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Summary This study evaluated the effects of voltage changes on beam patterns of low-beam headlamps. Seven different types of filament lamps were tested. The voltages used were 12.0, 12.8 and 13.5 V. The photometry was performed from 20° left to 20° right, and from 5° down to 5° up, all in steps of 0.5°. The main finding of this study is that, for all seven lamps tested, voltage changes between 12.0 V and 13.5 V caused light output to change by the same proportion throughout the beam pattern. Therefore, for filament lamps, it is reasonable to use a single constant for all values in a beam pattern when converting a headlighting specification at one voltage to a specification at a different voltage, at least if the voltages in question are between 12.0 V and 13.5 V. The constants obtained across the seven lamps tested were similar to each other. Furthermore, these constants were in general agreement with the constants derived using the standard IES formula relating light-output changes to voltage changes.

Do changes in voltage result in proportional changes throughout headlamp beam pattern?

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1 Introduction

Photometric patterns of low-beam headlamps are not homogeneous[1]. Instead, there is a deliberate attempt to maximise illumination (and thus visibility) in certain parts of the pattern, and to minimise illumination (and thus glare) in other parts of the pattern. Furthermore, the visibility and glare portions of the beam pattern are in close proximity. (In some parts of the beam pattern they are within 1° of visual angle.) Inhomogeneity of the beam pattern is essential for proper performance of low-beam headlamps, and this must be maintained under the conditions in which the headlamps are operated (e.g. dirt, vibration, changes in voltage).

Reduction of the built-in inhomogeneity of the beam pattern must therefore be ruled out when changes in test voltage are being considered. Such changes in voltage would be needed to harmonise the currently disparate test voltages in different parts of the world. Thus, the specific question of interest is as follows: Do changes in voltage result in changes that are proportional throughout the beam pattern? If the answer is 'yes', then a standard written for a given voltage (say 12.8 V) could easily be converted to an equivalent standard at another voltage (say 13.5 V) by multiplying all values by a single constant. If the answer is 'no', then no such simple conversion would be possible.

The proportionality that we are discussing concerns whether changes at two or more points in the beam pattern are proportional to each other, not whether any of the changes in light output are proportional to voltage. According to the *IES Lighting Handbook*[2], light output changes for filament lamps are related to changes in voltage by the formula $(V_2/V_1)^{3.4}$. For example, if the new voltage (V_2) is 13.5 V, and the old voltage (V_1) is 12.8 V, then to obtain the light output at 13.5 V one should multiply the light output at 12.8 V by 1.198 [$(13.5/12.8)^{3.4} = 1.198$)].

Sivak *et al.*[3] evaluated, for a representative sample of 35 US low-beam headlamps, changes in light output at one test point (H,V) as a function of test voltage between 12.0 V and 13.5 V. The results indicated that the light-output changes were in good agreement with the IES formula. However, Sivak *et al.*[3], by evaluating the changes at one test point only, were not able to address the issue of proportionality of light-output changes throughout the beam pattern.

One reason why voltage changes could lead to nonproportional changes in light output is that, as the voltage is increased, a larger section of the filament might emit visible radiation. Consequently, because the optical control for a given lamp is designed with respect to a given size of a filament that is emitting visible radiation, a change in the size of the 'active' filament might lead to deviations from proportionality. If there is, indeed, sufficient change in the size of the active filament to result in deviations from proportionality, then the presence of an internal shield (which certain types of lamps use to limit light output above the horizontal) might increase this effect.

The present study was designed to evaluate the effects of voltage changes on low-beam patterns of seven major types of filament lamps currently in use in the USA, including one with an internal shield. Detailed photometric matrices were obtained for three different test voltages (12.0, 12.8 and 13.5 V).

2 Method

2.1 Approach

The beam pattern of each of seven low-beam headlamps was measured at three voltages: 12.0, 12.8, and 13.5 V.

2.2 Lamps

The lamps tested were selected to include the major types currently in use in the USA[2]. Table 1 describes the lamps tested. The lamps were purchased at car dealerships.

2.3 Photometry

We determined the luminous intensities at 1701 test points in a rectangular matrix defined by the following horizontal and vertical angles (in relation to the headlamp axis). In the horizontal direction, the angles ranged from 20° left to 20° right in steps of 0.5. In the vertical direction, the angles ranged from 5° down to 5° up in steps of 0.5°.

Table 1 The lamps used in the study and their construction

Label in this paper	Bulb type	Internal shield	Optical control
9004	9004 (HB1)	No	Lens
H4	H4 (HB2)	Yes	Lens
9006	9006 (HB4)	No	Reflector
Projector	9006 (HB4)	No	Projector
9007	9007 (HB5)	No	Reflector
H7	H7	No	Lens
Sealed beam	Sealed beam (H6054)	No	Lens

All measurements were made in the same photometry laboratory.

2.4 Procedure

There are six possible orders of the three test voltages. In order to balance the effect of order, five of these orders were used for each of five lamps, and one order was used for two lamps.

Each headlamp was seasoned at 12.8 V for one hour a few days before the actual photometry. The three photometry sessions (one for each voltage) were performed on the same day. Immediately prior to the first photometry session, the tested lamp was seasoned for an additional 30 minutes using the first test voltage. Immediately prior to each of the other two photometry sessions, the lamp was seasoned for an additional 5 minutes using each of the respective voltages.

3 Results

The effects of voltage on luminous intensities were very well described by linear functions with zero intercepts ($y = ax$). (The best-fitting lines with zero intercepts originate in the (0,0) point, and thus make more theoretical sense than those with nonzero intercepts. However, the lines with and without zero intercepts were virtually identical. The differences in slopes, if any, were in the third decimal place.) The variance accounted for in each case was 99% or greater. Table 2 lists the slopes of these best-fitting linear functions and compares them with the predictions derived from the IES formula. Typical data are shown in Figures 1 and 2 for one of the seven lamps tested (9007). Figure 1 compares the luminous intensities at 12.8 V with those at 12.0 V at each of the 1701 test points. Analogous information for the test voltages of 13.5 V and 12.8 V is shown in Figure 2.

4 Discussion

The main finding of this study is that for all seven filament lamps tested the effects of voltage changes in the range from

Table 2 Slopes of the best-fitting linear equations with zero intercepts

Lamp	12.8 V vs. 12.0 V	13.5 V vs. 12.8 V
9004	1.225	1.188
H4	1.233	1.217
9006	1.263	1.211
Projector	1.239	1.171
9007	1.248	1.169
H7	1.221	1.181
Sealed beam	1.235	1.215
Mean	1.238	1.193
Using the IES formula	1.245	1.198

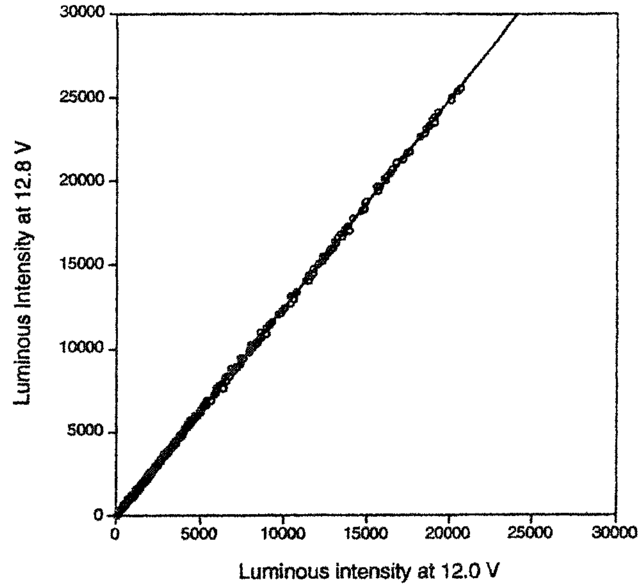

Figure 1 Luminous intensities (in candela) at 12.8 V and 12.0 V for the 9007 lamp

12.0 V to 13.5 V were well described by linear functions with no intercepts. This finding implies that voltage changes between 12.0 V and 13.5 V tended to result in proportional changes in light output throughout the beam pattern. Therefore, for filament lamps, it is reasonable to use a single constant for all values when converting a headlighting specification at one voltage to a specification at a different voltage, at least if the voltages in question are between 12.0 V and 13.5 V.

The constants obtained across the seven lamps tested were similar to each other. (For each of the two pairs of voltages, the difference between the lowest and highest constants was less than 4%.) Furthermore, these constants were in general agreement with the constants derived by using the standard IES formula relating light-output changes to voltage changes. (For each of the two pairs of voltages, the differ-

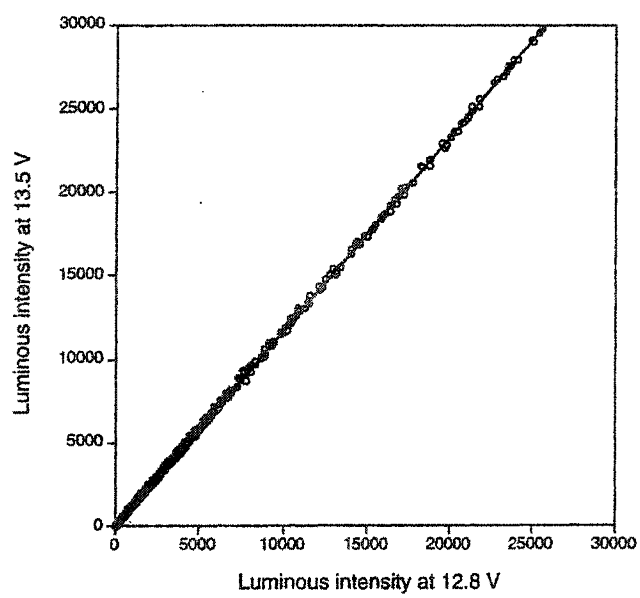

Figure 2 Luminous intensities (in candela) at 13.5 V and 12.8 V for the 9007 lamp

ence between the mean for the seven lamps and the value derived using the IES formula was less than 1%.)

The present findings suggest that the light-emitting part of the filament does not change appreciably with changes in voltage between 12.0 V and 13.5V. Furthermore, because the data for the one test lamp with an internal shield (an H4 lamp) did not differ from those for the other six lamps, the findings suggest that the presence of an internal shield does not necessarily lead to nonproportional changes in light output with changes in voltage.

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