NBS TECHNICAL NOTE 821

Photometric Data Variability of Automotive Lighting Components

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Photometric Data Variability of Automotive Lighting Components

Bert G. Simson and John Mandel

Four automotive lighting components were tested in three commercial testing laboratories to estimate the degree of photometric data repeatability and reproducibility. The laboratories used the photometric testing techniques required by Federal Motor Vehicle Safety Standard No. 108. The precision of this test method was placed in a range of about 10 percent coefficient of variation. However, this value should be considered more as an indication of existing conditions than as a predictive parameter.

Key words: Federal Motor Vehicles Safety Standards; interlaboratory test evaluation; motor vehicles; photometric testing; safety standards.

I. Introduction

FMVSS No. 108 [1][1] specifies minimum performance requirements for automotive lighting components such as tail lamps, stop lights, reflex reflectors, sealed beam headlights, etc. Requirements in the standard include detailed procedures for various mechanical, environmental and photometric tests. This paper discusses a round robin experiment designed to estimate the degree of photometric data repeatability for identical lighting components within a single laboratory, and the reproducibility among several laboratories. The sample consisted of two parking and two tail lamps representing three lighting component manufacturers. The components had previously been selected from automotive assembly lines for compliance testing of the Office of Standards Enforcement (OSE) [2].

II. Test Procedure

In practice, the photometric tests were conducted as follows: A lighting component, (such as a tail lamp), was mounted unto a test fixture built to simulate the component's orientation in its designated vehicle. The original bulb was

[1] Figures in brackets indicate the literature references at the end of this paper.

replaced with another bulb calibrated[2] in accordance with techniques specified in the SAE Lighting Standard [3]. Then, the fixture with the lamp was mounted on a goniometer with two angular degrees of freedom. The goniometer could be indexed ten degrees of arc from the normal in the vertical, and twenty degrees of arc from the normal in the horizontal plane. A photoelectric detector, facing the assembly from 100 feet away, and the associated electronic equipment completed the experimental setup.

FMVSS No. 108 [1] requires the measurement of directional luminous intensity (in candlepower) at 27 defined horizontal and vertical angle combinations of the goniometer's setting. To check for compliance with the minimum requirement in the standard, the 27 candlepower values are pooled into seven groups representing aggregates of three to five test point values. Figure 1, FMVSS No. 108 [1] lists minimum candlepower values for each group (also called "zone").

In this experiment, we tested four lamps in three laboratories under contract with the OSE [2]. While it is generally advisable to run interlaboratory studies on no less than six, and preferably fifteen or more laboratories [4], it was impossible in this case to conform to these requirements. Indeed, the three participating laboratories are the only commercial institutions in the U.S. engaged in this type of testing. To provide data for the within laboratory variability, we tested each lamp four times in each laboratory, using different rated bulbs. The bulbs were operated at the designated mean spherical candlepower [3], and they were calibrated by each laboratory in an integrating sphere. The sixteen lamp-bulb combinations were tested in a random order in each laboratory, the order being different from laboratory to laboratory.

III. Statistical Analysis of Data

The data were first arranged in a two-way table, (Table 1), in which the rows represented the 12 laboratory and bulb combinations (3 laboratories x 4 bulbs), and the columns represented the 28 lamp and zone combinations (4 lamps x 7 zones). An analysis of this table of data showed no significant systematic differences between the four bulbs used in the experiment. Therefore, the four results obtained by each laboratory for a particular zone on a given lamp, using the four bulbs, were treated as replicate measurements. The statistical analysis then proceeded to the calculation of the repeatability and reproducibility [4] of the test method.

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[2] Preceding the first calibration, the bulbs were seasoned for 1% of their rated average lifetime to assure stability.

The standard deviation of repeatability, s_r, is a measure of the variability obtained when the same laboratory measures repeatedly the same zone of the same lamp, using, however, a different bulb for each replicate measurement.

The standard deviation of reproducibility, s_R, is a measure of the variability obtained between single measurements made in different laboratories on the same zone of the same lamp. The estimate, s_R, is obtained by the formula $s_R = \sqrt{s_r^2 + s_L^2}$ where s_r^2 is the square of the standard deviation of repeatability defined above, and s_L^2 is the component of variance due to systematic differences between laboratories.

Table 2 lists, for each zone of each lamp, the average value over all laboratories and bulbs, as well as the standard deviation for repeatability and reproducibility, all expressed in units of candlepower. It should be noted that both s_r and s_R vary between lamps and between zones, and a closer examination of the data reveals that both s_r and s_R increase as the magnitude of the measured value increases. Thus, the coefficient of variation will be a less variable quantity than the standard deviation for both repeatability and reproducibility. Table 3 is analogous to Table 2, but lists the percent coefficients of variation (%CV) instead of the standard deviations.

IV. Conclusion

The average coefficients of variation of repeatability and reproducibility are listed in Table 4. It should be observed in the first place that the values relating to reproducibility (v_R) suffer from the severe shortcoming of being based on only three laboratories. Therefore these values should be considered more as an indication of existing conditions than as predictive parameters. This being recognized, the values in Table 4 place the precision of this test method in a range of about 10 percent coefficient of variation. This information will undoubtedly be of value to members of the lighting equipment industry who wish to evaluate their equipment by this method.

V. References

[1] Federal Motor Vehicle Safety Standard No. 108 Lamps, Reflective Devices and Associated Equipment-Passenger cars, Multipurpose Passenger Vehicles, Trucks, Buses, Trailers and motorcycles (Docket No. 69-18). 35 F.R. 16842, Octover 31, 1970; 37 F.R. 21328, October 7, 1972; 37 F.R. 25235, November 29, 1972.

[2] Office of Standards Enforcement, Motor Vehicle Programs, National Highway Traffic Safety Administration, U.S. Department of Transportation.

[3] Society of Automotive Engineers (SAE) No. J575e, August, 1970.

[4] Repeatability and Reproducibility, A simple analysis providing excellent parameters. Materials Research and Standards, Vol. 11, No. 8, pp. 8-16, 1971.

TABLE 1

DIRECTIONAL LUMINOUS INTENSITY - CANDLEPOWER

LAMP No. 1

Lab.	Bulb	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7
1	1	60.0	68.0	71.0	121.0	47.0	31.2	33.8
	2	51.9	67.0	71.0	133.0	53.0	33.0]	39.7
	3	54.9	66.0	75.0	138.0	52.0	34.0	36.9
	4	56.6	63.0	70.0	122.0	48.0	31.8	33.4
2	1	59.0	74.2	75.5	139.6	57.0	34.7	43.1
	2	52.1	71.5	65.5	131.5	58.4	29.5	42.1
	3	56.8	72.8	75.7	143.4	57.5	34.2	41.5
	4	56.0	68.1	70.4	127.6	52.2	32.1	36.9
3	1	53.19	62.50	67.30	118.1	45.70	30.35	32.29
	2	49.19	63.30	67.50	121.1	49.10	30.61	37.43
	3	51.10	63.70	69.30	127.7	50.10	31.20	36.90
	4	59.48	61.80	66.50	117.2	50.10	30.92	38.83

TABLE 1 (continued)

LAMP No. 2

Lab.	Bulb	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7
1	1	19.9	19.8	26.5	49.6	27.4	27.8	23.0
	2	19.1	20.5	21.7	52.2	33.8	25.9	28.8
	3	20.2	20.5	23.8	49.4	29.8	20.8	22.8
	4	19.7	20.3	23.6	46.4	27.1	24.8	22.6
2	1	16.5	17.6	24.7	43.7	21.3	23.1	17.5
	2	17.1	15.9	21.7	45.3	27.2	23.1	22.1
	3	16.8	17.3	20.2	40.5	24.2	23.8	18.5
	4	17.0	18.1	19.1	41.1	28.4	23.3	23.1
3	1	18.03	20.22	26.56	48.70	21.84	26.08	18.91
	2	19.64	20.08	24.73	53.98	31.03	27.15	23.20
	3	16.07	20.65	20.06	46.79	27.90	25.95	21.74
	4	20.48	18.64	26.56	45.65	23.46	30.32	22.21

TABLE 1 (continued)

LAMP No. 3

Lab.	Bulb	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7
1	1	14.7	9.8	15.9	30.1	15.4	17.3	14.1
	2	15.3	9.7	16.6	30.4	15.1	18.1	13.7
	3	15.1	9.7	15.6	29.8	15.4	18.2	14.8
	4	14.9	9.9	15.3	28.3	14.8	17.1	14.2
2	1	11.3	10.0	13.7	27.6	14.6	13.1	12.4
	2	11.0	9.8	13.6	28.0	14.7	13.0	11.8
	3	10.6	10.0	12.7	27.8	15.6	13.1	13.2
	4	11.5	10.0	13.9	27.9	14.7	13.7	12.8
3	1	12.26	10.73	14.96	29.62	15.29	13.93	12.50
	2	12.52	10.32	15.40	29.97	15.07	13.79	12.41
	3	12.17	10.93	14.36	29.91	16.26	14.47	13.73
	4	11.94	10.53	14.27	28.71	15.24	14.19	13.45

TABLE 1 (continued)

LAMP No. 4

Lab.	Bulb	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7
1	1	66.1	35.3	105.0	182.0	59.0	84.0	34.3
	2	61.8	31.9	103.0	192.0	66.0	96.0	34.6
	3	62.5	33.1	110.0	197.0	61.0	94.0	33.5
	4	66.2	34.4	106.0	165.0	54.0	85.0	33.1
2	1	64.1	36.6	107.0	206.3	69.5	94.8	38.0
	2	57.7	34.5	105.5	218.1	76.0	101.5	38.8
	3	63.5	37.8	114.6	221.7	73.1	98.3	37.5
	4	68.1	37.4	109.8	201.1	69.8	101.1	40.6
3	1	59.74	35.05	107.6	201.0	63.30	88.00	32.51
	2	62.32	34.95	104.6	183.2	58.40	84.20	32.51
	3	61.81	35.53	111.3	197.6	60.10	87.40	32.18
	4	63.63	38.37	110.0	184.6	58.70	84.20	34.16

TABLE 2

SUMMARY OF ANALYSIS
AVERAGES AND STANDARD DEVIATIONS OF
REPEATABILITY AND REPRODUCIBILITY (1)

Zone	Lamp 1			Lamp 2			Lamp 3			Lamp 4		
	Avg. (candlepower)	s_r	s_R	Avg. (candlepower)	s_r	s_R	Avg. (candlepower)	s_r	s_R	Avg. (candlepower)	s_r	s_R
1	55.0	3.6	3.6	18.4	1.2	1.8	12.8	0.3	2.0	63.1	3.0	3.0
2	66.8	2.0	4.8	19.1	0.8	1.8	10.1	0.2	0.5	35.4	1.5	2.0
3	70.4	3.2	3.6	23.3	2.5	2.7	14.7	0.5	1.3	107.9	3.3	3.3
4	128.4	7.0	9.4	46.9	2.8	4.5	29.0	0.6	1.2	195.8	11.2	17.3
5	51.7	2.6	4.6	26.9	3.5	3.8	15.2	0.4	0.5	64.1	3.6	7.6
6	32.0	1.6	1.7	25.2	2.1	2.7	15.0	0.2	2.4	91.5	4.1	7.6
7	37.7	2.8	3.7	22.0	2.6	3.0	13.3	0.6	1.0	35.1	1.0	3.3

(1) s_r = standard deviation of repeatability.
s_R = standard deviation of reproducibility.

TABLE 3

SUMMARY OF ANALYSIS
PERCENT COEFFICIENTS OF VARIATION OF
REPEATABILITY AND REPRODUCIBILITY (1)

Zone	Lamp 1			Lamp 2			Lamp 3			Lamp 4		
	Avg.(2)	v_r	v_R	Avg.(2)	v_r	v_R	Avg.(2)	v_r	v_R	Avg.(2)	v_r	v_R
1	55.0	6.6	6.6	18.4	6.3	9.6	12.8	2.3	15.8	63.1	4.7	4.7
2	66.8	3.0	7.2	19.1	4.0	9.4	10.1	1.7	4.6	35.4	4.3	5.7
3	70.4	4.5	5.1	23.3	10.9	11.7	14.7	3.7	8.7	107.9	3.1	3.1
4	128.4	5.4	7.3	46.9	6.1	9.5	29.0	2.2	4.0	195.8	5.7	8.8
5	51.7	5.1	9.0	26.9	13.1	14.1	15.2	2.9	3.2	64.1	5.6	11.9
6	32.0	4.9	5.3	25.2	8.2	10.8	15.0	1.5	15.9	91.5	4.5	8.3
7	37.7	7.5	9.8	22.0	11.7	13.8	13.3	2.4	7.4	35.1	2.9	9.3

(1) $v_r = 100\ s_r/\text{avg.}$

$v_R = 100\ s_R/\text{avg.}$

(2) in units of candlepower.

TABLE 4

Avg. % CV	Lamp 1	Lamp 2	Lamp 3	Lamp 4
$\bar{v}_r$	5.3	8.6	2.4	4.4
$\bar{v}_R$	7.2	11.3	8.5	7.4

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