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TECHNICAL NOTE

D-289

IGNITION OF A COMBUSTIBLE ATMOSPHERE BY INCANDESCENT CARBON WEAR PARTICLES

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empty tank that has been subjected to alternate cycles of temperature and/or pressure altitude changes so that the tank has alternately expelled vapors and drawn in air. A combustible atmosphere is especially likely to occur in tanks containing fuels with a volatility lower than gasoline. Positive-displacement priming pumps for use under the conditions described employ carbon vanes that allow extended dry operation without excessive wear or other surface failure. A schematic diagram of a typical vane pump is shown in figure 1. Concern for the possible ignition of combustible tank atmospheres by particles of carbon wearing away from vanes in pumps prompted the study reported herein.

It has been demonstrated that flash temperatures of high spots or asperities on surfaces in sliding contact can be 900° to 1800° F (500° to 1000° C, ref. 1) above the bulk temperatures of the slider materials. Wear particles from asperities may achieve incandescent temperatures and, in an oxygen-containing atmosphere, can burn (ref. 2). In particular, the wear of carbon is accelerated by operation at high altitude (ref. 3) and by an electric potential across the sliding interface. All of these conditions may be experienced in the aircraft flight operation of an electrically driven vane-type fuel pump.

An experimental investigation was conducted to determine whether carbon wear particles could cause ignition of a combustible mixture of propane and air. Propane was chosen as a convenient hydrocarbon fuel whose ignition characteristics are close enough to aviation fuels to be meaningful in this study. The experimental conditions and materials selected were characteristic of those in vane-type fuel pumps commonly used in current aircraft. Under normal circumstances, an electric potential would not be imposed on the interface between the carbon vane and the metal pump housing. Electrical failure in the pump motor may, however, place potential differences at the vane-housing interface by conduction along the drive shaft. The high electrical resistance of anodized aluminum surfaces and of lubricant films allows potential differences to appear in some pumps. These high resistances have been meas-used in an operating pump. They appear intermittently for short periods of time, presumably when the pump shaft is floating free in its bearings.

Experimental runs were made with an apparatus capable of simulating the sliding conditions that occur in some pumps. A carbon vane removed from a fuel pump was caused to slide on the flat surface of a rotating disk that simulated the surface of the pump housing. Visual and photographic observations were made as to the formation of incandescent wear particles in atmospheric air and in partial vacuum both without and with various electric potentials at the interface. When the conditions for producing incandescent wear particles were obtained in air, runs were repeated in the combustible atmosphere to determine whether ignition would occur.

E-984

CS-1 back

APPARATUS AND PROCEDURE

The apparatus used in this investigation is shown schematically in figure 2. The apparatus included a heater housing containing 12 resistance-type cartridge heaters that surrounded the test specimens. Experiments were made with specimen temperatures to 450° F. The specimens and heater housing were contained in a chamber that was sealed and filled with various gas atmospheres. In each test, a $2\frac{1}{2}$-inch-diameter disk that rotated and a stationary carbon vane were used as specimens. The carbon vane was mounted on a retaining arm. The retaining arm was pivoted through gimbals mounted to load the vane against the disk and to enable the measurements of friction torque. The face cover plate of the gas chamber contained a mica window for visual observation as well as photography of experiments; it also served as a blowout disk to prevent damage to the apparatus in the event of gas ignition.

The test specimens used in the study were carbon vanes removed from a fuel pump (fig. 3) and two types of $2\frac{1}{2}$-inch-diameter 440-C stainless-steel disks (fig. 4(a)). The specimens were designed to simulate the condition in the vane-housing assembly of a pump. X-ray diffraction examination indicated that the vanes contained some graphitic carbon. The 440-C stainless-steel disks were of the same material as the rotor housing of a fuel pump. To further simulate conditions in the pump, one of the two disk specimens had four series of holes drilled in the surface area traversed by the vane to reproduce the type of surface in contact with the vanes in a fuel-pump housing.

Each of the four sets of six 1/8-inch-diameter holes was drilled in the disk, as shown in figure 4(b), at an angle of 51° to the flat surface. This was the same angle employed in the pump rotor housing. In addition to the angle of the hole with respect to the surface, the angle of the vane with respect to the metal disk - or housing in the case of a pump - was reproduced. The smallest contact angle between the metal surface and the carbon vane was 55°. The angles formed with the vane and disk in contact can be seen in figure 4(b).

The environments employed in the experiments were: (1) air at atmospheric pressure, (2) partial vacuum, and (3) a combustible gas mixture. The partial vacuum was obtained by evacuating the air-filled test chamber to a pressure of 6 inches of mercury absolute (38,000-ft pressure altitude). The purpose of the partial vacuum was to explore the influence of wear particle size as well as reduced oxygen concentration on the system. It has been demonstrated in reference 3 that, at high altitudes (low pressures), increased wear of carbon is likely.

A combustible air-propane composition was used as the ignitible gas mixture. Propane was selected because it has an ignition temperature near that of JP-4 (aircraft fuel). Runs were made in the air-propane atmosphere to determine whether carbon wear particles could reach the ignition temperature of the atmosphere.

The temperature levels at which the experiments were carried out in air and in partial vacuum were 75°, 350°, 400°, and 450° F. The 75° F runs were to simulate normal pump operating temperature. The elevated temperatures were employed to consider what could occur during a pump malfunction. An example of such a malfunction might be an intermittently locked rotor. Under such conditions, pump temperatures up to 450° F have been measured. The large currents in the electric motor when the rotor is locked produce these high temperatures.

In order to obtain the various electric potentials desired in the investigation, two electrical systems were employed. The first consisted of a conventional ignition transformer rated at 10,000 volts, connected directly to the vane specimen to simulate voltages characteristic of electrostatic accumulation. The disk and transformer case were connected to a common ground. A voltage of several thousand volts and a maximum amperage of 23 milliamperes were obtained across the vane-disk interface. All voltages reported herein are measured with zero current flow; the voltage across the carbon-vane - disk interface is not known when current is flowing.

The lower voltages (115 to 90) and higher amperages (2.3 to 0.07) were obtained with two isolation transformers individually connected to a resistance leak and the vane specimen (fig. 5). In obtaining various amperages, a resistance tapping of adjustable power resistors was used. Again, the voltages are measured at zero current flow; hence the voltage when current is flowing is not known. With this system, the following voltages and amperages were used: 90 volts with 2.3 amperes, 110 volts with 1.0 ampere, 110 volts with 0.6 ampere, 106 volts with 0.3 ampere, and 115 volts with 0.07 ampere.

Prior to each experiment the specimens were thoroughly cleaned and then mounted in the apparatus. The chamber was provided with the environment required for the particular experiment. The carbon vane was loaded against the disk with a 0.5-pound load (calculated force on the vanes in the pump). The disk was rotated to maintain a surface speed of 3140 feet per minute. Experiments ranged in duration from 3 minutes to 1 hour.

The procedure followed in running the experiments was initially to run the plain disk in combination with the carbon vane at various temperatures in air and in a partial vacuum. These runs were designed to simulate contact of the carbon vane with the plain surface of the pump housing wall. This was followed by runs using drilled disk specimens under the same conditions of temperature and environment. The drilled disks reproduced the surface of the pump housing in the area of inlet and outlet fuel ports. Runs were then made with the drilled disk in an air-propane atmosphere with various electric potentials applied across the vane-disk interface. The air-propane mixture provided a combustible atmosphere analogous to that existing in a pump, and the electric potential provided conditions of electrical failures.

RESULTS AND DISCUSSION

No Interface Potential

Experimental runs first were made with a carbon vane sliding on a plain (no ports) 440-C stainless-steel disk in air at temperatures of 75°, 350°, 400°, and 450° F to determine whether carbon wear particles of an incandescent nature could be obtained without a potential difference at the vane-disk interface. Runs were made at atmospheric pressure and at a partial vacuum of 6 inches of mercury absolute. In the runs the carbon wear particles obtained could not be classified as incandescent. The results, together with the friction coefficient and wear values measured during 45-minute runs, are presented in table I, experiment numbers 1 and 2. Although the carbon wear particles obtained were not of an incandescent nature in either environment, the friction and wear values were somewhat higher in the partial vacuum (fig. 6).

The disk specimen with holes drilled in the surface to simulate fuel ports of a pump housing was used in all subsequent runs. The experiments with carbon vanes sliding against the disk surface containing holes produced carbon wear particles that were more numerous and larger in size than those obtained with the plain disk surface. The particles, however, were not incandescent. This condition existed in experiments conducted in air and in partial vacuum at temperatures from 75° to 450° F (see table I, nos. 3 and 4). It is of interest to note that the wear values obtained in air and in partial vacuum with the disk containing the drilled surface were approximately twice those obtained with the plain disk (fig. 6). This fact, coupled with the relative size of the particles, would seem to indicate that the sharp edges of the holes, or ports in the case of the pump, act as cutting edges for the carbon vanes.

Imposed Interface Potential

Since no incandescent particles were observed at the preceding experimental conditions, application of an electric potential across the vane-disk interface was next considered. Experiments were made under the same conditions as described previously except that 10,000 volts and 23 milliamperes was applied across the vane-disk interface (table I, nos. 5 and 6). In every run, incandescent carbon wear particles were obtained (fig. 7). Variation in the color of light emitted by the particles (yellow to bright white) indicated that the temperature varied over a wide range. The particles at white heat may well have exceeded momentary temperatures of 2000° C (ref. 2).

Once incandescent carbon particles were obtained, it became necessary to determine whether these particles could ignite a combustible gas atmosphere. The experiments run previously were repeated with the same electric potential across the vane-disk interface, but in a combustible air-propane mixture. Incandescent wear particles were observed; a motion-picture film supplement has been prepared and is available on loan; a request card and a description of the film will be found at the back of this report on the page immediately preceding the abstract and index pages. In six runs, one explosion was obtained (see table I, no. 7).

To determine whether voltage and amperage levels near those of an operating fuel pump motor could also cause ignition of the propane-air mixture, runs were made with interfacial potentials from 90 to 115 volts and from 2.3 to 0.07 amperes. Incandescent carbon wear particles and ignition of the combustible gas by these particles were obtained with as little current as 0.3 ampere (table I, nos. 8 to 12). Ignition of the gas mixture with 0.3 ampere at 106 volts across the vane-disk interface required an ambient temperature of 400° F.

With 0.07 ampere at 115 volts, no ignition was obtained at any of the test temperatures. The particles had a dull orange appearance (table I, no. 13). The appearance of carbon wear particles varied from a white heat at 2.3 amperes to a dull orange or red at 0.07 ampere; this indicates that the temperature of the particles was directly related to the amperage applied across the vane-disk interface.

In these experiments, sparks or glow discharge was frequently observed in addition to the hot wear particles. In no instance, however, did ignition occur in the absence of visible wear particles.

CONCLUDING REMARKS

From the results obtained with carbon vanes sliding on rotating metal surfaces, the following conclusions can be made:

1. Carbon wear particles from carbon elements sliding on a metal surface (440-C stainless steel) can become incandescent if there is an electric potential across the carbon-metal interface.

2. Incandescent carbon wear particles can ignite a combustible atmosphere (air-propane).

3. Electric discharge in the absence of incandescent carbon wear particles did not cause ignition of the air-propane mixture.

These results suggest that electrical insulation of additional motor and pump parts may be desirable. This can be achieved by use of nonconducting materials in some parts of the pump case and shaft assemblies.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, June 7, 1960

E-984

REFERENCES

1. Bowden, F. P., and Tabor, D.: Friction and Lubrication. John Wiley & Sons, Inc., 1957.

2. Bowden, F. P., and Lewis, R. D.: Ignition of Firedamp by Stationary Metal Particles and Frictional Sparks. Engineering, vol. 186, no. 4824, Aug. 22, 1958, pp. 241-242.

3. Mantell, C. L.: Industrial Carbon, Its Elemental, Adsorptive, and Manufactured Forms. Ch. XVII, Brushes. Second ed., D. Van Nostrand Co., Inc., 1946.

TABLE I. - EXPERIMENTAL DATA OBTAINED WITH CARBON VANES SLIDING ON 440-C STAINLESS-STEEL DISKS

[Load, 0.5 lb; sliding velocity, 3140 ft/min.]

Experiment number	Type of disk	Number of runs	Temperature, °F	Atmosphere (a)	Time, min	Friction coefficient (b)	Wear, wt. loss in mg	Applied voltage (at zero current)	Applied amperage	Sparks	Nature of sparks	Ignition of mixture
1	Plain	2	75,350, 400,450	Air	45	0.17	{1.0 1.2	None	None	None visible	----	-----
2		2	75,350, 400,450	6 in. Hg abs	45	0.28	1.7					
3	Drilled[c]	2	75,350, 400,450	Air	45	0.18	{2.0 2.5	None	None	None visible	----	-----
4		2	75,350, 400,450	6 in. Hg abs	45	0.30	{2.8 3.2					
5		5	75,350, 400,450	Air	--	----	---	10,000	0.023	Yes, at all temperatures	White to yellow intensity	-----
6		2	75,350	6 in. Hg abs				10,000	0.023		White to yellow intensity	-----
7		6	75	Air, propane				10,000	0.023		White to yellow intensity	Yes, one out of six runs
8		3	75					90	2.3		White to yellow	Yes, all three runs
9		1	75					110	1.0		White to yellow	Yes
10		1	75					110	0.6		White to yellow to orange	Yes
11		3	75					106	0.3		Yellow to orange	No
12		6	400					106	0.3		Yellow to orange	Yes, three out of six runs
13		3	75,350, 400,450					115	0.070		Orange to red	No

[a]Pressure is atmospheric unless otherwise noted; 6 in. Hg abs is equivalent to 38,000-foot altitude; air-propane mixture is 1.0 liter air, 1.1 liters propane.

[b]In experiment numbers 5 to 13, no friction values could be obtained because ignition wire was attached to vane specimen.

[c]Drilled disk specimens had four sets of six holes drilled at an angle of 51° to plane surface in area traversed by vane.

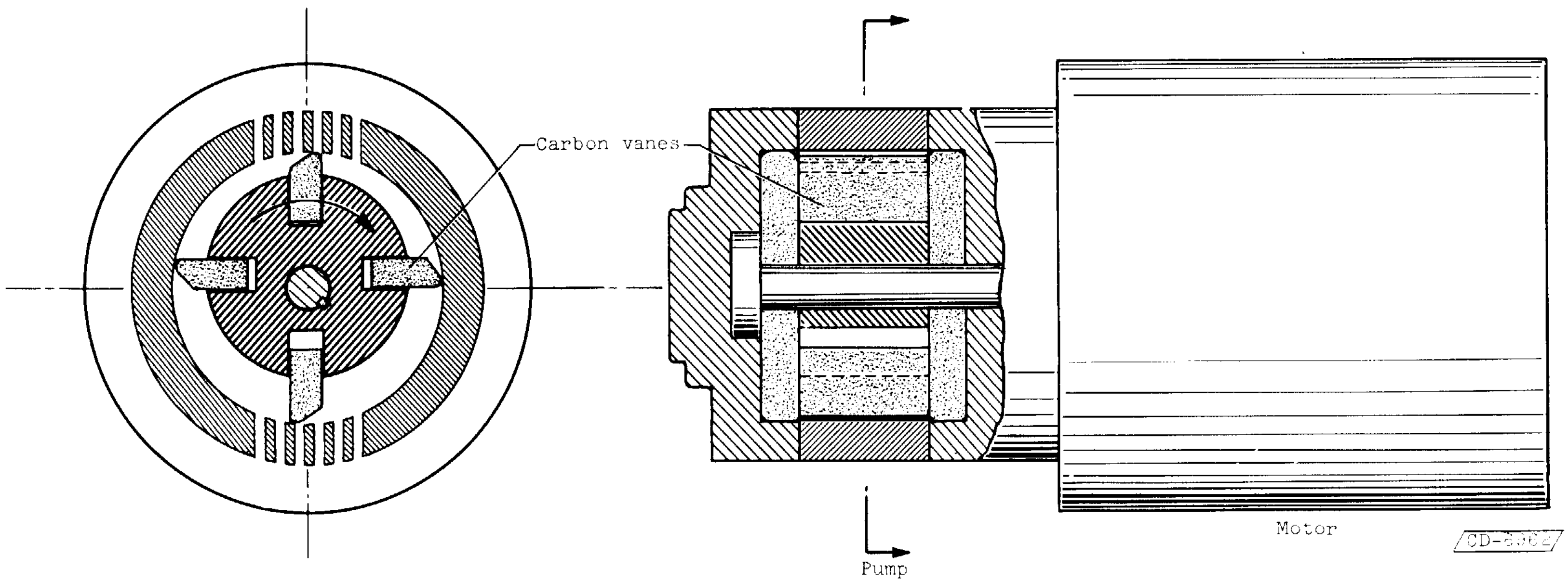

Figure 1. - Vane-type fuel pump.

E-984

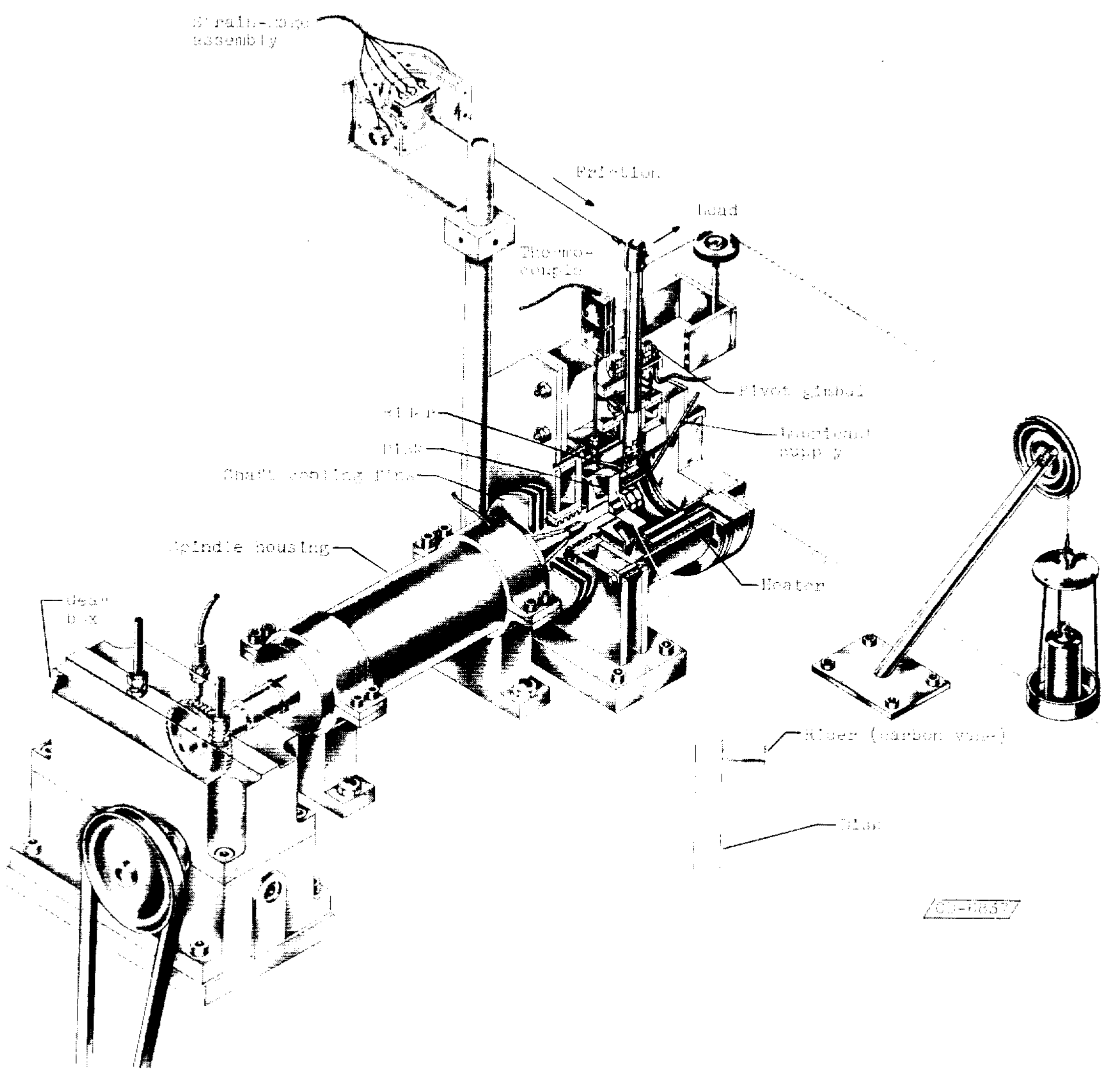

Figure 2. - High-temperature friction apparatus.

E-984

CS-2 back

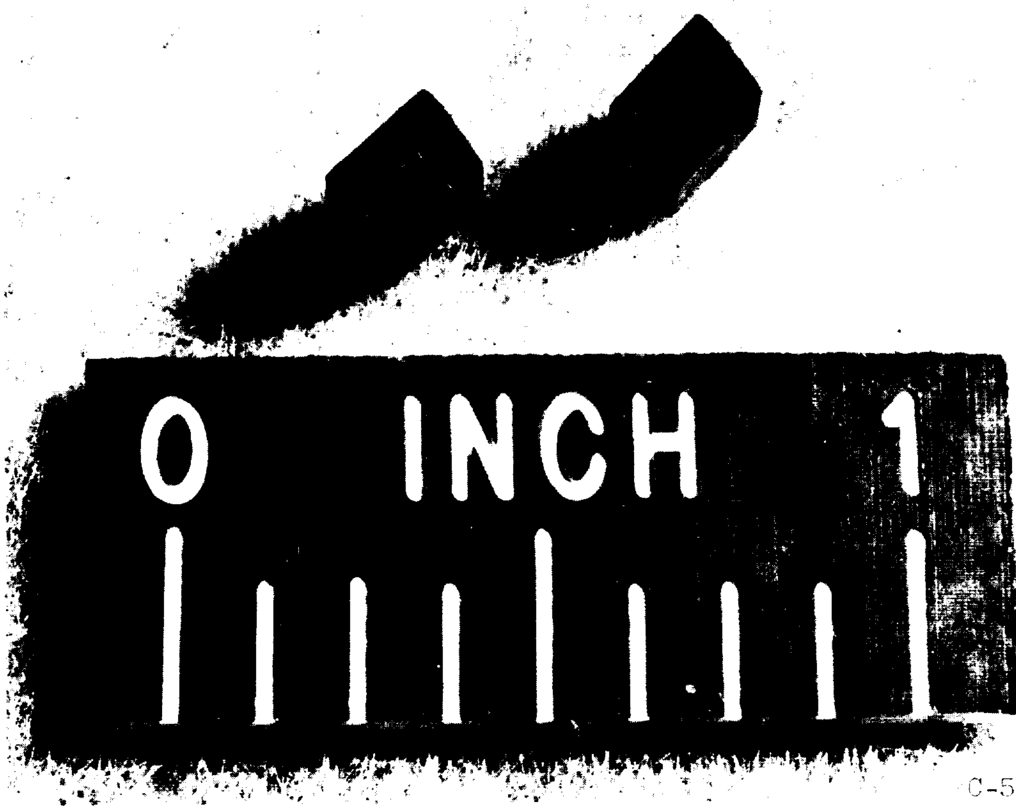

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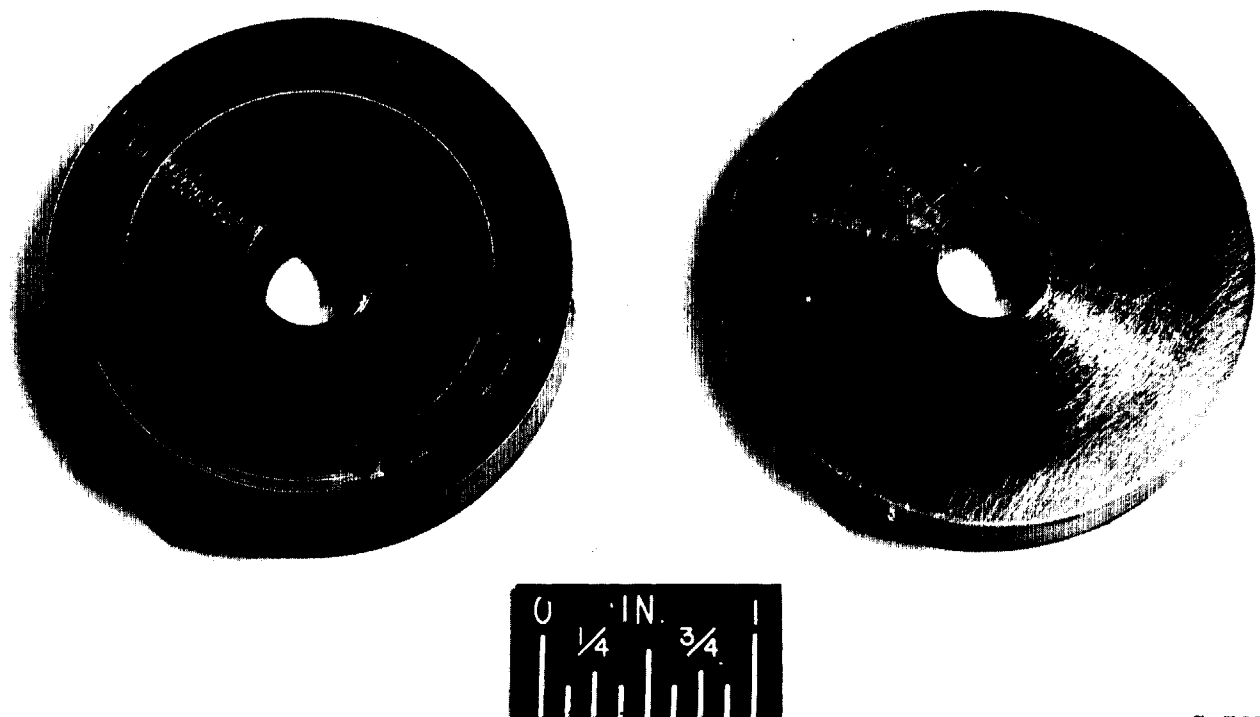
Figure 3. - Carbon fuel-pump vanes.



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(a) Two disk specimens used in combination with carbon vanes.

Figure 4. - 440-C stainless-steel disks.

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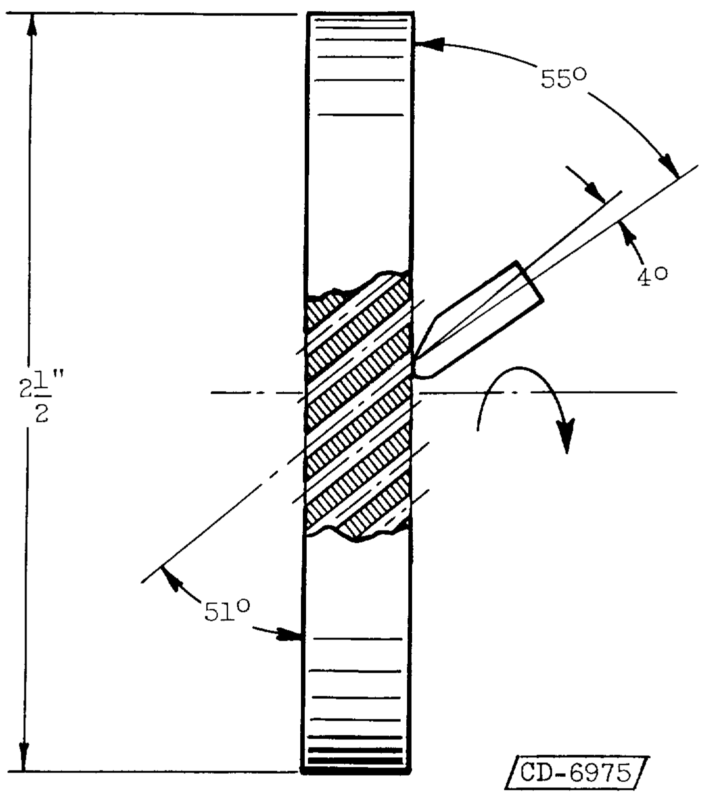

(b) Angles between disk and vane specimens.

Figure 4. - Concluded. 440-C stainless-steel disks.

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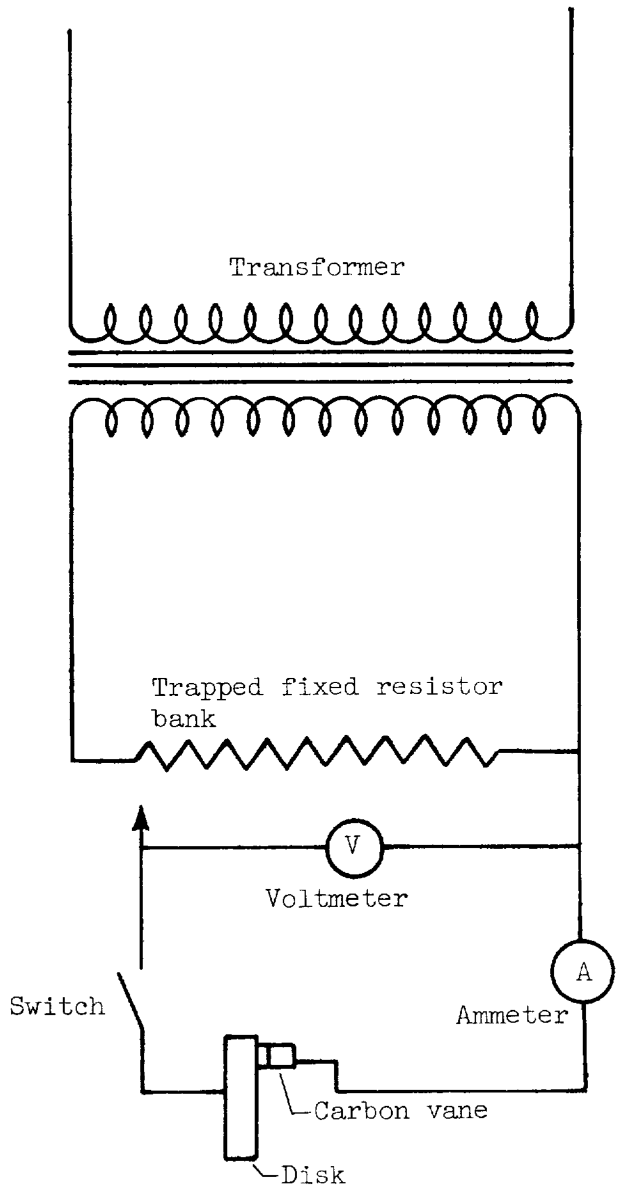

Figure 5. - Electrical circuit used in obtaining various voltages and amperages across carbon-vane - stainless-steel-disk interface. Various transformers were used to obtain desired voltages and amperages.

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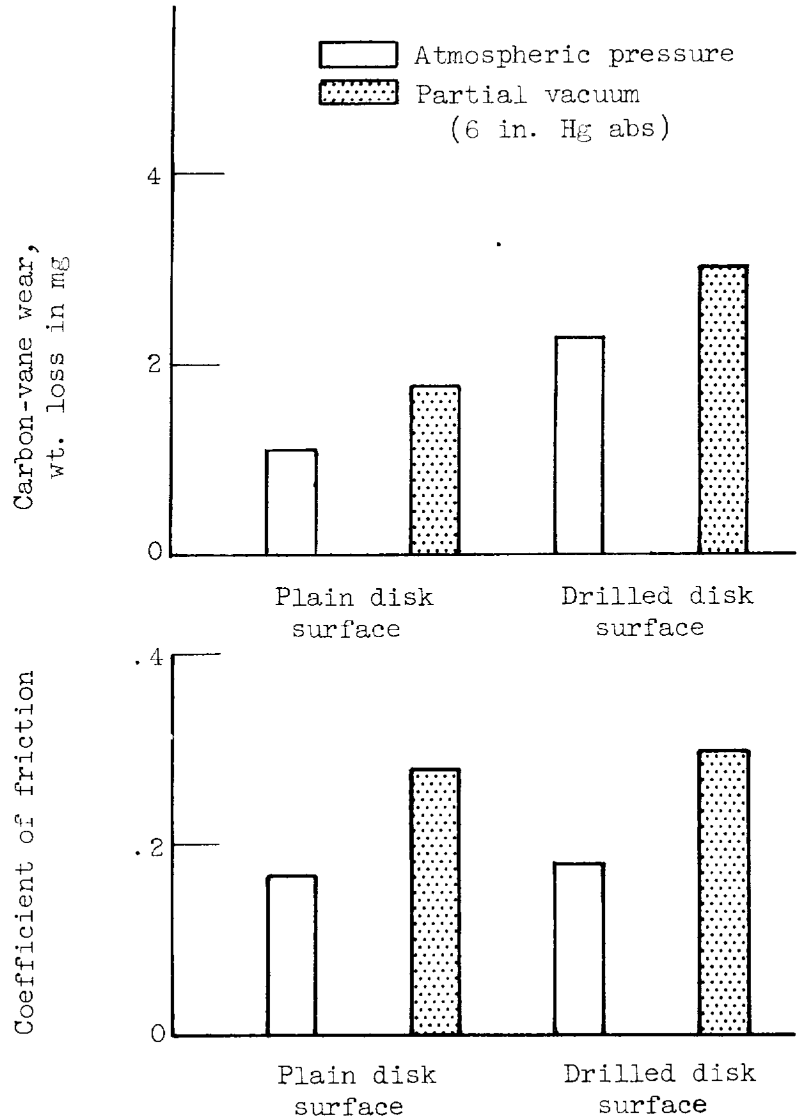

Figure 6. - Friction and wear of carbon vanes sliding on 440-C stainless-steel disks in air and in partial vacuum. Sliding velocity, 3140 feet per minute; load, 0.5 pound; temperature, room to 450° F; duration, 45 minutes.

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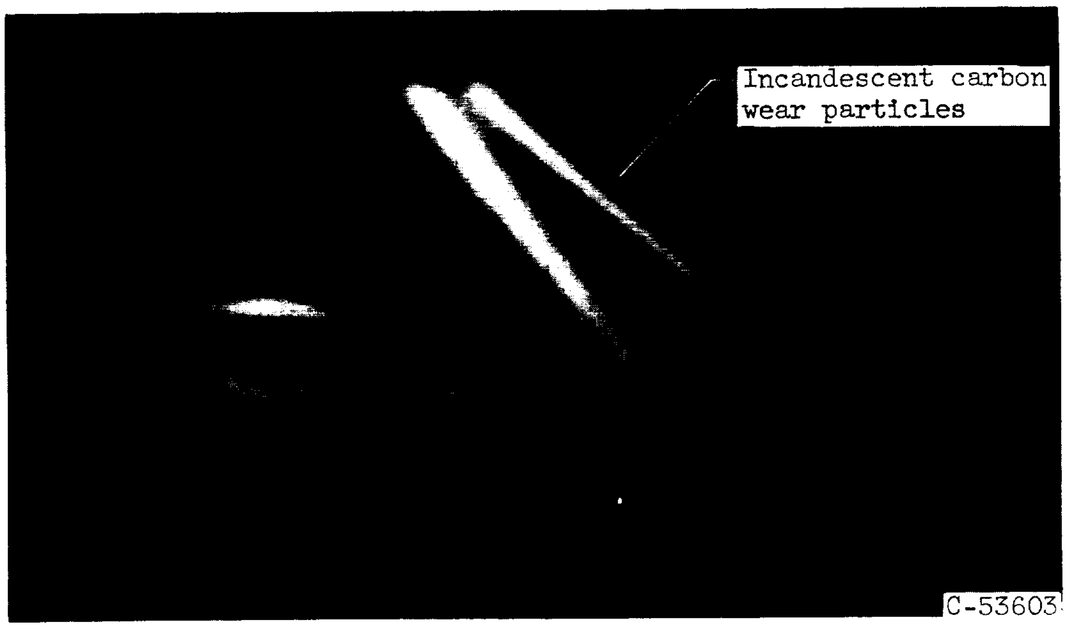

Figure 7. - General appearance of incandescent carbon wear particles obtained with carbon vane sliding on 440-C stainless-steel disk specimen.

A motion-picture film supplement is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, $5\frac{1}{2}$ min, B&W, sound) shows actual experiments in which incandescent carbon wear particles are liberated from carbon vanes sliding on stainless-steel disks. A number of explosions produced by these particles in a combustible atmosphere were recorded on film and are presented in this supplement.

CUT

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Please send, on loan, copy of film supplement to TN D-289

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