METHODS OF DETERMING THE SPEED OF PHOTOGRAPHIC EXPOSERS. PRINCIPLES INVOLVED IN THE CONSTRUCTION OF PHOTOGRAPHIC EXPOSERS, PP. 478-491

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METHODS

OF DETERMINING THE

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PRINCIPLES

INVOLVED IN THE

CONSTRUCTION OF PHOTOGRAPHIC EXPOSERS.

Description of Plates

ILLUSTRATING WORK DONE WITH A RAPID EXPOSER.

By WILLIAM H. PICKERING.

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XVIII. — METHODS OF DETERMINING THE SPEED OF PHOTOGRAPHIC EXPOSERS.

By William H. Pickering.

Communicated January 14, 1885.

One of the best-known methods for this determination depends on photographing a white clock hand, which revolves rapidly in front of a black dial. The chief difficulty in this case is to maintain a uniform rotation at high speed. To avoid this difficulty a method was suggested by me in "Science," Nov. 14, 1884, which depended on photographing a spot of light reflected in a mirror attached to a vibrating tuning-fork. The objection to this plan is that most photographers cannot readily obtain a proper tuning-fork and measure its pitch. Two other methods have therefore been devised in which this difficulty is obviated.

We sometimes see it suggested that, where a true "drop shutter" is used, we may determine its speed by the well-known laws of falling bodies. That this method, if adopted, would give only approximately correct results, is illustrated by the following experiment made with an exposer in which the grooves were of wood, and the shutter itself of hard rubber. The shutter measured 100 cm. (40 inches), in length in order that high speeds might be obtained. It fell apparently perfectly freely, and the friction was reduced to a minimum. The theoretical and measured lengths of exposure are given below, the measurements being made by the method about to be described. The first column gives the distance that the shutter fell before the middle of its aperture reached the middle of the aperture between the lenses. The second column gives the theoretical exposure with a 2.5 cm. aperture; and the third column gives the exposure as measured.

cm.	Theory.	Observed.
76.0	.012	.010
15.0	.029	.025
4.0	.060	.050
2.7	.083	.065

Several observations were made in each case, and it was found that they always agreed with one another within less than ten per cent. The reason why the observed exposures are somewhat shorter (about twenty per cent. in this case) than the theoretical ones is, that even a very brilliant object does not begin to produce a photographic impression upon the plate until quite a large portion of the lens is uncovered. The exposures are therefore somewhat shortened. This effect, which would be added to that of the friction introduced by the style, would seriously interfere with the accuracy of the method published a few months ago, of allowing a tuning-fork to trace a sinusoid on the smoked surface of the drop itself.

It was suggested in the British Journal of Photography, as early as August, 1883, to photograph a freely falling glass ball placed in the sunlight. Applying to this the laws of falling bodies, the exposures may at once be calculated. The suggestion occurs at once that the resistance of the air might be of sufficient importance to vitiate entirely the results thus obtained. In order to ascertain whether this was the case, the following experiment was devised. A glass ball, silvered on the inside, such as is used for Christmas trees, was procured. It measured 4.15 cm. in diameter, and weighed 25 grams. Some white silk threads were attached to a blackened board so as to form a scale of equal parts, and, this being set in the sunlight, the ball was dropped by its side into a box filled with cotton wool. A mirror was attached to the side of a tuning-fork, and the pitch determined. A camera was now placed so as to photograph the image of the ball as seen in the mirror. The fork was set in vibration and the ball dropped. On development, the plate showed a black sinusoidal line, the vibrations of which were near together at the top, but gradually widened out as the ball approached the bottom of its course. Several photographs were taken, and measured under a dividing-engine, with the following results.

As it was impossible to determine the exact time of starting, the nearest point which could be precisely measured was selected. Its distance from the starting-point was called s_1, and the distance of some other point somewhat lower down was called s_2. The distances that would have been traversed if the air had offered no resistance are designated by S_1 and S_2. The number of vibrations executed by the fork between the starting-point and the points observed is denoted by t_1 and t_2, and the acceleration of gravity during one vibration by g. The distance s_1 in general did not much exceed a centimeter, and the retardation of the atmosphere for this distance could for a first approximation be neglected. The theoretical distance S_2 traversed by the ball will equal

$$S_1 + (2\,S_1\,g)^{\frac{1}{2}}\,(t_2 - t_1) + \frac{g}{2}\,(t_2 - t_1)^2.$$

Substituting s_1 for S_1, we get an approximate value of S_2, from which S_1 may be calculated, and substituted in the above formula. A small correction to the observed distances had to be made, owing to the angular motion of the spot of light on the ball, but this did not exceed two millimeters in any case. From the measurement of five photographs taken on three different days, and with two different arrangements of the ball and scale, it was found that a ball of the above-mentioned size and weight was retarded proportionately to the distance traversed; and that the retardation amounted to exactly .03 of the distance. The maximum fall measured was one meter. This retardation would be proportional to the square of the diameter of the ball, and inversely as its weight; hence we have the equation:

$$\text{Retardation } r = \frac{.03 \times 25}{4.15^2}\,\frac{d^2}{w} = \frac{.0435\,d^2}{w}.$$

It will therefore be seen that for drop-shutter exposures where an accuracy of three per cent is entirely out of the question, we may neglect the retardation of the air entirely, or, better still, counteract it by placing the ball just in front of the scale to be photographed, at .03 of the distance between it and the lens.

APPARATUS FOR MEASURING INSTANTANEOUS EXPOSURES.

The apparatus which I have adopted as the most convenient for measuring drop-shutter exposures of .05 sec. or less consists simply of a box filled with cotton wool, to the back of which is nailed a vertical slat, 50 cm. in height, painted black, on which, at the intervals given below, are painted fine white horizontal lines, numbered from 0 up to 30. The apparatus is placed in the sunlight, and a glass ball hung by a silk thread is suspended at such a height that when focused in the camera the spot of light upon its surface shall coincide with the division marked 0. At a given signal the ball is dropped, and the exposer released. A long black line is produced on the plate, and the number of scale divisions that it covers measures the length of the exposure. As the ball requires .3 sec. to reach the bottom, there is no difficulty in catching it on some portion of its course.

In the following table, which was calculated by the formula $s = \frac{gt^2}{2}$, the first column gives the time required by the ball to fall in hundredths of a second; the second, the distance fallen in centimeters; and the third, the distance in inches.

sec.	cm.	in.	sec.	cm.	in.
.00	.0	.00	.18	15.9	6.26
.05	1.2	.48	.19	17.7	6.97
.06	1.8	.72	.20	19.6	7.72
.07	2.4	.94	.21	21.6	8.50
.08	3.1	1.23	.22	23.7	9.33
.09	4.0	1.56	.23	25.9	10.20
.10	4.9	1.93	.24	28.2	11.10
.11	5.9	2.33	.25	30.6	12.05
.12	7.1	2.78	.26	33.1	13.03
.13	8.3	3.26	.27	35.7	14.06
.14	9.6	3.78	.28	38.4	15.12
.15	11.0	4.34	.29	41.2	16.22
.16	12.5	4.92	.30	44.1	17.36
.17	14.2	5.59			

By painting the division marks at these distances, the length of the line made by the ball as photographed on the plate with the scale will give us at once the duration of the exposure in hundredths of a second. Four or five exposures may be made on the same plate, moving the camera slightly after each one. The results obtained will indicate the uniformity of the exposure.

For exposures longer than .05 of a second another method of measurement has been devised. It consists it photographing a seconds pendulum having a silvered glass ball for a bob. The pendulum is placed in the sunlight, and is swung before a painted scale spaced as follows. The scale is constructed on an arc of a circle whose radius is 39 inches, and it is symmetrical on both sides of the middle point. The following distances are measured both ways, starting from the middle, and each space save the last one represents the distance traversed by the pendulum in .02 sec. To traverse the last space requires .1 sec.

	cm.	in.		cm.	in.
Middle point	.0	.00		12.8	5.04
	1.3	.50		13.7	5.41
	2.5	1.00		14.6	5.75
	3.7	1.46		15.4	6.06
	5.0	1.97		16.2	6.38
	6.2	2.44		16.9	6.65
	7.4	2.91		17.5	6.89
	8.5	3.35		18.1	7.13
	9.6	3.78		18.6	7.32
	10.7	4.21		19.0	7.48
	11.8	4.65	The two ends	20.0	7.87

The scale is numbered from one end to the other, and as it takes the bob just one second to traverse the full length, there is plenty of time to measure any short exposure with accuracy. The string of the pendulum is attached to a screw at the top, enabling us to raise the bob. By this means we get several exposures on the same plate. The slight change in the length of the pendulum (an inch or so) makes no appreciable difference in its rate of vibration. By these two methods, involving no complicated apparatus, any exposure, no matter how short, can be readily measured with the greatest accuracy.