JOURNAL OF AUTOMOTIVE AND MECHANICAL APPLIED TECHNOLOGY

Vol. 3 No 1, 2026, pp. 26-33 https://journal.uny.ac.id/publications/jamat https://doi.org/10.21831/jamat.v3i1.3029

Performance Evaluation of a Modified LED Motorcycle Headlamp with an Acrylic Optical Limiting Plate

Dwi Prasetyo[1], Beni Setya Nugraha[1*], Ayu Sandra Dewi[2], Dangshe Qiu[3], Ruolan Li[4]

[1]Department of Mechanical and Automotive Engineering, Faculty of Vocational, Universitas Negeri Yogyakarta, Kulon Progo, Yogyakarta 55652, Indonesia
[2]Department of Automotive Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Sleman, Yogyakarta 55281, Indonesia
[3]Hunan Huanan Optoelectronic (Group) Co. Ltd., Hunan, Changde, 415000, China
[4]School of Optoelectronics Engineering, Changchun University of Science and Technology, Jilin, Changchun, 130022, China

*Corresponding author: beni_setyanugraha@uny.ac.id

ARTICLE INFO

Article history:
Received 14.02.2026
Revised 07.03.2026
Accepted 02.04.2026

Keywords:
Automotive lighting; LED technology; Light distribution; Energy efficiency; Thermal performance

ABSTRACT

Nighttime riding safety depends strongly on headlamp performance, especially for motorcycles operating in road environments with limited street lighting. Conventional halogen lamps are widely used but place a relatively high electrical demand and thermal load on the system. This study experimentally evaluates a modified 12 W light-emitting diode (LED) motorcycle headlamp equipped with a 3 mm acrylic optical limiting plate to improve beam control and reduce upward light scatter. A Honda Supra 125 FI with a 12 V direct-current electrical system was used as the test platform. The final quantitative comparison was limited to a standard 35 W halogen lamp and a modified LED configuration with an acrylic shield/baffle. Luminous intensity was measured at 1 m and 5 m, electrical current was measured under direct-current operating conditions, and surface temperature was monitored during a 75 min continuous operation test. The modified LED system produced 1342 lux at 1 m and 170 lux at 5 m, exceeding the halogen values of 1240 lux and 124 lux, respectively. The LED configuration reduced current draw from 2.92 A to 1.00 A and decreased peak operating temperature from 278 °C to 100 °C. The acrylic limiting plate produced a more clearly bounded beam pattern in qualitative projection tests; however, the present study does not claim full glare elimination because standard glare indices and complete photometric mapping were not measured. These results indicate that the proposed LED retrofit can improve energy efficiency and thermal behavior while providing better preliminary beam control for motorcycle lighting applications.

1. Introduction

Automotive lighting systems are essential elements of active vehicle safety, particularly for motorcycles operating under low-visibility conditions. In nighttime riding environments, headlamp performance affects object recognition, rider reaction time, and road-surface visibility. Insufficient illumination and excessive upward light scatter may reduce safety, particularly in areas with limited public lighting and uneven road conditions [1]. In Indonesia, motorcycles are widely used for daily transportation because of their affordability and operational flexibility, making headlamp reliability a practical safety concern.

The rapid development of automotive lighting technology has accelerated the transition from conventional halogen lamps to light-emitting diode (LED)-based systems. Halogen lamps generate light through filament heating; therefore, a considerable portion of the supplied electrical energy is converted into heat. In contrast, LED technology offers higher luminous efficiency, lower energy demand, longer service life, and faster response characteristics [2], [3]. Previous studies have reported that LED lighting can produce higher illumination intensity with lower electrical consumption than conventional halogen lamps [4].

Despite these advantages, retrofit LED systems can create compatibility problems when installed in reflector housings originally designed for halogen filament geometry. Differences in source position, emission direction, and chip arrangement can alter beam distribution and cause uncontrolled light scatter. As a result, a retrofit LED lamp may increase local illuminance while also producing unwanted upward light that may disturb other road users [1], [5]. This limitation is particularly important in motorcycle headlamp retrofits, where aftermarket components are often installed without redesigning the reflector system.

Thermal behavior is also a critical consideration in high-intensity LED applications. Although LEDs consume less electrical power than halogen lamps, heat can accumulate around the LED package, driver, reflector, and surrounding plastic components. Excessive temperature may affect optical stability, reflector durability, and the dimensional stability of added polymer components [6], [7]. Therefore, retrofit lighting evaluation should consider illumination intensity, electrical load, and thermal behavior as an integrated system rather than focusing solely on luminous output [8].

Previous studies on vehicle lighting have addressed photometric distribution, LED performance, and glare perception [1], [5], [9], [10], [11]. However, complete standard-based photometric evaluation requires dedicated equipment and specified photometric points. The present study is positioned as an applied laboratory comparison and preliminary retrofit assessment rather than a full homologation or certification test. The 1 m measurement distance was used as a near-field baseline for repeatable intensity comparison. In comparison, the 5 m distance was used to observe preliminary beam propagation and the formation of a horizontal cut-off on a projection surface within the available indoor test space. Therefore, all conclusions regarding beam control are limited to comparative laboratory performance and qualitative beam-pattern observation.

This study proposes an acrylic optical limiting plate integrated into a standard motorcycle reflector assembly. The component functions as an opaque shield or baffle to reduce upward light leakage and produce a clearer horizontal cut-off boundary. The objective of this research is to evaluate the preliminary performance of a standard halogen motorcycle headlamp and a modified aftermarket LED system on a Honda Supra 125 FI test platform. Luminous intensity, electrical current, calculated power consumption, operating temperature, and beam-pattern visualization were analyzed to determine whether the proposed modification can improve practical retrofit performance while reducing electrical and thermal loads.

2. Methodology

2.1 Comparative Experimental Framework and Scope

This study used a comparative experimental design to evaluate two final motorcycle headlamp configurations: a standard halogen lamp as the control condition and a modified LED lamp equipped with an acrylic optical limiting plate as the experimental condition. An unmodified LED condition was not included in the final quantitative comparison; therefore, the scope of the study was revised to avoid implying a complete three-configuration photometric comparison. The motorcycle used as the test platform was a Honda Supra 125 FI with a 12 V direct-current electrical system.

The control configuration used a conventional 12 V, 35 W tungsten-halogen lamp. The modified configuration used a 12 V, 12 W aftermarket LED lamp installed in the same headlamp housing and combined with a 3 mm acrylic optical limiting plate. Electrical power was supplied via the motorcycle's electrical system, and the charging voltage was monitored during the measurements to minimize voltage fluctuations.

.

2.2 Headlamp Configuration and Instrumentation

The specifications of the tested lamp configurations and measuring instruments are summarized in **Table 1**. Manufacturer-specific LED and instrument details should be recorded in the laboratory logbook or on product labels before final submission, as they are required for reproducibility and measurement uncertainty assessment.

Table 1. Headlamp configuration and measuring instrument specifications

Item	Specification
Motorcycle platform	Honda Supra 125 FI, 12 V DC electrical system
Halogen lamp	12 V, 35 W tungsten-halogen lamp
LED lamp	12 V, 12 W aftermarket LED
Optical limiting plate	3 mm opaque white acrylic shield/baffle mounted inside the reflector housing
Lux meter	Light Meter Digital KRISBOW 10176594
Infrared thermometer	FLUKE 59MAX+ Infrared Thermometer
Digital multimeter	Digital Multimeter Sanwa CD800A

2.3 Optical Modification and Mounting Design

The primary modification was the integration of an acrylic optical limiting plate intended to reduce excessive upward light scatter from the retrofit LED system. The plate was fabricated from 3 mm opaque white acrylic. In this study, the component was treated as a shield or baffle rather than a diffusive optical element. Its function was to intercept light directed toward the upper reflector quadrant so that a larger portion of the luminous flux was projected toward the lower road-surface illumination zone.

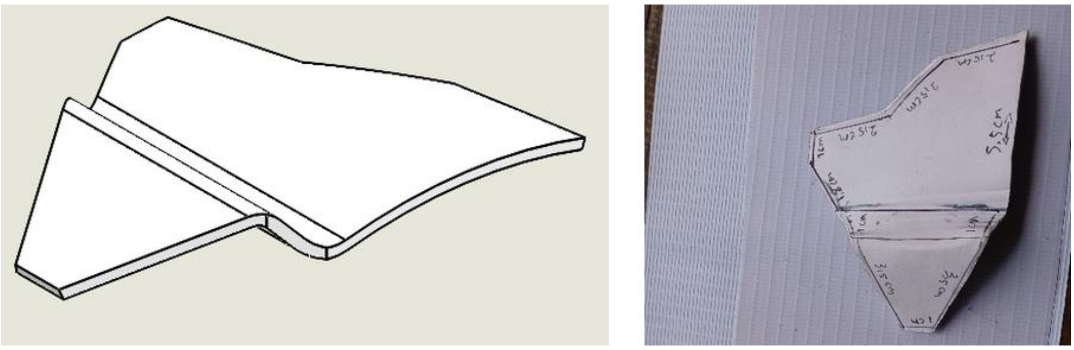

Figure 1. Design and prototype of the acrylic optical limiting plate

The limiting plate had an overall height of approximately 5.5 cm, a base width of 2.5 cm, and a 1 cm folded mounting section used to secure the component within the reflector housing. The plate was positioned between the LED source and the upper reflector quadrant. **Fig. 1** presents the design and prototype of the limiting plate, and **Fig. 2** shows its implementation inside the reflector assembly.

To maintain test repeatability, the motorcycle was placed on a center stand over a level indoor test surface. The headlamp orientation and optical axis were kept constant throughout the illumination and thermal measurements. The same reflector housing was used for the halogen and modified LED configurations to reduce variability caused by housing geometry.

Figure 2. Implementation of the acrylic shield/baffle inside the reflector assembly

2.4 Data Acquisition and Measurement Protocols

Experimental measurements were conducted in a controlled indoor environment with minimal ambient light interference. Data acquisition consisted of three primary evaluation categories: luminous performance, electrical efficiency, and thermal behavior.

Luminous intensity was measured using a digital lux meter positioned at 1 m and 5 m from the headlamp. The 1 m distance was used as a repeatable near-field baseline. In comparison, a 5 m distance was used for preliminary beam-propagation observations and projection-pattern comparisons. These distances were not intended to replace complete standard photometric test distances or regulatory measurement points.

Electrical efficiency was evaluated by measuring voltage and current using a calibrated digital multimeter under DC operating conditions. Power consumption was calculated using **Eq. 1,** where P is power consumption, I is current, and V is voltage.

$$P = V \times I \tag{1}$$

This method enabled direct comparison between the 12 W LED configuration and the conventional 35 W halogen system. Thermal evaluation was conducted using an infrared thermometer during continuous operation for 75 min. Measurements were recorded at 15 min intervals. Each condition was repeated five times. The previous data-handling statement that selected only “the three most stable datasets” was removed. In the revised analysis, all five repetitions should be reported as mean ± standard deviation. No dataset should be excluded unless objective criteria such as abnormal voltage deviation or instrument malfunction are explicitly defined before analysis.

3. Results and Discussion

3.1 Luminous Intensity and Propagation Performance

The modified LED configuration produced higher illuminance than the halogen control at both measurement distances, as summarized in **Table 2**. At 1 m, the modified LED produced 1342 lux, whereas the halogen lamp produced 1240 lux. At 5 m, the modified LED produced 170 lux compared with 124 lux for the halogen lamp. These values indicate better-measured illuminance at the tested points; however, they should be interpreted as point-based laboratory illuminance values rather than as complete photometric distribution data.

The improved illuminance at 5 m may be attributed to the higher luminous efficiency and more directed emission geometry of the LED source, combined with the acrylic shield/baffle [5]. Nevertheless, this result does not confirm full compliance with motorcycle headlamp photometric standards because only two measurement distances and qualitative projection images were used. The unsupported statement regarding a 40 m minimum visibility requirement was therefore removed from the revised manuscript.

Table 2. Luminous intensity and electrical performance were reported using all repetitions

Parameter	Halogen control	Modified LED with plate	Relative difference
Illuminance at 1 m (lux)	1240 ± 14	1342 ± 23	+8.2%
Illuminance at 5 m (lux)	124 ± 3	170 ± 2	+37.1%
Measured current draw (A)	2.92 ± 0.4	1.00 ± 0.2	-65.8% current draw
Calculated power at nominal 12 V (W)	35.0	12.0	-65.7% rated power
Battery endurance estimate using 3 Ah capacity (h)	1.03	3.00	+191% estimated endurance
Peak operating temperature (°C)	278 ± 17	100 ± 8	-64.0%

3.2 Beam Distribution and Qualitative Glare Control

The acrylic shield/baffle altered the projected beam pattern of the retrofit LED system. **Fig. 3** compares the projected beam patterns of the halogen and modified LED configurations. The halogen beam appeared more scattered on the projection surface. At the same time, the modified LED showed a more clearly bounded upper region. This visual evidence supports the claim that the limiting plate improved preliminary beam control; however, the study does not claim a glare-free condition because disability glare, discomfort glare, and standardized photometric points were not quantitatively measured.

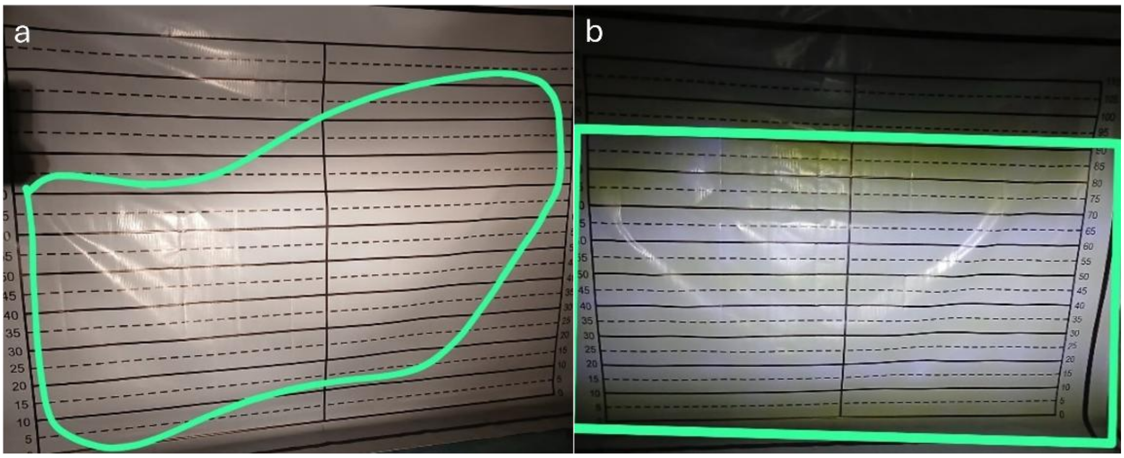

Figure 3. Comparative beam patterns: (a) halogen control and (b) modified LED with acrylic shield/baffle

The plate's optical function primarily involves shielding. Because the material used was opaque white acrylic, it was not intended to transmit or diffuse light. Instead, it physically blocked light rays directed toward the upper reflector quadrant [6]. This clarification was added to prevent confusion between a diffusive acrylic optical component and a non-transmissive baffle.

3.3 Electrical Load Characteristics

The electrical comparison in **Table 2** shows that replacing the 35 W halogen lamp with the 12 W LED configuration substantially reduced current draw. The halogen lamp drew approximately 2.92 A, while the modified LED drew approximately 1.00 A. For motorcycles with limited battery capacity and charging reserves, this lower load can reduce stress on the rectifier-regulator and battery system [2]. The values are reported as laboratory measurements and should be verified under dynamic engine-speed conditions in future studies.

3.4 Thermal Dynamics and Acrylic Compatibility

Thermal behavior was evaluated because excessive temperature may affect the durability of the reflector and the dimensional stability of the acrylic component. The halogen control reached a peak surface temperature of 278 °C, whereas the modified LED reached 100 °C under the 75 min test condition. To avoid the inconsistency noted by the reviewer, a peak-temperature comparison in **Fig. 4** replaced the previous thermal curve with a maximum axis near 120 °C, and the underlying time-resolved thermal data are summarized in **Table 3**.

Table 3. Luminous intensity and electrical performance were reported using all repetitions

Observation time (min)	Halogen control temperature (°C)	Modified LED temperature (°C)
0	0	0
15	90 ± 8	60 ± 2
30	143 ± 5	83 ± 7
45	187 ± 8	96 ± 4
60	235 ± 2	100 ± 5
75	278 ± 17	100 ± 8

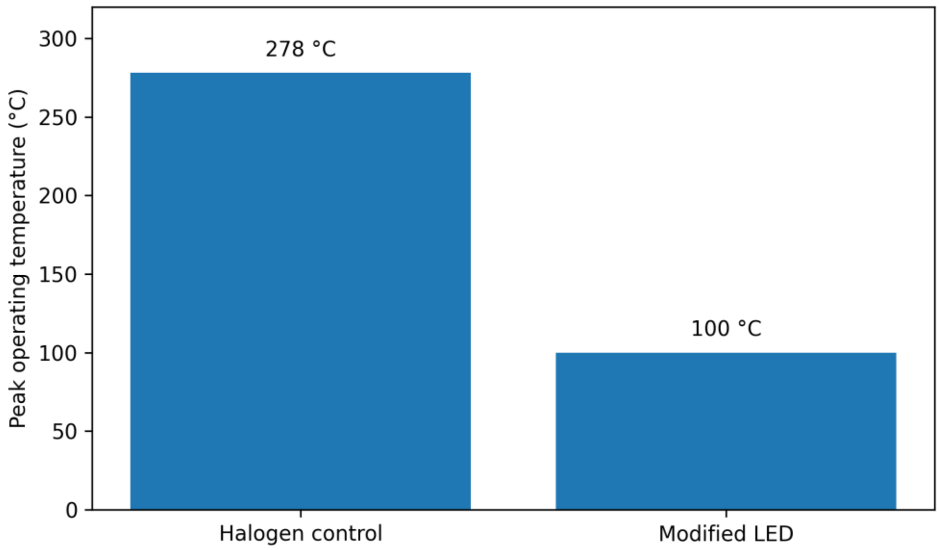

Figure 4. Peak operating temperature comparison between the halogen control and the modified LED configuration

The interpretation of acrylic safety was revised. The modified LED temperature of 100 °C is lower than the halogen peak temperature, thereby reducing the thermal burden on the reflector assembly. However, acrylic dimensional stability should not be evaluated only by comparing operating temperature with the melting point. For acrylic or polymethyl methacrylate (PMMA), the glass-transition region and heat-deflection temperature are more relevant to long-term deformation risk [8]. Because the observed LED temperature reached approximately 100 °C, the acrylic shield/baffle should be considered acceptable for the short-duration test; however, long-term durability, vibration, and thermal-cycling tests are still required before generalization for road use.

3.5 Practical Retrofit Performance and Limitations

The results indicate that the proposed LED retrofit can reduce electrical load and peak temperature while improving point-based illuminance at 1 m and 5 m. The acrylic shield/baffle also improved qualitative beam control by reducing upward scatter in the projection image. However, the findings are limited by the absence of complete photometric mapping, standardized glare metrics, and long-term durability testing of the acrylic component. Future work should include a full beam-distribution grid, standard photometric points, color-temperature measurements, driver thermal monitoring, and extended thermal-cycling tests.

4. Conclusion

This study evaluated a modified 12 W LED motorcycle headlamp equipped with a 3 mm opaque acrylic optical limiting plate. The title, abstract, and discussion were revised to limit the claims to the available evidence. The modified LED produced higher point-based illuminance than the 35 W halogen control, with 1342 lux at 1 m and 170 lux at 5 m compared with 1240 lux and 124 lux for the halogen lamp, respectively. The acrylic component functioned as a shield or baffle, reducing upward light scatter and producing a more clearly bounded beam pattern in qualitative projection testing. The revised manuscript does not claim that the system is glare-free because standard glare indices and complete photometric mapping were not measured. Electrically, the LED configuration reduced current draw from 2.92 A to 1.00 A, indicating a lower load on the motorcycle's electrical system. Thermally, the modified LED configuration reduced peak operating temperature from 278 °C to 100 °C. This reduction suggests lower thermal stress on the reflector assembly; however, acrylic compatibility should be assessed using dimensional stability parameters, such as glass transition behavior or heat-deflection temperature, rather than the melting point alone. Further studies should include standard photometric evaluation, full beam mapping, quantitative glare assessment, and long-term durability testing.

Conflict of interest

The authors declare no conflict of interest.

References

[1] J. D. Bullough, J. Van Derlofske, C. R. Fay, and P. Dee Jr, "Discomfort glare from headlamps: interactions among spectrum, control of gaze and background light level," 2003, doi: https://doi.org/10.4271/2003-01-0296.

[2] S. Liu and X. Luo, LED packaging for lighting applications: design, manufacturing, and testing. John Wiley & Sons, 2011.

[3] J. Y. Tsao, M. E. Coltrin, M. H. Crawford, and J. A. Simmons, "Solid-state lighting: an integrated human factors, technology, and economic perspective," Proceedings of the IEEE, vol. 98, no. 7, pp. 1162-1179, 2010, doi: 10.1109/JPROC.2009.2031669.

[4] T. Sugiarto, M. A. Rizal, D. Fernandez, and A. Arif, "Analisis Penggunaan Beberapa Jenis Lampu Utama Sepeda Motor Terhadap Intensitas Cahaya," JTPVI: Jurnal Teknologi dan Pendidikan Vokasi Indonesia, vol. 1, no. 1, pp. 133-144, 2023, doi: https://doi.org/10.24036/jtpvi.v1i1.14.
[5] M. H. Jamaludin, W. Z. Wan Ismail, E. M. Husini, and N. A. M. Bahror, "Investigation of photometric distribution of LED and HSPV for road lighting," Journal of Engineering and Applied Science, vol. 70, no. 1, p. 112, 2023, doi: https://doi.org/10.1186/s44147-023-00286-6.
[6] J. T. Waluyo and N. S. Widodo, "Pengendali Lampu LED Matrix Headlamp pada Kendaraan Bermotor," Buletin Ilmiah Sarjana Teknik Elektro, vol. 1, no. 1, pp. 35-45, 2019, doi: 10.12928/biste.v1i1.834.
[7] A. S. A. Karim, "Thermal-aware functional safety analysis of automotive LED drivers: FMEDA for junction temperature-induced failures," International Journal of Computational and Experimental Science and Engineering, vol. 11, no. 3, 2025, doi: https://doi.org/10.22399/ijcesen.3704.
[8] K. K. Ajekwene, "Properties and applications of acrylates," Acrylate polymers for advanced applications, vol. 6, pp. 35-46, 2020, doi: 10.5772/intechopen.89867.
[9] A. Y. C. Nee, Handbook of manufacturing engineering and technology. Springer Publishing Company, Incorporated, 2014.
[10] E. Wotton, "The IESNA Lighting Handbook and office lighting," Lighting, vol. 14, 2000.
[11] C.-C. Sun et al., "Review of optical design for vehicle forward lighting based on white LEDs," Optical Engineering, vol. 60, no. 9, pp. 091501-091501, 2021, doi: https://doi.org/10.1117/1.OE.60.9.091501.