CALIBRATION OF A PERMANENT CONTROL BEACON FOR A 300-METER PHOTOMETRIC RANGE

BY

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SUMMARY

This report describes the development and the results of a series of calibrations of a portable projector for the purpose of providing facilities for calibrating a permanent control beacon. This beacon was installed on a 300-meter outdoor photometric range at the National Bureau of Standards. Its calibration involved determinations of atmospheric transmission, and required a portable standard light source with sufficient intensity to be measured photometrically at the distance employed.

INTRODUCTION

The photometry of beacons and similar projectors requires the use of a photometric range of sufficient length that the unit may be considered as equivalent to a point source and the inverse square law may be considered valid. Such a range should be not less than required by the formula[1]

$$D = \frac{Rd}{r}$$

where D = photometric distance, or length of the range,

d = maximum length of optical path from the light source to the aperture of the reflector or lens,

R = maximum radius of aperture of unit,

r = minimum radius of the envelope of the projected light source, as seen from the point to which d is measured.

Where a multicoil filament is used as a source, each coil should be considered as a separate source, unless the optical system is designed to spread the beam transversely to the coil.

Using the values of R = 1.0 feet, d = 1.13 feet, and r = 0.0017 feet, which are approximately the values for 24-inch beacons now in use, D will be found to be 665 feet. For a 36-inch beacon the theoretical distance will be 1,500 feet, but experience has indicated that a range 900 feet long reduces the errors to an acceptable limit.

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[1] This formula was developed by Mr. Frank Benford, of the General Electric Company, in his "Studies in the Projection of Light" published in the General Electric Review, vol. 26, page 231, April 1923, Equation (42). It is also the formula for a photometric range required in the Civil Aeronautics Administration's Standard Specifications for Airport Lighting.

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The maximum convenient distance available at the National Bureau of Standards is 948 feet (289 meters), and the range was installed with this length. A permanent reference or control beacon was set up on the 948-foot range to serve as a means of determining the atmospheric transmission when beacons are being tested.

In the past, the transmission of the atmosphere during any test was taken as the ratio of the candlepower of the control beacon, as measured during the test, to the candlepower measured on the clearest days when the transmission is assumed to be 1.00. Disturbing discrepancies were found in the data and little could be done to guard against changes in the equipment or to determine the actual transmission on the clear days used for reference. Accordingly, this project was undertaken to provide a means of calibrating the permanent control projector at regular intervals. This could be accomplished by means of a portable projector which could be measured on the outdoor range and also on a 98-foot (30-meter) indoor range which is available at the National Bureau of Standards. The transmission of the atmosphere on the latter range is very close to 1.00. These two ranges will be referred to as the 300-meter and the 30-meter ranges, respectively.

The use of a portable projector and the 30-meter range appeared advisable for the following reasons:

1. The permanent control projector is not portable.
2. Candlepower measurements on a projector of this type over as small a distance as 98 feet would not be sufficiently accurate.
3. No convenient intermediate point was available between the permanent control projector and the photometer from which the projector could be calibrated.
4. It was considered advisable to provide an auxiliary projector and use it to calibrate the permanent projector only as frequently as the instability of the latter made it necessary. In this way the frequency of recalibration of the portable projector could be kept to a minimum.

PROCEDURE

An auxiliary portable projector was constructed. This projector was measured on the 30-meter range where the transmission of the atmosphere was considered to be sufficiently high so that the value of 1.00 could be used without appreciable error. The candlepower measurement thus obtained, with suitable corrections to be described, was used to determine the basic value of the candlepower of the projector for the measurements on the outdoor range. The ratio of the apparent candlepower actually obtained at the time of any measurement to the basic value obtained from the indoor measurement was taken as the transmission of the atmosphere at that time.

The requirements for the portable projector were that it be stable in its candlepower characteristics, capable of being transported without loss of alignment between its component parts, and of such design that it would provide sufficient illumination to be conveniently measurable on the 300-meter range and, at the same time, be sufficiently small to be accurately measurable on the 30-meter range.

In accordance with these requirements, the lamp chosen for the portable projector was an experimental type L lamp with a parabolic glass reflector and a front cover-glass constituting the bulb of the lamp. These lamps are similar to "sealed-beam" automobile headlight lamps, except that the cover-glass is plain instead of prismatic and they have 6-volt, 100-watt, C-6 filaments. Heavy filaments such as these tend to be more stable in operation than lighter ones. The location of the reflector on the inside of the bulb, where it is exposed only to the inert gas with which the bulb is filled, lessens deterioration and consequently further tends to promote stability. At first the lamps were operated at 15 amperes but later, to make more certain of the stability of the filaments, they were operated at 14 amperes. This corresponds to a power consumption of 63 watts, well below their rating of 100 watts.

In order to obtain sufficient candlepower, three of these lamps, mounted on a rigid panel, were used together. To make possible an accurate correlation between the measurements made on the 30-meter and the 300-meter ranges, a telescope with cross-hairs was mounted integrally with the three lamps on the panel. Figure 1 is a view of the complete assembly.*

By the aid of traverses taken with the auxiliary projector mounted on a goniometer, the telescope was fastened to the assembly in such a way that the intersection of its cross-hairs was directed approximately in the direction of the peak of the combined beams. For all measurements made on the 300-meter range, the assembly was directed so that the cross-hairs intersected at the center of the image of the photocell which received the light from the projector. Because the axes of two of the lamps were offset 5 inches and the axis of the third was offset 5-1/2 inches from the axis of the telescope, a parallactic error was present when the candlepower of the projector was measured on the 30-meter range and the telescope was directed in the same manner as on the 300-meter range. Accordingly, suitable targets were constructed and located in such a way that when two of the lamps were covered and the telescope directed at the proper target for the third lamp, the uncovered lamp was aimed in the same direction with relation to the photocell as when the projector was measured on the 300-meter range. By repeating this process for each of the other two lamps and adding the candlepower values for the three lamps, the basic value of the candlepower for the outdoor range was obtained. Measurements were also made with the telescope directed at the photocell, both with the lamps operated one at a time and with all three lamps operated together.

CALIBRATION RESULTS

Table I gives the results of the calibration measurements on the 30-meter range.

Table I
Results of Calibration Measurements on 30-meter Range

	Lamp	Intensity of Beam in Kilocandles				
Date	Current Amperes	ΣI	I_t	ΔI Percent	I_p	$\frac{I_p}{1/2\,(\Sigma I + I_t)}$
6/21/41	15	382.2	381.8	0.1	378.0	0.990
7/12/41	15	386.2	386.2	0.0	382.3	0.990
8/26/41	15		390			
7/14/42	15		383.4			
8/26/41	14	256.7	257.3	0.2	253.9	0.998
10/28/41	14		254			
7/14/42	14		252.8			

ΣI is the candlepower obtained for the portable projector with the telescope aligned with the photocell, the three lamp-beams measured separately, and their candlepowers added to give the reported value.

I_t is the candlepower of the unit with the same alignment as for ΣI, but with the combined beams of the three lamps measured at once.

ΔI is the percentage difference between the values reported in ΣI and I_t.

I_p is the candlepower of the projector corrected for parallax through the use of the parallax-correcting targets described herein under PROCEDURE. This is the basic value used for 300-meter range measurements. The last column gives the ratio of the parallax-corrected candlepower to the average of the two uncorrected candlepower values ΣI and I_t.

From Table I, it may be seen that on each of three separate calibrations, the basic candlepower measured in the manner described under PROCEDURE for avoiding errors due to parallax, was close to 1 percent less than the value which was obtained by directing the telescope at the photocell and taking a single candlepower reading without correction for parallax. It was decided, accordingly, that the procedure could be simplified by applying the 1 percent correction to the single reading, checking occasionally to affirm the validity of the method.

The following table gives the apparent transmissions obtained with the portable projector between June 1941 and June 1942, together with the candlepower of the permanent control beacon computed from these transmissions.

Table II

Apparent Transmission on 300-meter Range

Date	Time	Apparent Transmission	Permanent Control Beacon Kilocandles
June 28, 1941	10:30 A.M.	0.94	
June 30,	10:15 "	0.89	
	10·30 "	0.86	
	11:45 "	0.90	
July 8,	9:45 A.M.	0.95	
	10:15 "	0.95	
July 9,	9:15 A.M.	0.93	
	9:30 "	0.94	
	10:25 "	0.95	510
	10:40 "	0.95	510
Sept. 5,	1·30 P.M.	0.95	559
	3:30 "	0.95	544
Sept. 6,	11:15 A.M.	0.97	546
Sept. 8,	9:30 "	0.92	539
	10.45 "	0.91	
	11.00 "	0.92	540
	3:15 P.M.	0.92	532
Sept.18,	3:15 "	0.96	523
Oct. 1,	12:45 "	0.95	526
Oct. 2,	11:15 A.M.	0.96	523
Oct. 17,	2:45 P.M.	0.97	516
	3:00 "	0.98	511
Oct. 18,	9:00 A.M.	0.95	502
	10:00 "	0.93	510
Oct. 20,	9:15 "	0.97	
Oct. 21,	9:30 "	0.96	501
Oct. 22,	10:00 A.M.	1.02	502
	3·30 P.M.	1.02	497
Nov. 8,	11:00 A.M.	1.00	509
		1.02	497
		1.00	502
		1.02	491
	12:00 Noon	1.03	486
Nov. 13,	2:50 P.M.	0.88	491
	3:00 "	0.91	475
Nov. 21,	1:30 "	1.00	462
Dec. 26,	11:00 A.M.	0.80	508
	12.45 P.M.	0.83	494
	4:00 "	0.86	502
Jan. 7, 1942	10:00 A.M.	0.91	496
Jan. 12,	10:00 "	0.87	488
Jan. 13,	10:00 "	0.89	481
Jan. 14,	2:00 P.M.	0.88	492
Jan. 16,	2:00 "	0.94	468
Feb. 13,	9:00 A.M.	0.92	477
Feb. 23,	1:00 P.M.	0.92	479

Date	Time	Apparent Transmission	Permanent Control Beacon Kilocandles
Feb. 25,	9:00 A.M.	0.89	477
Feb. 27,	11:00 "	0.93	465
Mar. 5,	11:30 "	0.60	497
	2:40 P.M.	0.83	476
Mar. 6,	1.15 "	0.91	475
	1:45 "	0.90	465
Mar. 10,	9:45 A.M.	0.95	462
Mar. 26,	2:00 P.M.	0.93	458
Mar. 27,	10:30 A.M.	0.90	452
Apr. 14,	3 30 P.M.	0.91	472
May 11,	2:15 "	0.90	457
June 2,	2:30 "	0.89	460
	8:15 "	0.89	459

DISCUSSION

The transmission data obtained with the portable projector are in some respects unsatisfactory. Measurements made at different times on the outdoor range do not correspond very well with the prevailing condition of the atmosphere as observed by the eye. Anomalous values of the transmission of over 1.00 were obtained on several occasions. The candlepower of the permanent control beacon, computed from the transmission measurements made with the auxiliary projector, appears to be erratic.

The discrepancies between visual observation and measured transmission arise in part from the fact that the visual observations are usually made through a portion of the atmosphere differing materially in direction, length, and adjacent terrain from the atmosphere on the 300-meter range. Furthermore, it is known that there are appreciable variations in the refraction of the atmosphere along the range. The effect of these variations may be different for beams with different candlepower distribution and may account in part for the erratic candlepower values of the permanent control beacon. In addition to these atmospheric difficulties, large variations in the temperature of the apparatus encountered at different seasons of the year and at different times of the day make accurate electrical and photometric measurements difficult. Finally, the measurements on the portable and on the permanent projectors are not made simultaneously. To some extent the erratic candlepower values of the permanent projector may arise from actual variations in the atmospheric conditions.

On the other hand, measurements made on the 30-meter range appear consistent and precise. The readings of I_t reported in table I show a small drift upward followed by a small drift downward. The values of ΔI are very small, indicating satisfactory linearity in the photoelectric photometer used. The consistency of the values of the ratio reported in the last column is excellent. An examination of the data used to obtain the reported values in the table shows an unusually high precision.

CONCLUSIONS

The apparent reliability and consistency of the measurements on the 30-meter range indicate that the portable projector is satisfactory. The data thus far obtained are of value in making improvements in the equipment and in its operation, for the purpose of reducing errors in the measurements.

It is to be observed that the candlepower of the permanent control beacon appears to be drifting downward. This presumably is caused by some gradual change in the equipment, and if no allowance were made for it, a systematic error in the measurements made on the 300-meter range would result. It is to protect against such errors that the present project was undertaken. The auxiliary projector will afford such protection, in future tests.

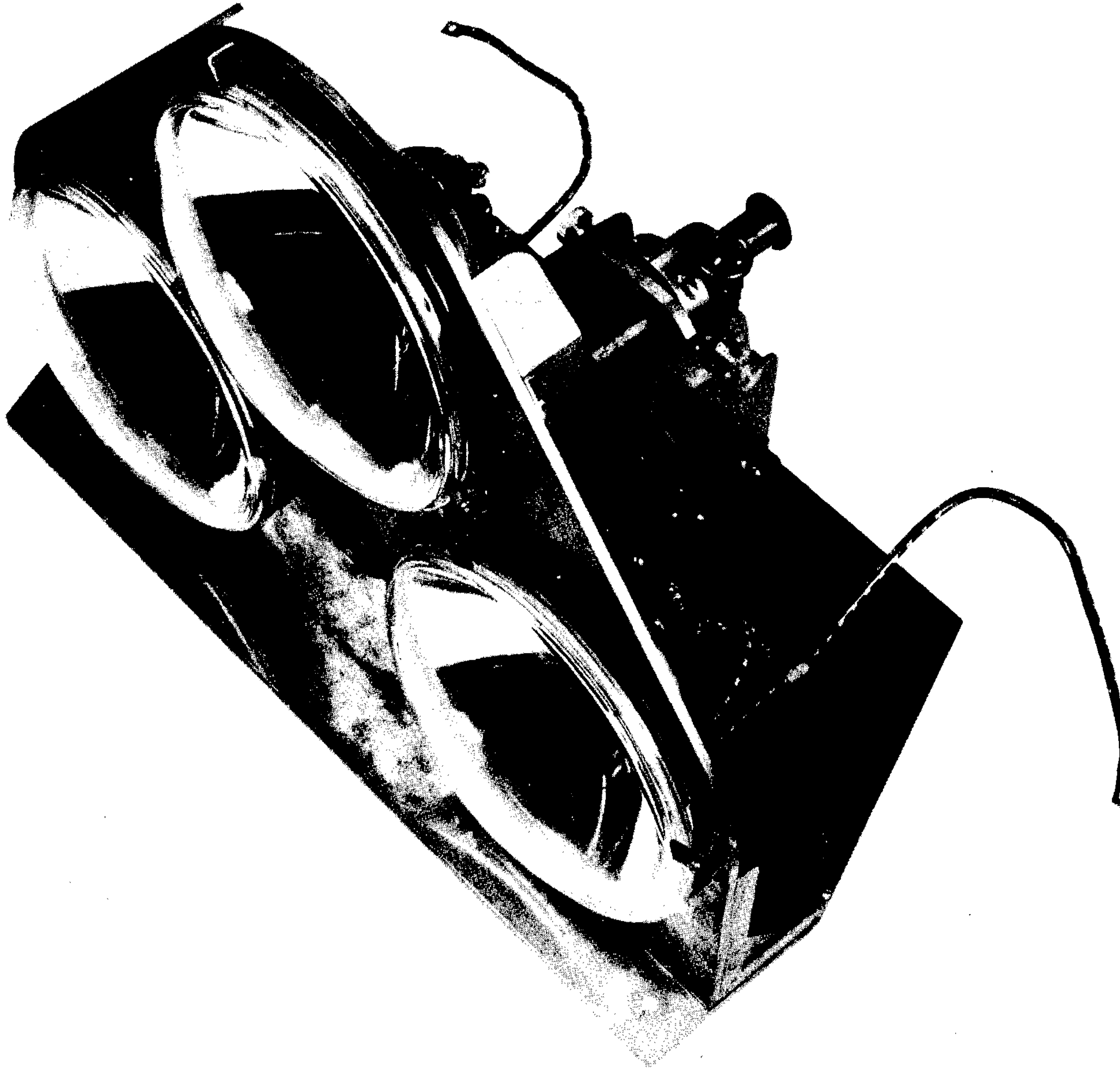

FIGURE 1. "General View of Portable Projector"

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