NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1442

FRICTION AT HIGH SLIDING VELOCITIES

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and Edmond E. Bisson

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SUMMARY

Information is presented that extends the range of existing fundamental friction knowledge to include sliding velocities encountered in rolling-contact bearings and reduction gears of aircraft power plants.

Experiments were conducted with a kinetic-friction apparatus consisting basically of an elastically restrained spherical rider sliding on a dry or lubricated rotating disk. The experiments were made with steel specimens over a range of speeds between 50 and 6600 feet per minute with loads from 169 to 2232 grams (108,000 to 255,000 lb/sq in., initial Hertz surface stress) and were supplemented by studies using standard physical, chemical, and metallurgical equipment and techniques.

It was determined that kinetic friction decreases with sliding speed for dry and for some boundary-lubricated surfaces at high sliding speeds. Amontons' law was verified at all speeds investigated with dry surfaces and with surfaces boundary-lubricated with oleic acid or a commercial SAE No. 10 oil. Changes in physical characteristics of material resulting from high surface temperatures caused by increased rate of surface stressing and the occurrence of ferrous oxide on the sliding surface are possible causes for the reduction in kinetic friction with high sliding velocities. Surface preparation was the most important single technique contributing to the investigation.

INTRODUCTION

The operation of sliding surfaces, such as occur in current aircraft power-plant rolling-contact bearings and reduction gears, at sliding velocities of 1000 to as high as 18,000 feet per minute, has indicated the need for more extensive information on kinetic friction at high velocities. A survey of applicable literature and consideration of current practice has demonstrated that the application of basic investigations on kinetic friction is fundamental to the design of certain power-plant components.

Amontons (reference 1) and Coulomb (reference 2) published the basic concepts of friction that are most widely held today. This work was developed by later investigators to the point that, for both dry friction and boundary lubrication with certain lubricants, it is well established that the resistance to relative motion of solid bodies is directly proportional to the normal load (Amontons' law), is independent of apparent area of contact, and within certain limits, is independent of sliding velocity. Considerable experimental verification exists for the first two concepts; however, the published results on the effect of velocity are conflicting. Beare and Bowden reported work on sliding velocity (reference 3) from which they concluded that, with unlubricated and with boundary-lubricated surfaces, the coefficient of kinetic friction is independent of sliding velocity; the range of velocities investigated, however, was limited to that between 60 and 600 centimeters per second (118 and 1181 ft/min). Other investigators (references 4 to 6) have accepted the concept of the independence of kinetic friction and sliding velocity and have made reference to the work of Beare and Bowden. Beeck obtained experimental verification of this concept at low sliding speeds and suggested (reference 7) that "the best criterion for this state [of boundary lubrication] is that the coefficient of friction is independent of viscosity and of the sliding velocity."

The weight limitations of aircraft-engine components have necessitated the use of small structural sections of parts, which results in high unit surface loads on sliding surfaces. These conditions have complicated the problem of dissipating heat generated in sliding friction and consequently may contribute to surface failure. Because heat dissipation is a rate process, the effects of sliding velocity on surface conditions become more critical at the higher sliding speeds. Little reference material on the fundamental effects of high sliding velocities on friction exists and the available information is not generally applicable because it deals with specific practical problems. For example, reference 8 shows that in a particular development application a continuous reduction in friction was obtained as the sliding velocity was increased to a value of 5280 feet per minute.

An experimental investigation made to determine the manner in which high sliding velocities (up to 6600 ft/min) affect the coefficient of kinetic friction of dry and of two types of boundary-lubricated steel surface is reported herein. The investigation also included physicochemical studies of experimental specimens before and after operation as a means of determining the mechanism leading to any of the effects observed. Friction measurements were made by means of apparatus that consists basically of an elastically restrained spherical rider sliding on a rotating disk.

APPARATUS AND PROCEDURE

Friction Apparatus

The experimental friction studies were conducted with equipment that is essentially the same as the Deeley-Herchel apparatus described in reference 9. Figure 1 is a schematic diagram showing the basic elements of the equipment and figure 2 is a photograph of the complete apparatus. The principal elements of the apparatus are the specimens, which are in the form of an elastically restrained spherical rider and a rotating disk. The rider is loaded by weights applied along the vertical axis of the rider holder. Friction force between the rider and the disk is measured by four strain gages so mounted on a copper-beryllium dynamometer ring as to compensate for temperature effects. The force is indicated by either a recording or an observation-type calibrated potentiometer converted for use as a strain indicator. An electrically driven radial-feed mechanism, calibrated to indicate radial position of the rider, causes the rider to traverse a spiral track on the rotating disk. The disk is mounted on an inertia ring that is supported and located by a bearing housing. The rotating specimen has a diameter of 13 inches and is driven by direct-current motors through a flexible coupling and a speed-reduction unit that allow speed control over a range of sliding speeds between 50 and 14,000 feet per minute. The disk and the rider are covered by a housing and shield, which permit the operating atmosphere of dried air to be pressurized slightly.

In the experiments, the disk was rotated at a predetermined speed and by means of a cam arrangement, the loaded rider was lowered onto the disk as the radial feed was started. As the rider traversed the disk, friction force was observed or recorded with a potentiometer and disk rotative speed was determined with an electric revolution counter and a synchronized timer. The run was terminated by lifting the rider from the disk surface. Mean sliding speed for the experiment was computed from the recorded rotative disk speed and the mean diameter of the rider path. A change in diameter of the rider path on the disk resulting from the radial travel of the rider caused a maximum deviation in sliding velocity of approximately 1 percent from the mean value. An unworn surface of a ball was used in each experiment.

As part of the experimental procedure, a survey was made to determine the effects that certain equipment peculiarities would have on the data obtained. The most questionable characteristic was that of change during an experiment in the type of contact and in the apparent area of contact caused by wear of the spherical rider. It was determined that with degrees of wear much more severe than those encountered in the experiments reported herein, the maximum effect observed caused less than a 3-percent deviation in the friction values. Under the extreme wear conditions at high velocities, the rate of radial travel of the rider was insufficient to prevent some slight overlapping of the wear tracks on the disk; experiments to investigate the effects of this condition on the friction measurements indicated that it was an unimportant variable. The effect of the natural frequency of the rider restraining assembly on the measurements of friction force was also considered. The mass of the restraining assembly and the spring constants of the components in the suspensions were varied and no change in the measured values was observed. The data obtained indicate that vibrations induced by the driving mechanism can be neglected as a source of error. Values obtained at constant sliding speed were unaffected by changes in rotative speed as great as 50 percent. Constant sliding speed at various rotative speeds was obtainable by placing the rider at several radial positions on the disk.

The physical and physicochemical conditions of the surface and subsurface material of the research specimens were studied before and after the sliding-friction experiments by means of surface-roughness and surface-hardness measurements, X-ray diffraction, electron-diffraction, and metallographic examinations.

Specimen Preparation

Careful preparation of the specimens was found to be the most important single requisite for success of the experiments. The disk specimens were of normalized SAE 1020 steel with a Brinell hardness number of 185. The disks were ground on a vertical grinder using a 12-inch-diameter No. 30 vitrified crystalline grinding wheel rotating at a speed of 600 rpm with a soluble-oil coolant flow of approximately 10 gallons per minute. The magnetic chuck that held the disk in place during grinding rotated at a speed of 24 rpm and reciprocated slowly. The vertical feed of the grinder was so adjusted as to lower the grinding wheel 0.0005 inch every fourth pass for a total of 20 passes, and then 0.0002 inch every fourth pass for 8 passes. The disk was then lapped on a surface plate mounted on a drill-press base, as shown in figure 3. The disk was eccentrically rotated at a rate of 20 rpm by means of a jig fastened to the drill-press spindle. The specimen was successively lapped for $1\frac{1}{2}$ hours each with 240-, 400-, and 600-grit silicon-carbide lapping compounds, using kerosene as a carrier. After the disk was removed from the lapping plate, it was wiped clean of loose abrasives and protected by a coating of vaseline for a later complete cleaning. This procedure was followed in order to minimize surface working and to provide a uniform nondirectional surface finish. The surfaces finished in this manner had a surface roughness of 3 to 6 microinches rms as measured with a profilometer. The rider specimens used were commercial SAE 1095 steel balls, $\frac{1}{4}$ inch in diameter, hardened to a Rockwell hardness number of C-60. The balls were used in the as-received condition.

The procedure used in cleaning the disk specimens was developed from that used in reference 10. The cleaning schedule consisted of the following steps:

(1) The specimen was submerged in a low-aromatic cleaning naphtha for 5 minutes and scrubbed with cotton to remove the protective vaseline coating.

(2) The specimen was placed on a turntable, rotated at a speed of 170 rpm, and cleaned by holding a clean white flannel cloth soaked with a solution of 50-percent benzene and 50-percent acetone against the moving surfaces until all the cleaning solvent was removed and the specimen appeared dry.

(3) The surface of the specimen was then scoured with 000 emery polishing paper by manually reciprocating the polishing paper radially at a rate of approximately 120 strokes per minute across the surface of the disk while it was rotating as in step (2). This scouring was continued until all the lapping compound was removed from the surface. A dull gray appearance of the surface indicated the continued presence of lapping compound.

(4) Step (2) was repeated to remove all loose material and was continued until the white flannel cloth no longer showed contamination.

(5) The surface was then scoured without rotation using levigated alumina and a clean white flannel cloth moistened with tap water; the technician wore clean white cloth gloves during this and the following steps. The procedure was followed until the cloth was no longer discolored by the scouring process.

(6) The specimen was then quickly placed under a stream of cold tap water and was rinsed and scrubbed with a clean white flannel cloth until all levigated alumina was removed. When the water formed a continuous film on the surface and interference colors were noted as the plate drained, the surface was considered to be free from grease.

(7) The specimen was quickly submerged in 190-proof ethyl alcohol for 5 minutes and agitated to remove water from the specimen.

(8) The specimen was rinsed with 190-proof ethyl alcohol and partly dried with warm air; the presence of water on the surface could be determined by a slight discoloration.

(9) Before drying was visibly complete, the specimen was mounted on the kinetic-friction apparatus and clean dry air directed over the surface for 30 minutes before an experiment was run.

The rider specimens were cleaned and rinsed with 190-proof ethyl alcohol before and after installation in the rider holder using a clean cloth for scrubbing the surface. The rinsed rider surface was allowed to dry on the kinetic-friction apparatus in the dry-air atmosphere.

Electron-diffraction patterns obtained from a specially prepared chemically clean steel surface and from an SAE 1020 steel surface cleaned by the procedure outlined are shown in figure 4. It should be noted that electron diffraction will not resolve the structure of the oxide film that is present on a surface such as that shown in figure 4(b) because the film is too thin. Reference 11 indicates that a surface prepared in a manner similar to that used in preparing the disk specimens has an invisible film of ferroso-ferric oxide (Fe_3O_4), which is shown in reference 12 to be approximately 15 to 25 A thick.

RESULTS AND DISCUSSION

Effects of Sliding Velocity

The principal friction data obtained in the course of this investigation are summarized in figure 5, which shows the effects of change in sliding velocity on the coefficient of kinetic friction for dry and for boundary-lubricated surfaces. The series of data that were used for these curves are from representative runs selected from a number of experiments covering a range of loads for dry and for boundary-lubricated surfaces. In all but isolated cases, these data were reproduced many times with a deviation of less than 5 percent.

The data of figure 5 show the manner in which the coefficient of kinetic friction μ_k between a dry plate and a rider varies as the sliding velocity is increased. The values of μ_k are essentially constant below a sliding velocity of 2000 feet per minute. As sliding velocity increases above 2000 feet, μ_k decreases rapidly at an approximately constant rate until the sliding velocity is about 5000 feet per minute. With a further increase in sliding velocity, μ_k decreases at a progressively lower rate and the results indicate that μ_k may become constant for some range of sliding velocities above the range covered.

Preliminary experiments indicated that for dry surfaces both the absolute values of the data and the forms of the curves appear to be functions of the type of surface film present, particularly at low sliding speeds. The invisible film present on the surfaces used in these experiments consisted mainly of ferroso-ferric oxide (reference 11) and was probably 15 to 25 A thick (reference 12). Presence of this film probably caused the observed friction values to be somewhat less than they would have been for chemically clean metal; a quantitative evaluation of the effect of this film, however, would require elaborate vacuum and degassing equipment and would serve little practical purpose. It is believed that the dry surfaces used have as little surface "contamination" as could possibly be encountered in engineering practice.

Data that show the relation between sliding velocity and the coefficient of kinetic friction of surfaces under conditions of boundary lubrication are also presented in figure 5. The lubricants used in these experiments, oleic acid and a commercial SAE No. 10 lubricating oil, were selected because they are one of the best polar-type boundary lubricants and one of the most widely used boundary lubricants, respectively. The data points obtained are so nearly coincident that a single line can be drawn to indicate the trend of both experiments. This trend is toward lower values of friction at the higher sliding speeds. Although the decrease in absolute values of friction for the boundary-lubricated surfaces is not great over the speed range investigated, the relative decrease approaches that obtained with the dry surfaces. This result indicates the validity of the practice of using dry sliding-friction data as a fundamental basis in the analysis of operating conditions for boundary-lubricated surfaces.

The experiments that were conducted on the effect of high sliding velocities on the coefficient of kinetic friction during this investigation have in all cases indicated a downward trend with increased sliding speed. In order to show that the downward trends observed in these experiments are not a function of the apparatus, unpublished data, obtained in the course of a different series of sliding-friction experiments, are presented in figure 6. Figure 6 compares the sliding friction of a dry surface (curve from fig. 5) with that of a surface having a silicone film. When the lacquer-like film (the resulting surface cannot be considered as either dry or boundary-lubricated) that is deposited from a silicone-type synthetic lubricant according to the procedure given in reference 13 is present on the disk surface, friction is greater as sliding velocity increases (fig. 6).

Correlation with Previous Investigations

A study of the reference literature shows a wide divergence in the quantitative data and in the trends reported by different investigators who experimented with similar materials. This disagreement is believed to be caused by surface contamination of the test specimens and in some cases by apparatus peculiarities. Reference 14 presents the following summary of the work that had been reported prior to 1877: "Morin and Coulomb say the coefficient of friction does not vary with the velocity. Bochet says that it decreases as the velocity increases. Hirn says that it increases as the velocity increases. Contradictory as these statements are, it is probable that each contains a partial truth." This divergence of results reported by these investigators has not yet been completely resolved. No information on the effects of sliding velocity on kinetic friction at velocities over 1500 feet per minute is available that has been published in the last 50 years. In the early experiments, which were conducted at the high sliding speeds and are reported in references 8 and 14, little or no attention is given to surface preparation. Figure 7 shows that the quantitative data reported agree closely with data obtained under similar conditions by Beare and Bowden (reference 3) for dry surfaces and by Beeck (reference 7) for boundary-lubricated surfaces. It has been possible to reproduce closely the available quantitative sliding-friction data when the method of surface preparation used has been described in detail. Figure 7 also compares data obtained at this laboratory using the surface preparation described by Dokos in reference 15 with comparable data reported in reference 15. The correlation obtained indicates that surface preparation is a principal variable, which, if uncontrolled, can be the causes of discrepancies in the quantitative data obtained by various investigators. Consideration of this variable may permit resolution of many of the disagreements in the literature on the subject of sliding friction.

Load and Wear Effects

Load. - Figure 8 presents representative data, which show that Amontons' law is obeyed over the entire range of sliding speeds investigated with dry and boundary-lubricated surfaces. In the range of loads between 169 and 2232 grams (108,000 to 255,000 lb/sq in., initial Hertz surface stress), the coefficient of kinetic friction is essentially independent of the load. It should be emphasized that the surface stresses were computed by the Hertz equations, which assume that the area of contact is a function only of elastic deformation of the spherical rider and the disk. Because of wear of the rider during the experiment, however, the apparent area of contact increases and the unit surface stress continually decreases. The maximum diameter of the wear spot observed after the experiments was approximately 1 millimeter; the resultant increase in apparent area of contact decreased the surface stress during the experiments. It was observed, however, that the change in stress had no appreciable effect on measured friction.

Wear. - Photomicrographs of wear areas on riders after representative 6-second runs on dry and on boundary-lubricated surfaces are presented in figure 9. It was observed in these experiments that at a sliding velocity of 2000 feet per minute with a rider loading of 269 grams, wear was least when friction was least. This relation is not necessarily limited to these conditions nor surfaces, but the literature indicates that the relation may not be true in all cases. Figure 9 shows that the type of surface damage is much different in the case of the dry than in the case of the lubricated sliders. The dry rider shows an apparent welding and a tearing-out of the surface whereas the lubricated rider appears as though the damage were caused by a plowing or abrading action rather than by welding and tearing-out.

Analysis of Velocity Effects

Analysis of the results indicates two possible reasons for the variation in friction with sliding velocity: (1) physical change of surfaces, and (2) chemical change of surfaces.

Physical change of surfaces. - It is proposed herein that the heat developed by the rapid stress variations at the disk surface is confined to the surface because of the time lag in the heat-transfer process and that the heat causes physical changes in the surface material. Agreement with this theory is contained in reference 16, which includes a discussion on the analogous case of thermoelastic effects of the rate of stress variation on internal friction of polycrystalline metals. Increased rate of sliding, within unknown limits, will consequently result in higher surface temperatures and a change in the physical characteristics of the material that will affect its resistance to sliding. The increase in temperature probably reduces the shear strength of the surface and in consequence decreases friction. Studies reported in reference 17 show that friction decreases with an increase in temperature.

In order to partly verify this theory, an experiment was made with a disk of a steel alloy (SAE 6150) in which surface working is more easily observed than in the carbon steel that was used for the reported friction determinations. Figure 10(a) shows a photomicrograph of a cross section of the steel-alloy disk after the regular surface-preparation procedure had been followed; a slight amount of surface working may be observed. A dry run on this disk produced friction data that were similar to that shown in figure 5 for the carbon steel. A metallurgical examination of the transverse sections of the sliding track and subsurface for runs made at both low and high sliding velocities showed that little surface distortion occurred at low sliding velocity and that appreciable distortion (fig. 10(b)) occurred during operation at high sliding velocity. It may be observed in figure 10(b) that the structure of the surface material on the wear track underwent considerable physical change as a result of the high sliding velocity. The lack of depth of the deformation would indicate that localized surface changes occurred during sliding. Because physical changes in such materials are not completely reversible, these results (fig. 10) indicate that the material alteration that occurred during sliding at high velocities was more severe than that at low velocities. Figure 10(c) is a photomicrograph of a steel disk specimen showing the wear track resulting from a friction experiment and the adjacent unrun area of a typical surface.

Chemical change of surfaces. - Continuous sliding of the rider over the same track (caused by elimination of radial traverse) at high sliding velocities was observed to produce a black powder on the surface that was visible without magnification. An X-ray-diffraction examination of the powder identified it as ferrous oxide (FeO). The diffraction pattern and examination data that were used to make the identification are presented in figure 11. The examination data included in figure 11 account for all but one of the diffraction rings (ring for a value of d of 3.02 A) that are present in the pattern. The intensities and the locations of the diffraction rings believed to be caused by ferrous oxide check very closely with those given for the standard pattern of ferrous oxide.

An appreciable reduction in friction was observed with the occurrence of the visible ferrous oxide on the surface. Evidence of this phenomena is presented in figure 12, which is a photograph of original data obtained with the recording potentiometer. The data for a plot of μ_k against time presented in figure 12 show that friction was practically constant with time when the rider traversed a spiral path on the disk; however, an abrupt decrease in friction occurred shortly after the radial feed of the apparatus was stopped. When operation over the same path on the rotating disk was continued, the friction began to stabilize at about the same time that the ferrous oxide became visibly present on the surface. It is therefore reasonable to associate the presence of the ferrous oxide with the observed decrease in friction, although the transition mechanism of the surface chemistry is unknown.

A study of the physicochemical changes occurring in metallic surfaces during run-in and wear reported in reference 18 has associated the formation of oxides on reciprocating-slider test surfaces with satisfactory surface conditions. This observation and the information presented herein indicate that the occurrence of ferrous oxide is a function of operating conditions, such as surface temperature, that are influenced by sliding velocity. The chemical change at the surface and the physical changes of the surface material, which are probably related and caused by operating conditions, may account for the reduction in kinetic friction with increased rate of sliding at high sliding velocities.

SUMMARY OF RESULTS

An experimental investigation was conducted with a kinetic-friction apparatus consisting basically of an elastically restrained spherical rider sliding on a dry or boundary-lubricated rotating disk. The experiments were conducted with steel specimens over a range of velocities between 50 and 6600 feet per minute with loads from 169 to 2232 grams (108,000 to 255,000 lb/sq in., initial Hertz surface stress). Supplemental studies were made using standard physical, chemical, and metallurgical equipment and techniques. The following results were observed:

1. Kinetic friction of dry surfaces and of boundary-lubricated surfaces with two different lubricants decreased with an increase in sliding velocity over a range of velocities commonly used in engineering practice.

2. Amontons' law was verified at all speeds investigated with dry surfaces and with surfaces boundary-lubricated with oleic acid or a commercial SAE No. 10 oil.

3. High surface temperatures and the occurrence of ferrous oxide on the sliding surface were possible causes for the reduction in kinetic friction that accompanies an increase in sliding velocity.

4. The divergence of results presented in literature by various investigators of dry friction may be partly explained by a study of the manner of surface preparation. Surface preparation is the most important single technique contributing to the investigation of kinetic friction between dry surfaces.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, July 22, 1947.

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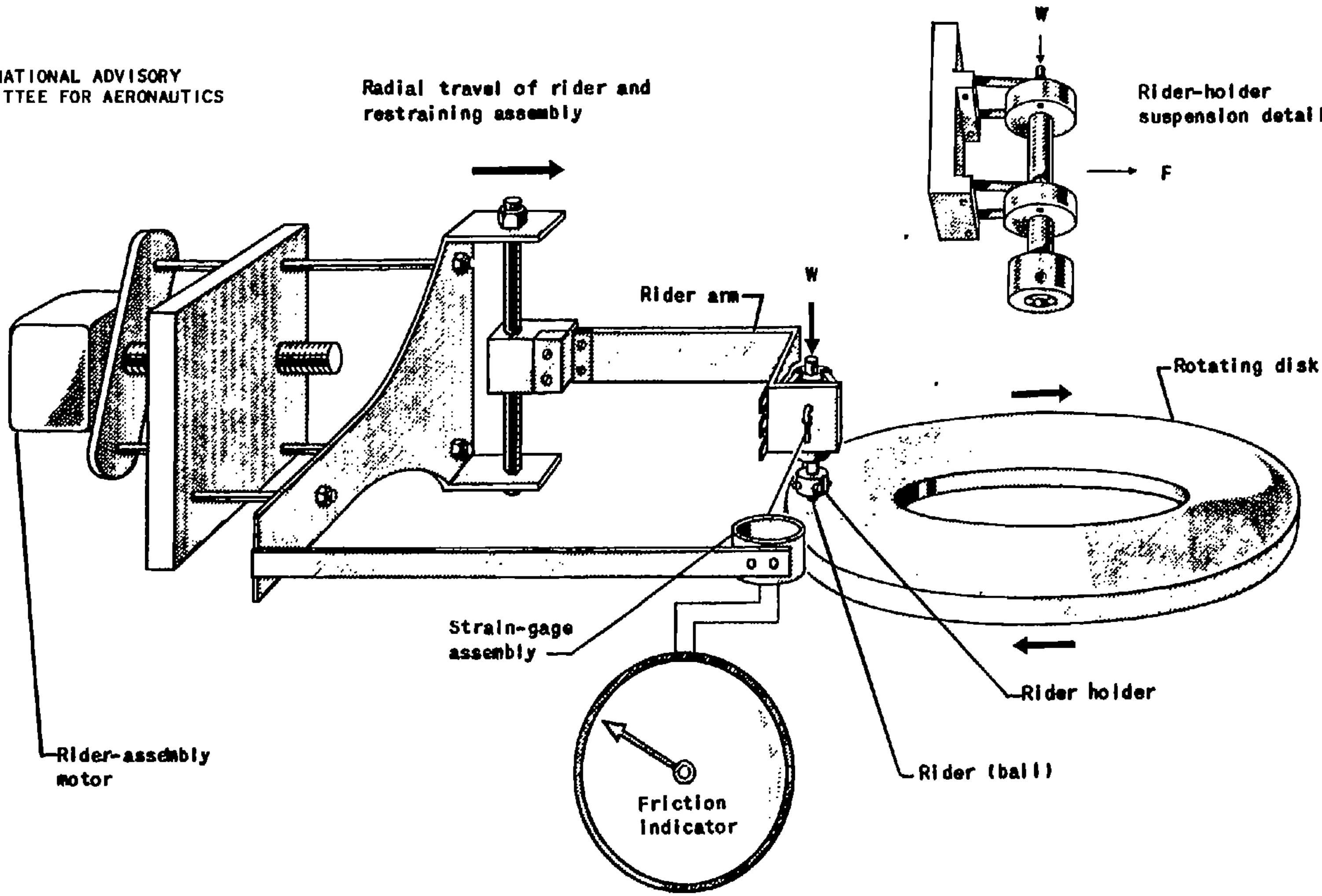


Figure 1. - Schematic diagram of sliding-friction apparatus.

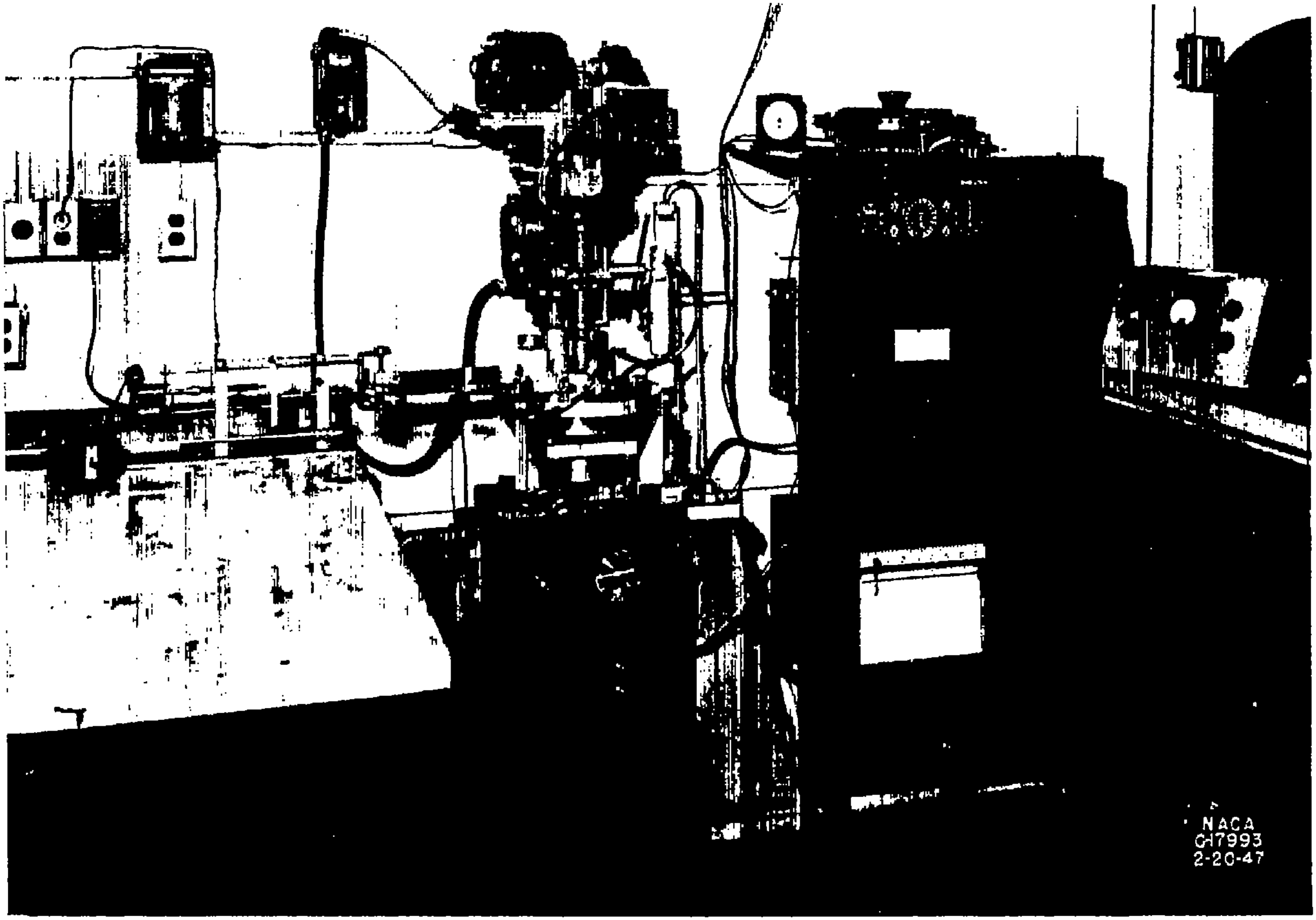


Figure 2. - Sliding-friction apparatus used for friction and wear studies.

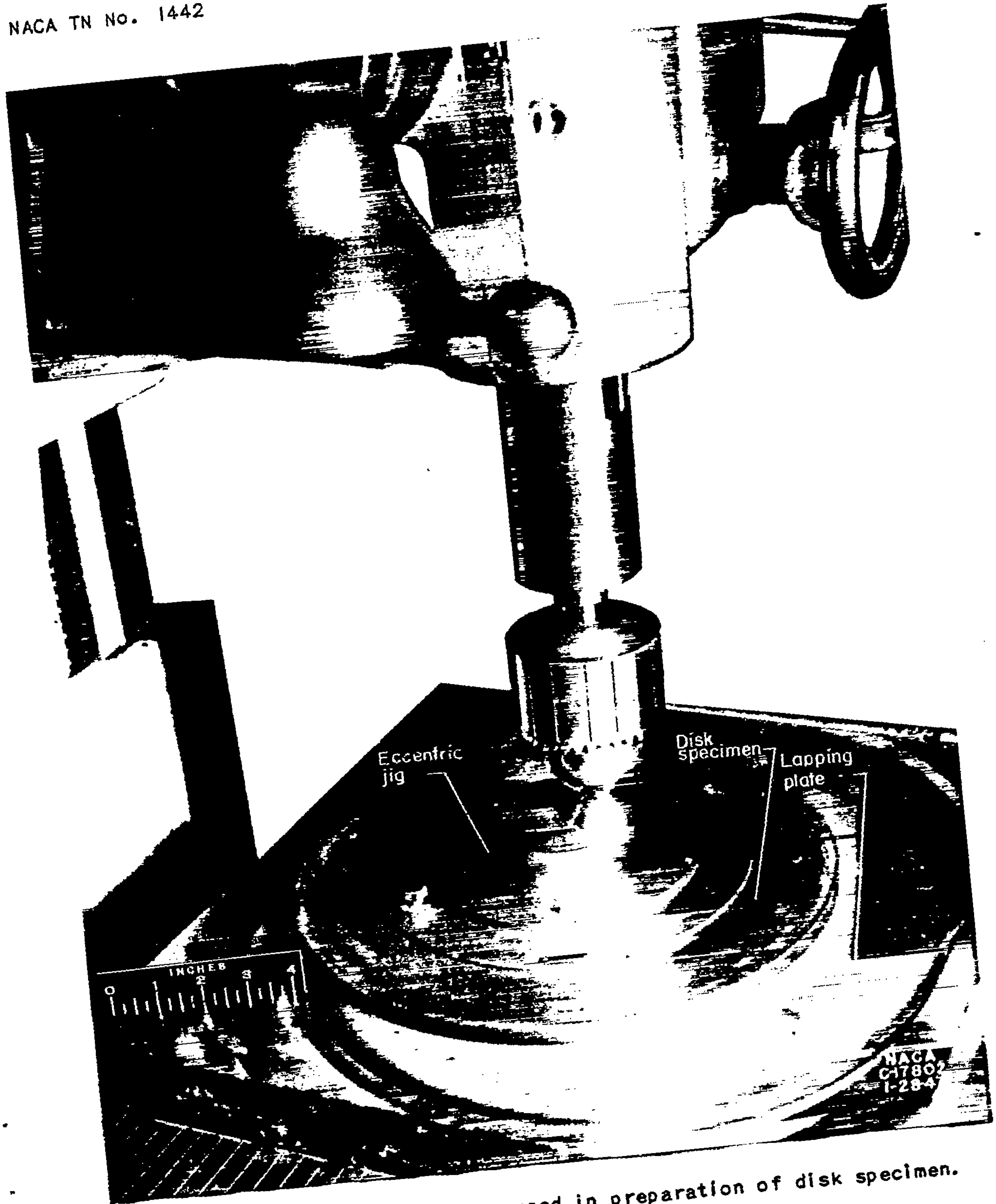
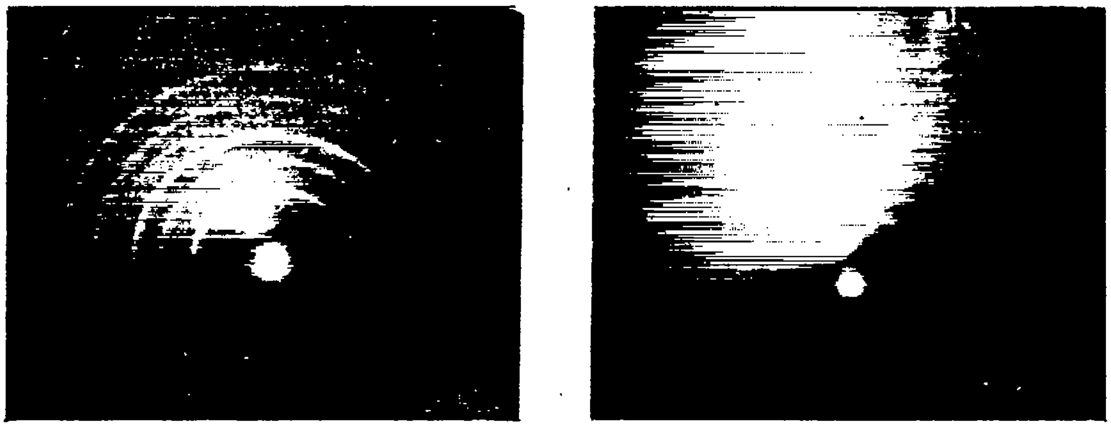


Figure 3. - Lapping apparatus used in preparation of disk specimen.



(a) Chemically clean steel.

(b) Specimen of SAE 1020 steel as used in experiments.

Figure 4. - Electron-diffraction patterns from surface of chemically clean steel and SAE 1020 steel cleaned by technique described in present report. The background scattering and extra alpha-iron rings on (b) are due to an invisible oxide film.

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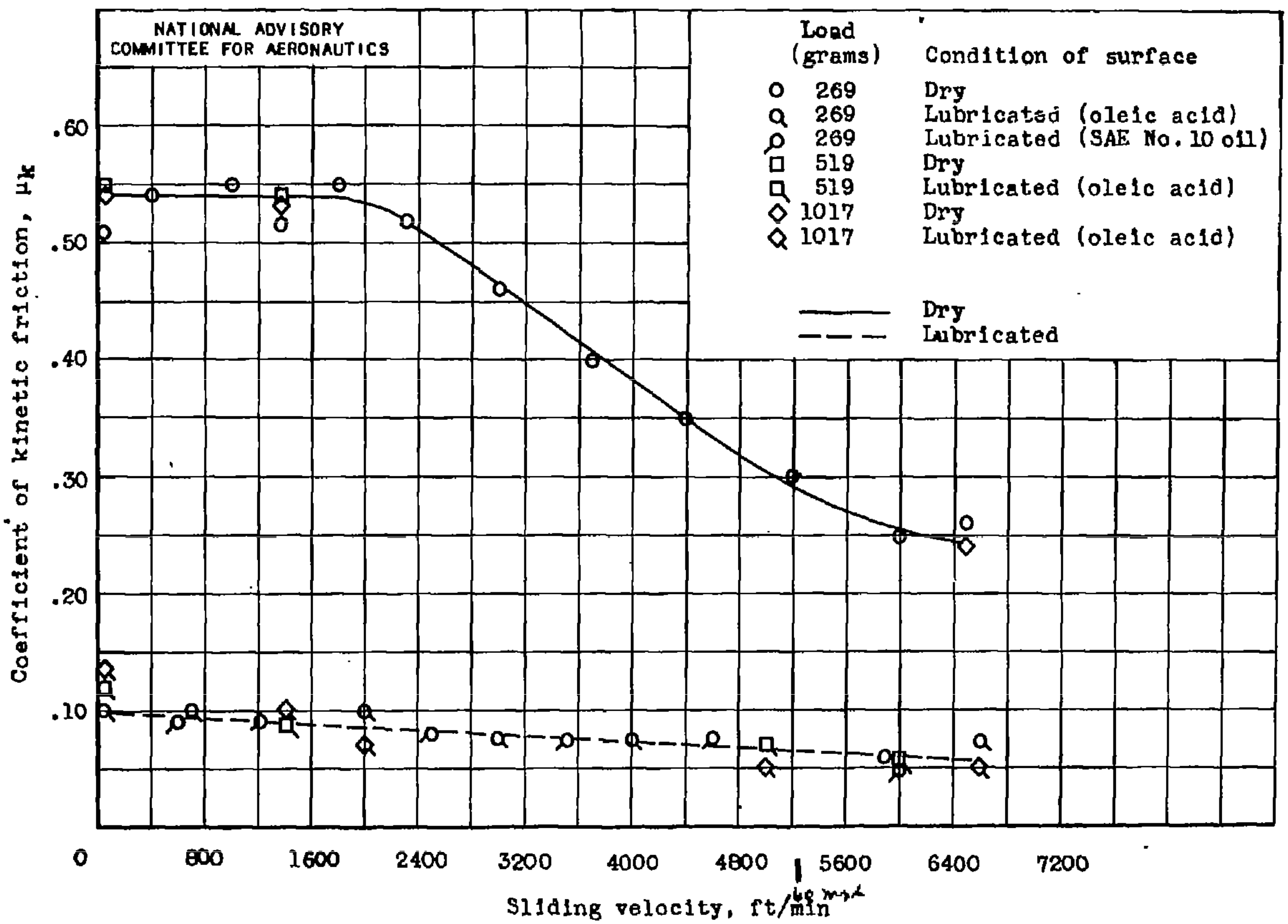


Figure 5. – Effect of sliding velocity on coefficient of kinetic friction for dry and boundary-lubricated steel surfaces.

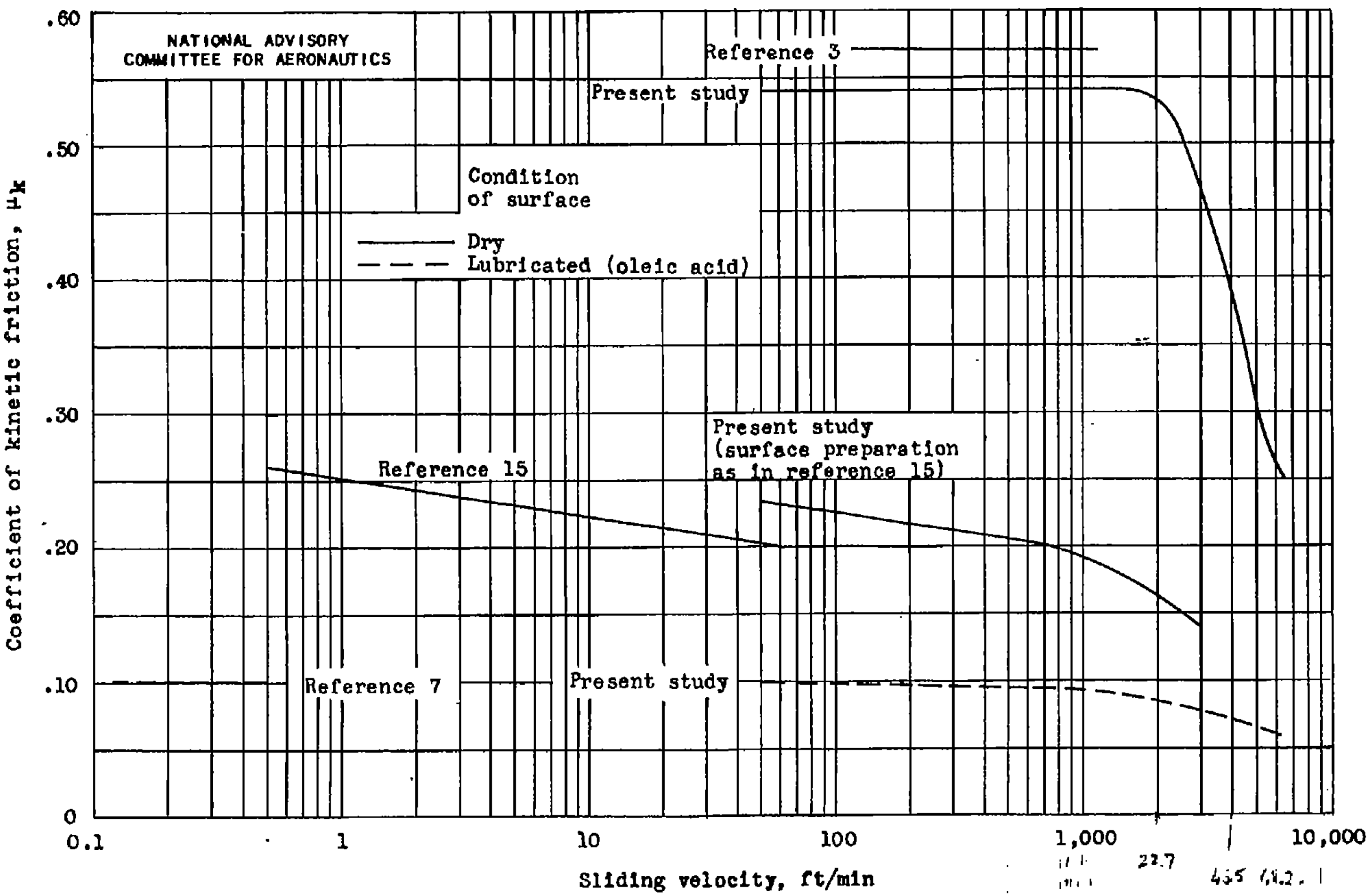
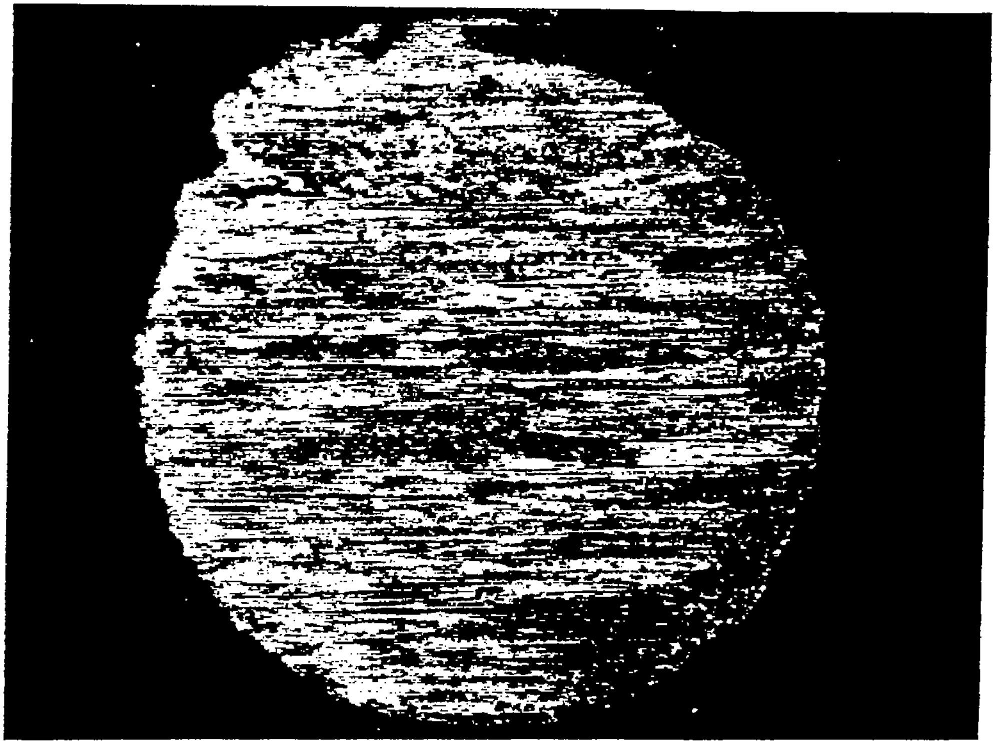
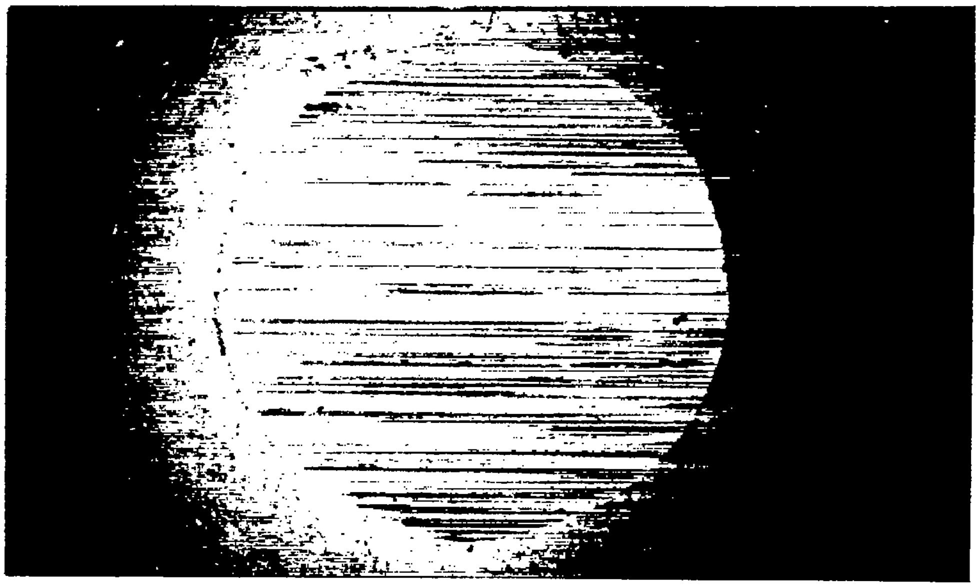


Figure 7. - Comparison of data from present study with that of other investigations.



(a) Dry steel disk; coefficient of kinetic friction μ_k, 0.48; wear-spot diameter, 0.96 millimeter (0.038 in.).



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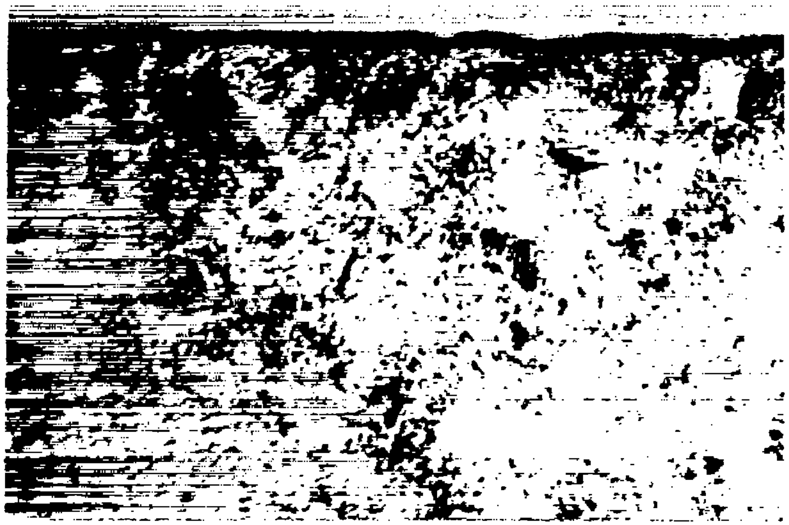
(b) Steel disk boundary-lubricated with oleic acid; coefficient of kinetic friction μ_k, 0.10; wear-spot diameter, 0.71 millimeter (0.028 in.).

Figure 9. - Photomicrographs of wear areas on spherical rider after runs for 6 seconds at 2000 feet per minute with load of 269 grams. X100.



(a) Cross section of unrun portion of steel alloy specimen showing uniform surface and small amount of cold working. X750.

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(b) Cross section of run portion of steel alloy specimen showing deformation of surface material. X750.

Figure 10. - Photomicrographs showing surface deformation that occurs under the action of sliding at high unit pressures.

(c) Surface of steel disk specimen showing wear track formed by spherical rider and an adjacent unrun surface with random finish. Load, 269 grams. X18.

Figure 10. - Concluded. Photomicrographs showing surface deformation that occurs under the action of sliding at high unit pressures.

Black powder formed during friction experiment		Standard X-ray pattern of FeO		Explanation of other rings in pattern	
[a]d (A)	Relative intensity	[a]d (A)	[b]I/I_o	[a]d (A)	Source
6.00	Fairly strong	-----	----	6.00	Binder for mounting powder
5.33	Fairly strong	-----	----	5.33	Binder for mounting powder
4.35	Weak	-----	----	4.35	Binder for mounting powder
3.89	Strong	-----	----	3.89	Thread for mounting powder
3.34	Very weak	-----	----	3.34	Thread for mounting powder
3.02	Very weak	-----	----	3.02	Unidentified
2.47	Strong	2.47	0.50	----	------------------------
2.14	Very strong	2.14	1.00	----	------------------------
2.02	Fairly strong	-----	----	2.02	Alpha-iron
1.51	Strong	1.51	.63	----	------------------------
1.28	Weak	1.293	.15	----	------------------------
1.23	Weak	1.238	.08	----	------------------------

[a]Interplanar spacing, angstrom units, A.
[b]I/I_o, A.S.T.M. standard intensity ratio.

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Figure 11. - X-ray diffraction pattern and analysis data from black powder formed on steel disk during sliding at high velocities without radial traverse. Powder identified as ferrous oxide (FeO).

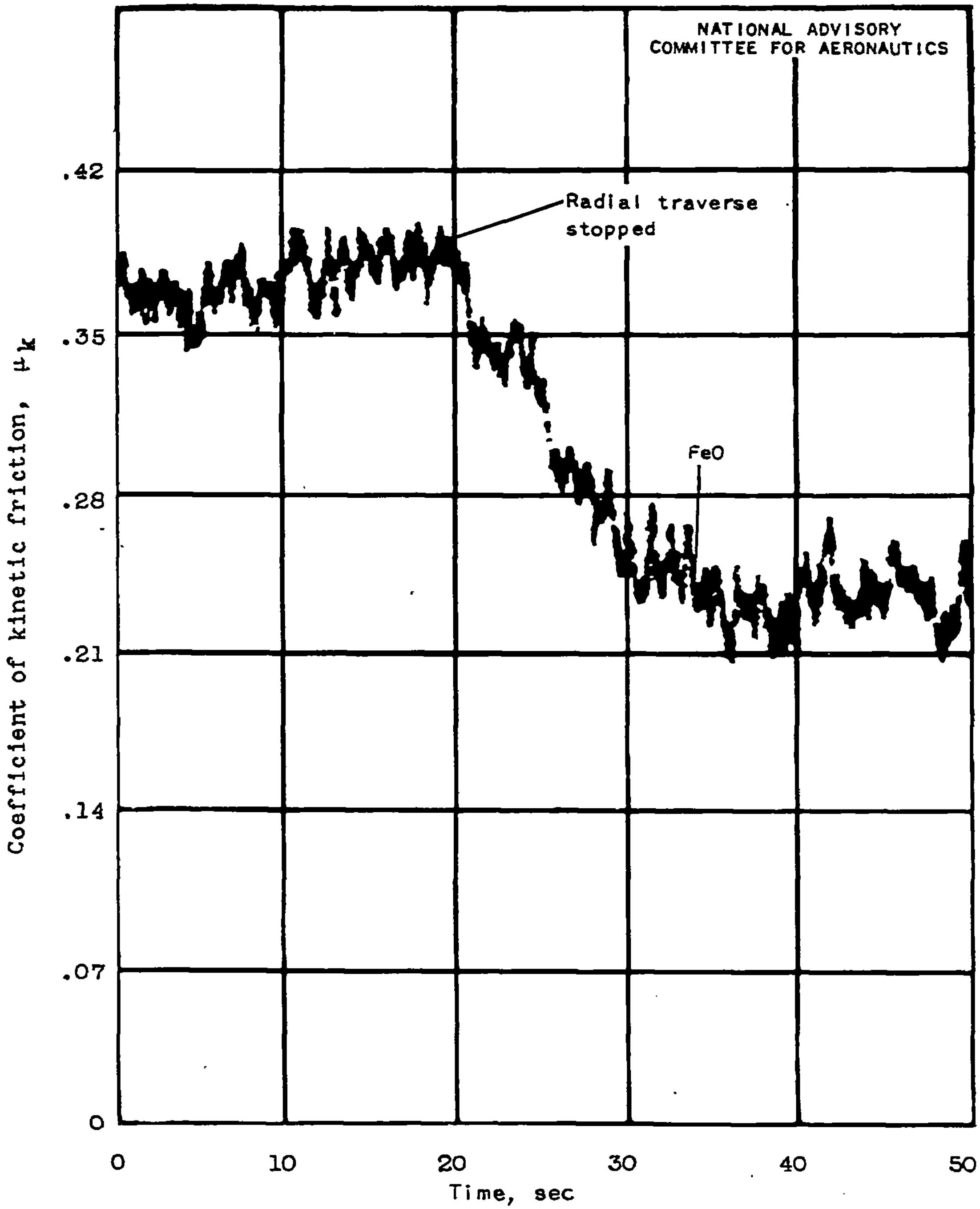

Figure 12. - Recording-potentiometer data showing effect of high-velocity sliding over a continuous path (without radial traverse) on coefficient of kinetic friction. Ferrous oxide (FeO) was visibly present as the decreasing friction trend began to stabilize. Dry steel; load, 269 grams; sliding velocity, 4000 feet per minute.

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ABSTRACT

Experiments were conducted with kinetic-friction apparatus with steel specimens over ranges of speeds between 50 and 6600 ft/min and loads from 169 t- ~232 grams. Kinetic friction decreases with sliding speed for dry and for some boundary-lubricated surfaces at high sliding speeds. Amontons law was verified at all speeds with dry and boundary-lubricated surfaces. Changes in physical characteristics of material resulting from high-surface temperatures caused by increased rate of surface stressing and occurrence of ferrous oxide on the sliding surface are possible causes for reduction in kinetic friction with high-sliding velocities.

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