PHOTOGRAPHY OF SOUND WAVES.

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Beautiful photographs of sound pulses have been taken by Dr. A. L. Foley and others by the so-called shadow-graph method developed in the Physics Laboratory of Indiana University. These pictures are much superior to those taken by the Schlieren method devised by A. Toepler[1] and used by Mach[2], M. Toepler[3] and Wood.[4] It seems worth while that a method yielding such beautiful results for sound pulses should be tested and further researches made photographically for trains of sound waves. The object of the present research was to determine whether or not the Foley method is applicable to continuous wave trains.

The problem is to get a vibrator of sufficient frequency which will give sound waves of sufficient intensity.

Various methods of generating sound wave trains have been employed. Lodge[5] first showed that the oscillatory discharge of a Leyden jar could be used as a source of audible sound waves. By using sufficiently large inductance and capacity in series with the spark gap he reached a pitch as low as 500. W. Altberg[6] produced short sound waves by the oscillatory current across a spark gap in a circuit containing oil condensers and inductance. The condensers were charged by an induction coil. Altberg succeeded in producing sound waves as short as 1 mm. The waves were measured with a diffraction grating. Duddell[7] showed that an arc light could be made a source of short sound waves by connecting in parallel with the arc an inductance and capacity. The highest vibration rate reached by him was 50,000. Poulson[8] improved this method and got a much higher vibration rate. The principal changes made were the use of copper for the upper electrode, causing the arc to burn in an atmosphere of hydrogen, in a chamber kept cool by running water and steadying the arc by means of a magnetic field. Dieckmann,[9] using a Poulson arc, measured with a grating, sound waves to a vibration rate of 800,000. He got a more nearly steady point source for his sound waves by cutting a notch in the upper and lower electrode, one notch being vertically above the other. C. W. Hewlett[10] devised a mechanical oscillator capable of producing sound waves of frequencies

[1] A. Toepler, Pogg. Ann., *131*, p. 33, N. 180, 1867.
[2] E. Mach, Sitzungsber. d. k. Akad. Wissensch. zu Wien, *98*, p. 1333, 1889.
[3] M. Toepler, Ann. d. Phys., *14*, p. 838, 1904; Ann. d. Phys., *27*, p. 1043, 1908.
[4] R. W. Wood, Phil. Mag., *48*, p. 218, 1899; Phil. Mag., *50*, p. 148, 1900.
[5] Lodge, Nature, *39*, p. 471, 1889.
[6] W. Altberg, Ann. d. Phys. *23*, p. 267, 1907.
[7] Duddell, Electrician, *45*, p. 310, 1900.
[8] Poulson, Electrotchn, *45*, p. 310, 1900.
[9] Dieckmann, Ann. d. Phys., 27, p. 1066, 1908.
[10] Hewlett, Phys. Rev., 17, p. 257, 1921.

"Proc. Ind. Acad. Sci., vol. 38, 1928 (1929)."

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up to 30,000. In this oscillator a light, slightly stretched diaphragm was caused to vibrate by an oscillating current through two flat (pan cake) coils placed close to the diaphragm, and on either side. The oscillating current was produced by a tube oscillator. Langevin devised a piezoelectric oscillator, based upon the piezoelectric property of quartz crystals. R. W. Boyle[11] used an oscillator of this type. Standing, ultrasonic waves were produced in water, and the nodes and loops were made evident by ridges formed by fine powder settling slowly through the water. Von Mark Holtzman has devised an apparatus which is a modification of the Kundt's tube, which serves as a powerful source of sound waves as short as one centimeter. A small glass tube was continuously rubbed by a belt actuated by pulleys. The rubbing surface of the belt was thick silk and this was kept wet with alcohol.

The sound source first tried in this research was the electric arc with inductance and capacity connected in parallel with it as shown in figure 1.

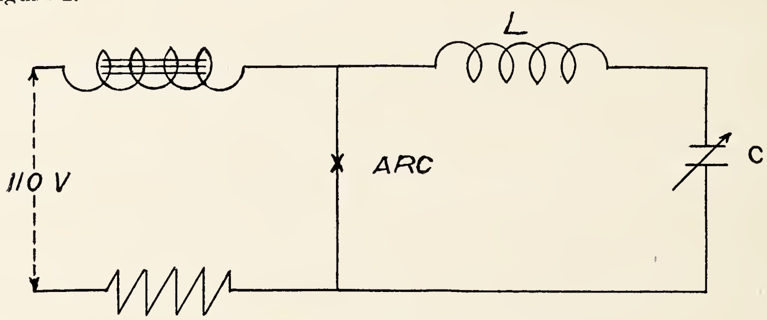

Fig. 1—Diagram of Circuit for singing arc.

The inductance L was continuously variable. The capacity C was a Leeds and Northrup ten-microfarad condenser variable by one microfarad steps. Different sized carbons, cored and solid, were tried; also copper electrodes. Small solid carbons 5/32″ seemed to give the largest current in the oscillating circuit. The camera used was the same as described by Dr. A. L. Foley in the Physical Review, November, 1912. The illuminating spark was between magnesium terminals at one end of the camera. The spark was produced by the discharge of Leyden jars, three jars being connected in multiple with each of the jars on the electrostatic machine. The total capacity on each side of the machine was about .006 microfarads.

The photographic plate was at the other end of the camera 2.9 meters from the illuminating spark. The arc which served as a sound source was placed in a light-tight box alongside the camera (fig. 2) communcating with the inside of the camera by an elliptical opening 8.9 cm. x 7.6 cm., the arc being 14 cm. from inside of the camera. The side of the box opposite the arc was cut away so that the light from the arc passed into a rectangular box with V-shaped ends attached to the opening and blackened on the inside. Thus the light was absorbed

[11] R. W. Boyle, Trans. Royal Canadian Soc., p. 90, 1925.

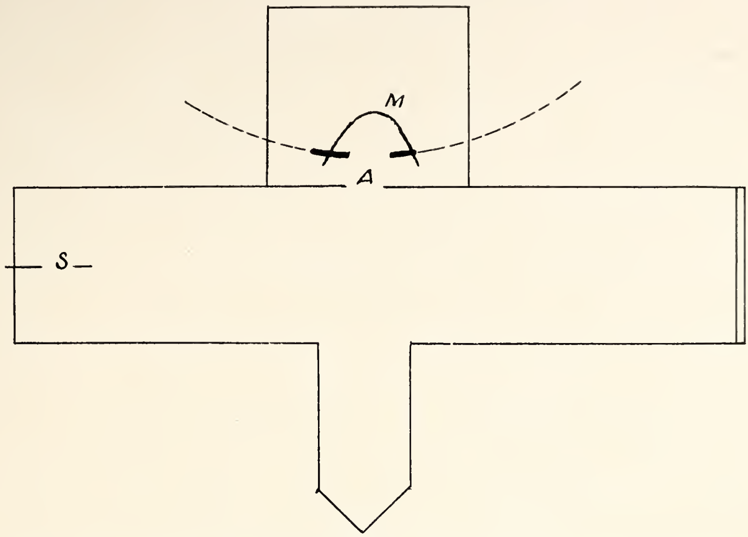

Fig. 2—Diagram of camera. S is the illuminating spark gap, A the arc. A parabolic mirror M was placed back of the arc.

and no noticeable fogging of the plates caused by light from the arc occurred.

In later tests the position of the arc was changed. It was placed close to the large end of a tin funnel 81 cm. long, with elliptical ends 2.5 x .7 cm. and 8.2 x 7.3 cm., respectively. The small end of the funnel projected into the camera and served as a slit source for sound waves.

Two difficulties were encountered. A current of up to six amperes was obtained in the oscillating circuit at audible frequencies, but at frequencies near or above audibility the current in the oscillating circuit was reduced to a small value. Also a wave meter showed a broad wave with a number of pronounced overtones. Apparently the above method will not give pictures of sound wave trains, at least not without some modifications. Some irregular impressions of doubtful origin were found on many of the plates but no plates were obtained with distinct indications of sound wave trains.

The next idea tried out was to increase the intensity of the oscillations of the current through the arc by imposing an alternating current from a tube oscillator on the direct current of the arc. If the direct current I through the arc is equal to or greater than $\sqrt{2}$ times the virtual amperes Iv of the alternating current through the arc, the square of the current through the arc will be a maximum n times per second, n being the frequency of the alternating current. If $I = \sqrt{2}\ I_v$ then the variation of the current through the arc will be from 2 I to O. The resulting expansion and contraction of the gases in the arc will result in a train of sound waves.

The method of producing and imposing the oscillating current on the arc is a modification of that used by Von Konstantin Palaiologus and may be understood from the diagram, figure 3.

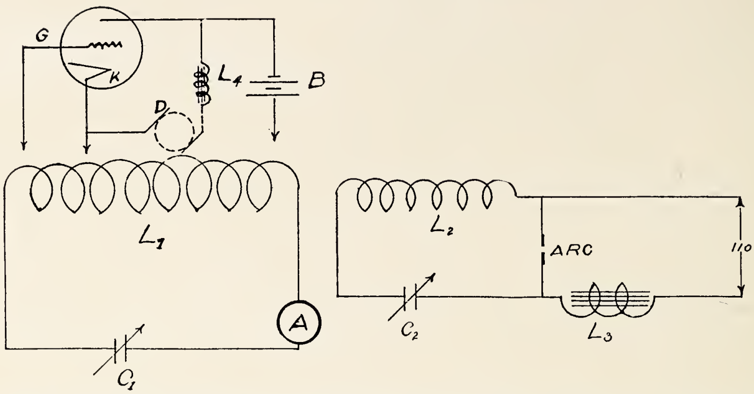

Fig. 3—Diagram of circuit for imposing oscillatory current induced by a tube oscillator on the direct current of an arc.

C_1 and C_2 are made up of Leyden jars and variable oil condensers, the capacity of each being about .018 microfarads. L_1 and L_2 were each about 100 microhenries, the electrical wave length of each circuit thus being about 2,000 meters and the resulting sound waves being .2 cm. First a 5-watt tube was used and later a 150-watt tube. L_3 and L_4 are choke coils—L_3 inductance 1½ henrys, L_4 a large transformer coil. B is a bypass condenser, .0012 microfarad. The plate voltage of the smaller tube was 450; for the larger tube 850 volts. The two circuits were tuned together.

The oscillating current obtained was not as large as expected, the maximum oscillating current through the arc being about two amperes. No definite indications of trains of sound waves were found on any of the plates.

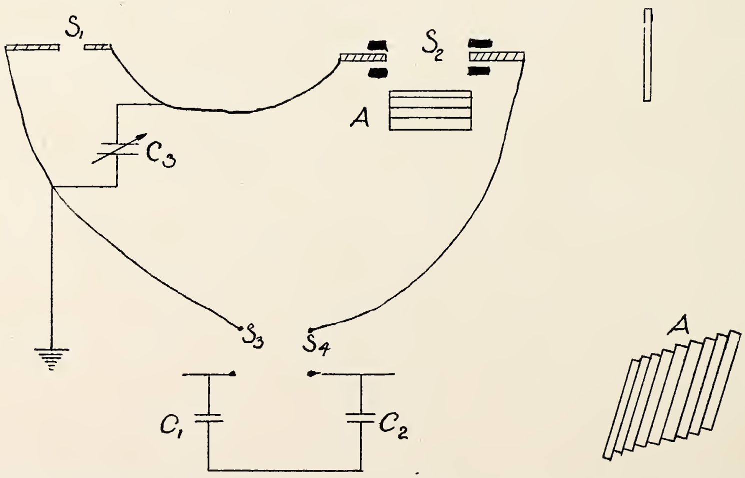

Fig. 4—Diagram of apparatus for producing a sound wave train by reflecting a sound pulse from a series of stops.

A Hewlett oscillator was tried as a source of sound waves. At high frequencies the current through the oscillator was small, the maximum being about .2 of an ampere. No results were obtained.

The last method tried was to produce a train of sound waves by reflection of a sound pulse from a flight of steps made by shearing a pile of selected four-by-five photographic plates. The method may be understood from the diagram, figure 44. S_1 is the illuminating spark gap. S_2, the sound gap, is 2.6 cm. long. S_1, the illuminating gap, was adjustable within wide limits by means of a lever reaching to the plate end of the camera. A is the flight of steps. For relative position of S_2 and A see also figure 6, where the steps are denoted by A and the hard rubber shield for the near terminal of S_2 by *a*. The terminals of the sound gap were platinum. S_3 and S_4 are auxiliary spark gaps at the electrostatic machine. C_1 and C_2 were each composed of one of the regular Leyden jars of the electrostatic machine, together with three other jars connected in parallel. The capacity of C_1 and C_2 were each about .006 microfarads. C_3 was a battery of from six to nine Leyden jars, the capacity of the jars being about .002 microfarads each. The distance of S_2 from S_1 was 1.6 meters. The distance from the plate to S_1 was 2.9 meters. The battery of Leyden jars, C_3, was used to retard the light spark at S_1. The spark could be retarded by increasing the number of jars in C_3, lengthening the spark gap S_1, or shortening the spark gaps S_3 and S_4. The hard rubber shield A helped to prevent the light from the sound spark fogging the plate.

Excellent pictures of sound waves were obtained. In figure 6, may be seen the sound pulse produced by the sound spark and also a series of waves produced by reflection of the pulse from the steps. An increase of speed of the sound waves as they pass through the space near the spark is clearly shown.

Later a plate of hard rubber with a slit .025x4 centimeters was placed above the pile of plates, as shown in figure 5. When each wave struck the slit S the slit became the source of a new sound wave. Thus was produced a train of short sound waves diverging from S as a center. These may be seen in figures 7, 8 and 9.

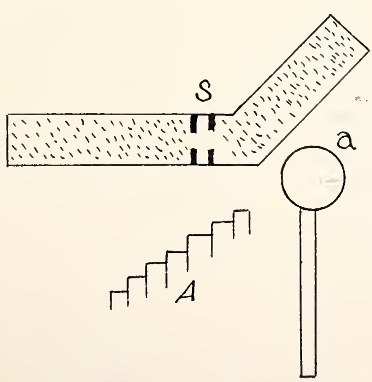

Fig. 5—Method of producing a divergent waves through a slit.

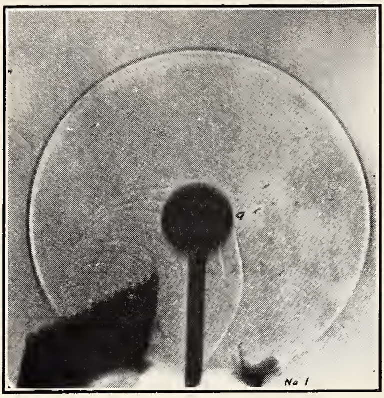

Fig. 6—A sound pulse being reflected from a series of steps. Shows the primary pulse, and a series of waves formed by the reflection from the steps; also shows increase in velocity as sound passes through hot gases formed by the spark.

Fig. 7—The first wavelet, formed by diffraction when primary wavelets strike a slit, diverging from the slit. Diffraction of primary pulse is shown.

On the photographs the wave length is .5 cm. To get the wave length of the sound waves we must divide by ratio of length of camera to distance of sound spark from illuminating spark. This gives .275 cm. as the wave length of the sound waves, corresponding to a frequency of 124,000.

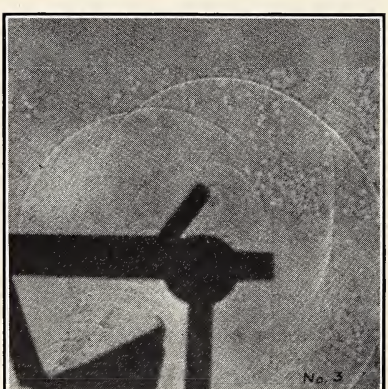

Fig. 8—Shows two wavelets diverging from the slit.

Fig. 9—A still later picture showing a series of waves formed by diffraction through the slit; frequency about 124,000. The wave length is only a little greater than the width of the slit, giving a rather uniform distribution of energy along the wave front.

In figure 7 may be seen the primary sound pulse, the waves produced by reflection from the steps and the first wave produced by diffraction through the slit. In figure 8 there are two waves diverging from the slit and in figure 9 some 17 waves are shown.

The shadow-graph method seems to be well adapted to the photography of sound wave trains; for the intensity of the waves diverging from the slit was exceedingly small. There may be some question as to whether the method will apply so well to a sine wave train or wave trains approximating more closely to such a wave train.

In conclusion I wish to thank Dr. A. L. Foley for proposing the subject, and for his interest and many helpful suggestions during the progress of the work. I wish also to express my appreciation for the assistance given by Dr. R. R. Ramsey, Dr. J. B. Dutcher and Dr. M. E. Hufford.