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AN EVENT RECORDER FOR OBTAINING MISSILE HEAT-SHIELD ABLATION DATA

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ABSTRACT

A miniature 84-channel event recorder designed to record in-flight measurements of heat-shield ablation has been developed. The flight data which are a series of times at which flight events occurred are stored in the instrument and read out after recovery of the reentry payload. Although the event recorder has been used primarily to record heat-shield ablation data, it is not limited to measurements of this type and can record any data which are provided in the form of an event.

The instrument consists of a metallic recording disk rotated at a constant speed by a spring-driven motor, and fuse wire marking elements which mark the disk when an event occurs. The time between events is found by angular measurement of the distance between the marks. The device occupies a volume of 13 cubic inches and weighs 8 ounces. Test results indicate that the instrument will operate properly when subjected to a vibration of 15g, an acceleration of 130g, a shock of 300g, and temperatures from 40° to 160° F. The results also show that the stored data are not degraded when the recorder is exposed to a temperature of 600° F for 15 minutes, a shock of 1000g and sea water for 1 month.

This paper describes the principle of operation, the design and construction, and the results of the tests conducted in the event recorder development.

INTRODUCTION

Current interest in flight testing of heat-protective materials for spacecraft has created a need for recoverable systems which will record experimental data during the peak heating of reentry and will survive exposure to high temperature, mechanical shock, and sea water after reentry. To meet this need a flight event recorder that is particularly suitable for use in reentry flight tests has been developed at the Langley Research Center. Basically, the instrument consists of a metallic recording disk rotated at a constant speed by a spring-driven motor, and fuse wire marking elements which mark the disk by ignition of a fuse when an event occurs. The time between events is obtained by angular measurement of the distance between the marks. The occurrence of each event is correlated with a reference time by recording the time of occurrence of a reference event such as a "g" switch activation at launch in a flight test. Figure 1 is a simplified sketch of the instrument which illustrates the principle of operation. The primary application of the event recorder thus far has been to record heat-shield ablation data but it can also be used to record data from any transducer that provides the data in an event form.

The salient features of the recorder design are its simplicity, small size, and light weight which make the device particularly useful as a backup instrument to the telemetry in reentry experiments. If the telemetry should fail, selected flight data can still be acquired from the event recorder. Also, the device could be a substitute for the telemetry in research payloads too small to carry a telemetering system.

The development program undertaken to qualify the event recorder included both ground and flight testing. The ground tests consisted of environmental, operational, and data survival tests which simulated conditions that the instrument was expected to experience during flight and recovery. The device was also used in an actual flight test to record heat-shield ablation data. Design considerations, details of the design, and results of these tests are discussed in the following paragraphs.

INSTRUMENT DESIGN

Primary considerations in the design of the event recorder were its ability to operate during the high deceleration of reentry and to survive the high temperature which could occur in the payload due to heat soak through the ablation material after reentry. In addition, the instrument could encounter high shock loads resulting from payload separation, parachute opening, and water impact. The data record must also be able to survive submergence in sea water contaminated with recovery dye for several days.

The design of the recording disk was governed by the high shock loads and temperatures that the instrument might encounter after reentry and its possible exposure to sea water for prolonged periods of time during recovery. Titanium was selected as the material for construction of the disk because of its resistance to corrosion by sea water and its dimensional stability at elevated temperatures. The recording surface was sandblasted to form a smooth mat finish to improve the adhesion of the residue from the fuse wire marking elements.

The constant-speed motor used to drive the recording disk must be capable of performing properly during the high deceleration experienced during reentry, must provide timing with a high degree of accuracy, and must be designed to permit remote starting. A 1/2 rpm Raymond Engineering Company Model 1926 spring-driven motor was chosen for this application after testing verified that it could provide sufficient timing accuracy under flight environmental conditions. This motor was also selected because it has demonstrated high reliability as part of an ignition timing system for rocket vehicles.

The recording disk is marked by using a component constructed from a ceramic cartridge and 0.002-inch-diameter Pyrofuze wire. Pyrofuze is a wire developed by the Pyrofuze Corporation, which consists of palladium and aluminum in intimate contact with each other so that when it is heated to the melting point of aluminum, an exothermic alloying action takes place. The wire is coated with a suitable material that provides a residue for marking the metallic disk. Pyrofuze ignition requires an average current of 2 amperes for 7 milliseconds which is controlled by a switch closure when an event occurs. The only time lag before the disk is marked is the 7 milliseconds required for wire ignition.

Sharp and well-defined marks are formed on the disk by mechanically focusing the residue emanated from the fuse wire. Details of the technique are illustrated in Figure 2. The marking element is inserted in an aluminum fixture so that the Pyrofuze is suspended in a small chamber formed by a 0.044-inch-diameter hole which tapers down to 0.010 inch near the bottom of the fixture. The tapered hole directs the residue so that a sharp and well-defined spot is formed on the disk. A typical example of the type of spots formed is shown in the photograph of Figure 3.

Two methods have been used to identify a particular data point on the disk and to correlate it with an event. The first method requires positioning each marking element on a different but known radius on the disk so that each event correlates with only one particular radius. Twenty-eight radial locations on a 2-inch-diameter disk is a practical limit with this technique. An expansion of this recording capacity has been achieved by using differently colored spots on each of the 28 radii. Three Pyrofuze wire coating materials have been used successfully to obtain differently colored spots; number SD-52 powder produced by the Hercules Powder Company for obtaining a black spot; red toner powder (1-2 nitro-para-tolyazo-2 napthol) which yields a red spot, and number C-198 powder produced by the Bermite Powder Company which provides a green spot. With these powders, the recording capacity has been increased from 28 to 84 channels.

The possibility exists of data point overlap and, therefore, loss of data when more than one spot is located on a single radius but this problem is not considered serious. Through proper selection of the angular positions of the marking elements and careful choice of events to be recorded with each marking element, the probability of data point overlap can be made negligible.

DATA READOUT

The recorded data are reduced to final form by measurement of the angular distance between the reference point and all other data points on the disk. If the elapsed time from placement of a reference mark on the disk to the beginning of the flight-data period is longer than the time required for one revolution of the disk, the approximate time at which the data period began must be known. This information is necessary in order to determine the number of revolutions of the disk which elapsed before the data occurred. After determining all angles, the time of occurrence of each event is obtained by using a calibration curve of angular position of the motor output shaft plotted against time.

In order to facilitate measurement of angles on the small recording disk, a readout mechanism was designed and constructed. A photograph of the unit is shown in Figure 4. The device is a mechanical-optical system designed so that the recording disk can be easily installed and removed with good centering accuracy. Angular measurements of displacements on the disk are provided by a calibrated dial indicator system. The optical portion of the device is used to magnify an image of the data record in order to determine more precisely when a reference cross hair is centered over a data point. The resolution of the readout device is 0.05°.

CONSTRUCTION

The event recorder as currently designed is packaged in a 2.3-inch-diameter aluminum cylinder 2.4 inches long. The total weight is 8 ounces. Figure 5 is a sketch of the assembled recorder which shows the method used to support the marking elements and to position them over the recording disk. The marking elements are inserted into the fuse support housing, and the lead wires from the elements are channeled to the electrical connector. The connector is held in position and void spaces are filled with a potting compound to form the fuse support assembly. Once constructed, the assembly is mechanically strong and provides a reliable means of attaching the small wires leading from the marking elements to the heavier lead wires coming from the transducers. In a flight experiment several fuse support assemblies can be constructed so that should any channels be inadvertently ignited during preflight checkouts, it is a simple operation to replace the damaged assembly. Interchangeability of the fuse support assemblies is made possible by using accurately positioned dowel pins. Figure 6 is a disassembled view of the event recorder hardware showing the component parts, and Figure 7 is a photograph of an assembled flight unit.

GROUND TESTS

The tests necessary to qualify the recorder for flight use can be separated into two general categories - the flight environment where instrument operation is of prime importance and the recovery environment where data survival is the main consideration. The tests performed for each of these regimes will be briefly discussed.

The most important consideration in the flight regime is the determination of final data accuracy and the effects of the environment on accuracy. Since the ultimate data accuracy is governed by the constant-speed motor, most of the effort was spent in establishing timing accuracy of the motor and in improving its performance. The timing accuracy was determined under a variety of conditions which included a vibration of ±15g, a shock of ±300g, a steady-state acceleration of 130g, and temperature tests over a range from 40° to 160° F. The results of the tests indicated that the motor is most affected by steady-state acceleration but the effect does not become appreciable until a level of 70g is applied. In the worst case observed, the speed of the motor slowed down 0.2 percent at 70g and 2 percent at 130g. Under 1 g bench conditions, the absolute timing accuracy is within ±0.05 second.

After a number of ground tests were made, the overall accuracy of the event recorder under bench conditions was found to have a 1σ value of 0.14 second. These tests included use of the event recorder in arc-jet and rocket exhaust tests to record data from ablation sensors imbedded in heat protection material. In each test, data obtained from the event recorder were compared with data recorded at the same time by ground recorders. Oscillograph-type ground recorders which included crystal controlled timing signals on the oscillogram were used. In order to verify that the event recorder would operate properly after exposure to environmental conditions that would be encountered in missile flight, part of the above tests were conducted after the assembled recorder had been subjected to a vibration of ±15g, a shock of ±300g, an acceleration of 130g, and temperatures over the range from 40° to 160° F. Figure 8 is a photograph of a record which is typical of those obtained in these tests.

The data survival capabilities provided by the recorder design were tested by subjecting a recorder disk to the recovery environments described previously. These tests included soaking the unit in sea water contaminated with recovery dye for a period of 1 month; subjecting it to a shock of 1000g for 1 millisecond and subjecting it to a temperature of 600° F for 30 minutes. The only environment having any significant effect on the stored data was temperature. The black and green data points were unaffected by the 600° F temperature but the red spots were destroyed. Additional testing verified that the red spots cannot survive a temperature higher than 360° F but because of the thermal mass of the recorder, the assembled unit can be exposed to a temperature of 600° F for 15 minutes before the red data points are destroyed.

FLIGHT TEST

The event recorder has been used in one flight test to date. The purpose of the experiment was to evaluate the performance of a low-density charring-type ablator during reentry. Temperature gradients in the heat shield were measured using thermocouples, and surface and char interface recession was measured using event-type ablation sensors. The primary instrumentation system was the telemetry but in order to obtain backup data, part of the signals from the ablation sensors were recorded by a 28-channel event recorder.

Since the ablation material did not recede as much during flight as was predicted, only three ablation sensors connected to the event recorder were activated. Only one of these three events was duplicated through the telemetry system. The time correlation between these two sources for the one event was good (0.1 second) and the instrument survived the recovery environment, including exposure to sea water, without being damaged. The results of the flight test, therefore, were in good agreement with those obtained in all previous ground tests.

CONCLUSIONS

A small, simple event recorder which is applicable in reentry experiments that employ a recoverable payload has been developed. The device uses a spring-driven motor and the only electrical power required is that necessary to ignite a fuse wire marking element. Because of its small size and light weight it is particularly useful as a backup instrument to a telemetry system and could possibly be substituted for the telemetry in very small payloads. Qualification tests have shown that the instrument can be subjected to a vibration of ±15g, a shock of ±300g, an acceleration of 130g, and temperatures from 40° to 160° F without degradation of performance. Data survival tests indicate that it can withstand exposure to a temperature of 600° F for 15 minutes, a shock of 1000g, and sea water for extended periods without loss of data. The instrument has been used successfully in a flight reentry materials experiment to record event data from ablation sensors imbedded in the heat shield.

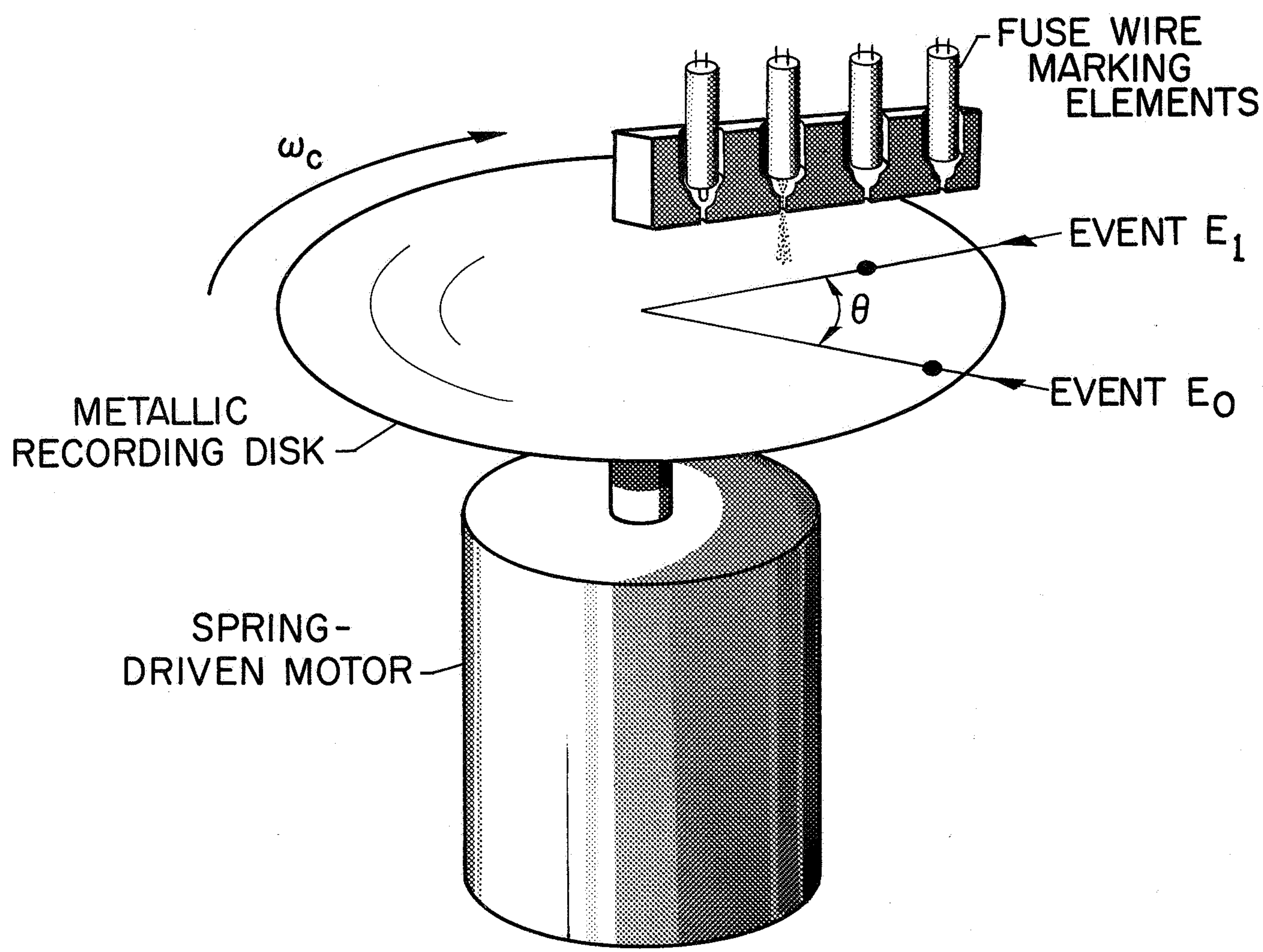

Figure 1.- Event recorder principle of operation.

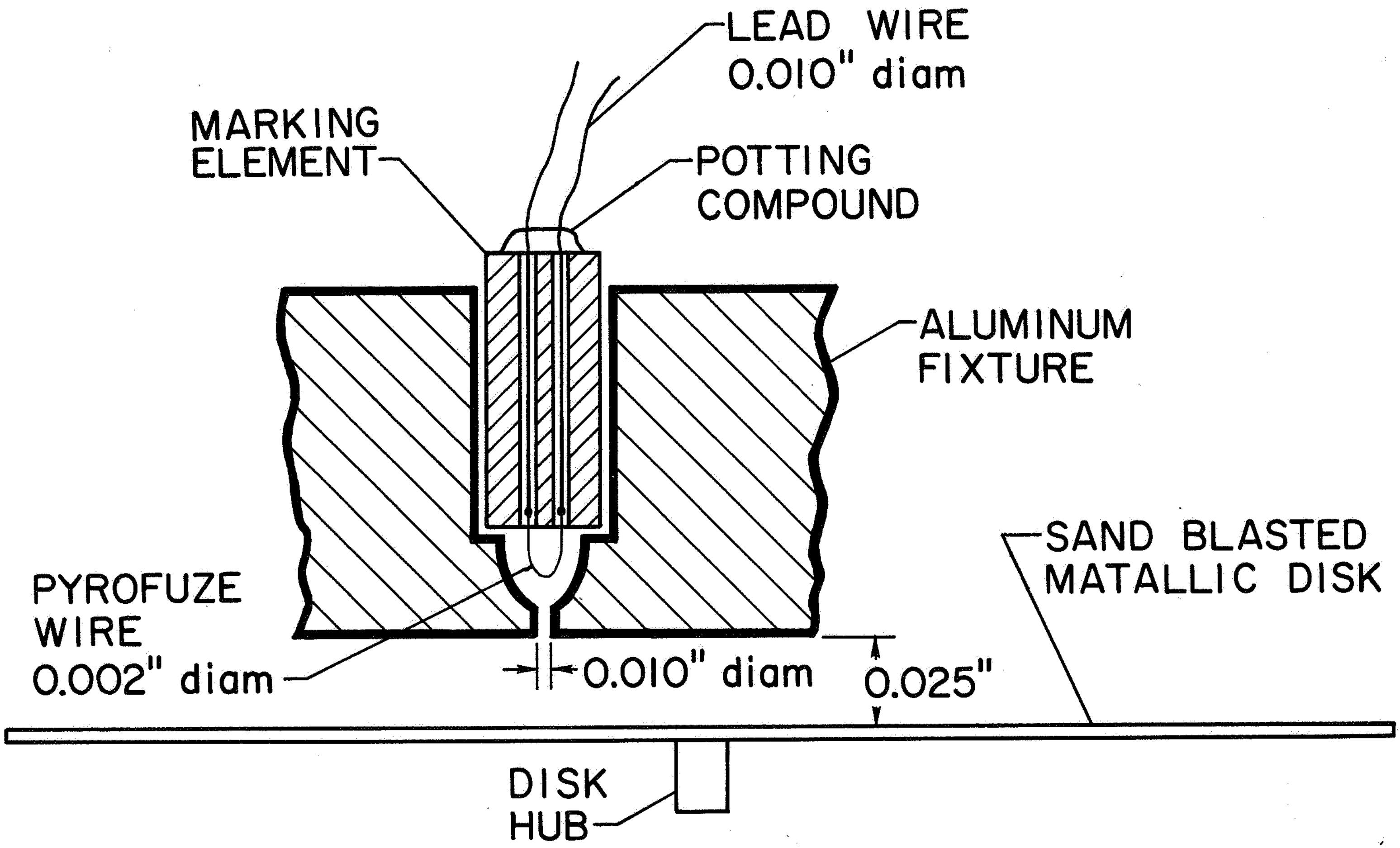

Figure 2.- Fuse wire marking element.

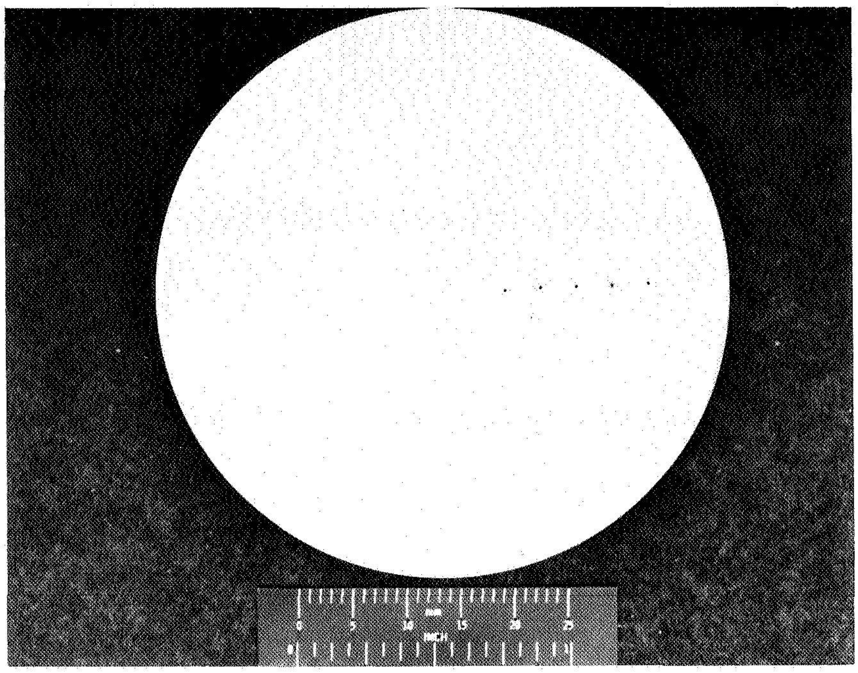

Figure 3.- Data points on a recording disk.

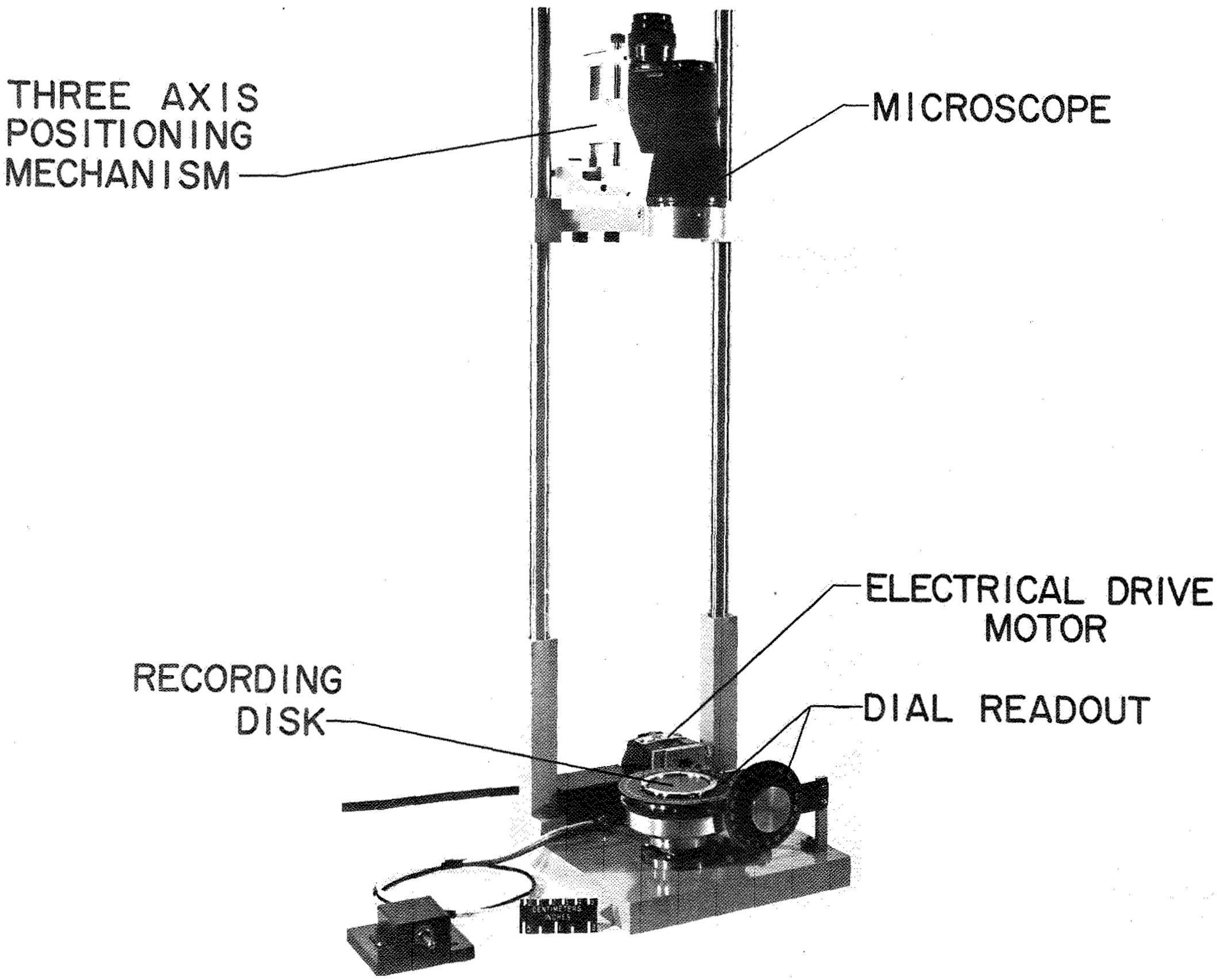

Figure 4.- Data readout mechanism.

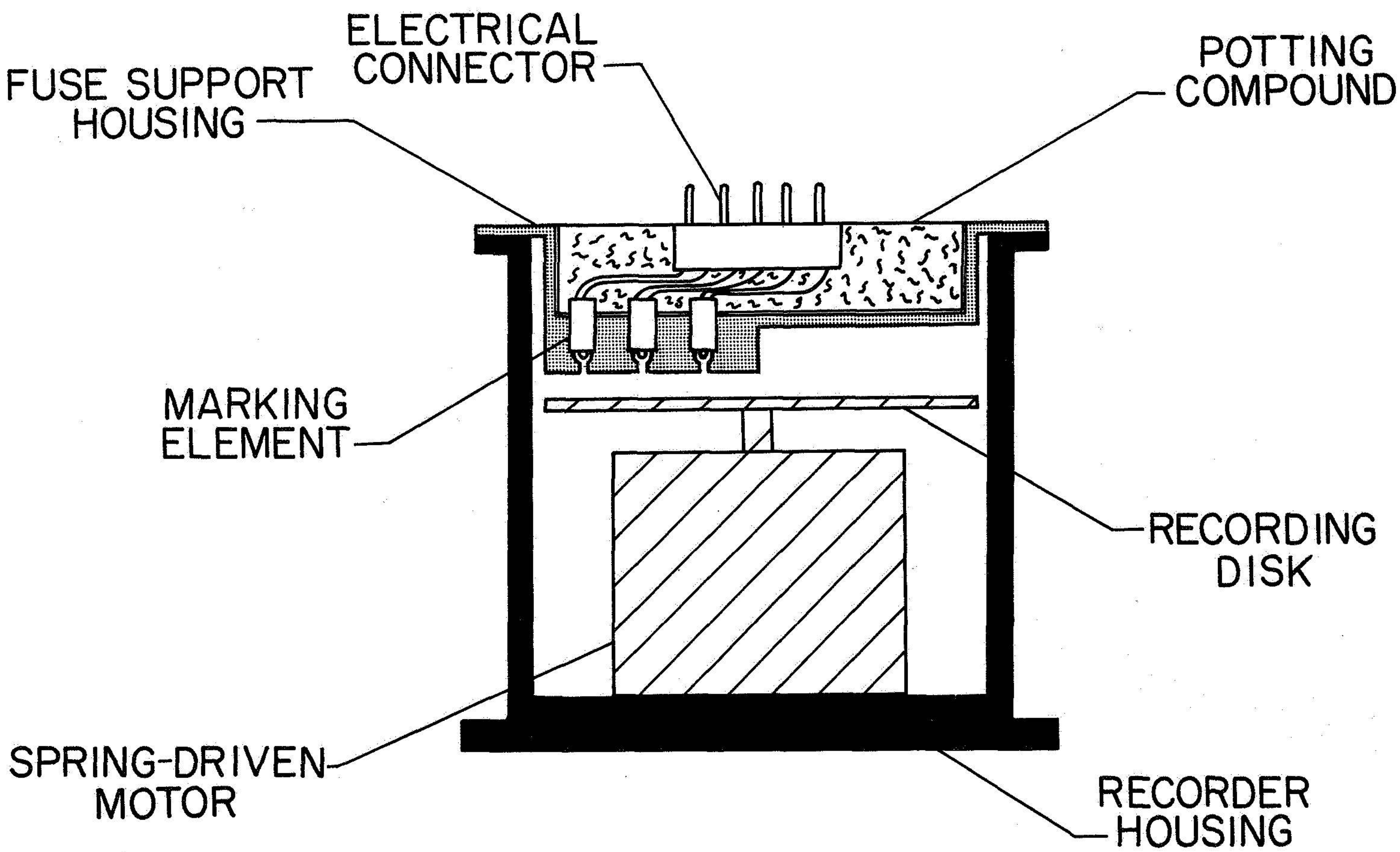

Figure 5.- Event recorder sketch.

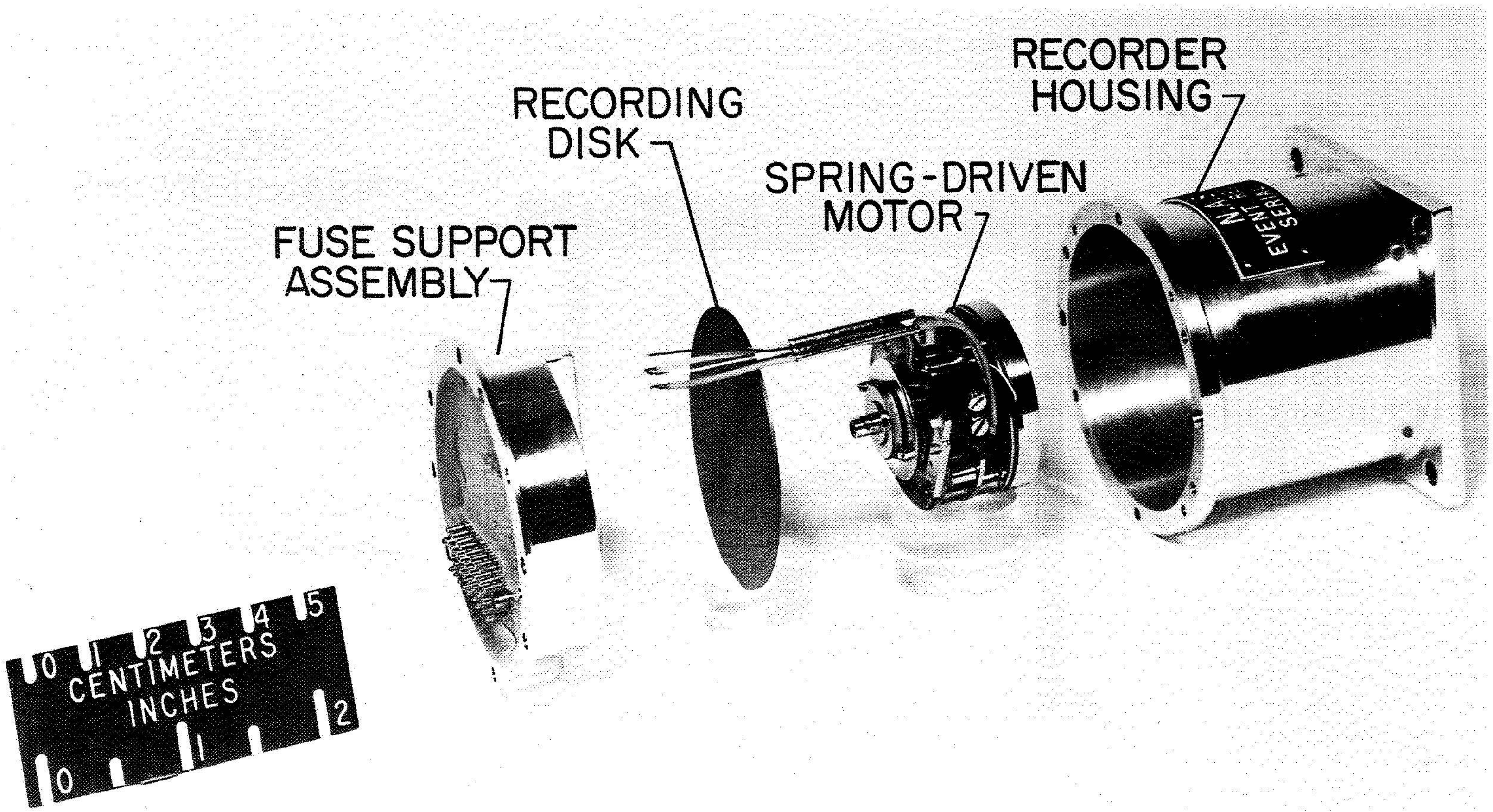

Figure 6.- Disassembled view of the event recorder.

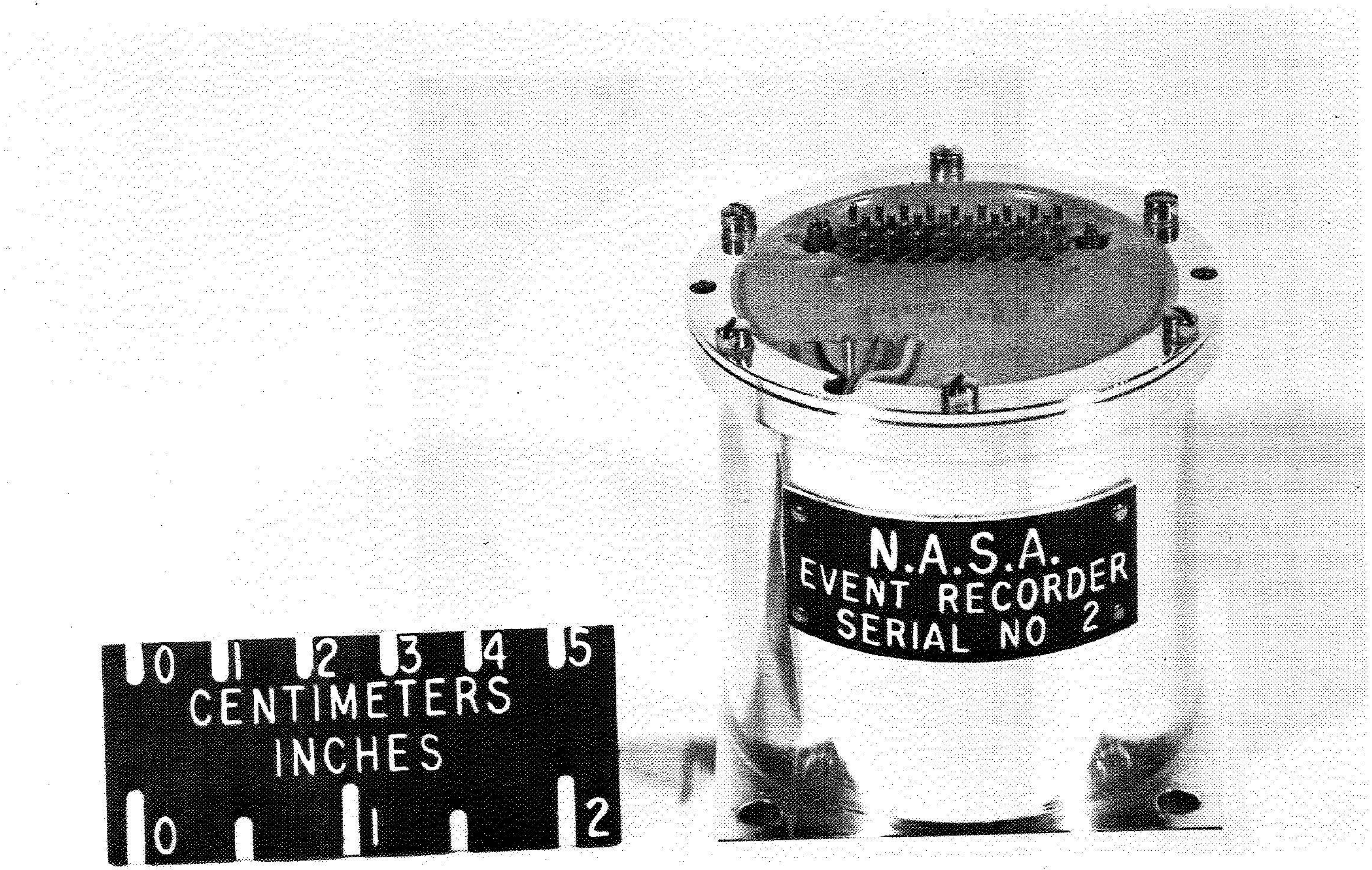

Figure 7.- Event recorder assembly.

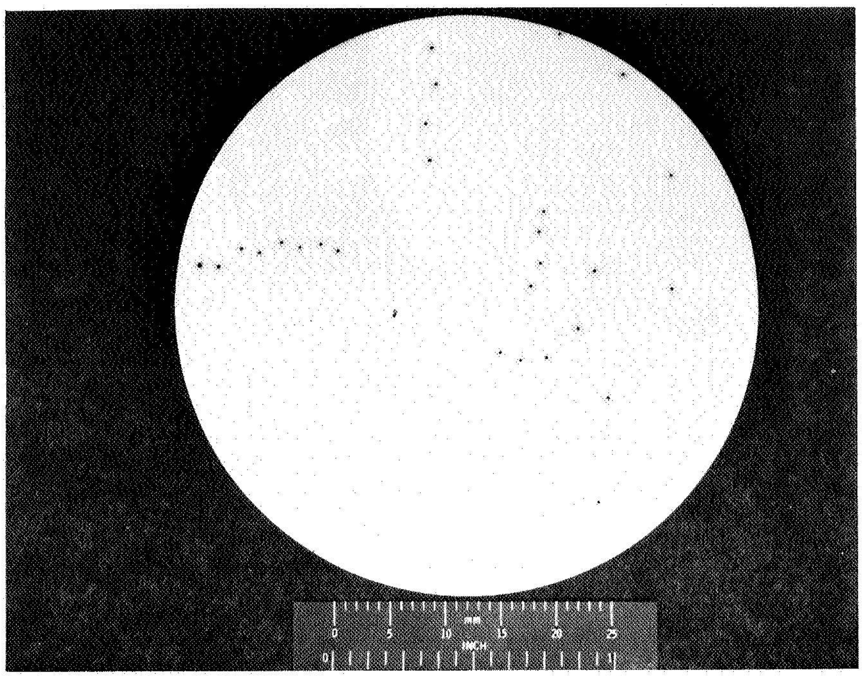

Figure 8.- Arc-jet test record.