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UC-25 - Metals, Ceramics, and Materials

RECORDING EQUIPMENT FOR
INTERNAL FRICTION MEASUREMENTS

R. L. Stephenson
H. E. McCoy, Jr.

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

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ABSTRACT

An apparatus has been developed for recording internal friction data in such a manner as to circumvent many of the laborious and time-consuming observations and calculations usually associated with these measurements. As in the conventional method, an optical lever is used. Instead of following the oscillations visually, however, the passage of the beam across the scale is detected by photoconductive cells. The cells are strategically located so that, when their signals are fed through a multichannel switching circuit to the pens of an operation recorder, a plot of the logarithm of the vibrational amplitude versus the number of cycles is recorded on the chart. From the definition of the logarithmic decrement, (δ), it can be shown that the slope of this curve is $-\delta$. The apparatus is inexpensive and requires a minimum of maintenance. It has been used for accurate determinations of values of δ from below 0.0001 up to 0.3.

INTRODUCTION

The processing of internal friction data in the low-frequency range is laborious and time consuming. Vibrational amplitude is usually measured by an optical lever arrangement in which the amplitudes of successive swings of the pendulum are observed on a convenient scale and recorded manually. The logarithm of the amplitude is then plotted as a function of the number of cycles. The slope of this curve is the negative of the logarithmic decrement. Hence, several data points must be recorded, plotted, and the slope of the resulting plot measured in order to obtain a single point on the damping curve. This entire process must be repeated many times in order to determine a complete damping curve.

One further experimental difficulty is encountered when one attempts to determine activation energies. It is desirable to vary the frequency over as wide a range as possible in order to make the determination more accurate.

If, however, the frequency exceeds two cycles per second, the manual observation of the amplitude becomes most fatiguing and difficult.

A device has been developed which greatly lessens the physical burden associated with making internal friction measurements. A brief description of this equipment and its operational features and capabilities follows.

GENERAL DESIGN OF SYSTEM

The primary features of the experimental equipment are illustrated by the schematic drawing in Fig. 1. As in the visual method, a mirror reflects a beam of light onto a scale. However, instead of following the oscillations visually, the passage of the beam across the scale is detected by a series of photoconductive cells. The signals from these cells pass through a multi-channel switching circuit and actuate the pens of an operation recorder. The photoconductive cells are strategically positioned such that the chart from this recorder is essentially a plot of the natural logarithm of the vibrational amplitude versus the number of cycles. Figure 2 is a photograph of the apparatus showing the light source (A), the operation recorder (B), the switching circuit (C), and the photoconductive cells (D).

THE LOGARITHMIC DECREMENT AND RELATED MATHEMATICAL EXPRESSIONS

Although several parameters are used to measure the internal friction of metals, the quantity most commonly used in the case where the specimen is a freely vibrating member is the logarithmic decrement. The logarithmic decrement, δ , is defined by the following relationship:

$$\delta = \ln \frac{A_n}{A_{n+1}}, \quad (1)$$

where A_n and A_{n+1} are the amplitudes of successive oscillations. Since δ is in most cases independent of the amplitude, Eq. (1) may be generalized:

$$\delta = \ln \frac{A_n}{A_{n+1}} = \ln \frac{A_{n+1}}{A_{n+2}} = \ln \frac{A_{n+2}}{A_{n+3}} = \dots = \ln \frac{A_{n+N-1}}{A_{n+N}}, \quad (2)$$

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Fig. 1. Schematic Drawing of Experimental Arrangement.

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Fig. 2. Photograph of Recording Equipment.

where N is the number of cycles during which the vibrational amplitude decayed from A_n to A_{n+N} . Equation (2) may be rewritten as

$$\delta = \frac{1}{N} \left[\ln \frac{A_n}{A_{n+1}} + \ln \frac{A_{n+1}}{A_{n+2}} + \ln \frac{A_{n+2}}{A_{n+3}} + \dots + \ln \frac{A_{n+N-1}}{A_{n+N}} \right]. \quad (3)$$

Further simplification of Eq. (3) yields

$$N\delta = \ln \frac{A_n}{A_{n+N}}. \quad (4)$$

Equation (4) can be rearranged to give

$$\ln A_{n+N} = -\delta N + \ln A_n. \quad (5)$$

Thus for the case where δ is independent of vibrational amplitude, δ can be calculated when A_n , A_{n+N} , and N are known. Usually the amplitudes of several oscillations are observed and their natural logarithms are plotted versus the number of cycles. The result is a straight line given by Eq. (5), whose slope is $-\delta$.

POSITIONING OF PHOTOCONDUCTIVE CELLS

Although the logarithmic decrement can be determined by measuring the number of cycles required for the amplitude to decay any given increment (Eq. 4), four increments are used in the present recording system to obtain a value of δ . These four amplitude increments are formed by five photoconductive cells. Let the distances of the cells from the center of the scale be designated at X_1 , X_2 , X_3 , X_4 , and X_5 as shown in Fig. 3. These are not to be confused with the A 's which have been used. The A 's designate amplitudes of successive cycles whereas the X 's refer to amplitudes which are fixed by the positions of the cells. Equation (4) may be written for each of the four increments of amplitude which are bounded by X_1 , X_2 , X_3 , X_4 , and X_5 .

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Fig. 3. Scale Showing Positions of Photoconductive Cells.

$$\begin{aligned}
 N_{5,4} \delta &= \ln \frac{X_5}{X_4}, \\
 N_{4,3} \delta &= \ln \frac{X_4}{X_3}, \\
 N_{3,2} \delta &= \ln \frac{X_3}{X_2}, \\
 N_{2,1} \delta &= \ln \frac{X_2}{X_1},
 \end{aligned} \tag{6}$$

where $N_{5,4}$, $N_{4,3}$, etc., denote the number of cycles required for the vibrational amplitude to decrease from X_5 to X_4 , X_4 to X_3 , etc.

In each case δ is the slope of a line segment drawn between adjacent X values on a plot of the natural logarithm of the vibrational amplitude versus the number of cycles. If the values of X_1 , X_2 , X_3 , X_4 , and X_5 are chosen such that the ratios of adjacent distances are equal, i.e.,

$$\frac{X_5}{X_4} = \frac{X_4}{X_3} = \frac{X_3}{X_2} = \frac{X_2}{X_1},$$

then the respective values of N measured over each increment are equal, since δ is independent of amplitude (Eq. 6). Since the ratios of adjacent distances are equal, the differences of the logarithms of adjacent distances will be equal and they will have equal spacings on a logarithmic scale. Thus, for this choice of the positions of the photoconductive cells, the chart from the operation recorder is a plot of the logarithm of the vibrational amplitude versus the number of cycles.

To compute the values of X_1 , X_2 , X_3 , X_4 , and X_5 , the following boundary condition was used: The upper and lower limits of the scale shall be 5 and 1, respectively. The following values were obtained:

$$X_1 = 1.000, X_2 = 1.495, X_3 = 2.236, X_4 = 3.344, \text{ and } X_5 = 5.000.$$

Any convenient unit of measurement or scaling factor can be used. In the present experimental assembly, X_5 was chosen as 20 cm and the other values were adjusted accordingly.

ELECTRONIC CIRCUITRY

The pens of an Esterline Angus model AW operation recorder are actuated by the five channel switching circuits (shown in Fig. 4) in response to the signals from the photoconductive cells (Clarex CL-403). There is no apparent interdependence of the five channels. Each cell is hooded with a 3-in. length of black tubing. The output of the photoconductive cells is such that the apparatus can be used with ordinary room lighting, and the results are not affected by widely varying amounts of stray light. An ordinary projection lamp is used as a light source. Although the maximum frequency of oscillation at which this recorder will operate satisfactorily has not been determined, measurements have been made over the frequency range of 30 to 300 cycles/min.

CHART AND CALCULATIONS

Figures 5a and 5b are photographs of typical charts from the operation recorder. Initially, the pendulum is set into vibration so that the light beam sweeps past all five cells, thereby actuating all five pens. As long as this condition is maintained, all five pens will produce broad traces on the chart. When the light beam ceases to reach the extreme cell, the fifth pen is no longer actuated and draws only a narrow line, thus marking the time at which the amplitude decayed to this point on the scale. The time to decay to each of the remaining four points is marked in the same manner.

Since the vertical coordinate of the chart is a measure of time, the vibrational frequency can be obtained from the recording by counting the number of cycles recorded by any one of the five pens over a certain length of the chart paper. The frequency remains essentially constant over a wide range of temperatures for a given test setup. Hence, it is not necessary to count the number of cycles during succeeding determinations since the vertical length of a trace on the chart can be converted to number of cycles by multiplying it by the frequency and dividing it by the chart speed. Because of the conditions which were imposed in choosing the positions of the photoconductive cells, the chart is effectively a plot of the natural logarithm of the amplitude of vibration versus the number of cycles. From the slope of this plot, the

Fig. 4. Multichannel Switching Circuit for Photoconductive Cells.

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Fig. 5a. Photograph of Recorder Chart (Low Speed).

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Fig. 5b. Photograph of Recorder Chart (High Speed).

logarithmic decrement, δ , may be computed. Although the traces of any two pens could be used to calculate δ by Eq. (3), all five traces are used to obtain a graphical average. The best straight line is drawn through the end points of the traces, and the distance, $(L_1 - L_5)$, between the end points of traces 1 and 5 is measured. The logarithmic decrement is calculated by substituting the proper values in Eq. (4):

$$\delta = \frac{(\ln 5 - \ln 1)}{\frac{(L_1 - L_5)(\text{frequency})}{(\text{chart speed})}} \quad (7)$$

Equation (7) may be further simplified to obtain the final computational form:

$$\delta = \frac{(1.609)(\text{chart speed})}{(L_1 - L_5)(\text{frequency})} \quad (8)$$

CONCLUSIONS

A device for automatically recording vibrational amplitude versus time has been developed which circumvents many laborious observations and calculations. The apparatus has been operated satisfactorily for several months at the time of this writing and has been used to measure values of δ from below 0.0001 up to 0.3 over the frequency range of 30 to 300 cycles/min. It has been found to be durable, accurate, and relatively insensitive to amplifier sensitivity and stray light.

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