in the drum forces the diaphragm holding the aluminum disk D outward relative to the drum, thereby decreasing the volume and increasing the pressure in the instrument case. The major retarding force to a movement of the diaphragm is then the attending pressure change in the instrument case. By increasing the effective volume of the instrument case, the sensitivity may be increased to a point at which the major retarding force is due to the rubber diaphragm. This is shown in Fig. 2 in which the deflection of the more sensitive manometer is plotted as a function of effective case volume. The effective volume was increased by connecting the case to a suitable flask. It is important that the flask be heat insulated, since a slight change of temperature will cause a change of pressure to which the differential manometer will respond. If the instrument were to be used at maximum sensitivity, it would be desirable to check the calibration at frequent intervals.

To test the maximum frequency of response the manifold was connected to a variable speed mechanical vibrator, and the movements of the manometer pointer followed with a stroboscope. It was found in this way that the manometer is capable of responding to impulses at the rate of 15 per second.

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A High Speed Mechanical Recorder

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A mechanical recorder is described having a resolving time of 0.8×10^{-3} sec. It will follow regularly spaced pulses at the rate of 1200 per sec. and should miss no more than one percent of pulses spaced random in time at an average counting rate of 10 per sec. A circuit is also described giving a pulse of short enough duration and at the same time of sufficient magnitude to satisfactorily operate the recorder.

IN recording events spaced at random in time, a mechanical recorder is often used. All such devices have an inherent time of reaction determined by their mechanical or electrical constants and will not record as distinct two electrical pulses separated by a period less than this natural reaction or resolving time. In counting pulses spaced at random it can be shown that, if τ is the time spacing between two pulses which the recorder will just distinguish as two, and N is the average number arriving per unit time, the number of pulses not recorded will on the average be $N\tau$.[1] Thus if the average rate of arrival is 10 per sec., a recorder must have a reaction time of at least 0.001 sec. if no more than one percent of the particles are to be missed. Corrections can be applied in some cases where the average spacing between pulses becomes comparable with the resolving time of the recorder but becomes quite uncertain for most recorders if the correction becomes too large.

To overcome such difficulties a number of scaling circuits[2–6] have been proposed. All of these have the property of reducing the original counting rate by a known factor to a rate which can be followed with ease by the usual mechanical recorder. The fastest commercial recorder available has a reaction time of about 10^{-2} sec. This means that if accuracy is an important factor, random counting rates should be limited to 1 to 2 per sec. with a recorder of this type.

The other attack is to construct a mechanical recorder with a shorter resolving time. Such a

[1] This is only an approximation. The more accurate expression is $(1-e^{-N\tau})=N\tau-(N\tau)^2/2+\cdots$.

[2] C. E. Wynn-Williams, Proc. Roy. Soc. **A132**, 295 (1931).
[3] W. B. Lewis, Proc. Camb. Phil. Soc. **30**, 543 (1934).
[4] W. G. Shepherd and R. O. Haxby, R. S. I. **7**, 425 (1936).
[5] H. Lifschutz and J. L. Lawson, R. S. I. **9**, 83 (1938).
[6] T. H. Johnson, R. S. I. **9**, 218 (1938).

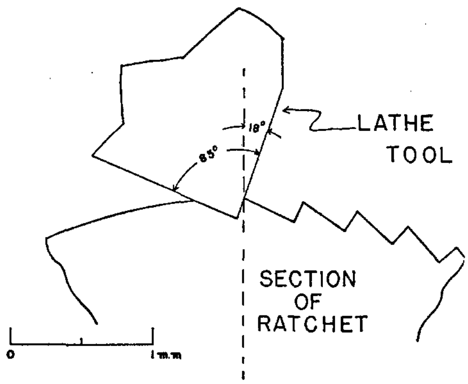


FIG. 1. The ratchet is cut by running a lathe tool parallel to the grooves. Sixty teeth, approximately 0.015 cm deep are cut in a $\frac{5}{16}$-inch steel rod. The ratchet is case hardened to prevent excessive wear.

recorder has been made and tested having a reaction time of about 0.8×10^{-3} sec. It takes the place of the usual recorder operated by a scale-of-eight or a scale-of-sixteen. The latter usually requires 12 radio tubes with all of the accompanying capacities and resistances. The recorder to be described is only slightly larger than a watch and took several days to construct.

Design of the Recorder

Mechanically the periods of vibration of all elements of such a device must be somewhat less than the expected reaction time. Since the forces required to move the masses vary inversely with the square of the time of reaction, all parts must be made small enough for the forces available.

For best efficiency the mechanical and the electrical systems should be matched. This means that the electrical period should be as short as the mechanical period. The electrical period is determined by the L/R of the electrical circuit, where L is the inductance and R is the resistance. In general, the reaction time of the recorder will be determined by that part having the longer period.

An additional requirement is that the mechanical and electrical parts each be nearly critically damped.

The recorder to be described employs a ratchet rotated by an arm upon which is mounted an armature which in turn is caused to move with an electromagnet. Two methods are available for transmitting the motion to the ratchet. Either it can be made to move while the armature is being attracted to the magnets, or it can be moved on the return of the armature to its normal position. In the former case the accelerations increase as the motion takes place until the movable arm either strikes a stop or the armature strikes the faces of the pole pieces. The tendency is for the ratchet to continue its motion beyond the point where it is actually moved by the arm. On the other hand, if the ratchet is made to move when the arm returns to its normal position, the accelerations are large at first because of the restoring forces and die to zero gradually as the normal position is approached. There should, then, be less tendency for the recorder to count double with this latter construction.

Construction of the Recorder

A seventeen-jewel, size 18 watch movement was used as a basis with which to start. Everything was removed from the inside except the train of three gears from the second hand to the minute hand. The large gear from the second hand shaft was removed and a ratchet having 60 teeth was put on in its place.

Since the ratchet is a vital part of the device, it will be described in some detail. The 60 teeth were cut in a $\frac{5}{16}$-inch piece of cold-rolled steel with a lathe tool sharpened to the proper angle. The tool was mounted in a milling machine and the bed run back and forth by hand. The method of cutting and the angles on the ratchet are shown in Fig. 1. A section of the grooved rod was cut out and turned to a thickness of 0.012 inch. It was then case hardened to prevent excessive wearing, by clamping it between two flat pieces of cold-rolled steel of the same diameter, heating the whole to a red heat and melting on potassium cyanide. Clamping the thin ratchet between these flat pieces eliminated warping and burning of the teeth due to excess temperature.

The electromagnets were made $\frac{1}{4}$ inch in diameter and $\frac{3}{8}$ inch long with a $\frac{1}{8}$-inch iron core. Each was wound with about 1200 turns of No. 40 B & S enamel wire. When connected in parallel and a 1 μf condenser charged to 180 volts discharged through them (with armature on) the oscilloscope showed a current which rose to 0.58 ampere in 2.5×10^{-4} sec. and died off in a similar time. The circuit appeared to be slightly over-damped under these conditions.

The details of the vibrating arm and armature can be seen in Fig. 2. Since the bending all takes place near the point of support, the restoring forces can be changed markedly by only slight adjustment of the length of the arm. The motion of the arm with its armature was not quite critically damped. However no serious difficulties arose from this fact. The ratchet was prevented from turning backward by a pawl as shown in Fig. 2. It was necessary to apply some friction to the ratchet by pushing the pawl against the ratchet to keep the recorder from counting double.

Testing the Recorder

If the recorder records accurately evenly spaced pulses up to a certain maximum, it is evident that the process of going from one tooth of the ratchet to the next is all over in a time determined by this maximum rate. The point at which failure of linearity occurs determines, then, the resolving time of the device. It is also evident that, for randomly spaced pulses, if two pulses arrive separated by a time equal to or greater than this resolving time, they will be properly recorded. It was found that correspondence between the number of pulses recorded and the number of evenly spaced pulses delivered began to fail at about 1200 per second. Thus the resolving time was about 0.8×10^{-3} sec.

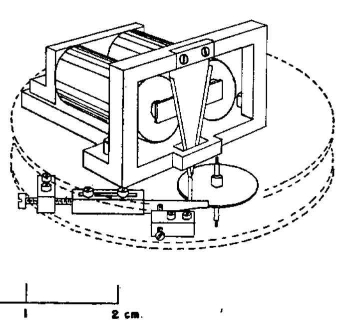
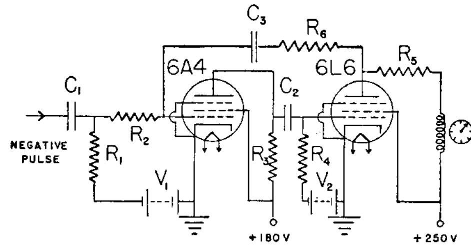


Fig. 2. The above shows the method of actuating the ratchet. (The frame of the watch works is shown dotted.) The vibrating vane is made of 10-mil shim steel.



$R_1=R_2=R_4=10^5$ ohms
$R_3=10^4$ ohms
$R_5=500$ to 1000 ohms
$R_6=10^6$ ohms
$C_1=10^{-2}$ to 10^{-4} μf
$C_2=0.5$ μf
$C_3=2\times10^{-3}$ μf
$V_1=10$ volts
$V_2=45$ volts
K = Mechanical recorder

Fig. 3. Multivibrator circuit for operating the recorder.

Circuit for Operating the Recorder

The usual methods of operating a recorder failed for this recorder. The thyratron circuit of Pickering[7] was found to be too slow. The same objection held for another circuit tried using two thyratrons. A power tube operating in a so-called multivibrator circuit[8] was finally adopted. The circuit is shown in Fig. 3.

This circuit has been described elsewhere. Suffice it to say here that it has the property of giving a square wave pulse of constant length and size independent of the size of the input pulse, provided (1) the maximum voltage of the input pulse is above a certain minimum (usually 3 volts or less) and (2) the time length of the input pulse is less than the natural time length of the output pulse. The voltage swing of the plate is the maximum provided by the plate supply. With the circuit and constants shown in Fig. 3 the time width of the output pulse was 0.5×10^{-3} sec. and the maximum plate current 0.3 amp. The length of the pulse can be determined by the condenser C_3. By changing C_3 any length of pulse from 10^{-5} sec. to say 0.1 sec. can be obtained. The type 6 L 6-tube used in the output will handle more current than the argon filled 885 and has the advantage of long life, and the possibility of reacting as rapidly as desired.

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[7] W. H. Pickering, R. S. I. **9**, 180 (1938).
[8] I. A. Getting, Phys. Rev. **53**, 103 (1938).