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Innovative reduction of CO_2 emission through application of energy-saving electroluminescent external lightning of passenger vehicles

Streszczenie**. Przemysł motoryzacyjny konsekwentnie rozwija technologię LED stosowaną do oświetlenia zewnętrznego pojazdów osobowych. Nadając pojazdom nie tylko nowy ciekawy wygląd, ale również przyczynia się do spadku zużycia energii elektrycznej co przekłada się na zmniejszenie emisji CO_2. Ograniczenie emisji dwutlenku węgla to jeden z podstawowych warunków jakie założyła sobie Unia Europejska w niedawno przyjętym pakiecie energetyczno – klimatycznym. Sektor transportu drogowego jest drugim co do wielkości źródłem emisji gazów cieplarnianych w UE odpowiedzialnym za 12% wszystkich emisji dwutlenku węgla. Obniżenie emisji do przeciętnego poziomu 130g CO_2/km z nowych samochodów ma zostać osiągnięte poprzez postęp technologiczny w procesie produkcji pojazdów. Dodatkowe ograniczenie o 10g CO_2/km można uzyskać poprzez inne usprawnienia techniczne, takie jak lepsze ogumienie, sprawniejsze systemy klimatyzacji, bardziej efektywne oświetlenie czy wykorzystanie biopaliw. W artykule autorzy zaprezentowali założenia i wytyczne techniczne oraz metodę badań innowacyjnego pakietu technologicznego w odniesieniu do stosowania energooszczędnego oświetlenia zewnętrznego pojazdów wykorzystujących diody elektroluminescencyjne. Energooszczędne oświetlenie zewnętrzne wykorzystujące diody elektroluminescencyjne w światłach mijania, światłach drogowych, przednich światłach pozycyjnych i światłach tablicy rejestracyjnej w samochodach typu M1 uznane zostało przez Komisję Europejską za innowacyjne rozwiązanie z kodem ekoinnowacji „10". **Innowacyjne zmniejszenie emisji CO_2 przez zastosowanie energooszczędnego elektroluminescencyjnego oświetlenia zewnętrznego samochodów osobowych

***Abstract**. Automotive industry constantly develops LED technology applied to external lightning of passenger vehicles. It gives vehicle not only a new interesting look, but also contributes to reduction of electricity consumption and reduction of CO_2 emission. Reduction of CO_2 emission is one of the basic conditions of European Union in recently passed energy and climate package. Sector of road transport is the second biggest source of greenhouse gas emission in the EU, which is responsible for 12% of all CO_2 emissions. Reduction of emission to an average level of 130g CO_2/km from new cars will be reached through technological progress in a process of production of vehicles. Additional reduction by 10g CO_2/km can be reached through other technical improvements, such as better tyres, more efficient air-conditioning systems, more effective lightning or use of biofuels. In this article, the authors present technical assumptions and guidelines and method of research innovative of technological package with reference to application of energy-saving external lightning of vehicles, which use light-emitting diodes. Energy-saving external lightning with the use of light-emitting diodes in dipped headlights, driving lights, position front lights and number plate lights in M1 type cars was recognized by European Commission as innovative solution with a code of eco-innovation „10".*

Słowa kluczowe: transport, ekologia.
Keywords: transport, ecology.

Introduction

Leaders of 28 countries of European Union decided that CO_2 emission will be reduced by at least 40 per cent till 2030.[15] European Union also established that will increase energy efficiency, by at least 27 per cent, and share of energy from renewable sources in total electricity consumption in the EU will be, at least 27 per cent in 2030. [14] All decisions, and also compromise is not only ambitious, but also balanced and fair.[7],[18],[20],[21 Each country will bear its costs in accordance with its level of wealth and capabilities to protect climate.[8],[9] EU countries with lower income will receive support in a form of both adequate goals and additional funds, which will help them in transitional period until they will have extended sector of clean energy.[12],[19] Such actions will support competitive international position of industry and jobs in the EU. [13],[17]

One of the activities reducing CO_2 emission in EU is acceptance by European Commission, energy-saving external lightning using Daimler AG light-emitting diodes to use in M1 vehicles (vehicle for transport of people, which has no more than eight places, apart from driver's seat) and approval as innovative technology in accordance with art. 12 directive (WE) No. 443/2009.

The individual eco-innovation code to be entered into type approval documentation to be used for the innovative technology approved through this Decision shall be "10". [1] The decision of the EU Commission 2015/206 dated 9 February this year refers to efficient exterior lighting with the use of light emitting diodes in the low beam headlamp, the high beam headlamp, the front position, and the licence plate. [1] This technology package is similar to the innovative technologies approved as an eco-innovation in Commission Implementing Decisions 2013/128/EU[2] and 2014/128/EU. [3] Applicant Daimler AG has demonstrated satisfactorily that the emission reduction achieved by the innovative technology is at least 1 g CO_2/km. [1]

In order to determine potential within the scope of reduction of CO_2 emission, which can be achieved thanks to application of innovative technology in a vehicle, it is necessary to accept halogen lightning as a reference technology, which in a reliable way compares level of emission of a vehicle equipped with innovative technology, in accordance with art. 6 of implementing regulation (UE) No. 725/2011. [1]

Reduction of CO_2 emission as a result of applying energy-saving lightning with the use of light-emitting diodes in dipped headlights, driving lights, position front lights and number plate lights is determined with the use of research method and procedure, which is presented in a further part of this publication.

Method and procedure of examination of reduction of CO_2 emission as a result of applying energy-saving lightning with the use of light-emitting diodes in passenger cars

In order to determine the CO_2 emission reductions that can be attributed to the efficient exterior lighting with the use of light emitting diodes (LED) in an M1 vehicle, it is necessary to establish the following:

- The testing conditions,
- The test procedure,
- Calculate the power savings,
- Calculate the CO_2 savings,

– Calculate the statistical error in the CO_2 savings,
– Verify the threshold value.

Test conditions meet the requirements of UN/ECE Regulation No 112 [4] on Uniform provisions concerning the approval of motor vehicle headlamps emitting an asymmetrical passing beam or a driving beam or both and equipped with filament lamps and/or light-emitting diode (LED) modules shall apply. For determining the power consumption, the reference is to be made to point 6.1.4 of Regulation No 112, and points 3.2.1 and 3.2.2 of Annex 10 to Regulation No 112. [1]

The test procedure to reduce CO_2 emissions due to the use of energy-efficient lighting should include measurements are to be performed as shown in figure 1.

For the measurement, the following equipment is to be used:

– Two Digital Multi Meters, one for measuring the DC-current, and the other for measuring the DC-voltage,
– The power supply unit of the measuring system,

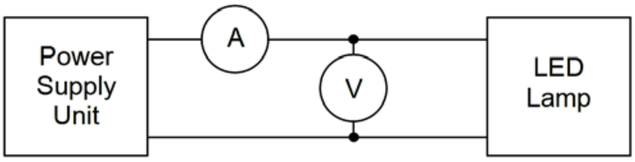

Fig.1. The measuring system for testing (energy-efficient lighting) LED lamps

In total 5 measurements of the current should be done at the voltage of 12,8 V for the low and high beam headlamp and the front position, and 10,7 V for the licence plate. The exact voltage level and the measured current is to be recorded in four decimals. [1]

On the basis of the measurements, the following steps are to be taken to determine the CO_2 savings and to determine whether the threshold value of 1g CO_2/km is met.

Calculate the power savings

For each of the 5 measurements the power which is used is to be calculated by multiplying the installed voltage with the measured current. When a stepper motor or electronic controller is used for the supply of the electricity to the LED lamps, then the electric load of this component part is to be excluded from the measurement. This will result in 5 values. Each value must be expressed in 4 decimals. Then the mean value of the used power will be calculated, which is the sum of the 5 values for the power divided by 5. The resulting power savings are to be calculated with the following formula 1.

(1) $$\Delta P = P_{baseline} - P_{eco-innovation}$$

where: ΔP – Power savings in [W], $P_{baseline}$ – Power of the baseline [W], $P_{eco\text{-}innovation}$ – Mean value of the used power of the eco-innovation in [W].

Table 1 shows the Power requirements for different baseline type of lighting given to them from the total electric power charged.

Table 1. Power requirements for different baseline type of lighting

Type of lighting	Total electric power [W]
Low beam headlamp	137
High beam headlamp	150
Front position	12
License plate	12

Calculate the CO_2 savings

The total CO_2 savings of the lighting package are to be calculated by formulae 2 and 3. During calculations, we must divide vehicles into petrol and diesel oil powered. It results from chemical properties of both fuels and energy efficiency.

For a petrol-fuelled vehicle formula 2:

(2) $$C_{CO_2} = \left(\sum_{j=1}^{m} \Delta P_j \cdot UF_j \right) \cdot \frac{V_{Pe-P}}{\eta_A} \cdot \frac{CF_P}{\nu}$$

For a diesel-fuelled vehicle formula 3

(3) $$C_{CO_2} = \left(\sum_{j=1}^{m} \Delta P_j \cdot UF_j \right) \cdot \frac{V_{Pe-D}}{\eta_A} \cdot \frac{CF_D}{\nu}$$

These formulae present the total CO_2 savings of the lighting package in gCO_2/km. Applying above dependencies to calculations of CO_2 reduction, we must take into account the following input data:

ΔP_j – Saved electrical power in [W] of the type of lighting j, which is the result of formula 2,
F_j – Usage factor of the type of lighting j, specified in table 2,
m – a number of types of lightings in the innovative technology package,
ν – Mean driving speed of the NEDC, which is 33,58 km/h,
V_{Pe-P} – Consumption of effective power for petrol-fuelled vehicles, which is 0,264 l/kWh,
V_{Pe-D} – Consumption of effective power for diesel-fuelled vehicles, which is 0,22 l/kWh
η_A – Efficiency of the alternator, which is 0,67
CF_P – Conversion factor for petrol fuel, which is 2 330 gCO_2/l
CF_D – Conversion factor for diesel fuel, which is 2 640 gCO_2/l

Table 2. Usage factor for different type of lighting

Type of lighting	usage factor UF [%]
Low beam headlamp	0,33
High beam headlamp	0,03
Front position	0,36
License plate	0,36

Calculate the statistical error in the CO_2 savings

The statistical error in the CO_2 savings is to be determined in two steps. In the first step the error value of the power is to be determined as a standard deviation being equivalent to a confidence interval of 68%. The statistical error in the CO_2 savings is to be calculated by formula 4.

(4) $$\sigma_{\bar{x}} = \sqrt{\frac{\sum_{i=1}^{n} \left(X_i - \bar{X} \right)^2}{n(n-1)}}$$

where: $\sigma_{\bar{x}}$ – Standard deviation of arithmetic mean [W], X_i – Measurement value [W], $\bar{X}$ – Arithmetic mean [W], n – Number of measurements, which is 5.

In order to calculate the error in the CO_2 savings for a petrol and diesel -fuelled vehicles, the propagation law, expressed in formula 5, is to be applied.

(5) $$\overline{\Delta C_{CO_2}} = \sqrt{\sum_{j=1}^{m} \left(\frac{\partial C_{CO_2}}{\partial P_j} \cdot \sigma_{P_j} \right)}$$

where: $\overline{\Delta C_{CO_2}}$ – Mean total error of the CO_2 saving [gCO_2/km], $\frac{\partial C_{CO_2}}{\partial P_j}$ – Sensitivity of calculated CO_2 saving related to the type of lighting P_j, σ_{P_j} – Error of the type of lighting P_j [W], m – a number of types of lightings in the innovative technology package.

Substituting formulae 2 in formula 5 results in formula 6 for calculating the error in CO_2 savings for petrol fuelled vehicles.

$$\overline{\Delta C_{CO_2}} = 0,\frac{0273 gCO_2}{kmW} \cdot \sqrt{\sum_{j=1}^{m} \left(UF_j \cdot \sigma_{P_j}\right)^2} \quad (6)$$

Substituting formula 3 in formula 5 results in formula 7 for calculating the error in CO_2 savings for diesel fuelled vehicles.

$$\overline{\Delta C_{CO_2}} = 0,\frac{0258 gCO_2}{kmW} \cdot \sqrt{\sum_{j=1}^{m} \left(UF_j \cdot \sigma_{P_j}\right)^2} \quad (7)$$

Verify the threshold value

In order to demonstrate that the 1,0 gCO_2/km threshold is exceeded with a statistic relevance, the following formula 8 should be used.

$$MT = 1,\frac{0 gCO_2}{km} \leq C_{CO_2} - \overline{\Delta C_{CO_2}} \quad (8)$$

Where: MT – Minimum threshold [gCO_2/km], ΔC_{CO_2} – Total CO_2 saving [gCO_2/km], which must be expressed in 4 decimals, $\overline{\Delta C_{CO_2}}$ – Mean total error of the CO_2 saving [gCO_2/km], which must be expressed in 4 decimals.

Where the total CO_2 emission savings of the innovative technology package, as a result of the calculation using Formula 8, are below the threshold specified in Article 9(1) of Implementing Regulation (EU) No 725/2011, the second subparagraph of Article 11(2) of that Regulation shall apply.

It means that minimal reduction achieved thanks to innovative technology is 1g CO_2/km. This threshold value is achieved, when total value of reduction resulting from application of innovative technology is at least 1g CO_2/km. If total CO_2 reduction resulting from application of innovative technological package was below 1g CO_2/km, then Commission may not take into consideration CO_2 reduction while calculating average value of emission of a producer for a next calendar year. [5]

Application of innovative systems of energy-saving lightning with the use of light-emitting diodes in passenger cars

Technology of LED lightning in passenger cars has been applied and introduced for a few years. Until now, we would observe single and selected places in vehicles, in which traditional sources of light were replaced (halogen lamps, xenon) with LED lightning. Nowadays, there is a new trend of LED technology, which means there won't be any incandescent lamp in vehicles. LED diodes illuminate now the road, car, cab and boot.[10]

Long life-span and colour temperature equivalent to daylight speak in favour of technology.[16] There was also a huge progress, which increased efficient and life-span.[14] In comparison to conventional lamps, energy consumption decreased by one quarter. For example, new, energy-saving dipped headlights LED need 34 W, while halogen bulbs need 120 W and xenon lamps 84 W. All values concern one vehicle, which means reduction of fuel consumption and reduction of CO_2 emission in comparison to a car with traditional halogen bulbs.[11]

One of the most well-known world solutions is application of ILS (Intelligent Light System) in passenger vehicles. System was worked out and implemented by concern Daimler AG. Application of standard LED reflectors decreased by 72 per cent electricity consumption in comparison to traditional halogen version. CO_2 reduction as a result of this innovation amounts to 2,1 g/km. Colour of light, which is 5500 K is in comparison to light emitted by halogen or xenon lamps (4200K) much more closer to daylight (6500K). Driving comfort is better due to the fact that reflectors adjust automatically to weather conditions, lightning and road conditions, guaranteeing the best visibility in a given situation.

ILS LED system was developed last year through introduction of a new, precise innovative technology of high-resolution front LED lightning called Multibeam LED. New solution is precise high-resolution LED modules.[6] Each of them consists of 24 LED diodes controlled independently, which illuminate the road with a stream of exceptionally bright light, not blinding other road users. Multibeam LED reflectors are new chapter in field of lightning - numerous advantages of LED technology connect with modern technologies of control. They extend current functionality of intelligent system of ILS lightning. In fact, Multibeam LED is equipped with 7 fully independent sources of light in every reflector. In addition, one of them consists of 24 individual modules, which can be activated and send 24 individual light beams. Multibeam LED allows to cut out the are from a light beam, which shouldn't be illuminated– other road user. In the future, Multibeam LED will be equipped with modules with 84 or even 1024 diodes controlled independently. It will allow for more precise and efficient road illumination. There will be no necessity to switch on all diodes of driving lights, only these modules, which are not necessary will be switched off. It allows to use lightning effectively and hence causes considerable reduction of CO_2 emission.

Current solutions in vehicles did not achieve expected reduction of emission to the level of 1g CO_2/km. However, in next year, not only dipped beams, but also rear lights and stop lights will be produced in passenger vehicles, what will allow to meet requirements of European norms, and will guarantee reduction of emission achieved thanks to innovative technology to at least 1g CO_2/km. It will be guaranteed by the newest technology of Organic Light Emitting Diode. In contrast with currently applied diodes, built of semiconductive crystals, they are made of organic material. Thin layer of such material, a few microns thick, is put on extremely smooth surface, for example, polished display window. After connecting voltage, particles give protons back and surface is lightening. Emitted light is distributed in more homogenous and energy-saving way.

Conclusion

Future of lighting technique is LED diodes. Diodes have been applied in monitors and other devices. Introducing them to new generation of vehicles equipped with full-diode dynamic reflectors proves that they may reduce energy consumption of lighting system, and also improve visibility and safety on the road.

Accepting by European Commission, energy-saving external lightning with the use of Daimler AG light-emitting diodes for M1 vehicles aims at reduction of harmful impact of vehicles on natural environment through reduction of CO_2 emission. Moreover, executive decision of European Union Commission contributes to increase of competitiveness of the automotive industry through simplification of binding legislation within the scope of homologation of such vehicles with reference to reduction of CO_2 emission. Conducted research, tests and also technical guidelines indicate that introduction of this technology as a standard equipment in new vehicles would bring considerable benefits. Establishing common obligatory requirements would also prevent fragmentation of internal market, what would happen if different norms in particular member states was introduced.

Method of examination of reduction of CO_2 emission presented in the publication includes patterns and assumptions, which enable a real assessment of CO_2 reduction. Procedure of examination will provide reliable results of tests, which will indicate statistically relevant benefits of reduction of CO_2 emission resulting from introduction of new innovative technology.

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