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OSCILLOGRAPHER

A SINGLE-SWEEP STOPWATCH AND ITS USE IN A BIOLOGICAL PROBLEM

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ABSTRACT

The first of two events whose time separation is desired is used to trip the single-sweep circuit of a cathode-ray oscillograph. A sixty-cycle signal, obtained from the commercial power lines and applied to the vertical deflection circuit of the instrument, is used to provide a time standard. The second event is used to cause a potential difference of several volts to be impressed instantaneously on the vertical deflection circuit, thus abruptly terminating the trace by deflecting it off the screen. The vertical length of the signal retained on the screen is then used as a measure of the time lapse between the two events. The application of this stop watch in an investigation of the latent period of muscle is discussed.

In the June-July, 1940 issue of this publication, there was described by H. N. Brailsford an excellent application of the cathode-ray oscillograph as a stop watch. Brailsford's method, however, cannot be used in cases where the two events whose time difference is required are in electrically isolated circuits, or in cases where the first of these events is an electrical pulse of shorter duration than the time difference. It is for such systems that the method described in this paper can be used. Although this stopwatch may have general application, it has been devised and used for some time in an investigation of the latent period in the mechanical response of frog skeletal muscle.

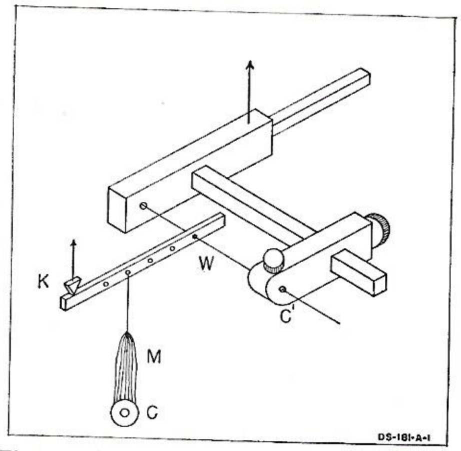

Figure 1: Isometric lever. Muscle, M, clamped at C, pulls on lever-arm against torsion of wire, W, which is clamped at the end C'. K is an electrical contact. The upper contact point is fixed, while the lower is movable along the lever-arm.

METHOD

An excised muscle, such as the gastrocnemius or the sartorius is set up with one end clamped in position and with the other end connected to a recording lever. Figure 1 is an isometric illustration. The muscle is stimulated with an electrical shock, obtained for example, from the discharge current of a gas triode. The shocks are similar to those produced by the Type 210 Variable-Frequency Stimulator. When the muscle responds, its tension is recorded by a slight turn of the lever arm, and the latent period is the time between the instant that the stimulus is applied to the muscle and the instant at which tension begins to develop.

The circuit for determination of the duration of the latent period is shown in Figure 2. The output of the stimulator is directed to the muscle, M, and to both the External-Synchronization- and the Vertical-Input-Terminals of a

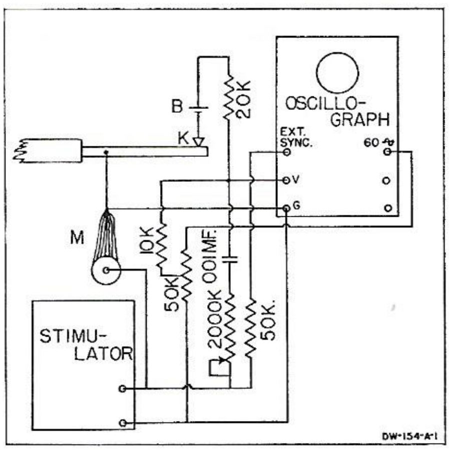

Figure 2: Circuit for determination of time intervals as applied to measurement of latent period of muscular contraction. The circuit constants have been chosen to give necessary coupling with minimum interaction.

Type 175-A Cathode-Ray Oscillograph. A potential taken from one of the sixty-cycle output terminals of the oscillograph is simultaneously applied to the vertical input. The single-sweep circuit is adjusted so that it is tripped by the small fraction of the stimulator output that is connected to the external synchronization input. With the adjustment generally used, the beginning of the sweep coincides to within 0.1 millisecond with the instant of muscle stimulation. As the sweep circuit moves the spot horizontally across the cathode-ray tube

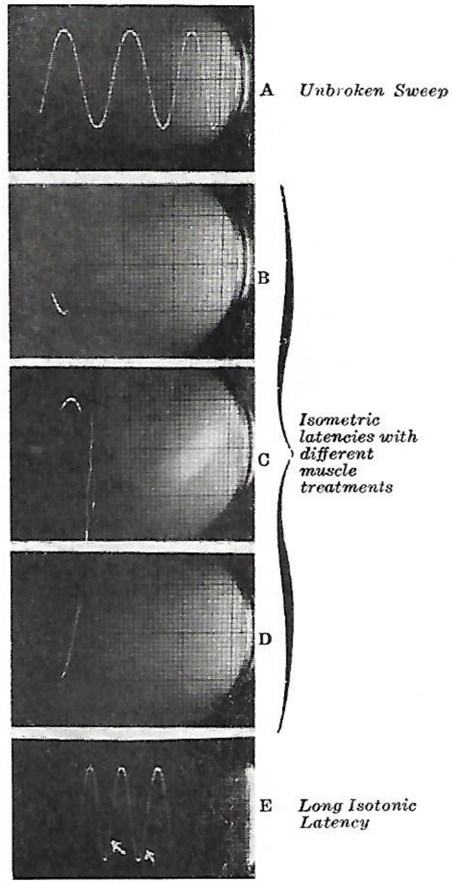

Figure 3: Single-sweep records showing latent periods in muscular contraction.

screen, it traces the impressed sixty-cycle voltage, and, if the muscle did not contract, it would complete its transit across the screen as shown in Figure 3a. When the muscle contracts, however, the initial pull on the lever breaks the contact poles of the key, K, and this motion causes the beam to be thrown instantaneously off the screen. For as long as K is closed, the input condenser within the cathode-ray oscillograph is charged to the potential of the battery, B. At the instant that the muscle contracts and opens K, however, the input condenser discharges through the resistor in the grid circuit of the first stage of the oscillograph and the suddenly-impressed potential on the grid of the first stage causes the beam to be deflected off the screen.

PHOTOGRAPHY

The timing pattern is traced on the oscillograph with the calibrated scale over the screen of the cathode-ray tube. Using the full intensifier voltage on the cathode-ray tube, as supplied with this oscillograph, the pattern is easily photographed with a Leica camera at a lens opening of *f*/3.5 on Eastman Panchromatic or Super-XX film. With the beam quiescent and positioned to the right of the screen, by means of the position controls, the camera shutter is opened for some 7-10 seconds in order to obtain an exposure to the scale background; the stimulator is then operated, and at the completion of the cycle of operation the shutter is closed. Development of the film is carried out in Sease No. 4 developer for fine grain and high contrast. Figures 3b-d show several latent period records.

OTHER FEATURES

Figure 3e illustrates a much longer latent period record, and it is presented in order to show other features of the method. Longer latencies may prevail in isotonic contractions in which the muscle contracts and lifts a weight, which in the illustrated contraction was a relatively heavy one, as soon as the necessary force has been developed. To excite such tensions, several closely spaced shocks are used to produce a so-called tetanic stimulus. It is in order to record these shocks that the stimulator output is connected to the vertical deflection axis of the cathode-ray oscillograph as shown in Figure 2. The separate shocks are recorded as breaks in the otherwise continuous trace. This type of recording, therefore, shows not only the latent period of the muscle but also the number of shocks required to excite tension equal to the load, the frequency of these shocks, and the duration of each shock. Examination of the record shown here shows that in this case three shocks were required. (The first coincides with the beginning of the sweep.) The frequency of the shocks was about 60 per second, and the duration of each was 0.2 millisecond.

The measured latencies in Figure 3, which have not been corrected for lever lag, are: (b)-3.9, (c)-3.6, (d)-5.2, (e)-44.0 milliseconds.

MEASUREMENT OF THE RECORD

If the sweep circuit were perfectly linear, measurement of the records would be exceedingly simple, for then horizontal distances would be linear with time. Since in a practical design of such an instrument this is not so, vertical displacements along the sixty-cycle timing wave are used. The expression for vertical motion of the timing wave is

$$y = \sin 2\pi 60t,$$

where y is the vertical displacement, t is the time in seconds, and the amplitude is taken as equal to unity. Converting from radians to degrees, it is obvious that

$$t = \frac{\sin^{-1} y}{21{,}600}$$

If, therefore, the amplitude of the wave on the screen is one inch, then the relation between t and y may be used to construct a curve which gives the time for any vertical distance up and down the wave, Since the sweep may be initiated at any phase of the timing wave, care must be exercised to allow for this in reading off the times from the curve. The precision of this time measurement will vary with the particular phase of the sixty-cycle timing wave at which the sweep is initiated, for the wave is moving vertically at a much greater speed near the equilibrium position than it is at the turning points. (This holds true with any sinusoid, for such a signal moves the fluorescent spot in simple harmonic motion along the deflection axis upon which the sinusoidal signal has been impressed. —Ed.) The average precision, however, is about plus or minus 0.1 millisecond, and this is sufficient for this latent period research.

This measuring procedure may seem cumbersome. In actual practice, however, it actually is simple and rapid. Moreover, the use of a vertical time-base possesses several advantages that are not found with the horizontal time base. Namely: (1) Excepting for very short-time sweeps, e.g.: one sixty-cycle wave, the vertical method is more precise; for if a single wave of the timing signal is spread over one inch horizontally, then in all its vertical motion it traverses a length of four inches. Hence the vertical measurements will be four times as precise as are the horizontal. Furthermore, still greater precision may be obtained by increasing the amplitude of the wave. (2) Once the vertical calibration is made for a given amplitude of deflection, it holds regardless of the speed chosen for the horizontal sweep. This is quite important since, as longer latencies are recorded and hence slower sweeps are required, no change in the time calibration need be made.

The stop watch described here has been applied to other phases of the latency-period research as e.g.: the determination of the inertial lag of the levers that are used. No attempt, however, has been made to use it in entirely different systems; but it is clear that if any event can be made to deliver an electrical impulse, no matter how short, which can be used to trip the single-sweep circuit, and another event can be utilized to deflect the beam, then the time separation of the two events, provided it is less than the duration of the sweep, can be measured. Not only does the oscillograph record the time lapse, but, in its sixty-cycle voltage record, it also provides for a time calibration of the record.

It is hoped that the latency research described here will lead to an elucidation of the mechanism of energy release. Be that as it may, however, the method for measuring the latent period aptly illustrates anew the precision and the endless versatility obtainable from the cathode-ray oscillograph.

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