltage divider, and the change in voltage produced by the rotation (and hence change in resistance ratio) was displayed on a recorder. This type of system requires high spring pressures to operate, and it produces adverse loading effects on the simulated commutator apparatus used in these tests. Additionally, the system is cumbersome, requires lubrication, and is limited in application.

EXPERIMENTAL APPARATUS

The linear voltage differential transformer (LVDT) is a transducer that will generate an output voltage proportional to the displacement of its armature from the electrical center of its transformer windings. Normally, it is constructed with two primary windings connected series additive and two secondary windings connected series subtractive (ref. 6). If the primary winding is energized by an alternating current and the armature is positioned so that the magnetic flux linkages between the primary pair and the secondary pair are equal, the resultant output is zero, since the secondary windings are 180 electrical degrees out of phase and cancel each other. Movement of the armature from this electrical center position produces an output voltage that is directly proportional to its displacement. This occurs because the movement alters the flux linkage from primary to secondary pair to increase the voltage on one secondary winding and to decrease the voltage on the other. The LVDT is capable of producing linearity of better than 0.05 percent and an accuracy over a 0.1-inch displacement of ±0.1 percent. The device is small, light in weight, and because it contains only insulated wire, a soft iron armature, and a non-magnetic shell, it is completely compatible with vacuum operation. Since the mass of the armature is small and is a direct readout device, it can be used directly in contact with the brushes and does not require rods, gears, levers, or cams for operation. The only penetration required for the vacuum systems is to accommodate the four electrical leads.

The LVDT system is shown schematically in FIG 1. Two support brackets are attached to the frame of the brush tester to form a saddle in which the LVDT case is mounted. The LVDT armature is accurately positioned by the two nylon sleeve bearings and is not restrained from linear movement. The collar and spring are positioned on the armature shaft to provide positive movement of the armature. The end of the armature shaft rests on the back edge of the brush and is ground convex to prevent any interference with the operation of the brush. The LVDT unit is shown installed on the brush tester in FIG 2.

A special vacuum chamber was designed for the LVDT system. This chamber is shown in FIG 3 mounted on the multiple port vacuum system. A stainless steel body was fabricated with a reduced end section of thin wall stainless steel provided for the magnetic drive system. An optical view port was fabricated from a glass vacuum jar by cutting off one section and replacing it with a flat glass disc. The view port was then soft soldered to the chamber. An "O" ring sealed side chamber houses the projecting LVDT unit. This chamber is removable, and it allows installation and calibration of the LVDT system after the brush tester and chamber have been installed.

Excitation for the LVDT is supplied from the external control unit at 1,600 cps and 3 volts. Output from the control unit is taken from a 10 to 1 voltage divider that is fabricated from one percent precision resistors and displayed on a ten millivolt floating zero adjustable span potentiometric recorder. The internal range switch of the control unit permits full scale recorder readings of from 0.0125 inch to 0.100 inch to be made. This arrangement is shown in FIG 4.

EXPERIMENTAL PROCEDURE

The brush test apparatus is set up, and the vacuum chamber is placed in position. The LVDT is mounted on the side of the tester with the clamping bolts loosely in place. With the armature of the LVDT in firm contact with the back of the brush and the recorder zero control at mid position, the case is moved as necessary to electrically center the armature as close as possible. The clamping bolts are then tightened to securely fasten the LVDT in this position. Then, the recorder zero control is used as a fine control to set the recorder precisely on zero. The range switches of the control unit are used to set the desired full-scale span on the recorder. The LVDT chamber is bolted in place, the entire chamber evacuated, and the test begun.

CALIBRATION PROCEDURE

The LVDT unit is clamped in place on a test bench, and a depth micrometer is clamped securely to the same fixture in line with and contacting the armature of the LVDT. The recorder is zeroed, and the range controls on the control unit are adjusted for the span desired. The micrometer is advanced in even units, and the corresponding displacement is read on the recorder. Both the micrometer and the LVDT are read to one ten thousandth of an inch. The calibration curves for displacements of .025 and .100 inch are shown in FIG 5 and 6.

With any device measuring small displacements, the temperature must be carefully controlled or compensated for by corrections applied to the resulting data. Both the LVDT unit and the control unit are sensitive to temperature change. Room temperature variation of approximately 20°F has indicated an instrument drift of approximately 0.0005 inch. In practice, it has been possible to wait until the room temperature has stabilized or to apply mild heating to the LVDT system to restore the data base line rather than to apply a numerical correction to the data.

EXPERIMENTAL RESULTS

A wear curve taken on a brush during initial run-in is shown in FIG 7. The corresponding wear rates as function of time are shown in FIG 8. The system is entirely capable of following this relatively large change in wear rate while maintaining sensitivity and accuracy; this is demonstrated even more graphically in FIG 9. This is a plot of brush wear as a function of time for a rotational speed of 2,000 rpm and a brush current of 1 ampere. The corresponding brush wear rates are shown in FIG 10. This is a very small total wear and, consequently, an extremely small wear rate, but entirely within the capability of the LVDT system. This also indicates that there are no adverse loading effects on the brush by the LVDT armature.

Figures 9 - 18 provide even more graphic proof of the sensitivity and accuracy of the LVDT system. Figures 9 - 14 are plots of wear and wear rate for brushes of 85 percent MoS_2 - 15 percent Ag, running at 1.0 ampere with the rpm varied from 2,000 to 4,000 rpm. The wear rate curves are of particular interest since they indicate the ability of the system to measure wear rates varying from 10^{-5} inches per hour to 10^{-7} inches per hour range occuring over a span of a few hours. Figures 15 and 16 are the composite for all three speeds of total wear and wear rate, respectively.

The LVDT system was able to resolve the change in wear rate which occurred when changing rpm with no difficulty.

Figures 17 - 18 display the same information for brushes of 85 percent MoS_2 - 15 percent Ag run at 2,000 rpm, at currents of 0.5, 1.0, 1.25, and 1.50 amperes. Again, the LVDT system is able to resolve the relatively small changes in wear rate which were observed.

The sensitivity of the apparatus is sufficient to enable easy determination of the factors which influence brush wear and the relative magnitude of these effects. However, this information is not pertinent to this report and will be discussed elsewhere.

As a further indication of the sensitivity of the system, it is standard test procedure to hold the total commutator run-out to less than .001 inch; normally 0.0005 inch is used. Rotational speeds less than 1,000 rpm produce large excursions of the recorder pen because the brush and the LVDT are following the commutator run-out.

CONCLUSIONS

a. The apparatus is capable of measuring total brush wear of 0.0001 inch and brush wear rates of 1×10^{-7} inches/hour accurately, with excellent reproducibility.

b. The instrument can be adjusted to measure total wear of from 0.0125 to 0.100 inch, with no adjustment required of the LVDT unit.

c. The LVDT armature does not produce adverse loading effects on the brush, and it is entirely compatible with vacuum operation.

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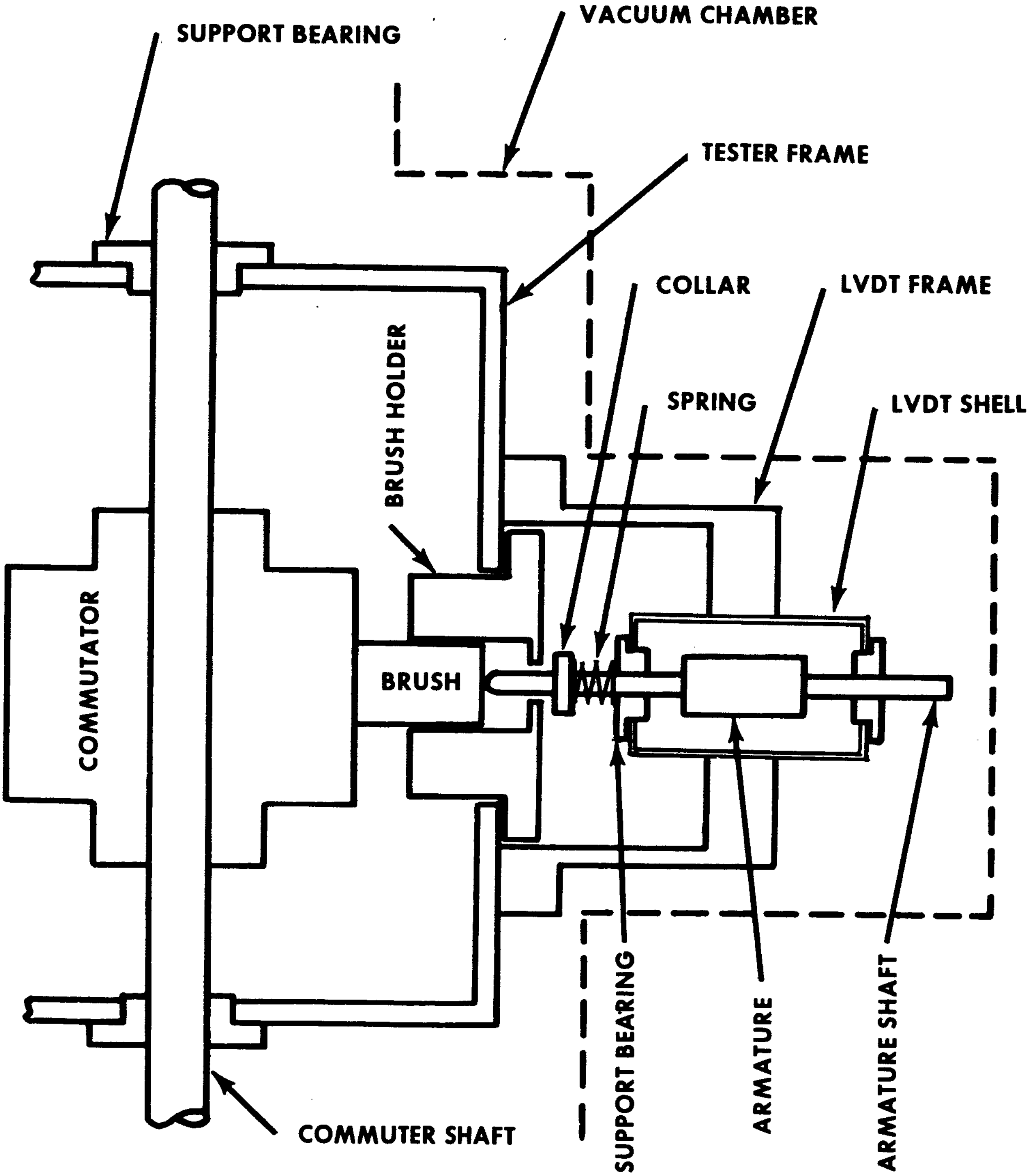

FIGURE 1. - LVDT SCHEMATIC

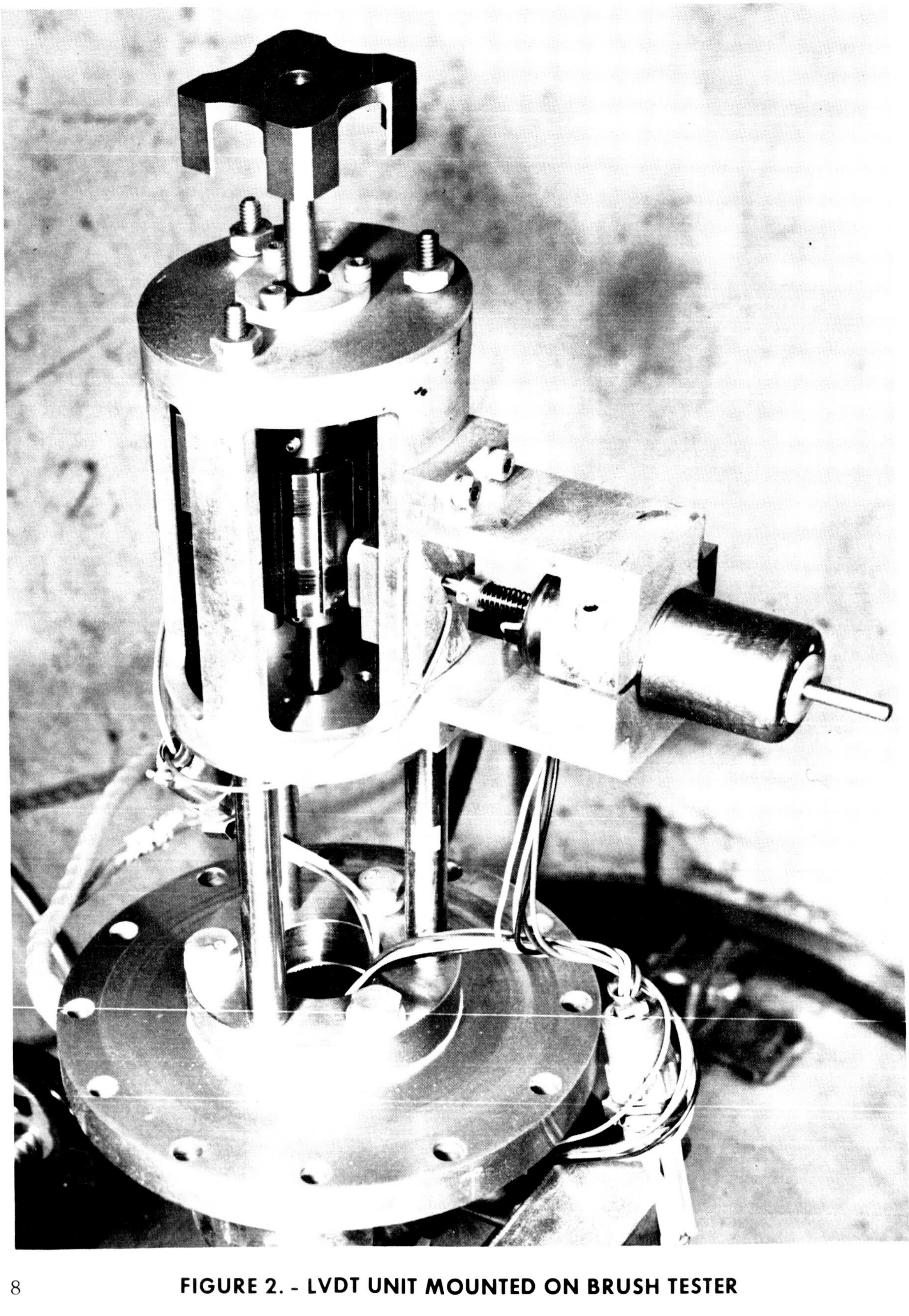

FIGURE 2. - LVDT UNIT MOUNTED ON BRUSH TESTER

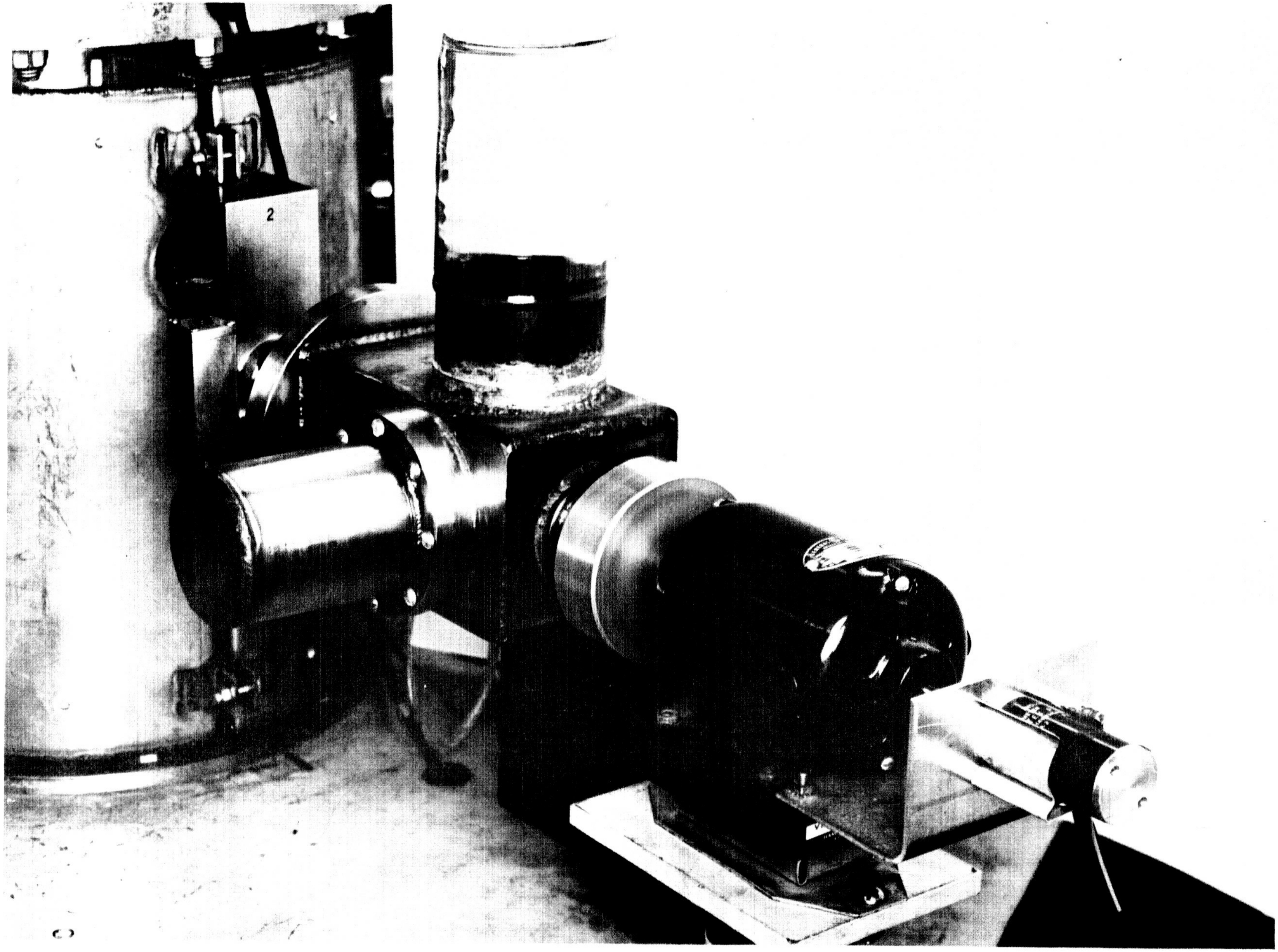

FIGURE 3. - TEST CHAMBER MOUNTED ON VACUUM SYSTEM

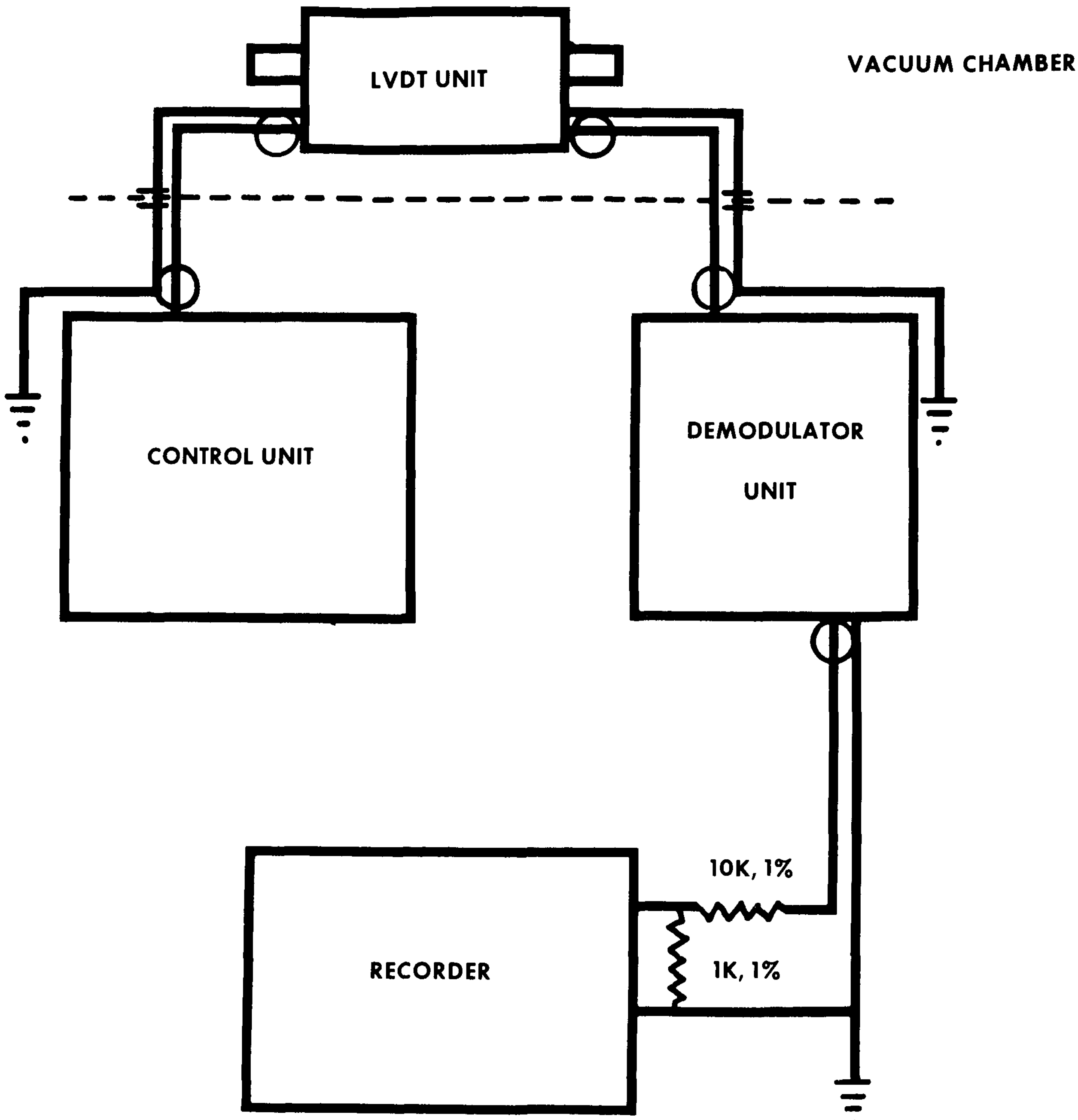

FIGURE 4. - MEASURING SYSTEM

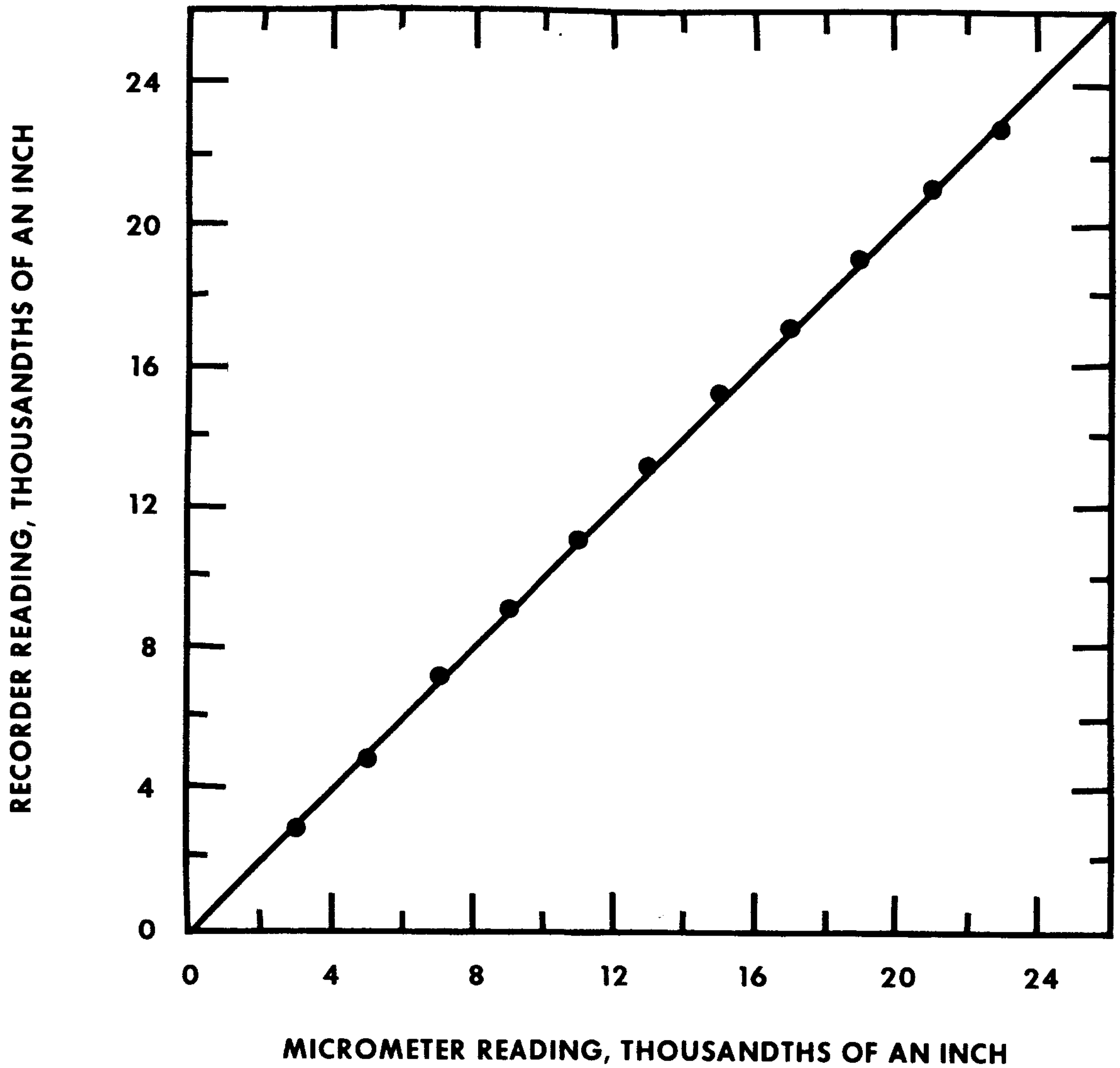

FIGURE 5. - CALIBRATION RUN, 0 TO 0.025 INCH

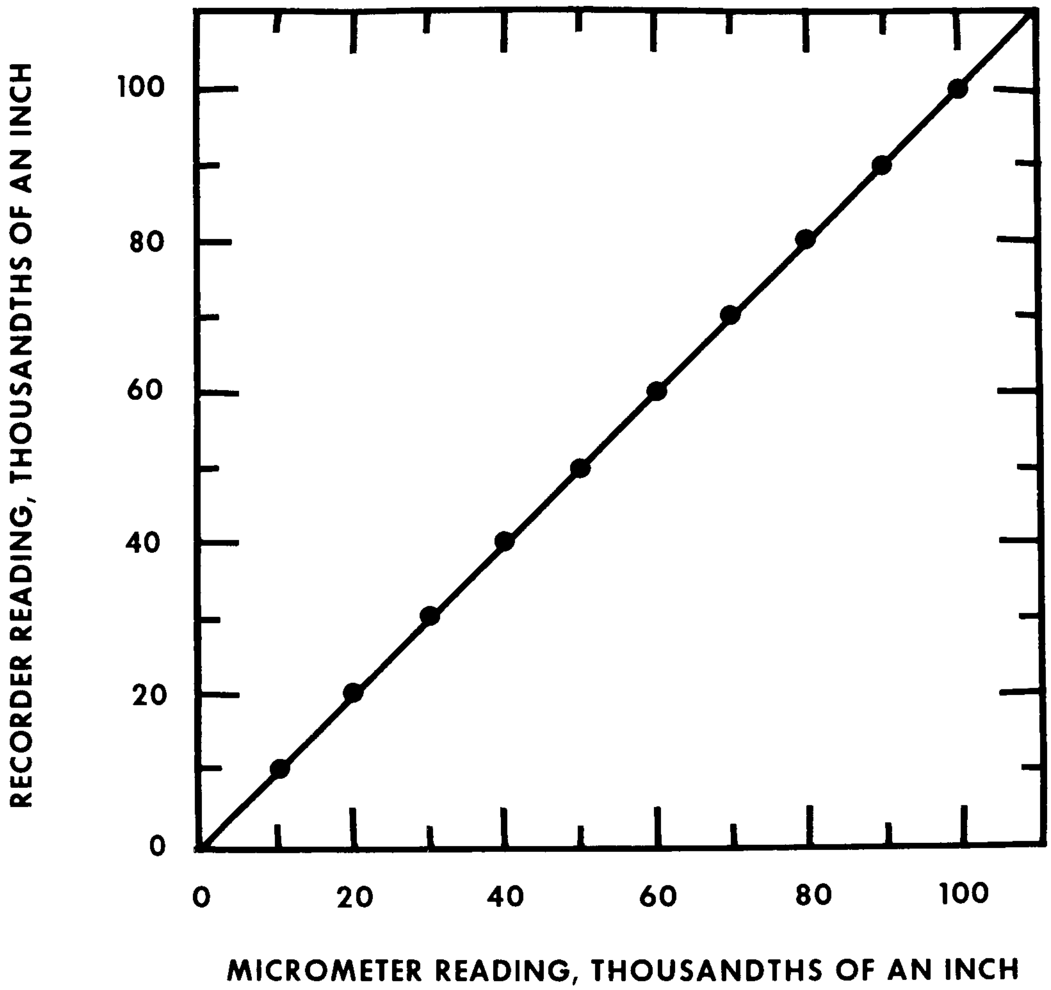

FIGURE 6. - CALIBRATION RUN, 0 TO 0.100 INCH

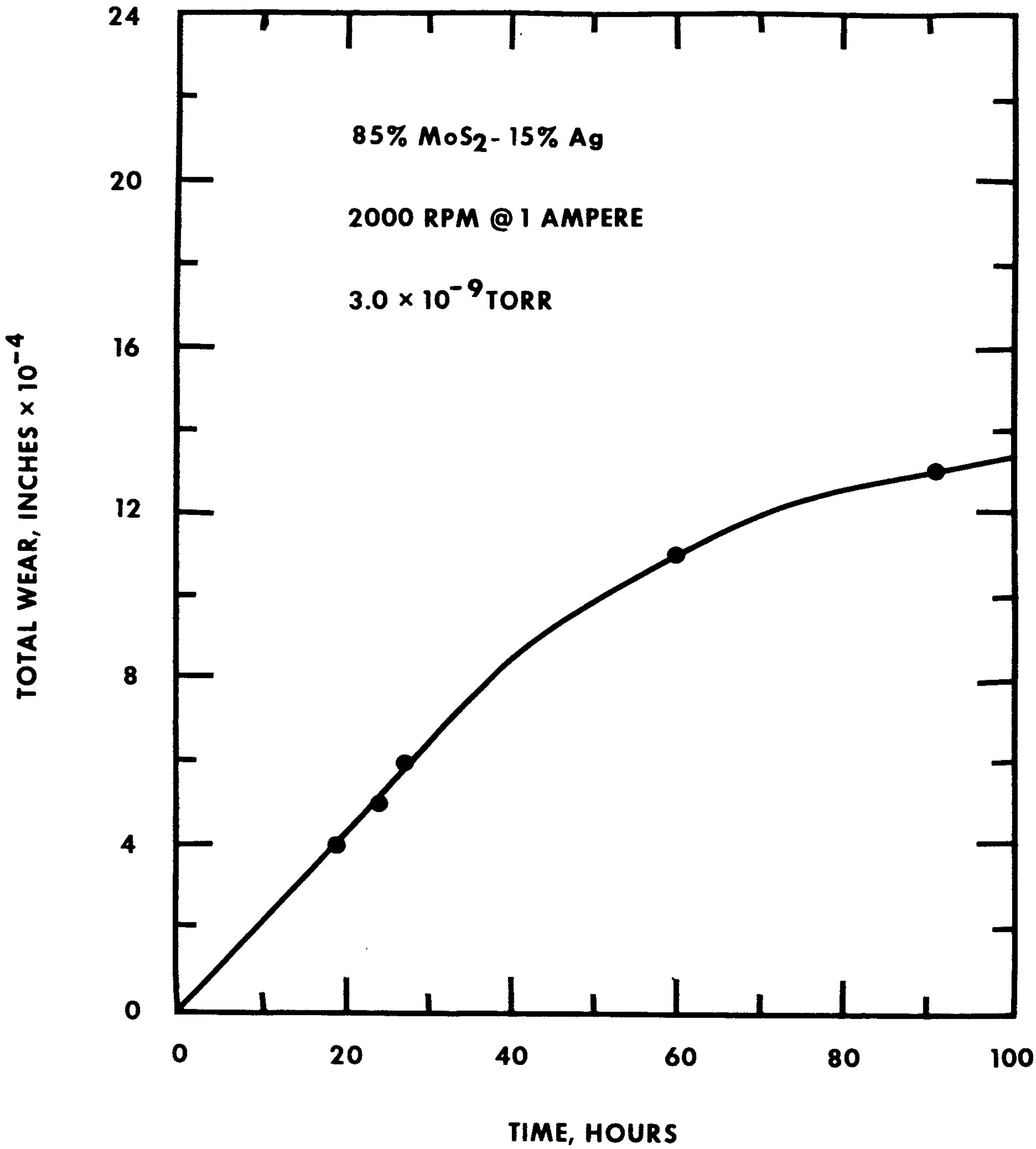

FIGURE 7. - TOTAL WEAR DURING RUN-IN

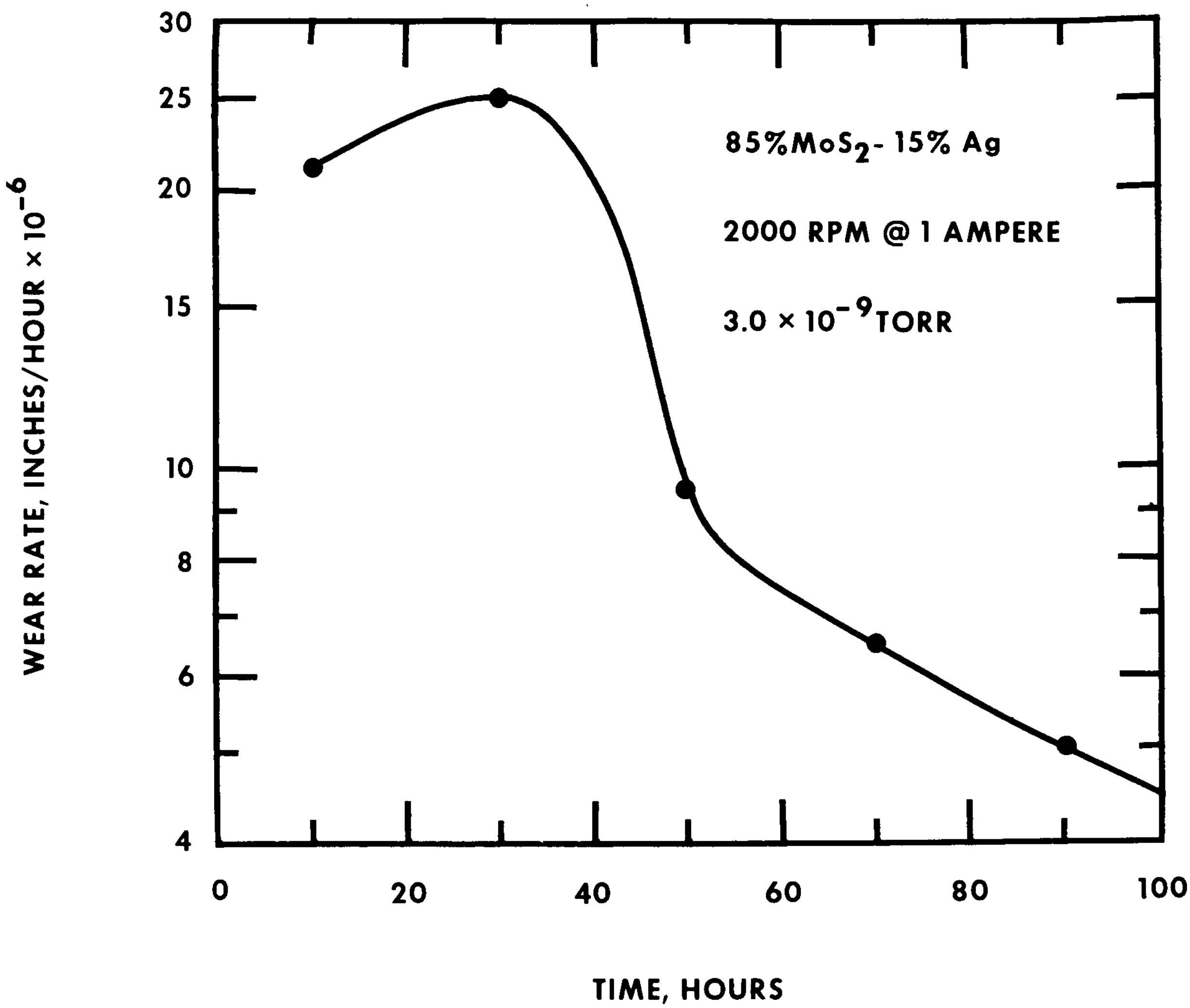

FIGURE 8. - WEAR RATE DURING RUN-IN

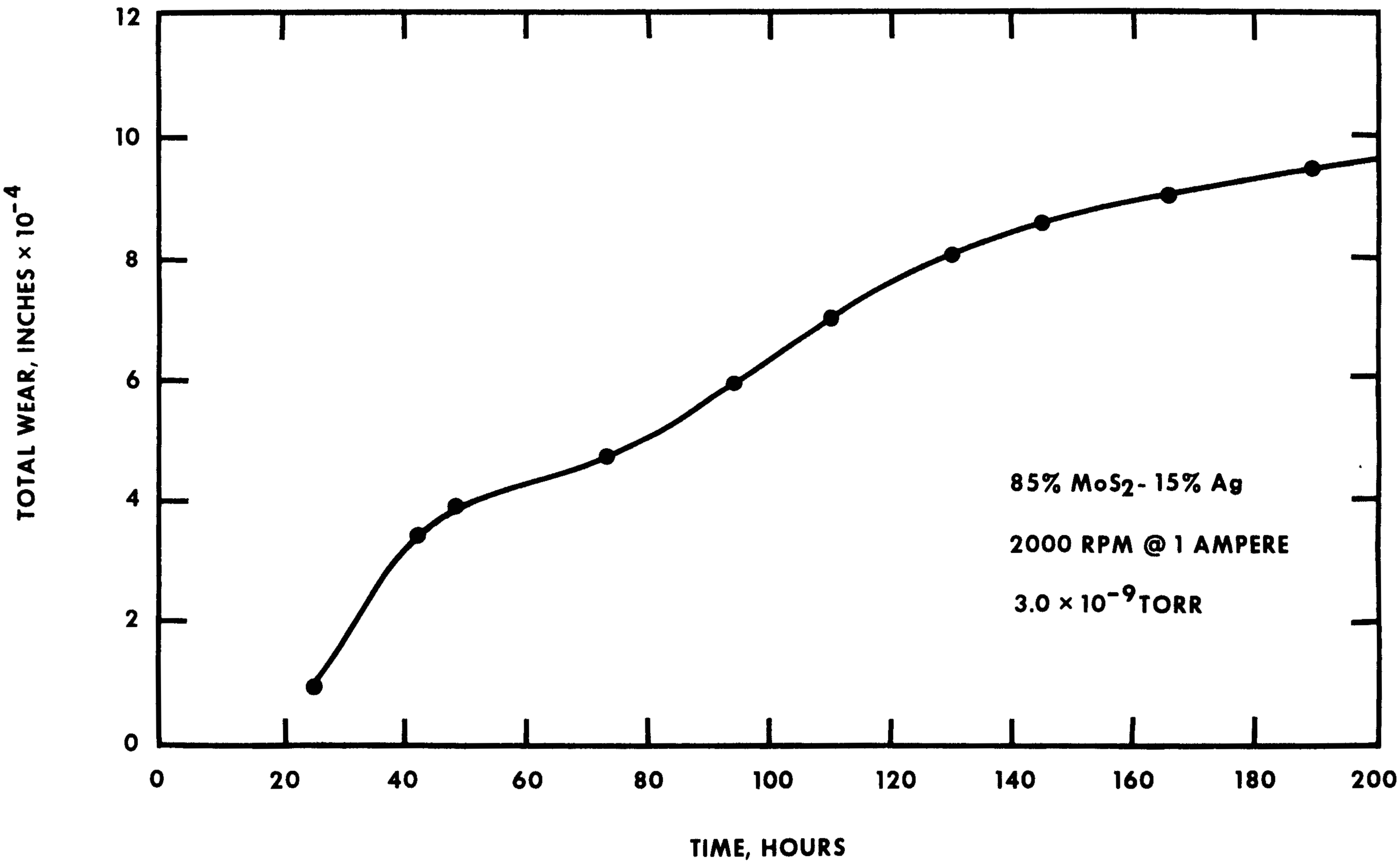

FIGURE 9. - TOTAL WEAR AT 2000 RPM

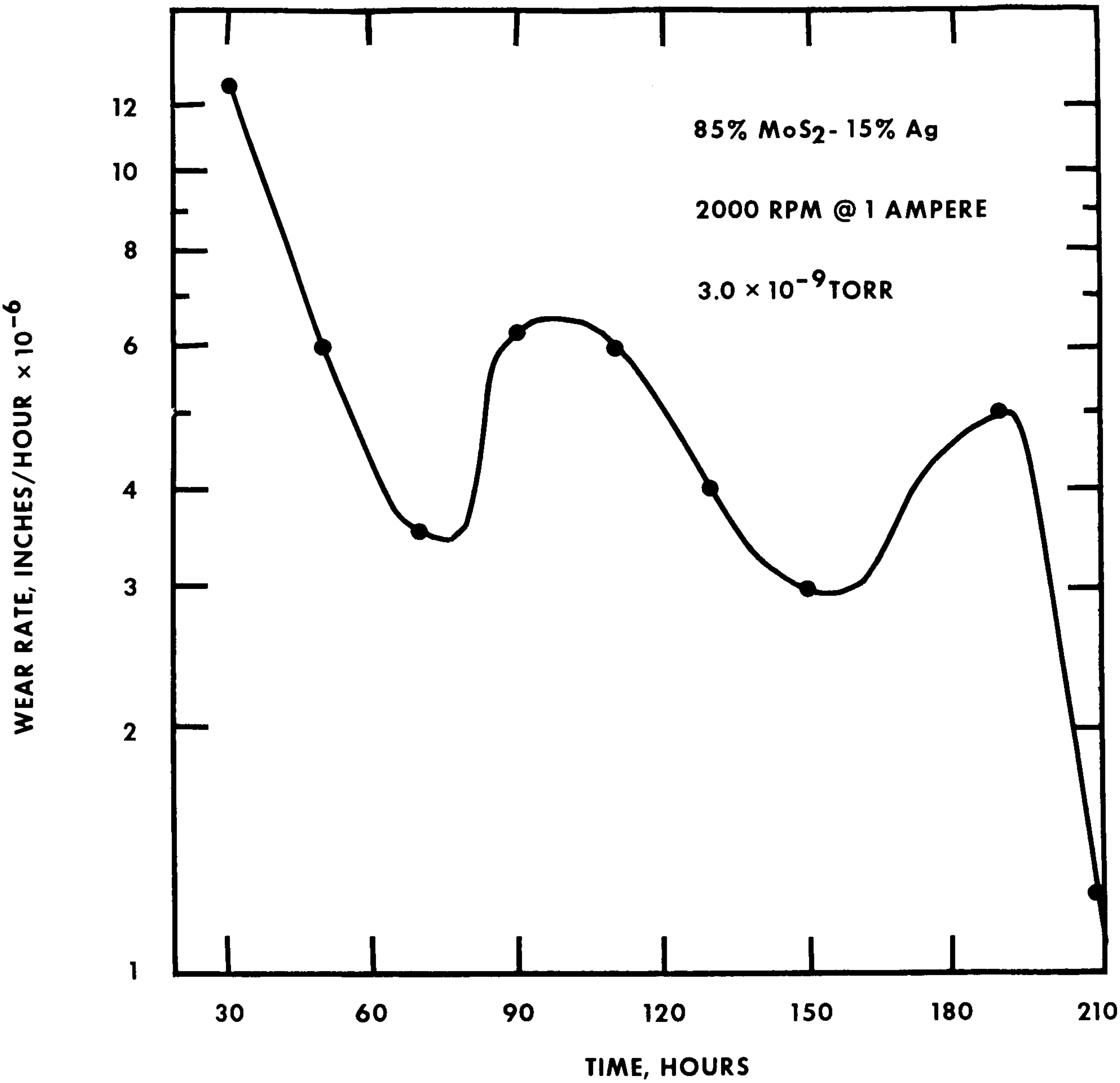

FIGURE 10. - WEAR RATE AT 2000 RPM

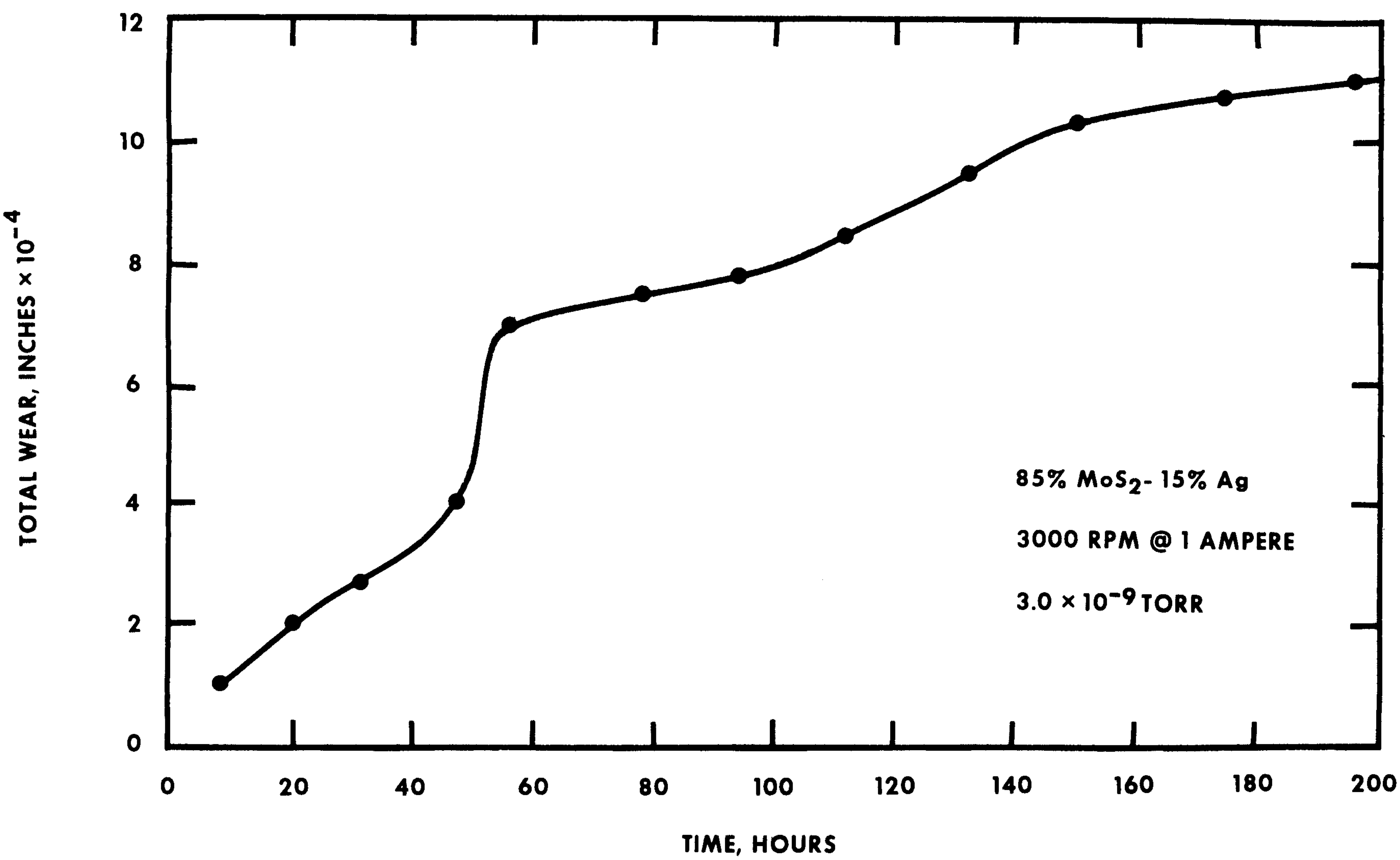

FIGURE 11. - TOTAL WEAR AT 3000 RPM

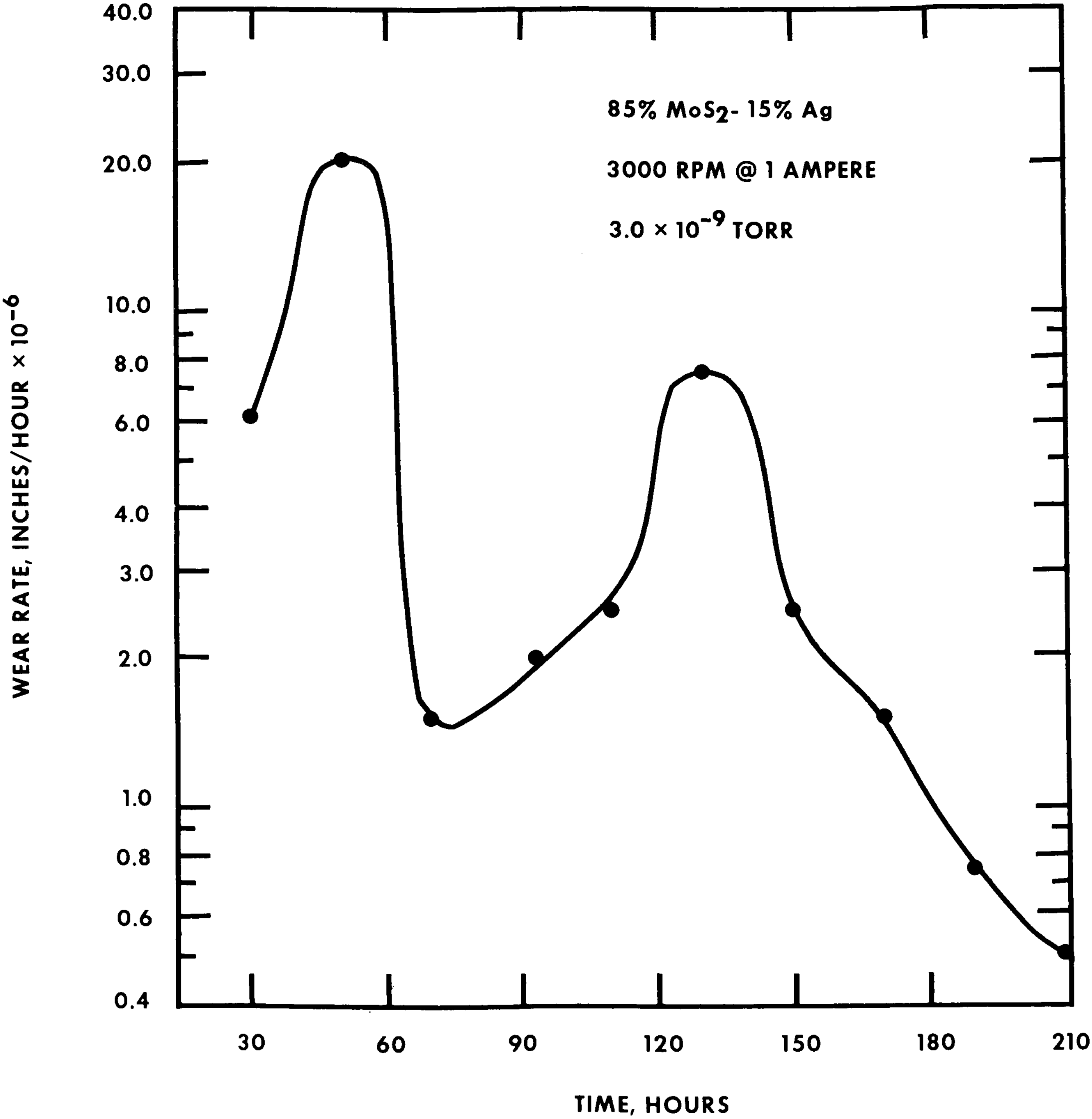

FIGURE 12. - WEAR RATE AT 3000 RPM

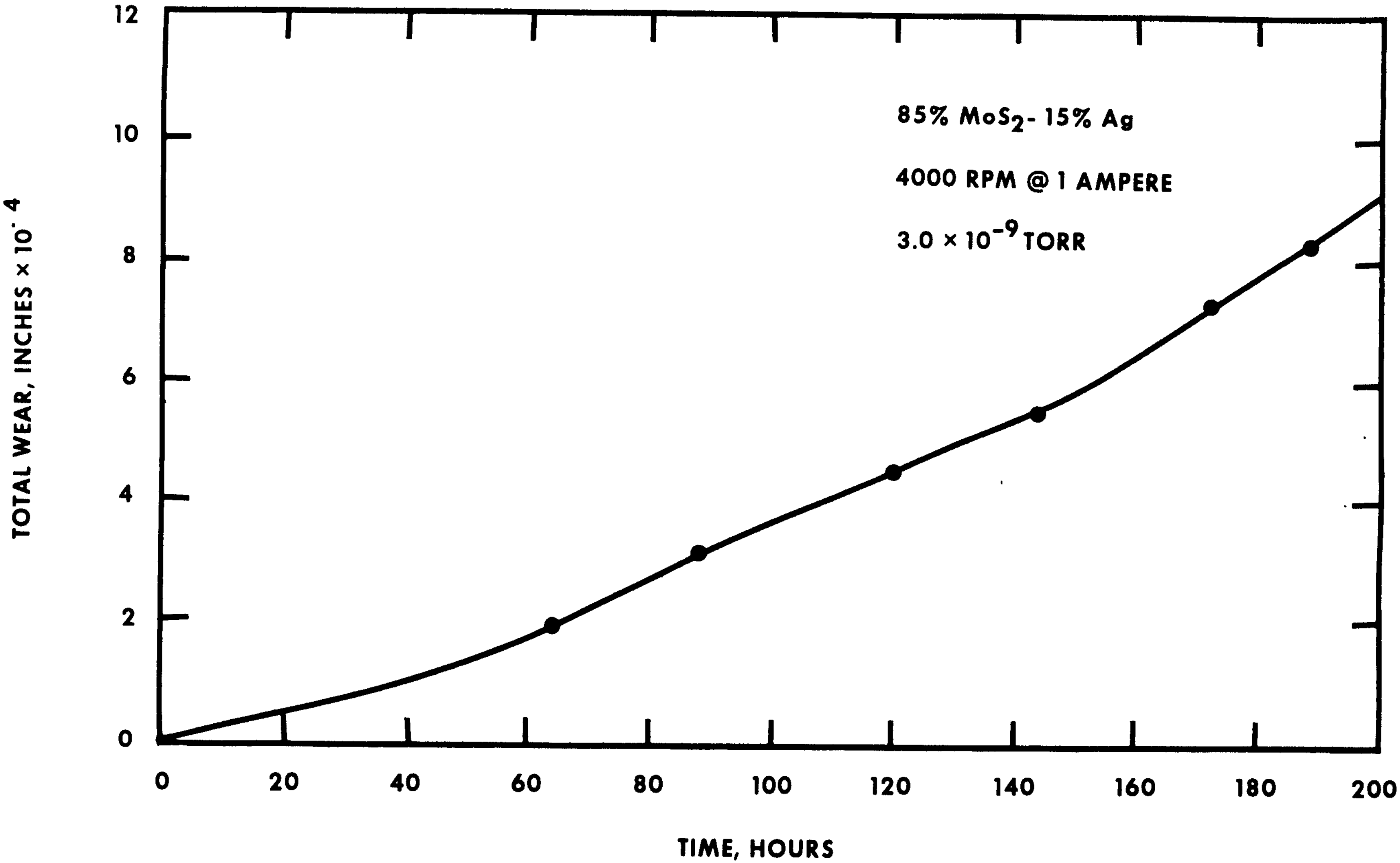

FIGURE 13. - TOTAL WEAR AT 4000 RPM

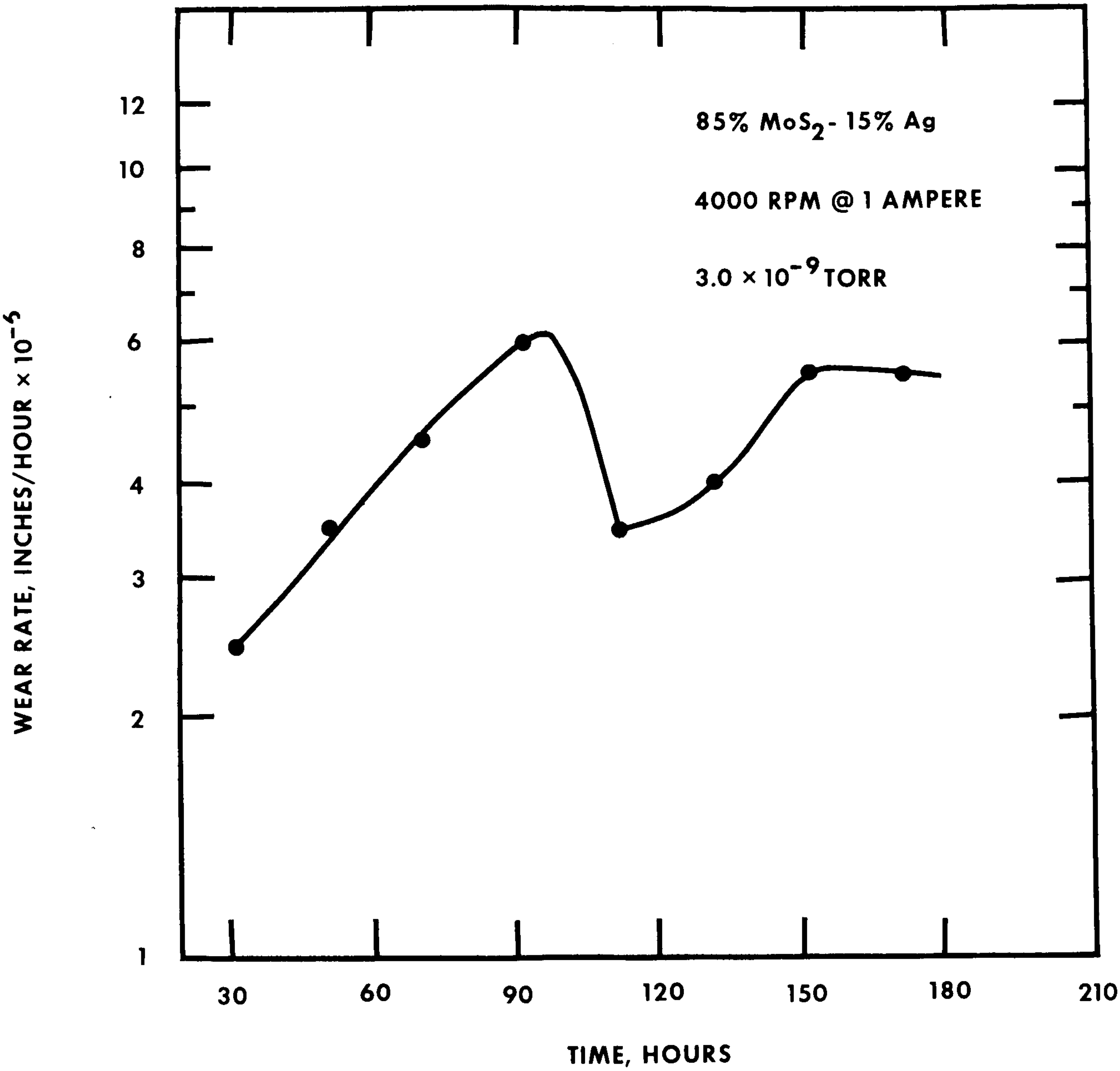

FIGURE 14. - WEAR RATE AT 4000 RPM

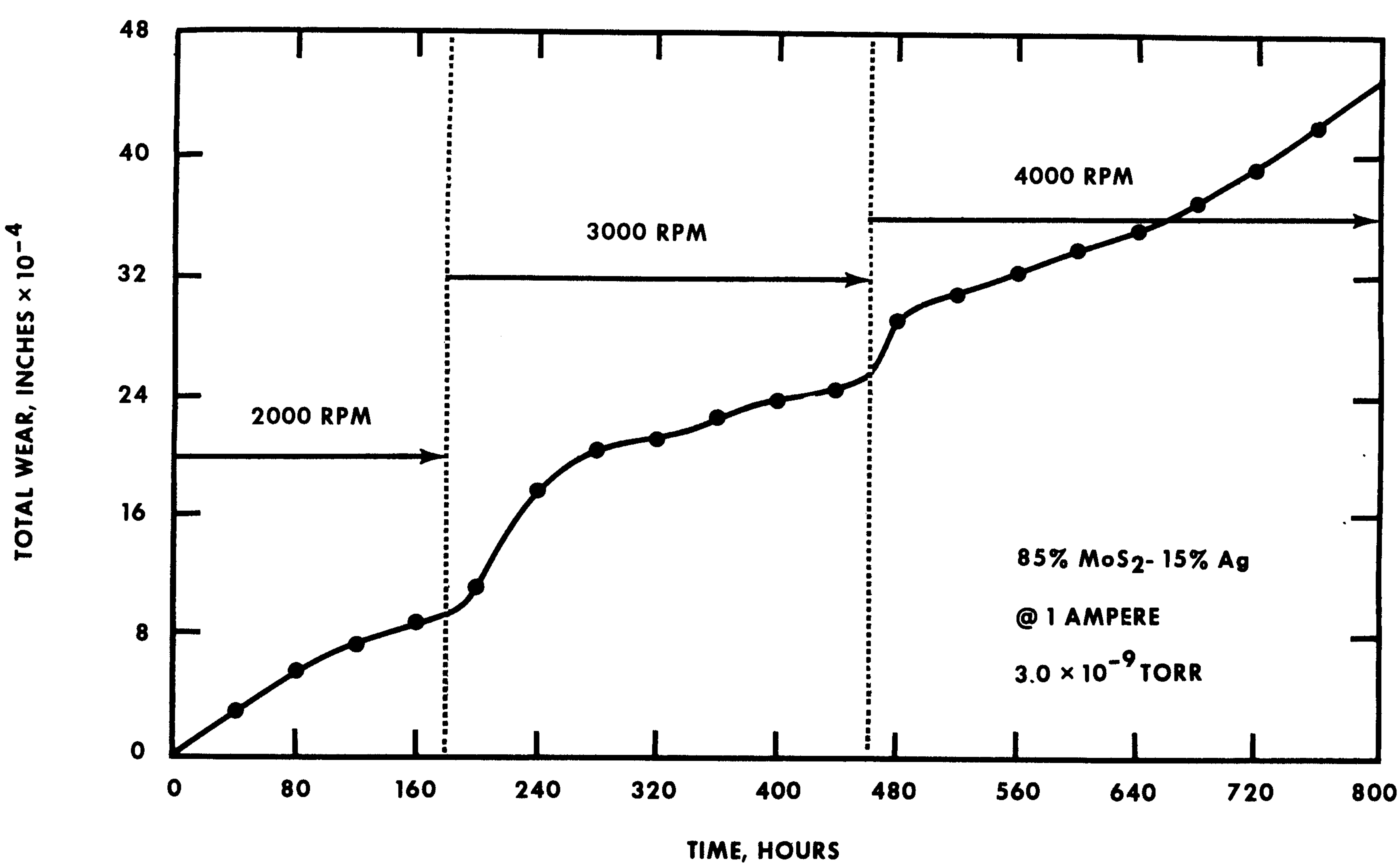

FIGURE 15. - COMPOSITE RUN

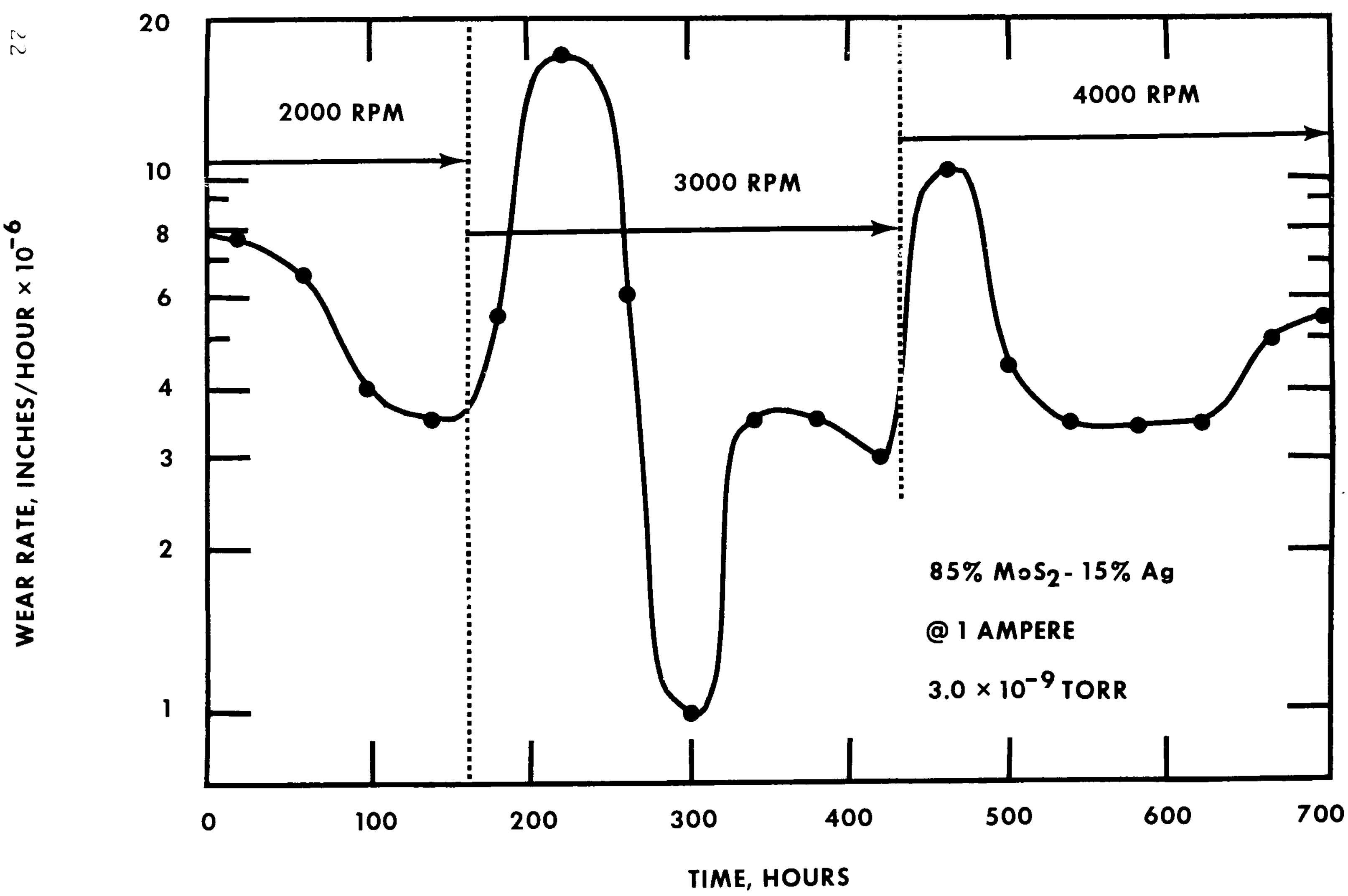

FIGURE 16. - COMPOSITE WEAR RATE

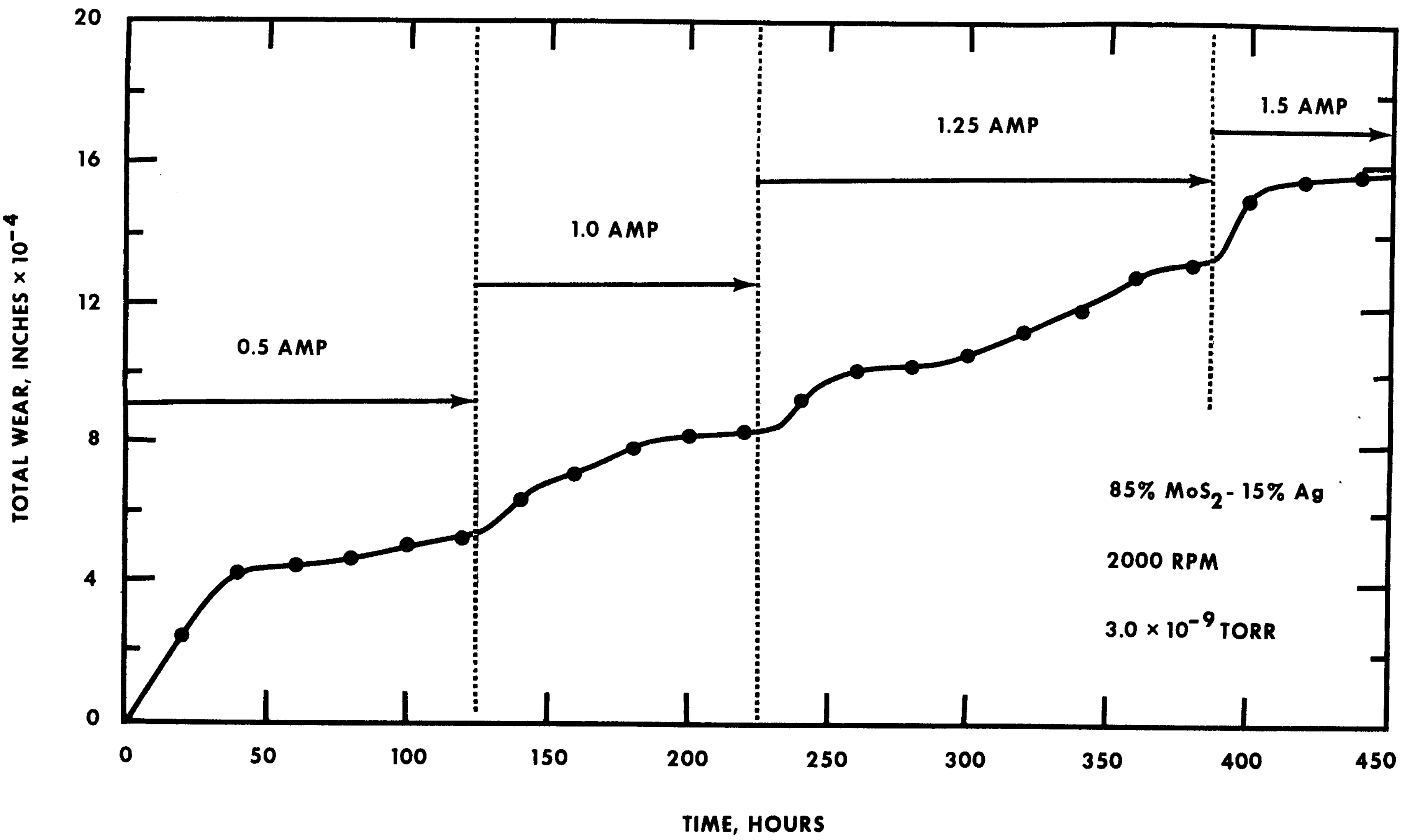

FIGURE 17. - TOTAL WEAR WITH INCREASING BRUSH CURRENT

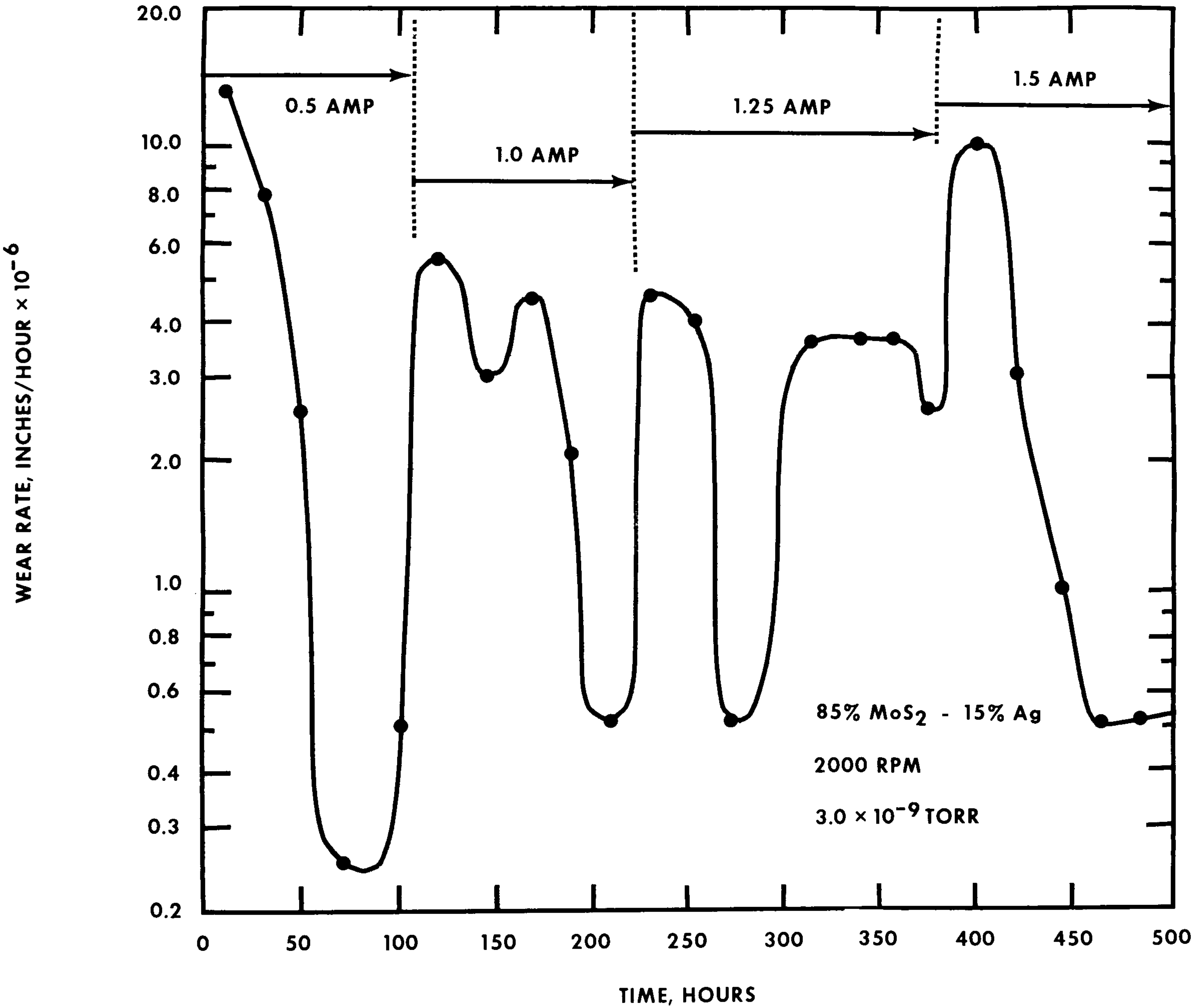

FIGURE 18. - WEAR RATE WITH INCREASING BRUSH CURRENT

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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

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