NEW METHODS OF MEASURING THE SPEED OF SOUND PULSES NEAR THE SOURCE.

By ARTHUR L. FOLEY, Waterman Research Professor and Head of Department of Physics, Indiana University.

In the Proceedings of the Indiana Academy of Science for 1915 the writer showed that the relative speeds of sound pulses at some distance from the source and of different intensity are apparently the same. The experiments described threw no light on the question of the actual speed of a pulse at different distances from the source. This paper deals with a method, rather with two methods, of finding the actual and instantaneous speed of the pulse at any point less than a meter or so from the source. The method could be used for greater distances by increasing the intensity of the spark producing the sound pulse, so as to give the wave sufficient intensity to cast a "shadow" on a plate or film.

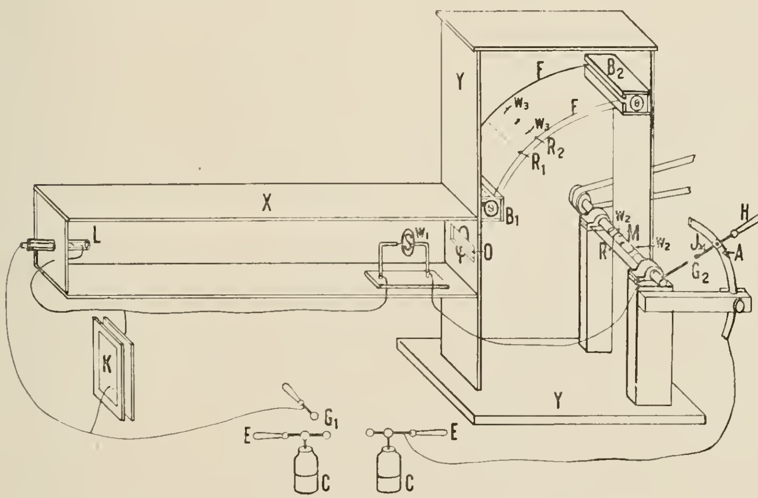

FIG. 1.

Figure 1 shows the arrangement of the apparatus used in this experiment. M is a plane steel mirror made by grinding and polishing the flat surface formed by cutting an axial longitudinal section 20 cm.

long from a piece of steel shafting about 5 cm. in diameter. The shaft was arranged for rotation at a high speed inside a light-tight box Y connecting with another light-tight box X, with a rectangular opening O, 2 x 15 cm. between them. B_1 and B_2 are boxes to hold the full and empty spools for photographic film. Guides F on each edge of the film caused it to lie, when unwound, on the surface of a cylinder with the rotating mirror M on the axis. Just in front of the mirror is a horizontal rod R, of small diameter. A spark from the terminals E of an electric machine jumps the gaps G_1, G_2, S and L, the spark at S occurring before the one at L. When the sound spark occurs the light passes through O, falls upon the mirror M, and is reflected on the film, the rod R producing a shadow R_1 on the film. Suppose that the sound pulse arrives at W_1 by the time the retarded light spark occurs. A part of the shadow of W_1 is intercepted by the wall of the box. A part passes through O, falls upon the mirror at W_2, W_2, and is reflected on the film at W_3, W_3, together with a second shadow of the rod R, now at R_2, due to the fact that the mirror has rotated through a measurable angle during the interval between the sound spark and the light spark. The distance between the shadows R_1 and R_2 together with the mirror speed and the distance from the mirror to the film, enable one to calculate the time interval between the sparks.

From the measured distance W_3—W_3, together with the distance from the light spark to the sound spark, and from the sound spark to the mirror, and thence to the film, one gets the true radius of the sound wave. The quotient of the radius by the time gives the average speed. If one plots radius by time for a considerable number of observations the tangent at any point on the curve gives the instantaneous speed at that point.

The films used were eight inches wide and four feet long, and included about sixty degrees of the arc about the mirror. As the image rotates twice as fast as the mirror it is evident that if the sparks were produced at random, there would be but one chance in twelve of the mirror being in the proper position to give a picture. To avoid this difficulty and to enable one to get several pictures on the same film a metal rod was fastened in such a position on the end of the mirror shaft that it shortened the gap G_2 to such an amount as to cause a spark to pass at the proper time. The position of the gap G_2 was varied by fixing the electrode J at different points along the arc A. J was arranged so it could be slid back and forth through a sleeve. When a spark was desired J was pushed forward and the gap G_2 thus shortened until a spark occurred. The gap was then lengthened before the electric machine had time to generate a sufficient potential for a second spark. In practice, however, this device was found to be somewhat erratic, probably due to the powerful air currents set up by the whirling electrode. Nevertheless it was possible to get three or four pictures on each film and to get sufficiently well defined sound pulse and rod shadows to permit of reliable speed calculations for waves of radius greater than 2 or 3 cm. The polish of the metal mirror was not sufficiently good to give well-defined wave pictures close to the source, where the wave is more or less confused with other spark effects. It was decided, therefore, to eliminate the mirror entirely and get the picture directly on a moving film. The mirror shaft was removed and in its stead was placed a shaft carrying an eight-inch flat-face steel pulley two feet in diameter. The film was fastened to the face of the pulley and rotated within 1 cm. of the opening O, across the center of which the rod R was fastened in a horizontal position and exactly in line with the sound and light sparks. The distance on the film between the sound spark and the light spark shadows of R together with the pulley speed gave the time interval between the sparks. From the radius of the wave shadow together with the distances from the light and sound sparks to the film the true radius of the sound pulse was calculated. As before, the quotient of radius by time gave the sound speed.

The definition of both sound wave and rod shadows was much better in this case than when the rotating steel mirror was used. However, the experiment did not yield better results for waves of small radius, because it was impossible to rotate the film fast enough to make the distance between the rod shadows sufficiently large to be measured with accuracy, when the time interval was small. The film was thrown off and torn to fragments whenever the speed exceeded some twenty-five revolutions per second, regardless of the precautions taken to hold the film on the pulley. Even when both the edges and the ends of the film were cemented to the pulley, the film was thrown off at a speed of some twenty turns per second. The highest rotational speed was obtained when the film was held on the pulley by placing over it a strip of strong cotton net of about 5 cm. mesh, with edges laced securely on the inside of the pulley rim. The string shadows were readily differentiated from the rod and wave shadows, and were not so objectionable as the writer feared they might be.

On account of the limited speed at which the film could be rotated, the increase in the accuracy of the time interval measurements resulting from the better definition of the rod shadows was offset by the fact that the distance between the shadows was much less than by the rotating mirror method. Both the rotating mirror method and the moving film method gave results that show that if there is any difference between the speed of a sound pulse of the intensity used and the speed of an ordinary sound wave, the difference is less than two per cent.

The writer is now at work on a third method which promises more accurate results than either of the ones described in this paper.

It may be noted that a photographic method of measuring sound speed eliminates sources of error found in all methods where the sense of hearing or any mechanical device is used to register the time of arrival of a sound wave, and where the distances traversed by the wave are large. There is no question as to personal error, time lag, wind velocities, differences in temperature, humidity, density, change of wave form, etc. The method gives the instantaneous speed at points up to the source of sound itself. These points will be discussed and data submitted in a later paper.

The writer wishes to thank Professor Cogshall of the Department of Astronomy, of Indiana University, for his kindness in grinding and polishing the steel mirror used in this experiment.