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VIBRATION TOLERANCE OF A MERCURY-COLUMN COULOMETER

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ABSTRACT

A mercury-column coulometer was subjected to and successfully survived vibration tests which consisted of those specified for components of the SERT-II spacecraft and a single scan at the frequencies and acceleration levels of MIL-STD-202, Procedure 204, Condition D. The impedance of the coulometer was found to be lower during vibration than without vibration. Its integrating ability was not affected by these vibration tests.

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SUMMARY

A mercury-column coulometer was subjected to and successfully survived vibration tests which consisted of those specified for components of the SERT-II spacecraft and a single scan at the frequencies and acceleration levels of MIL-STD-202, Procedure 204, Condition D. The impedance of the coulometer was found to be lower during vibration than without vibration. Its integrating ability was not affected by these vibration tests.

INTRODUCTION

The major applications of space secondary-battery systems in the past have been in space vehicles that operated in a known orbit or flight and had a known electrical load. Battery size, system integration, and charge control were primary considerations in the design of these systems. The actual state of charge of the battery at any one time was of lesser importance because the system could be designed for the known application. However, in future higher power systems which will be used for manned space stations or interplanetary missions, batteries will serve as backup or emergency power supplies. The electric load and the use of the batteries in these higher power systems are not predictable. A method to indicate the state of charge of a battery will aid in crew safety and mission success by providing continuous information on the amount of energy available. Such an indicator would be used in a manner similar to a fuel gage.

At present, there does not appear to be a practical method to measure and indicate state of charge directly from battery parameters. The most practical approach at this time is that of using some form of ampere-hour device to integrate the ampere-hours into and out of the battery. When the charge-discharge characteristics of a battery are known and the ampere-hour device is designed to match them properly, the value of the charge-discharge current-time integral is a good indication of the state of charge.

The mercury-column coulometer is an ampere-hour integrating device which is feasible for use in a battery state-of-charge indicator (ref. 1). It consists of a sealed glass tube containing two columns of mercury separated by a gap containing an electrolyte. The linear position of the gap in the tube is an indication of the ampere-hour integral. These coulometers have been studied in the past for use in space battery systems. However, it was found that the shock and vibration which would exist during the launch of space vehicles such as GEOS and Transit caused the mercury to bridge the electrolyte gap (unpublished data from Louis Wilson and Eugene Stroup, both of NASA Goddard Space Flight Center). The electrolyte dispersed through the mercury, and the gap and integrating capability of the coulometer were lost. The design of mercury-column coulometers has changed since these problems were observed. More recently, they have survived the shock and vibration present during launching and operated successfully in destruct timers in several operational satellites (unpublished data from Franklin Kelly, TRW Systems Group, Redondo Beach, California).

These differing data indicated that further investigation of the effects of vibration on a recent design of the mercury-column coulometer was needed. A commercially available coulometer has been subjected to vibration tests which included those specified for components of the SERT-II spacecraft. The results of these tests are presented and discussed in this report.

DESCRIPTION OF COULOMETER

Figure 1 shows the mercury-column electrochemical coulometer in a simplified form. It consists of a sealed glass capillary tube with an electrode at each end and filled with mercury except for a small gap formed by a liquid electrolyte. The gap separates the mercury into two columns. When a current is passed through the coulometer, mercury will be electrochemically transferred from one column across the electrolyte gap to the other column. The amount of mercury transferred is proportional to the time integral of current through the coulometer. As the mercury transfers from one column to the other, the lengths of the columns change and the gap moves along the length of the coulometer. The position of the gap, then, is an indication of the time integral of current, or ampere-hours. References 2 and 3 provide a more complete description of this type coulometer. The coulometer used for vibration testing was approximately 1.0 centimeter long and 0.5 millimeter in outside diameter. It was encapsulated in a metal case of approximately 1.2 cubic centimeters. Figure 2 shows this assembly with the metal case removed.

APPARATUS AND PROCEDURE

The coulometer was mounted on a rigid fixture, as shown in figure 3, for vibration testing in accordance with the requirements of Specification 3-71C for the SERT-II spacecraft components. Table I gives the frequency range and acceleration levels required by that specification. Specification 3-71C includes a 20-g random noise test. Table II gives the more widely known vibration requirements of MIL-STD-202, Method 204, Condition D, which are generally more severe than the sine vibration requirements of Specification 3-71C. To give additional significance to the test results, a single sweep test was made at the vibration levels of MIL-STD-202 as shown in table II. The coulometer was vibrated to the levels of tables I and II along each of its three mutually perpendicular axes; X, Y, and Z.

The voltage drop across the mercury-column coulometer with a constant current passing through it is an indication of the coulometer impedance. This impedance is primarily determined by the electrochemical process taking place in the gap. A loss of the gap would result in a significant drop in coulometer impedance because the current conducting path would be all mercury. The normal electrochemical process would be absent.

Figure 4 shows the electrical monitoring used during vibration tests. The voltage drop across the coulometer was monitored with both an oscilloscope and an X-Y recorder. Any loss of the gap would be indicated by a displacement of the oscilloscope trace to near zero. The X-Y recorder provided a record of coulometer voltage drop as a function of vibration frequency.

RESULTS AND DISCUSSION

The test sample coulometer survived the vibration tests described in this report without evidence of any damage or permanent change in operating characteristics. No loss of gap, as would be indicated by the oscilloscope or subsequent failure to function, occurred.

During vibration at 20 g's (MIL-STD-202) the impedance of the coulometer, as indicated by voltage drop, varied to a maximum of approximately 116 percent and a minimum of approximately 45 percent of its value without vibration. Figures 5a and 5b show the experimental data on voltage drop as a function of frequency under Y and X axis vibration. Data for the Z axis is essentially the same as that for the X axis. The variation in impedance under the sine vibration of SERT-II Specification 3-71C was generally less than that found with MIL-STD-202. After vibration, the impedance returned to its original value.

The change in impedance was probably caused by agitation of the mercury-electrolyte interface and/or vibration-induced distortion of the gap dimensions. The current-time integrating ability of the coulometer, however, was not impaired by vibration. This is demonstrated by the fact that after testing, a sufficient number of microampere-hours were passed through the coulometer so that the net current-time integral recorded by the coulometer during and after vibration test was zero. The position of the gap was then checked with an electronic readout and found to be unchanged from its initial position before vibration test, within measurement error.

Operation of the coulometer as a current-time integration was the same after as it was before vibration tests.

CONCLUDING REMARKS

A recent design of a commercially available mercury-column coulometer has been shown to successfully survive vibration tests which included those specified for components of the SERT-II spacecraft. This is additional evidence that the mercury-column coulometer is a feasible device for use in space power systems.

REFERENCES

1. Secunde, Richard R.; and Birchenough, Arthur G.: Mercury Electrochemical Coulometer as a Battery State-of-Charge Indicator. NASA TN D-5773, 1970.

2. Corrsin, L.: Operating Time Indicator. Patent No. 3, 045, 178, United States, July 17, 1962.

3. Marwell, E. M., et al: Electro-Chemical Coulometer Including Differential Capacitor Measuring Elements. Patent No. 3, 225, 413, United States, June 7, 1966.

TABLE I

VIBRATION TEST LEVELS OF SERT-II SPECIFICATION 3-71C

A. Sinusoidal Sweep Frequency Schedule

Freq. Range	Acceler. Level
5-19 Hz	0.05 inch D.A.*
19-2000 Hz	9.0 g's

Sweep Rate: 2.0 octaves per minutes

Sweep Time: for 5-2000 Hz approximately 4.3 min.

B. Random Noise Vibration Schedule

Freq. Range	Acceler. Level	Spec. Density
20-400 Hz	6.5 g's rms	0.11 g^2/Hz
400-2000 Hz	18.9 g's rms	0.22 g^2/Hz

Overall Level: 20.0 g's rms
Duration: 4.5 minutes per axis

*D.A. - double amplitude (maximum total excursion)

TABLE II

VIBRATION TEST LEVELS OF MIL-STD-202, METHOD 204, CONDITION D (Sinusoidal Sweep Test Only)

Frequency Range	Acceleration Level
10-80 Hz	0.06 inch D.A.*
80-2000 Hz	20 g's

Sweep Time: 20 minutes 10 to 2000 to 10 Hz each axis

*D.A. - double amplitude (maximum total excursion)

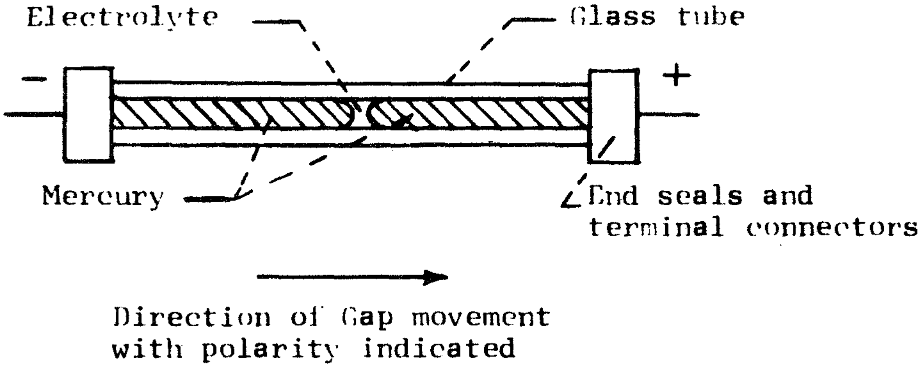

Figure 1 - Simplified View of Mercury-Column Coulometer

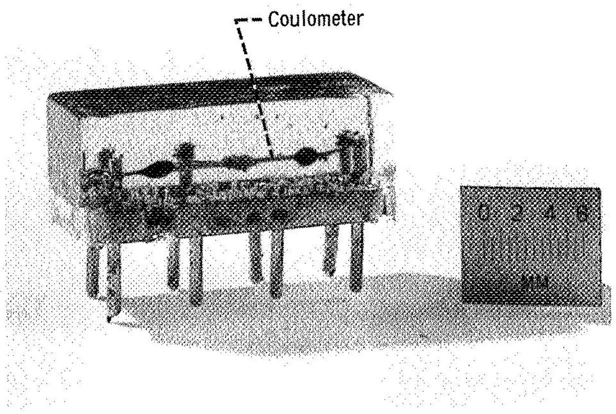

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Figure 2. - Encapsulated coulometer assembly.

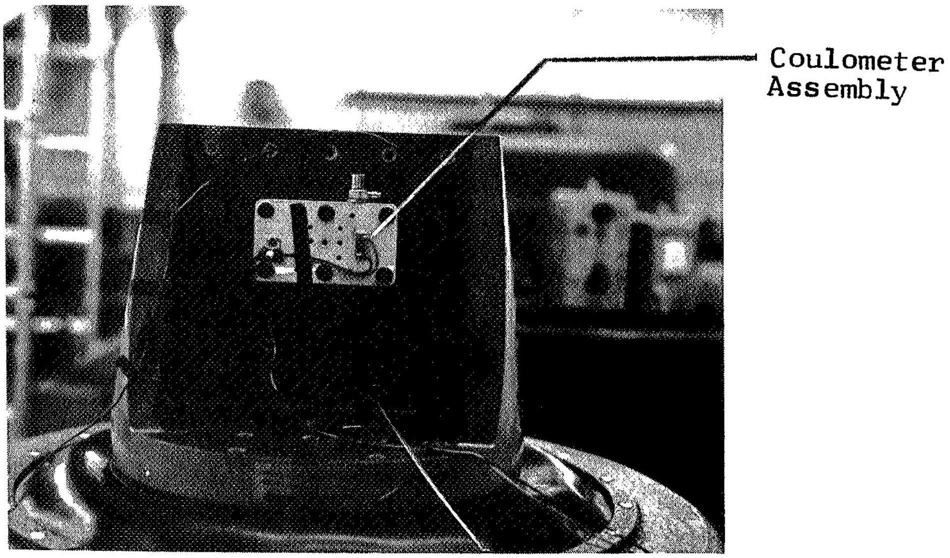

Figure 3 - Coulometer Mounted on Vibration Test Fixture

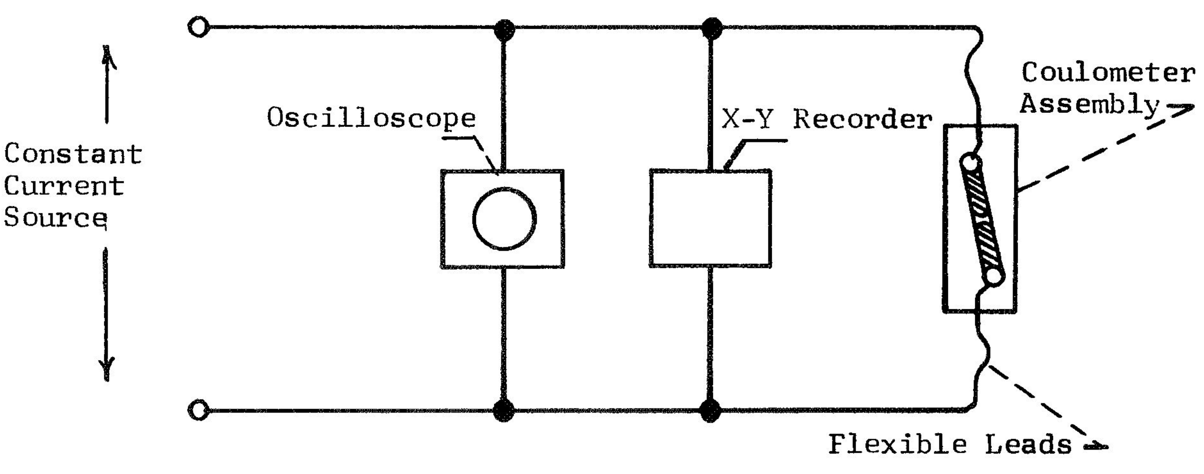

Figure 4 - Electrical Power and Monitoring
For Vibration Tests

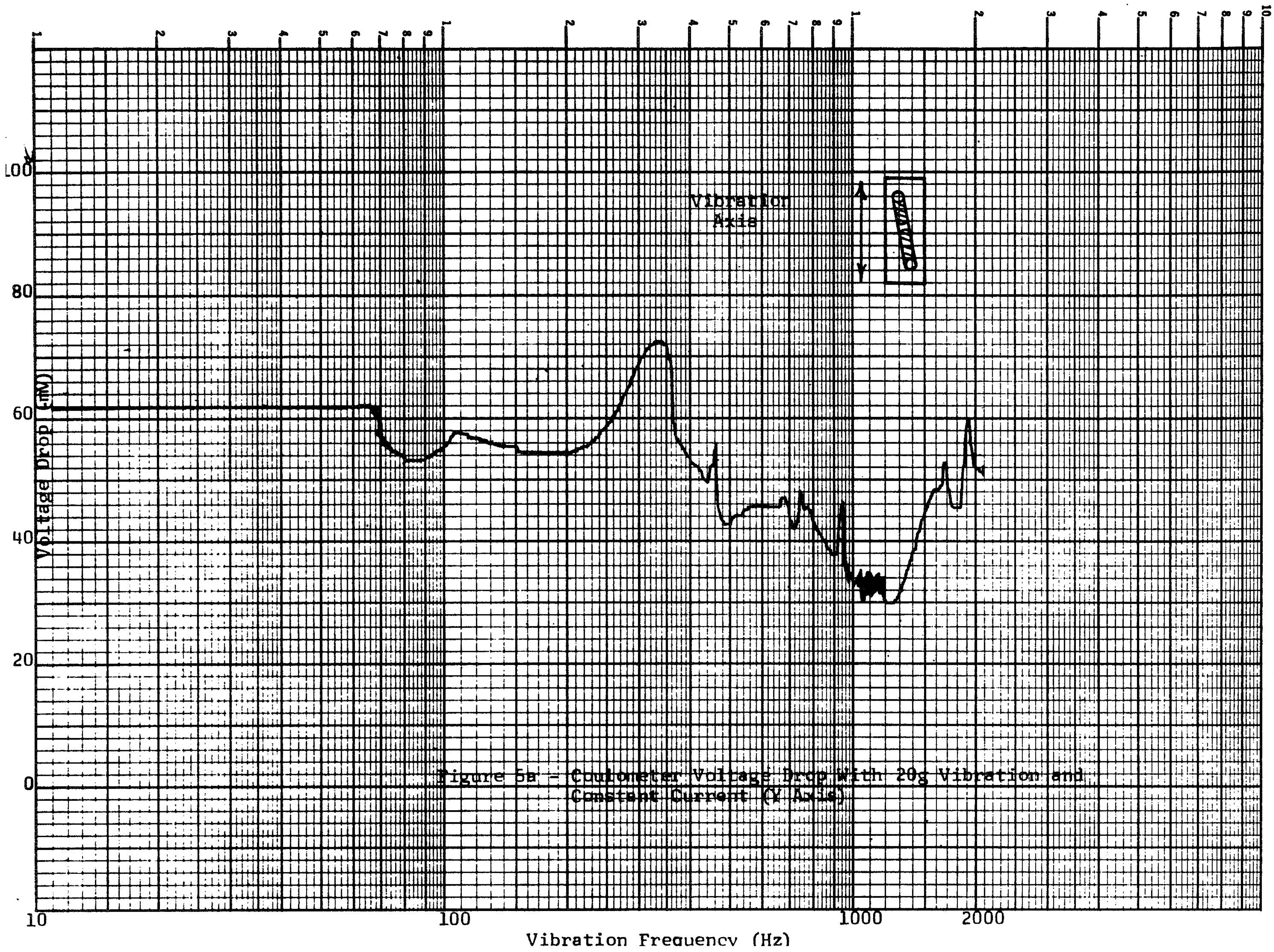

Figure 5a - Coulometer Voltage Drop With 20g Vibration and Constant Current (Y Axis)

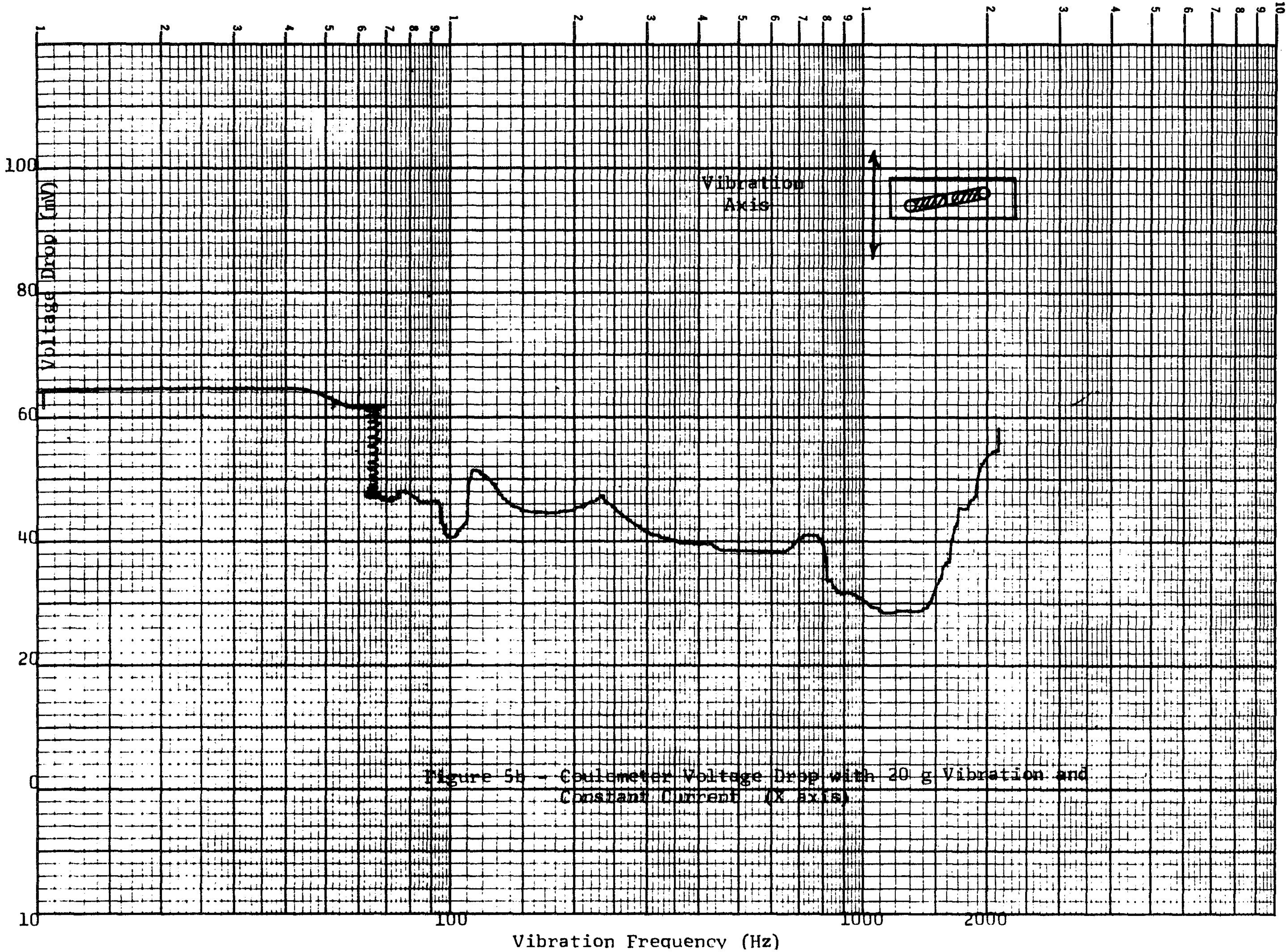

Figure 5b - Coulometer Voltage Drop with 20 g Vibration and Constant Current (X axis)