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OPTIMIZATION OF LIGHTING FOR TRUCK WITH LIFTING PLATFORM MP13

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Abstract

Fuel economy and improved vehicle safety are key to the modernisation of cars. With more vehicles on the road, efficient lighting is essential. LED vehicle lighting technology offers energy savings, improves fuel consumption, extends service life and reduces service costs, making it a popular choice for higher-end vehicles. Improved brightness in low visibility reduces driver reaction times. This study investigates a lighting retrofit for an MP13 lift truck and its effect on alternator loads. The results show significant improvements in brightness, energy consumption and lifetime compared to conventional bulbs. Strategically placed LED lights improve safety and reduce engine load, especially when the platform is stationary.

Keywords:

Increased vehicle safety, LED lighting technologies, System efficiency

1 INTRODUCTION

Currently, in the market for trucks with special modifications for specific purposes, we are observing a decline in the availability of new vehicles and a high purchase price, which may pose a problem for new entrepreneurs. The main purpose of modifying older vehicles is to maintain safety, increase efficiency, and modernize with the aim of improving the vehicle's utility. Using CAD (Computer aided design), we can quickly design and, with FDM (Fused Deposition Modeling), manufacture parts that can continue to operate older vehicles.

Thanks to additive technology, we can take advantage of many benefits not only in the automotive industry but also in aerospace and manufacturing. Additive technology offers opportunities for modernization without high initial costs. The advantages include waste reduction and shorter time for producing prototypes or final products [Lim, 2016]. For investigating the difference between conventional bulb and LED technology we created new headlight brackets. With this project, we have effectively replaced antiquated lighting systems with LED (Light Emitting Diodes) technology. Conventional lightbulbs, which lose an astounding 98% of their energy as heat, are infamous for their poor energy conversion efficiency. Using LED, we decrease the load on the alternator and minimize pollutants by using less energy and increasing brightness. While both light bulbs and LED are artificial light sources, there are differences between them in terms of technology, longevity, efficiency, and environmental impact. Comparing LEDs to traditional bulbs, they are more robust, eco-friendly, energy-efficient, and have a longer lifespan. They are extensively utilized in applications for ornamental, automotive, commercial, and residential lighting [Shun, 2019].

2 FDM PRINTING

Fused Deposition Modeling is known as FDM. By depositing molten material in the form of fibers (filament) onto a substrate, this rapid prototyping technique makes it possible to create intricate objects with 3D geometries. Since FDM technology allows for the flexibility to create and incorporate novel materials, including composites, it has become widely used in a variety of applications [Dudek, 2013].

The reason we decided to use FDM printing is because it's economical, fast, and allows us to customize exact shapes quickly. Fig. 1 shows the first prototype made of PLA material, which we further modified. Without any milling, brushing, or drilling, we can produce precise parts for plug-and-play usage. Volkswagen transformed their process and reduced the expenses and time needed for jig and fixture development by more than 90% [Jordan, 2018], [Su, 2018].

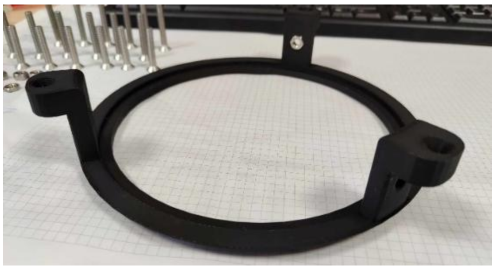

Fig. 1 PLA prototype of headlight bracket

2.1 STL format

Charles W. Hull, the pioneer of 3D Systems, with the Albert Consulting Group collaborated to create the STL format so that it could be used for 3D printing. Later on, this standard evolved into the gold standard, making it possible to interpret and print 3D models on a variety of printers. Many people refer to Charles W. Hull as the "father" of 3D printing, and he made a substantial contribution to the advancement of this technology[Su, 2018].

2.2 FDM and CAD

3D printers are usually controlled using a Cartesian coordinate system. CAD (Computer-Aided Design) is the place of creating precise shapes based on specific software. CAD software is a tool that provides engineers and designers with an architectural view and exact geometric shape of the final part. In these fields CAD enhances efficiency and creativity alongside technologies like 3D printing. The simplicity of 3D printing, enabled by CAD-driven production, is particularly beneficial for generating original ideas. CAD software provides the STL format for printing the final part. [Lim, 2016], [Mikolajczyk, 2019].

A polymer that is both biodegradable and bioactive, polylactic acid (PLA) is made from renewable materials like sugarcane or maize starch. Because it is simple to use and environmentally benign, it is a popular material for 3D printing. PLA has more strength but is less flexible than ABS in terms of mechanical qualities. [Arockiam, 2021].

Luzanin experimented with flexure force and PLA printing parameters. ISO 178:2001 was followed in defining the specimens' geometry for the experiment; see Tab. 1 below. To construct the specimens, PLA (polylactic acid) filament was utilized. There were no rafts utilized, the extrusion temperature was 235°C, and the extrusion speed was kept at 60 mm/s. These variables didn't change during the investigation. Throughout the experiment, the ambient temperature was 24°C [Luzanin, 2014].

Tab. 1 Dimensional parameters [Luzanin, 2014]

Dimensional parameter	Value
Loading radius	R1=5±0.1 mm
Support radius	R2=5±0.2 mm
Test specimen	
Length	l=80±2 mm
Width	b=10±0.2 mm
Thickness	h=4±0.2 mm

Luzanin observed through his experiment that the strongest sample using PLA filament meets the following settings. The layer thickness must be set to 0.1 mm and the deposition angle should be 0°. The required infill value is 30%. With these settings, the measured sample had a flexural force of 177,6 N [Luzanin, 2014].

When using FDM, PLA filament is chosen over ABS filament because of its many benefits, including low cost, low melting point, and high mechanical qualities without toxic fumes during printing, on the other hand, when heated, ABS can resolve into poisonous compounds such acrylonitrile-monomer, butadiene-monomer, and styrene-monomer, but PLA can breakdown into ecologically acceptable components [Xinhua, 2015].

Thermoplastic polymer ABS filament is widely utilized in 3D printing, especially using FDM. Because of its strength, resilience to abrasion, and longevity, it is a good choice for mechanical parts and functional prototypes. Compared to other materials, ABS filament requires higher bed and printing temperatures. ABS offers strong heat resistance [Xu, 2016].

An additional component for a 3D printer that improves performance by controlling the cooling of 3D-printed materials is a heat bed. Heat beds prevent issues such as thermal runaway, poor adhesion between layers, and poor adherence to the print bed. The temperature of the mounting plate should be set according to the filament manufacturer's recommendation [Amridesvar, 2020].

ABS printing often uses a hot end nozzle and bed at the recommended temperature. Depending on the printer, it is produced at a temperature of roughly 230–256°C with a bed temperature of 80–110°C. It is recommended to use ABS juice and polyimide tape (also known as PET or Kapton tape) for ABS adherence on the print bed. Acetone and ABS are essentially combined to create ABS juice. To ensure that the first layer of prints adheres, the print bed is coated by thin layer of ABS juice or one layer of polyimide tape. Also, we can use primer glue for FDM printing [Hamod, 2014].

3 MATERIALS AND METHODS

To improve the lighting of a vehicle manufactured before the turn of the millennium, it is necessary to find headlights that are similar in shape, technologically innovative, and affordable. Rounded lights are used by Jeep, as shown in Fig.2 [Foster, 2014].

Fig. 2 Jeep rounded headlights

3.1 Evolution of Headlight

The first battery-operated headlamp installed in a car was the Bosch illumination system in 1913. Since its introduction in 1964, halogen lights have been widely employed because of their inexpensive cost and moderate road illumination when combined with the newest reflector and lens technology. There are several kinds of halogen bulbs: H1, H3, HB4, and H11, which has a single filament. These days, twin filament H4 category bulbs are commonly found in cars that were introduced in 1971 [Rammohan, 2017]. This particular type of bulb has two filaments: one for the high-beam and one for the low-beam headlamps. With this arrangement, a single bulb may act as both low and high beams [Horvat, 2010]. Taking into account the advancements in technology, the 1980s employed projectors and reflectors to direct the light beam straight ahead. This traditional method involved gathering light from the lightbulb using a parabolic reflector and directing it onto a lens to produce the final beam pattern on the road [Suhas, 2020].

In the car industry today, xenon bulbs—known for providing excellent white illumination like daylight—are becoming increasingly popular. Compared to halogen lights, xenon bulbs use the same amount of power but produce more light. However, a main disadvantage of xenon bulbs is that they do not reach full brightness immediately upon activation. Instead, it can take up to 20 seconds for the xenon gas to achieve its maximum light intensity [Rammohan, 2017].

3.2 LED technology

The first LED headlamps were introduced in 2007. While a typical filament bulb emits 27 lm/W, the LED manufacturer Osram Ostar has managed to increase this to 140 lm/W. Additionally, the color temperature of LED lighting is cooler at 6100K compared to the filament bulb's 3200K [Bielawny, 2016]. An LED is an electrical component that emits light when powered on. LED headlights produce light efficiently and have a lifespan of more than 50,000 hours. Halogen bulbs need a short time to reach maximum brightness because of filament ignition, LEDs emit light almost instantly when powered. [Shun-Kun, 2019].

3.3 Benefits of optimalization

Indian researchers Rammohan A and RameshKumar C conducted a study on headlight modification. Unlike our experiment, see Fig. 3, they replaced the original halogen bulb with an LED lighting system using the same holder. The experiment was performed on a TATA SUMO VICTA vehicle.The measurement results showed an increase in light intensity of nearly 100% and a reduction in power consumption of the LED by 42.5W. The surface temperature of the LED bulb reached 82°C, while the halogen bulb reached 231°C. This means that the temperature of the halogen bulb was nearly 300% higher compared to the LED bulb [Rammohan, 2017].

Fig. 3 Changed headlights on AVIA

The H4 bulb, also known as the 9003 or HB2, is affordable and versatile, making it a common choice in many automobiles. According to Mashkov and colleagues' investigation, LED lamps have a substantially reduced power consumption when compared to normal halogen lamps of the same type, even if they produce a same amount of light. LED lights are said to use two to four times less power than conventional halogen bulbs [Mashkov, 2018].

In the following two tables (Tab. 2, Tab. 3), you can see the input and output parameters of Mashkov's research. Mashkov notes that at a constant input voltage [U] of H4 bulbs and H4 LEDs have different current draws [I] and input power [P]. Based on these observations, we can conclude a reduction in current consumption when using LED technology and a decrease in energy consumption over time, resulting in higher luminous flux [Φ] in low beam mode. For high beams, we also observe a lower current draw [I] and lower input power [P], but in this case, there is a slight decrease in luminosity [Φ].

According to Mashkov's research, the tested LED H4 lamp has a light flux that is roughly 10%–15% higher while using about 3.9 times less power when compared to ordinary halogen lights (for low beam) The UNECE Regulations are met by the color characteristics of the samples of LED headlamps with low beam.

Tab.2 H4 (low beam) comparison [Mashkov, 2018]

	H4 LED (low beam)	H4 standard bulb (low beam)
U [V]	13.2	13.2
I [A]	1.21	4,7
P [W]	15.972	62.04
Φ [lm]	997	848

According to Mashkov's findings, the H4 LED high beam headlight uses around three times less energy while light flux is roughly identical to that of a typical halogen bulb. The H4-1 LED high beam headlamp samples' color characteristics adhere to UNECE standards. Whether comparing low beam or high beam, these comparisons unequivocally demonstrate the benefits of LED technology, such as lower energy costs and increased luminary [Mashkov, 2018].

Tab.3 H4 (high beam) comparison [Mashkov, 2018]

	H4 LED (high beam)	H4 standard bulb (high beam)
U [V]	13.2	13.2
I [A]	1.82	5.4
P [W]	24	71.28
Φ [lm]	1400	1445

3.4 Regloscope

The device for checking the headlight setting, also known as the regloscope, which is shown in Fig. 4, works on the basis of direct projection of the light image emitted by the headlight. The car headlights can be inspected and aligned, and they can be positioned between 200 and 1300 mm above the road [Regulation 211/2018].

The Motex regloscope consists of 11 basic parts:

1. Chassis
2. Rails
3. Brake for horizontal adjustment
4. Supports of tubus
5. Tubus of regloscope
6. Adjustment knob
7. Light intensity meter
8. Brake for vertical adjustment
9. Mirror
10. Brake for mirror
11. Limiter

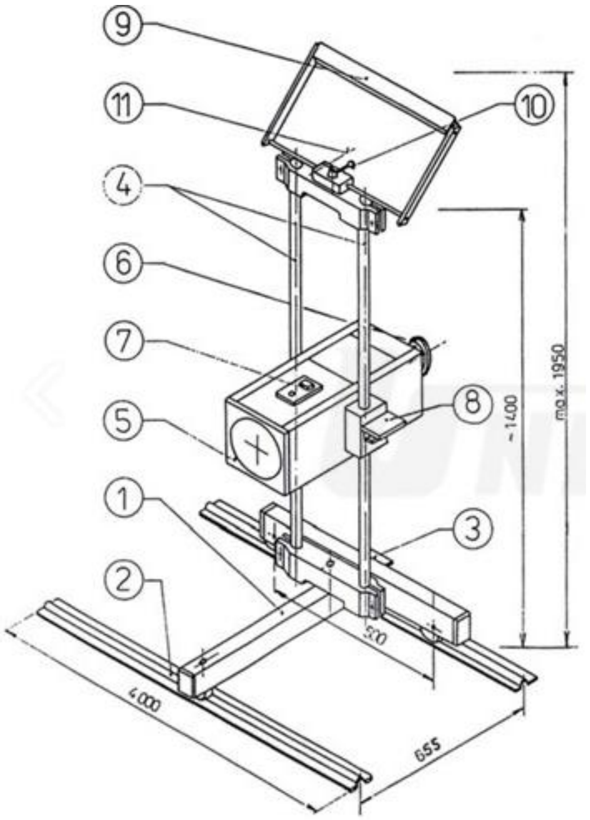

Fig. 4 Regloscope MOTEX [Motex 7535 SK, 2018]

The regloscope must display the headlight dip in percentage (%). It must have a dip display range of at least 0% to 4%.The dip value must be shown in increments no larger than 0.1%.The reticle of a mechanical regloscope must have a central intersection consisting of a vertical and horizontal line; the center of the intersection indicates the point where a horizontal light beam, parallel to the longitudinal axis of the measured vehicle, is projected when the headlight dip indicator is set to 0%.Two horizontal solid lines on the left half of the reticle. The upper line starts above the central intersection at a distance corresponding to a dip value of 0.5%.The lower line starts below the intersection at a distance corresponding to a dip value of 1%. The regloscope must have an aiming device that allows the alignment of its optical system parallel to the vehicle's longitudinal axis. The functional movement of the regloscope is defined by a track length of 2.5 meters, symmetrical to the longitudinal axis of the inspection [Ondrejka, 2018].

4 EXPERIMENT

The experimental part consisted of the design, production and subsequent assembly of adapters for replacing headlights. A light utility vehicle from DemiAutocentrum Ltd, which functions as a lifting platform, was converted into a Facelift version with the aim of implementing aftermarket LED headlights. We also verified the functionality and adjustment of the headlights on an accurate and homologated regloscope from the company STEKO Ltd., which performs Slovak technical and emission inspections. The next step was the measurement of intensity, consumption of electric current under constant voltage by MajstriSvetla Ltd.

The production of the brackets used two different materials: biodegradable PLA fiber and flexible ASA fiber. ASA (acrylonitrile-styrene-acrylate) and ABS (acrylonitrile-butadiene-styrene) are both commonly used thermoplastic polymers in 3D printing and manufacturing. They have similar chemical components including acrylonitrile and styrene. However, the key difference lies in the third component – ASA contains acrylate, while ABS uses butadiene. This distinction gives ASA excellent UV resistance, making it more suitable for outdoor applications, such as the headlight brackets, we have produced.

4.1 Size of Facelift AVIA MP13

The initial process of installing the newer version of the bumper involved fitting and aligning the part with the rest of the body. As you can see in Fig. 7, so the bumper reaches a width of up to 2100mm. After careful measurement, we marked the points for drilling the holes. To install the facelift bumper, we drilled eight new holes and fitted them with threaded inserts. We then screwed in M6 bolts to secure the bumper in place. We purchased a used bumper due to the limited availability of parts for this vehicle The hole in the facelift bumper for the front headlight has a diameter of 184 mm, see Fig.5. This single diameter served as a reference, which we applied in the Autodesk Inventor program to the photograph of the opening, thereby obtaining the other dimensions necessary for modeling the component.

Fig. 5 Hole for Headlight

At the beginning, we needed to design precise mounts that would perfectly match the facelift bumper. Therefore, we carefully measured the bumper with a caliper and created a 3D model with the help of Autodesk Inventor, generating an STL file for FDM printing. We inserted a photo with an attached scale into the CAD program and then fine-tuned the shape of the hole. We measured the outer diameter of the light with a caliper as in Fig.6.

Fig. 6 Measuring the JEEP headlight

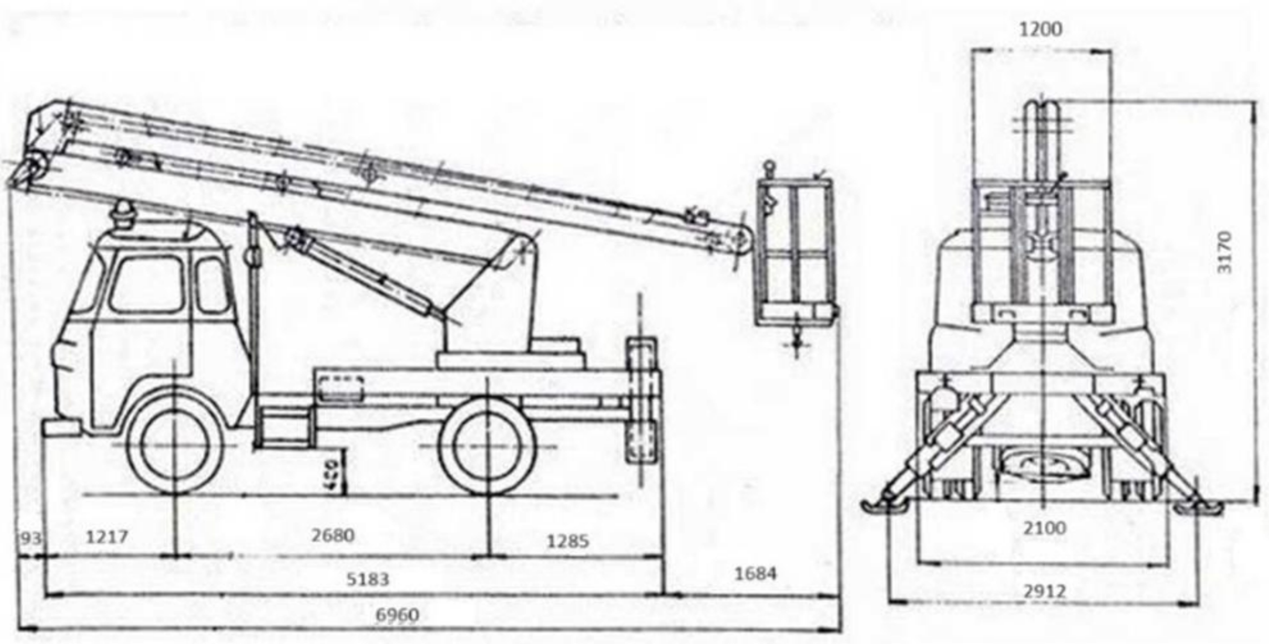

Fig. 7 Avia MP13 [MP 13, 2015]

The measured value was 168 mm. The first prototype was designed with three brackets and stainless-steel screws that firmly pressed the bracket from the back. However, this prototype had problems with bending and the brackets broke due to the less flexible PLA material. PLA is not suitable for outdoor use as it degrades with changes in temperature and exposure to UV radiation.

Subsequently, we replaced PLA with ASA (Acrylonitrile Styrene Acrylate), which is more heat resistant than PLA and has better UV resistance than ABS. We used ASA filament from C-TECH. C-TECH printing filaments are designed to prevent 3D printers from jamming [ASA, 2012]. Then we redesigned the mount to be permanently attached to the bumper with the headlight bolted to the rear. This type of mounting turned out to be fully satisfactory, as it allowed us to adjust the position and angle of the headlight and at the same time ensure its safe and reliable mounting on the bumper.

4.2 Printer and Settings

For printing we used FDM 3D printer Ender 3 V2 NEO by Creality. The reason why I decided to use this printer was to prove that the cheap and basic printer has a multipurpose usage. The advantage of this affordable printer is the automatic leveling, an all-metal extruder, and a durable build plate made of spring steel. The printer records the output during printing, and in case of a power outage or unexpected stop, it can pause the print and resume once restarted, saving both material and production time [Ender,2024].

The nozzle temperature for the 0.4 mm diameter nozzle was set to 250°C. The bed temperature was maintained at 100°C. The speed of the first layer was set to 25 mm/s to ensure better adhesion and prevent the filament from detaching due to high speed. To increase adhesion, we used homemade ABS juice on the build plate. To protect the print from drafts, we printed a wall around the perimeter, as the printing took place in an open chamber. The total printing time for one bracket was was 23 hours, 46 minutes, and 18 seconds.For sufficient strength we choose 25% infill and headlight bracket demand 75.38 meters of ASA filament. Additional information and parameters applied in the research are shown in Table 4.

Tab. 4 Settings and description of printer

Machine Name	Ender-3 V2
Machine Height	250mm
Machine Width	220mm
Machine Depth	220mm
Material Name	ASA
Layer Height	0.22mm
Wall Thickness	1.2mm
Out Wall Width	0.4mm
Inner Wall Width	0.4mm
Wall Line Count	3
Infill Pattern	GRID
Infill Density	25%
Print Temperature	250°C
Bed Temperature	100°C
Support Enable	TRUE
Support Density	25%
Support Angle	40°
Support Pattern	TRIANGLES
Adhesion Type	BRIM
Print Speed	50 mm/s
Travel Speed	120 mm/s
Initial Layer Speed	25 mm/s
Brim Speed	25 mm/s

4.3 Testing the light

Part of the headlight modernization process involved testing at the STEKO technical inspection facility. STEKO provided us with homologated devices by MOTEX. The homologation was valid and conducted by the specialized company HOMOLA spol. Proper calibration of the devices is crucial for accurate functionality.

The dipped beam angle, also known as "headlight dip," is the percentage difference between the drop in the headlight's beam from the horizontal plane that passes through the center of the headlight to the horizontal distance where this drop occurs. The light source was placed at 0.5 m. The slope is set within the tolerance band according to the attached diagram. The manufacturer of the tested vehicle specifies a basic slope setting of 1.5%. We set this value on the back of the regloscope, then measured and adjusted the headlight within the tolerance band.

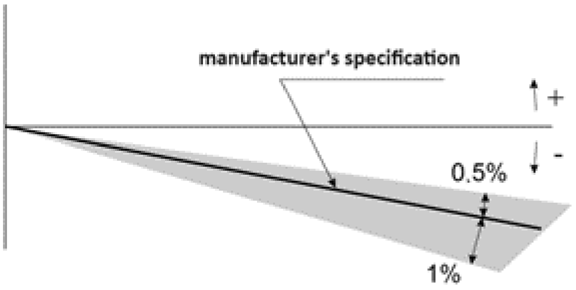

Fig. 8 Adjustment of headlight (Ondrejka, 2018)

Another important step was to adjust the reticle to ensure accurate alignment, preventing oncoming or overtaking vehicles from being dazzled by the vehicle's lights. Before adjusting the headlights, we cleaned the transparent window with isopropyl alcohol and microfiber cloth.

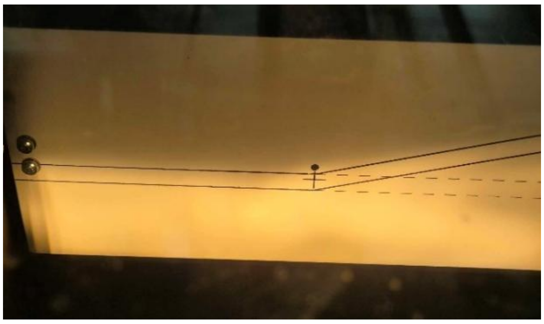

Fig. 9 Reticle of the regloscope using LED headlight (Low beam)

The original headlight for the pre-facelift version was defect-free, and adjusting its alignment was straightforward. Using the vertical adjustment of the regloscope, we were able to align the light and shadow interface with the regloscope's reticle. The regloscope allows us to read the tilt angle and adjust the headlights accordingly. The headlight fully complies with regulations and is suitable for use on public roads. The Jeep Wrangler headlight, mounted in the custom-made bracket, also meets regulatory standards and does not negatively impact road safety.

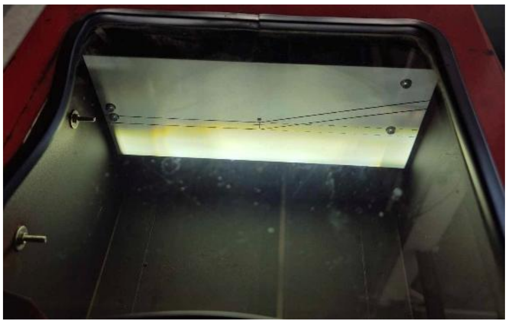

Fig. 10 Reticle of the regloscope using LED headlight (Low beam)

The regloscope was also equipped with an analog light intensity meter which we use to measure original headlights. The original lighting system, using a conventional bulb, provided informative values for light intensity based on the emitted spectrum. However, it was not possible to measure LED lighting due to its different light temperature and emission spectrum, which the analog measuring device is not calibrated for. The measurement was purely informational, as regulations do not specify exact values, and this additional device serves only as a supplementary measurement during the lighting test. Homologation does not apply to this additional regloscope device.

Fig. 11 High beam light intensity meter

Fig. 12 Comparison of Led headlight and original headlight

When measuring the intensity with a regloscope, the LED lighting showed zero values. Subsequently, we conducted an additional measurement in the test room at MajstriSvetla Ltd., where we connected both headlights to a power source with indicators for electric current consumption, power input, and set voltage. We then observed the values in different modes. At a distance of 5 meters from the white surface, which was recommended by the company's employees because the shape and impact of the light on the white surface are clearly visible, we connected the headlights to a constant voltage of 13.51V. We used a digital Luxmeter ST6813 to measure the light intensity. For LED high beams, they measured the maximum value of the illumination intensity of 260 lux, but the light beam was wider and covered the entire width of the white surface. The measured maximum value of the main beam of the H4 bulb was 730 lux, but the light was concentrated only in the central part of the white area, and at the edge the headlight reached a value of up to 20 Lux. In the attached Tab. 5 and Tab. 6 you can observe the comparison and decrease of power input [P] and electric current consumption [I]. It was a matter of course that the dipped headlights were also measured, when the LED reached a maximum value of 273 lux, and the maximum illumination intensity of the halogen bulb was higher, namely 465 lux. In both cases, the value of the halogen lamp is higher, but the light beam is concentrated in the center of the white surface and does not cover a sufficient width of the road.

The lighting manufacturer for the JEEP Wrangler reports pure road lighting with a color temperature above 6000 K, the total amount of visible light emitted by the source up to 5400 lm for high beams and 3600 lm for low beams. with energy savings of up to 60% and a lifetime of more than 50,000 hours. The headlights have IP67 protection.[Halo Headlights, 2024].

Tab. 5 High beam headlight comparison

	LED (high beam)	H4 standard bulb (high beam)
U [V]	13.52	13.51
I [A]	1.56	5.184
P[W]	21.19	70.02
E [Lux]	260	730

The measurement of the high beams showed us a lower value of the lighting intensity with LED than with the original lighting by 64.38%, but the percentage decrease of the consumed current was by 69.91%. The explanation for the decrease in intensity is simple due to the better scattering of light, which better illuminates the white surface that simulates the road. The power consumption of the LED headlight decreased by 69.73%.

Tab. 5 Low beam headlight comparison

	LED light (low beam)	H4 original light (low beam)
U [V]	13.52	13.51
I [A]	1.19	4.67
P[W]	16.03	63.13
E [Lux]	273	465

The measurement of passing lights showed us a lower value of illumination intensity with LED than with original lighting by 41.29%. however, the percentage decrease in consumed current was 74.6%. The explanation for the decrease in intensity is simple due to the better scattering of light, which better illuminates the white surface that simulates the road. The power consumption of the LED headlight decreased by 74.6%.

5 CONCLUSION

By replacing the original bulb headlights with new LED headlights, we have increased safety and reduced the load on the vehicle's alternator. Measurements show a decrease in electric current consumption with the new LED lights by 74.6% in low beam and 69.91% in high beam. We also observed a decrease in maximum light intensity by 41.26% in low beam and 64.38% in high beam. The original headlights focus the light beam centrally and concentrated to one point, whereas LED lighting disperses the light beam evenly across the width.

The regloscope used complies with legal regulations [§ 20 par. 1 letter p)] and is suitable for our experimental measurements. According to § 136 par. 2 letter a) of Act No. 106/2018 Coll. on the operation of vehicles, the Ministry of Transport of the Slovak Republic has issued a methodology for checking headlight settings. Our experiment adheres to these regulations and guidelines, ensuring that the modification is safe and fully compliant with road traffic standards.

Using FDM additive 3D printing technology, we adapted the headlights of another vehicle to meet the manufacturer's recommendations and regulations. The certified homologated equipment enabled accurate adjustment and verification of the headlights' operation. We used the Motex headlight tester to precisely align the light beams to avoid dazzling other drivers. The use of innovative ASA material, instead of the original headlight mount design, has resulted in increased durability, strength, and corrosion resistance, ensuring that the headlight adjustment mechanism remains functional and rust-free.

To calculate the adjustment costs, we considered the consumption of materials, energy, and other consumables required to maintain the printer. LED headlights and stainless-steel fasteners are also included in the price. For producing one holder, 193.78 grams of ASA fiber were used, costing 4.45 euros gross. Considering all costs, the total modification expense is under €200. The potential to produce a retrofit kit for the AVIA MP13 vehicle in small series is promising due to the low costs and the extended lifetime of the headlights, up to 50,000 hours. Additionally, the improved lighting efficiency reduces the load on the alternator, leading to lower vehicle emissions. The use of stainless-steel fasteners and ASA material ensures excellent resistance to weathering and corrosion.

6 ACKNOWLEDGMENTS

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