An Instrument for Precision Photometry Of Reflex Reflective Materials

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● IN RECOGNITION of the growing need for scientific reflector evaluation, a few state highway agencies have installed extensive laboratory test facilities for this purpose. While these laboratories constitute the only accurate means presently available for testing reflector performance, the procedures employed require unusual space, delicate equipment, and skilled personnel.

Previous attempts have been made to reduce the size and complexity of this apparatus. The ESNA Photometer, however, represents the first portable testing instrument whose measurements correlate completely with full-scale laboratory data and actual highway conditions. Unlike its predecessors, it provides accurate measurement of performance at discrete viewing angles throughout the range of modern reflector usage. The simplicity of its operation makes it suitable for production quality control as well as for laboratory evaluation. It fills the long-felt need for a practical, reliable device capable of testing a wide variety of reflex reflector materials for conformance to specifications.

Reflex reflectors are optical devices having the ability to accept light from a near or distant source and reflect this light back to the source in a confined beam, regardless of the angle at which the light becomes incident on the reflector. For most commercial reflectors the return beam is concentrated within a cone of 2-deg half angle, the axis of the cone being the line between the light source and the reflector. The manner in which the light is distributed within the returned light cone directly affects the visibility characteristics of the reflector under actual highway viewing conditions. As a vehicle approaches a reflector mounted on a sign, delineator, or disabled vehicle, a constantly changing angle is formed between the line from the headlights and the reflector and the line between the reflector and the driver's eyes. This angle, termed "observation angle," is inversely proportional to the distance between the vehicle and reflector. For the average passenger automobile the observation angle is equal to the angle whose tangent is 1.746 divided by the distance, in feet, between the automobile and the reflector. The value 1.746 is the average vertical distance, in feet, between the headlights and the driver's eyes. For example, at 1,000-ft distance the observation angle is $\frac{1}{10}$ deg; at 600 ft the observation angle is $\frac{1}{6}$ deg; and at 300 ft the observation angle is $\frac{1}{3}$ deg. The visibility of the reflector when viewed at any distance depends on the candlepower intensity of the reflector at the observation angle formed at that distance.

Because the candlepower intensity of the reflector at any observation angle is dependent on the quantity of light incident on the reflector, performance is measured in terms of candlepower output per foot-candle illumination. The term for this efficiency value is "specific intensity." To illustrate the importance of measuring specific intensity at discrete observation angles, certain fundamental laws of light must be introduced.

A source of light emits luminous intensity in terms of candlepower. Any surface in the path of this light is illuminated by the source in terms of foot-candles of illumination, the foot-candle level being inversely proportional to the square of the distance between the source and the illuminated surface. A source emitting one candlepower will produce one foot-candle of illumination on a surface at 1-ft distance; $\frac{1}{4}$ foot-candle at 2 ft; $\frac{1}{9}$ foot-candle at 3 ft, etc.

A reflector at distance D feet from headlights of candlepower, CP_H, is therefore illuminated by $\frac{CP_H}{D^2}$ foot-candles. The driver's eyes at distance D feet from a reflector of candlepower, CP_R, are illuminated by $\frac{CP_R}{D^2}$ foot-candles.

$$\text{Illumination at reflector} = \frac{CP_H}{D^2}$$

$$\text{Illumination (signal) at eye} = \frac{CP_R}{D^2}$$

$$\text{Specific intensity of reflector} = S.I. = \frac{\text{Candlepower of reflector } (CP_R)}{\text{Illumination at reflector } \left(\frac{CP_H}{D^2}\right)}$$

$$CP_R = S.I. \times \frac{CP_H}{D^2}$$

then

$$\text{Signal at eye} = \frac{S.I. \times CP_H}{D^2 \times D^2} = \frac{S.I. \times CP_H}{D^4}$$

Assuming the candlepower of the headlights to be a constant, it is obvious that the specific intensity of a reflector must increase proportionally to the fourth power of the distance for a constant signal at the eye. In other words, the specific intensity of a reflector at 1/10-deg observation angle (1,000 ft) must be 123 times greater than the specific intensity at 1/3 deg (300 ft) so that the driver receives the same signal at both distances.

Although no commercially manufactured reflector approaches this ideal, the discussion makes clear that in testing reflex reflectors the photometer must be capable of measuring extremely small portions of the reflected cone of light at discrete observation angles and converting measurements into values of specific intensity. The ESNA Reflex Photometer was designed and constructed to accomplish these goals accurately and efficiently.

INSTRUMENT COMPONENTS

The basic components of the photometer are: (a) a light source which illuminates the reflector, (b) a photoelectric receiver which measures the intensity of the reflected beam at discrete observation angles and converts these measurements to specific intensity values which are indicated on a galvanometer, and (c) a goniometer on which the test reflector is mounted.

Light Source

The light source consists of an optical system coaxial with the photometer tube. The heart of the system is a 10-watt Zirconium arc lamp with an intrinsic brightness of approximately 29,000 candles per square inch. The light output of the arc is amplified by a system of lenses, and finally passes through an 0.200-in. diameter aperture which simulates the headlights of a vehicle.

Receiver

Surrounding the aperture at a nominal radius of 0.208 in. is a ring of photosensitive material 0.050 in. in width. The receiver ring simulates the eyes of the driver. Light falling on this ring produces a photocurrent proportional to the quantity of light, which is indicated on the galvanometer. An Aryton shunt in the receiver-galvanometer circuit extends the range of the photometer by decade factors of 1 to 1,000, making possible the testing of all reflective materials from lowest to highest brightness.

Goniometer

The test reflector is mounted on an adjustable holder designed to accommodate a variety of reflective materials. The sample holder pivots to permit varying the entrance angle, and rotates at 300 rpm about the reflector axis to obtain an average value. The entire unit may be removed from the photometer tube and placed at various stations in the tube to change the observation angle.

INSTRUMENT CAPABILITY

The photometer is capable of measuring the specific intensity of reflex reflectors from $\frac{1}{10}$-deg observation angle to $\frac{1}{3}$-deg observation angle. Simulating actual highway viewing, the observation angle is changed by changing the distance between the source-receiver plane and the reflector. At $\frac{1}{10}$-deg observation angle the reflector is positioned 10 ft from the source-receiver plane and the 0.05-in.-wide receiver ring in the photometer corresponds to a 5-in.-wide observation zone on the windshield of a car at 1,000-ft distance from the reflector. The 5-in. width takes into account variations in drivers' height from average. As the reflector is moved closer to the source-receiver plane for measurements at larger observation angles, the source and receiver dimensions remain constant—as do the observation zone and headlights under actual conditions.

The relation of source and receiver dimensions in the photometer duplicate those recommended by the Society of Automotive Engineers for testing of reflex reflectors, where a light source of 2.00-in. diameter, receiver of 0.50-in. diameter and test distance of 100 ft is described.

CALIBRATION OF PHOTOMETER

Included with the photometer is a calibrating mirror which is used to calibrate the device for absolute specific intensity. Also included are color filters to be used in conjunction with the calibrating mirror for the testing of colored reflex reflectors. Before starting a test, mount the mirror on the goniometer and switch the Aryton shunt to the least sensitive range. Turn on the light source and allow the unit a warm-up period of 10 min. After warm-up switch the shunt to higher sensitivity ranges until a galvanometer deflection of over 10.0 divisions is obtained. Mask the mirror with the black zeroing mask and adjust the galvanometer to zero. Unmask the mirror and record the galvanometer deflection. Multiply by the shunt factor for a final reading of R_a. Repeat at all observation angles to be tested, and record R_a for each observation angle.

For conversion of galvanometer readings to specific intensity multiply by

$$\frac{D^2KT}{4R_a}$$

in which

D = test distance;
R_a = mirror value previously recorded for each observation angle;
K = reflection factor marked on back of calibrating mirror; and
T = 1.00 when testing crystal reflectors, or transmission factor marked on color filter used in calibrating for colored reflector testing.