Proceedings of the Iowa Academy of Science

Volume 19 | Annual Issue | Article 33

1912

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A NEW APPARATUS FOR MEASURING SMALL INTERVALS OF TIME INDEPENDENT OF CLOCK OR CHRONOGRAPH.

BY F. C. BROWN.

In the Physical Review for June, 1912, the author discusses the theory of an electrical method for measuring small intervals of time. Time is measured in terms of the throw of a ballistic galvanometer, which is in the circuit of a Wheatstone's bridge during the interval.

The time to be measured is that which elapses between closing the key K_1 and the opening of key K_2, as diagramed in Fig. 1. This time is a direct function of the resistance, the galvanometer constant and the electro-motive-force of the battery. It may be expressed as $\triangle t = \frac{K.D.(K.X+K_2)^2}{\triangle X.E(bK_2+K_1aR)}$

where k_1 and k_2 are such functions of the resistance that $k_1=Gb+aG+bR+ab+aR$, and $k_2=aRG+bRG+abR$, and where Δx is the amount by which the resistance of x varies from that required for balance.

The constant K is a function of the quantity of electricity that is necessary to give one division throw of the galvanometer as determined by discharging a condenser through it.

The desired sensibility of the apparatus may be obtained by a suitable choice of galvanometer, resistance and battery. With these quantities fixed we may obviously write equation 1 in the form,

$\Delta t=K.d$, where K is the time interval corresponding to one division deflection. The value of this last constant may be satisfactorily found in either of two ways. The first may be called an absolute method. The constant K is determined by discharging a known capacity when charged to a potential E through the galvanometer. The other quantities are determined from the resistances used. The constant K is then calculated.

The second method for obtaining the constant, is to measure the deflection obtained when the keys are operated by a body falling a short distance under the action of gravity. This time can be calculated very accurately, even where the value of gravity is not known accurately for the place of observation. Which method is to be used may well depend upon the aptitude of the observer. If he is at all familiar with the working of electrical apparatus the first method would probably be chosen. For very accurate work the two methods should be checked against each other. This insures the accurate working of the keys and the correctness of the electrical quantities.

The following illustrates the reliability of the two methods of calibration. By letting an iron ball fall 6.2 cm. the deflections were

28.5
28.2
28.4
29.0
28.9

28.2
28.7
28.4
28.8
28.9

av. 28.6 scale divisions.

The time required for the ball to fall 6.2 cm is 0.1125 seconds. Thus the value of K, i. e. the time required for one division deflection, is 0.00393 sec.

By discharging a 0.1 micro farad condenser, after charging to the same potential, viz., 19.2 volts, the deflections were:

109.
108.5
109.0
109.1
109.
108.9
109.3
109.0
108.7
108.6

av. 108.7 scale div.

By the calculation with the aid of equation 1, the value of K is 0.00387 sec. per scale division.

SOME ADAPTATIONS OF THE APPARATUS.

The apparatus can be adapted wherever time can be marked by making and breaking electrical contacts. One illustration is in the verification of the laws of falling bodies. It is well known that the laws of gravity can not be verified directly for bodies falling any large distance because the friction of the air becomes an appreciable factor. But for short distances the velocity is so small that the air friction can be neglected. The photograph in Fig. 2 shows the apparatus as used to verify the laws directly for a ball falling a distance varying from 1 mm to 400 mm. The moving part of the keys shown were made of light aluminum, so that a very short time would be required for them to get in action. The upper key is held up by a thread which runs over a smooth rod, and also supports the ball. The ball and the upper key are released simultaneously by burning the thread. The lower key is thrown by the impact of the ball. The resistances, a, b, R, x and Δx are all included in the one small box behind the ball.

A sample of some observations are given in the curve in Fig. 3. The time as plotted was calculated from the formula $s=1/2\ gt^2$. Three readings were averaged for each indicated point on the curve. The deflection is here shown to vary directly as the time.

A second application of the method is for the measurement of the velocity of rifle bullets. The great difficulty in this adaptation was in getting keys of such small inertia that they would close and open the electrical circuits by the passing of the bullet. A bullet will pass through a screen of paper or thin metal and exert very little moment of force on the key, because of the very small time required to pass through. However, we did succeed in making keys of very light spring wire which operated quite satisfactorily. A small bristle board card was attached to the wire. The whole moving part weighed only a little over a gram. The contact was made or broken in a mercury cup by a motion of less than one millimeter. The apparatus as used for measuring the velocity of rifle bullets is shown in Fig. 4. The rifle is at the left, seen only in part. The two keys are just above and back of the galvanometer. The bullet hole in the paper screen and the wires leading to the keys may be seen.

Two sets of observations were taken with this apparatus for Peters 22 short cartridges when shot from a rifle such as is used in target practice. The data is given in the following table. 1 division corresponds to 0.00054 seconds.

distance between keys	deflection	time	velocity
3 ft. 1 in.	9.8, 9.4, 7.0, 4.5,		
	7.0, 6.5, 6.3, 4.9,		
	7.5, 4.0, 8.2, 7.0,		
	7.8, 7.1,		
	av. 7.2	0.00388 sec.	800 ft./sec.
14 ft. 2 in.	33, 30, 35, 33, 33,		
	33, 33, 31, 32, 34.		
	av. 32.7	0.0176 sec.	810 ft./sec.

The agreement between the velocities as calculated from the average time interval with the keys 3 ft. apart and 14 ft. apart is better than one might expect from a small number of observations, considering the individual variations. At 14 ft. between the keys the probable error of a single reading was only about 3%. I believe that the moment of inertia of the keys can be further reduced and that thereby the errors would be reduced still more.

The advantage that this apparatus has over clock and chronograph, aside from simplicity and ease of manipulation, is that there is no lag in the record arising from self induction or heavy moving parts. An electro-magnetic marking device must show a retardation from these causes.

A further adaptation that commends itself is in the measuring of small intervals of time in psychological research, such for example as the measurement of reactance time. The following is a set of observations on the reactance time of the motor auditory type. Each scale division represents 0.0039 seconds.

deflections
30 scale divisions
27
33
27
28
30
33
28.5
31
29.7
av. 29.7 scale divisions or 0.1158 seconds

The above shows a mean probable variation 0.007 second, which variation is probably entirely in the observer and not in the apparatus inherently.

The apparatus described should be useful in colleges, high schools and in the industries, wherever it is not convenient to keep a chronograph, chronoscope, or other arrangement always in working order, and where it is frequently desirable to measure small units of time.