Keywords: emission CO_2; high-efficiency alternator; energy efficiency; New European Driving Cycle – NEDC; Start–Stop system

Zbigniew ŁUKASIK, Jacek KOZYRA*, Aldona KUŚMIŃSKA-FIJAŁKOWSKA
Kazimierz Pulaski University of Technology and Humanities in Radom,
Faculty of Transport, Electrical Engineering and Computer Science
Malczewskiego 29, 26-600 Radom, Poland
**Corresponding author*. E-mail: j.kozyra@uthrad.pl

REDUCTION OF CO_2 THROUGH APPLICATION OF A HIGH-PERFORMANCE ALTERNATOR

Summary. Road transport causes emission of 1/5 of the carbon dioxide produced in the European Union. Actions aimed at reduction of emission of CO_2 of various vehicles are becoming an increasingly important issue. In this article, the authors present an innovative technology of use of a high-performance alternator in passenger vehicles. They proposed a method of calculating reduction of CO_2 through application of a high-performance alternator. Moreover, application of new technology based on the measurements performed in accordance with the guidelines of the New European Driving Cycle allowed calculation of fuel savings and reduction of CO_2 emission in road transport.

1. INTRODUCTION

In recent years, one of the main goals in the automotive industry has been to make cars more environmentally friendly. The requirements forced manufacturers to develop and apply solutions aimed at reducing combustion and emission of harmful substances generated during the operation of petrol and diesel engines [1-2]. One such technology is the Start–Stop system. This solution allows reducing fuel consumption; however, the requirements in terms of the starter, alternator and battery are higher. In the traditional solution, when a car stops, engine speed decreases to the level of idling, maintaining the drive unit in the start state [3, 10-11]. Turning the engine off may then save fuel, for example, during the stop at traffic lights. This is why the Start–Stop system was developed. This system consists of the following elements: an engine control unit with software, a DC/DC 12 V converter, a battery adapted to a larger number of working cycles (AGM - Absorbent Glass Mat or EFB - Enhanced Flooded Battery) and a battery state sensor, a starter for Start–Stop systems, neutral gear and a speed sensor and an active sensor of rotations and location of a crankshaft and alternator with the function of brake energy recovery. The new generation of alternators adapted to the function of brake energy recovery is particularly interesting [4, 12]. These alternators are very efficient due to reduction of the following three losses:

- related to the process of rectification through optimization of this process thanks to application of the „MOSFET" module, that is, application of a metal-oxide-semiconductor field-effect transistor,
- in the iron of a stator through application of a thinly laminated core made of magnetic steel, optimization of the system and length of tooth of the iron core of a field magnet, optimization of the slots between poles and air gap and
- in the copper of a stator through application of a „segment conductor", which has a higher spatial factor and shorter tip of a coil.

It allows reducing fuel consumption and emission of CO_2, which is beneficial for both the driver and the environment. Moreover, advanced electric structure and optimized materials applied in the modern alternators make them more efficient than ever before.

2. CERTIFICATION OF CO_2 SAVINGS

T support innovative implementations of new technologies to reduce CO_2 emission in vehicles, the European Commission, by Order (EC) no. 443/2009, gives suppliers and producers the opportunity to support implementation and approval of new technologies that efficiently reduce CO_2 emission in new passenger cars [18]. Therefore, it is necessary to explain the criteria of this order qualifying new technologies as ecological innovations.

A significant goal of the order is to promote technologies that have the highest potential to reduct CO_2 emission, which is released due to the use of passenger vehicles. The main goal of promotion and qualification of new technologies is development of new drives related to functioning of a transport vehicle that shall be qualified as considerably improving the general energy consumption of a vehicle [5, 14]. Other associated solutions focused on improving the comfort of the driver or passengers according to the order shall not be qualified as ecological innovations reducing CO_2 emission.

Therefore, it is necessary to develop a high-accuracy measuring method to determine the reduction of CO_2 emission that will result from qualified ecological innovation. It is assumed that appropriate accuracy shall be a reduction of 1g CO_2 / km or higher [6,15].

To obtain a certificate of potential reduction of CO_2 emission of a vehicle, a manufacturer proposing technical solutions containing efficient alternators of output voltage 12 V should fulfill the following requirements [16]:

- the proposed ecological innovation is used only for charging up a battery of a vehicle or supplying the electric system of a vehicle with simultaneous combustion engine operation;
- the proposed efficient alternator can be at a maximum 3 kg heavier than the basic alternator, which is 7 kg in weight; and
- the effectiveness of the proposed efficient alternator is at least
  - 73,8 % for petrol-fueled vehicles,
  - 73,4 % for petrol turbo-fueled vehicles and
  - 74,2 % for diesel-fueled vehicles.

The reduction of CO_2 emission of a vehicle as a result of application of new highly efficient alternators will be determined using the computational methodology below.

3. METHODOLOGY OF DETERMINATION OF REDUCTION OF CO_2 EMISSION OF A VEHICLE WITH AN APPLIED EFFICIENT ALTERNATOR

For the determination of reduction of CO_2 emission of a vehicle equipped with an eco-innovative efficient alternator, the following factors need to be assessed:

- the conditions that the research was conducted under,
- the measuring devices applied during the research,
- the method of determination of efficiency of an efficient alternator and basic alternator of a vehicle,
- the calculations of reduction of CO_2 emission and
- the calculations of an error of determination of reduction of CO_2 emission.

The conditions of conducting the research should fulfill the requirements specified in ISO 8854. Tests shall be carried out a temperature of T_{amb}= (23 ± 5) °C and may optionally also be performed at higher temperatures. Tests shall be carried out at the standard atmospheric pressure. Deviating conditions (e.g. measuring location, altitude, weather) shall by recorded. Sense or alternator rotation shall be in accordance with the supplier's specification. The drive control shall set alternator frequency values with a limit deviation of ($n_{G\ set}$ ± 5) min^{-1}. The load current control shall meet the requested set current values with a limit deviation of (I_{Set} ± 1,0) A.

The measuring devices applied during the research must meet the requirements specified in ISO 8854: 2012. The test equipment shall allow measurements of all parameters to be carried out within the limit deviation specified in Table 1.

Table 1

Accuracy of test equipment

Parameters	Limited deviation
Voltage	± 0,1% of the measured value
Current	± 0,2% of the measured value
Torque	± 0,5% of the rated value of torque sensors
Rotational frequency	± 2 min^{-1}
Ambient temperature	± 1 K
Air pressure	± % hPa
Test period	± 1 s

All measured values shall be obtained at the end of each holding of an operating point. Each datum recorded shall comprise at least the following measured values:

$n_{G\ actual}$ - alternator rotational frequency (actual value = measured value),
$I_{G\ actual}$ - alternator current (actual value = measured value),
U_G - alternator voltage,
M - alternator torque if needed,
T_{amb} - ambient temperature and
t_M - time of acquisition of the measured values from the start of testing.

3.1. Test bench

The setup of the test bench and the testing procedure is such that it aims to fulfill the precision requirements specified in ISO 8854:2012 [20]. On the test stand an alternator that will have direct drive is examined and measured. The examined alternator must be directly connected with a measuring gauge of torque and coupled with a drive shaft. In addition, the examined alternator is loaded with a battery of a vehicle and a receiver, which is a load-simulating electronic subassembly of a vehicle. The test bench configuration is shown in Fig. 1.

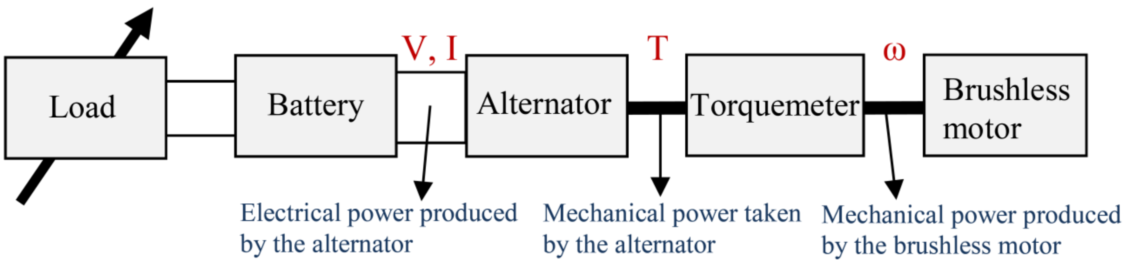

Fig. 1. Test bench configuration, where: V, I is the alternator voltage and alternator current, T is the alternator torque and ω is the brushless motor rotational speed

In Fig. 1, an overview of the test bench configuration is given. The alternator transfers the mechanical power of the brushless motor into electrical power. The brushless motor generates an amount of power that is defined by the torque (Nm) and by the rotational speed (rad. s^{-1}). The torque and the speed are to be measured by the torque meter. The alternator produces power to overcome the load, which is connected to the alternator. This amount of power is equal to the alternator voltage times the alternator current. The efficiency of the alternator is defined as the electric power (output of the alternator) divided by the mechanical power (output of the torque meter).

3.2. Measurements and determination of the efficiency of an efficient alternator

The determination of the efficiency of an efficient alternator must fulfill the requirements of ISO 8854: 2012 [11]. The efficiency of the alternator must be determined by performing measurements at different speeds: 1 800, 3 000, 6 000 and 10 000 revolutions per minute. At each speed, the alternator is charged at 50 % of the maximum load. For calculating the efficiency, a time distribution should be 25 %, 40 %, 25 % and 10 % for, respectively, 1 800, 3 000, 6 000 and 10 000 revolutions per minute (the VDA approach described in the Technical Guidelines) [17].

The load should be installed at 50 % of the current, which is guaranteed by the alternator at 25 °C and a rotor speed of 6 000 rpm; e.g., if the alternator is a 180 A class alternator (at 25 °C and 6 000 rpm), the load is installed at 90 A. For each speed, the voltage and the output current of the alternator are to be kept constant, the voltage at 14,3 V and the current for a 180 A-alternator at 90 A, i.e., for each speed, the torque should be measured by means of the test bench (Fig. 1) and the efficiency should be calculated using formula (1). The goal of conducted research is to check whether an efficient alternator is efficient enough for 4 various set velocities expressed in the rotations per minute (rpm). The measurements are performed for determined operating points of an alternator *i*. The measurements are presented in Table 2.

Table 2

Measurement points

Operating point i	Measurement time [s]	Rotational speed n_i [min^{-1}]	Frequency h_i
1	1 200	1 800	0,25
2	1 200	3 000	0,40
3	600	6 000	0,25
4	300	10 000	0,1

The efficiency of an efficient alternator is calculated from formula (1) as follows:

$$\eta_{EI_i} = \frac{60 \cdot U_i \cdot I_i}{2\pi \cdot M_i \cdot n_i} \cdot 100, \tag{1}$$

where η_{EI} is the efficient alternator efficiency [%]; U_i is the voltage operating point i [V]; I_i is the current operating point i [A]; M_i is the torque operating point i [Nm] and n_i is the rotational speed [min^{-1}] as defined in Table 2.

The measurements of efficiency of an alternator must be performed 5 times in subsequent measurement sessions. For the measurements, the average $\overline{\eta_{EI_i}}$ for every measurement session must be calculated. The efficiency of an ecoinnovative efficient alternator η_{EI} is determined using formula (2) as follows:

$$\eta_{EI} = \sum_{i=1}^{4} h_i \cdot \overline{\eta_{EI_i}}, \tag{2}$$

where h_i= is the frequency as defined in Table 2 and $\overline{\eta_{EI_i}}$ is the mean of the alternator efficiency at operating point i [%].

T determine the saving of mechanical power under real conditions (ΔP_{mRW}) and under conditions of homologation (ΔP_{mTA}) for an applied efficient alternator, formula (3) is applied as follows:

$$\Delta P_m = \Delta P_{mRW} - \Delta P_{mTA}, \tag{3}$$

Saved mechnical power under real conditions (ΔP_{mRW}) and under conditions of homologation (ΔP_{mTA}) is calculated using formulas (4) and (5) as follows:

$$\Delta P_{mRW} = \frac{P_{RW}}{\eta_B} - \frac{P_{RW}}{\eta_{EI}} \quad , \tag{4}$$

$$\Delta P_{mTA} = \frac{P_{TA}}{\eta_B} - \frac{P_{TA}}{\eta_{EI}} \quad , \tag{5}$$

where P_{RW} is the power under real conditions [W], which is 750 W; P_{TA} is the power under conditions of homologation [W], which is 350 W, and η_B is the efficiency of a basic alternator [%], which is 67%.

3.3. Calculation of the CO_2 savings

The reduction of CO_2 emission for an efficient alternator is calculated using formula (6) as follows:

$$C_{CO_2} = \Delta P_m \cdot \frac{V_{Pe} \cdot CF}{v} \quad , \tag{6}$$

where V_{P_e} is the effective power consumption of the vehicle as presented in Table 3; CF is the conversion factor (l/100 km) – (g CO_2/km) [gCO_2/l], as defined in Table 4, and v is the mean driving speed of the NEDC [km/h], which is 33,58 km/h.

Table 3

Effective power consumption of the vehicle

Type of engine	Effective power consumption of the vehicle (V_{Pe}) [l/kWh]
Petrol	0,264
Petrol turbo	0,280
Diesel	0,220

Table 4

Fuel conversion factor

Type of fuel	Conversion factor (1/100km)-(g CO_2/km) (WK) [gCO_2/l]
Petrol	2 330
Diesel	2 640

3.4. Calculating the error in determining CO_2 savings

The reduction of CO_2 emission for a vehicle equipped with an innovative efficient alternator should be determined to identify errors in the research methodology. For specific measurements performed at operating points of an alternator from formula (7), standard deviation is calculated as follows:

$$S_{\overline{\eta_{EI_i}}} = \frac{S_{\eta_{EIi}}}{\sqrt{m}} = \sqrt{\frac{\sum_{j=1}^{m}\left(\eta_{EI_{ij}} - \overline{\eta_{EI_{ij}}}\right)^2}{m(m-1)}} \, , \tag{7}$$

where m is the number of measurements.

The standard deviation of the efficiency value of the efficient alternator ($S_{\overline{\eta_{EI}}}$) is calculated using dependency (8) as follows:

$$S_{\eta_{EI}} = \sqrt{\sum_{i=1}^{4} h_i \cdot S_{\overline{\eta_{EI_i}}}^{\,2}} \quad , \tag{8}$$

The standard deviation of the alternator efficiency ($S_{\eta_{EI}}$) contributes to the error of the CO_2 savings value ($S_{C_{CO_2}}$). The error is calculated from dependence (9) as follows:

$$S_{C_{CO_2}} = \sqrt{\left(\frac{\partial C_{CO_2}}{\partial \eta_{EI}} \cdot S_{\eta_{EI}}\right)} \frac{\left(P_{RW} - P_{TA}\right)}{\eta_{EI}^{\ 2}} \cdot \frac{V_{PE} \cdot CF}{v} \cdot S_{\eta_{EI}}, \tag{9}$$

where

$\frac{\partial C_{CO_2}}{\partial \eta_{EI}}$ is the impact of calculated CO_2 savings related to alternator efficiency.

3.5. Significance of Calculations

Calculations are necessary for passenger vehicles equipped with an efficient alternator. The calculations must be performed for every type, variant and version of a transport vehicle. In the calculations, it should be shown that an error from the obtained reduction of CO_2 emission calculated from formula (9) is smaller than or equal to the difference between the total reduction of CO_2 emission and the minimal program of reduction specified in art. 9 sec. 1 of the Executive Order (EU) no. 725/2011 expressed as formula (10):

$$MT \le C_{CO_2} - S_{C_{CO_2}}, \tag{10}$$

where MT is the minimum savings threshold [g CO_2/km], which is 1 g CO_2/km.

In order to issue homologation, the issuing authority may certify the obtained reduction based on the measurements for an efficient alternator and basic alternator (without eco-innovation).

However, the measurements must be in conformity with the presented research methodology. If reduction of CO_2 emission is below the threshold value specified in art. 9 sec. 1, art. 11 sec. 2, the second paragraph of the Executive Order (EU) no. 725/2011 [19] shall apply.

4. TESTS CONFIRMING CO_2 SAVINGS

Start–stop systems that automatically turn off a warm engine during a stop and start it before moving are becoming increasingly more popular. In 2008, only 5 % of new vehicles in Europe were equipped with start–stop systems. Every second new car in Europe is currently equipped with this technology [9, 13]. The first tests conducted on 4 vehicles showed lower combustion. The way in which this function works was also checked. The vehicles were tested in two large cities and practical savings amounted to a few per cent. However, there are no benefits during continuous rides, whereas in urban traffic with frequent stops at crossroads with traffic signals, they savings sometimes amount to about 8%. In some cars in the test, especially those with powerful engines, combustion is low even without the start–stop function turned on. This shows how fuel consumption can be reduced during a smooth, but relatively fast ride. The assessment of savings was performed on the basis of typical sizes. The working time of a combustion engine for analyzed rides was determined. The total time of during which the combustion engine was off in every variant of the route was determined. On the basis of the rotational speed of idling and the exact duration for which the engine was off, the probable number of cycles not made by the combustion engine was determined. The mass (volume) of fuel saved when the combustion engine is turned off and when the car stops in each of four rides was determined. The amount of fuel saved was determined and calculated as the mass of carbon dioxide not emitted into the atmosphere.

The mass of fuel was determined based on the measurements of emission of carbon dioxide of a combustion engine working with rotational speed of idling [7-8]. The Start–Stop system can be activated, if the condition of the thermal state of an engine is met; therefore, the measurements were performed when the required parameters of an engine were achieved. When using a passenger car that burns 1 kg of petrol, 3.1 kg of CO_2 will be obtained as a product of this combustion (i.e. 1 kg of CO_2 is generated as a result of burning 0.322 kg of gasoline). Therefore, the amount – mass of fuel for idle running engine of a vehicle can be calculated. CO_2 emission for the idle running engine examined is 0,76 g/s. Using formula (11), the mass of fuel for a unit of time of an engine operation can be determined as follows:

$$0{,}76\ g/s\ CO_2 \cdot 0{,}332\ g\ Petrol/g\ CO_2 = 0{,}245\ g/s\ Petrol\ , \quad (11)$$

The volumetricity of intensity of fuel consumption, assuming the density of petrol ρ = 0,745 g / cm^3, is determined using formula (12) as follows:

$$0{,}76\ g/s\ CO_2 \cdot 0{,}332\ g\ Petrol/g\ CO_2/0{,}745\ g/cm^3 = 0{,}33\ cm^3/s\ Petrol\ , \quad (12)$$

The values of fuel savings under normal traffic conditions and calculated reduction of emission of CO_2 are presented in Table 5.

Table 5

Reduction of fuel and emission of CO_2 with activated start–stop function

Tested vehicle	Petrol consumption [l/100km]	Petrol savings [l/100km]	Saving CO_2 [kg/100km]
BMW X3	11	0,83	1,90
Porsche Panamera	10	0,41	0,94
Opel Astra	6,3	0,78	1,78
Smart Fartwo	5,3	0,58	1,33

Reduction of fuel with activated start–stop function is shown in Fig. 2.

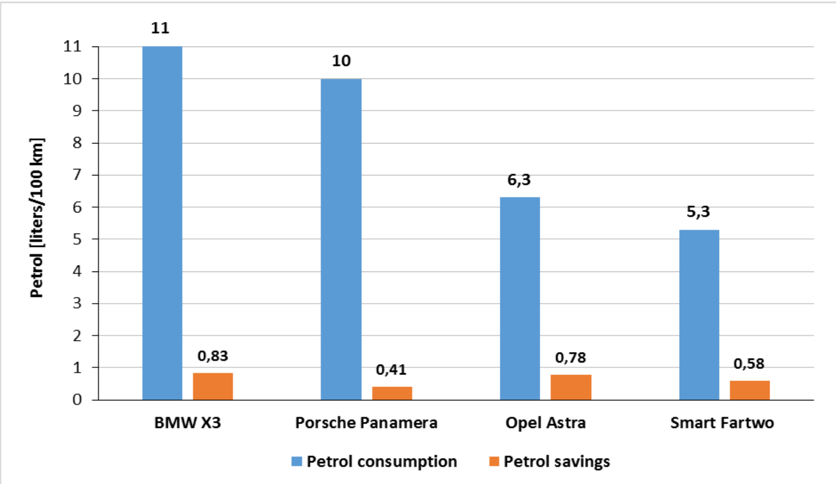

Fig. 2. Reduction of fuel with activated start–stop function

Reduction emission of CO_2 with activated start–stop function is shown in Fig. 3.

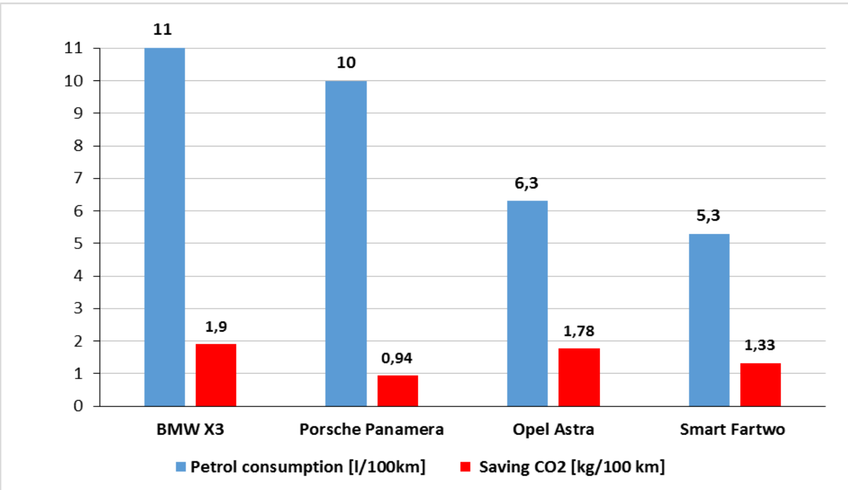

Fig. 3. Reduction emission of CO_2 with activated start–stop function

Assuming, in accordance with [21], the average annual mileage at the level of 12,700 (km/year), the following savings were obtained, presented in Table 6.

Table 6

Annual reduction in fuel consumption and CO_2 emissions
with active start–stop function

Tested vehicle	Petrol savings [l/year]	Saving CO_2 [kg/year]
BMW X3	105,41	245,11
Porsche Panamera	52,07	119,38
Opel Astra	99,06	187,96
Smart Fartwo	73,66	168,91

The annual values of petrol savings under normal traffic conditions and calculated reduction of emission of CO_2 are presented in fig. 4.

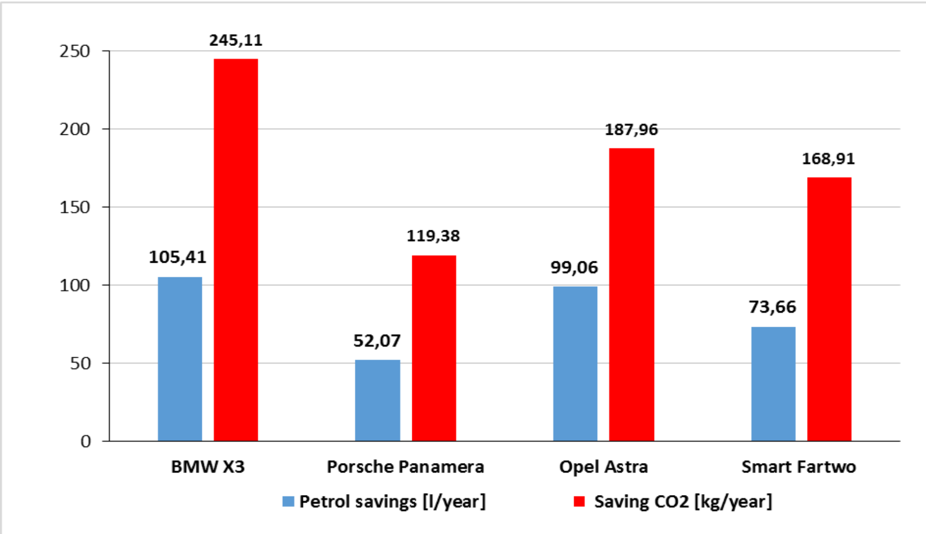

Fig. 4. Annual reduction of fuel and emission of CO_2 with activated start–stop function

5. CONCLUSIONS

The measurements performed in accordance with the guidelines of NEDC - New European Driving Cycle showed that fuel consumption was reduced and emission of pollutants was reduced by about 8%. In actual urban traffic, it may even be reduced by 15%. In a modern petrol engine, the amount of fuel equal to 0,7 seconds of idling is needed to start it. Therefore, turning the engine off is profitable from the first second. It is beneficial both for the driver and the environment. For a modern system with a high-performance alternator, the requirements in terms of the components of a vehicle are higher, including increased resistance of a starter to higher number of warm-ups and higher resistance of a battery to cyclical work with deep discharge and quick recharge. Moreover, the electrical system must be equipped with a unit managing electric energy in a vehicle and system stabilizing voltage. Increasing the density of stator winding from 45% to 70% enables design of an alternator that is 20% lighter and whose power is 50% higher than a conventional alternator. Higher efficiency and lower fuel consumption are achieved thanks to the higher efficiency of an alternator, exceeding 70%, and while applying optional HED technology (high-efficiency diode), even exceeding 77%. Applied innovation also enabled achievement of a uniquely low level of noise. Even magnetic noise was considerably reduced – especially when the engine works slowly, for example, at idling. The development of a fan in the alternator reduced aerodynamic noise with high engine rotational speed by 50%.

The start–Stop system is currently fitted in cars on a mass scale. However, the opinions on this system are divided. The basic argument of those not in favor of this system is that the parts that need greasing quickly wear out and their repair and/or replacement of subassemblies such as turbo compressors or dual mass flywheels are relatively expensive. In addition, car engines with the Start-Stop system are much more prone to service negligence. Especially those inspection activities that determine the long service life of highly heated elements during frequent starts in the Start - Stop system. Another argument of those not in favor of this system is that it requires properly reinforced and more expensive starters, alternators and batteries.

References

1. Fontaras, G. & Zacharof, N-G. & Ciuffo, B. Fuel consumption and CO_2 emissions from passenger cars in Europe – Laboratory versus real-world emissions. *Progress in Energy and Combustion Science*. 2017. Vol. 60. P. 97-131.
2. Ji, C. & Yu, M. & Wang, S. et al. The optimization of on-board H_2 generator control strategy and fuel consumption of an engine under the NEDC condition with start-stop system and H_2 start. *International Journal of Hydrogen Energy*. 2016. Vol. 41. No. 42. P. 19256-19264.
3. Kirchhoff, R. & Thele, M. & Finkbohner, M. & Rigley, P. & Settgast, W. Start–Stop system – distributed in-car intelligence. *ATZextra worldwide*. 2010. Vol. 15. No. 11. P. 52-55.
4. Nalbach, M. & Hoff, C. & Korner, A. *Power system architectures for 2nd generation micro hybrids.* ATZelektronik worldwide edition. 06. 2013.
5. Łukasik, Z. & Kuśmińska-Fijałkowska, A. & Kozyra, J. Eco-friendly technology to reduce CO_2 emissions of passenger cars based on innovative solutions. *Przegląd Elektrotechniczny*. 2016. Vol. 92. No. 8. P. 255-258.
6. Malfettani, S. & Lodi, C. & Huld, T. & Bonnel, P. Latest Developments on the European Eco-innovation Scheme for Reducing CO_2 Emissions from Vehicles: Average Input Data for Simplified Calculations. *Transportation Research Procedia.* 2016. Vol. 14. P. 4113-4121.
7. Cieślak, W. & Pielecha, J. Effects of utilization of the start-stop system in urban traffic conditions. *Logistyka*. 2015. Vol. 3. P. 779-788.
8. Cieślak, W. & Pielecha, J. & Borowski, P. Effects of start-stop system on the operation of drive system in urban traffic conditions. *Journal of Mechanical and Transport Engineering*. 2015. Vol. 67. No. 2. P. 15-26.
9. Ibarra, D. & Ramirez-Mendoza, R.A. & López, E. & Bustamante, R. Influence of the automotive. Experimental study. *Applied Acoustics*. 2015. Vol. 100. P. 55-62.
10. Ball, P.D. Developing and Start-stop Production System Concept. *IFAC-PapersOnLine*. 2017. Vol. 50. No. 1. P. 9321-9328.
11. Pinar, F.J. & Rastedt, M. & Pilinski, N. & Wagner, P. Effect of idling temperature on high temperature polymer electrolyte membrane fuel cell degradation under simulated start/stop cycling conditions. *International Journal of Hydrogen Energy*. 2016. Vol. 41. No. 42. P. 19463-19474.
12. Ozdemir, A. & Mugan, A. Stop / Start System Integration to Diesel Engine and System Modeling & Validation. *IFAC Proceedings Volumes*. 2013. Vol. 46. No. 25. P. 95-100.
13. Ramos, A. & Muñoz, J. & Andrés, F. & Armas, O. NO_x emissions from diesel light duty vehicle tested under NEDC and real-word driving conditions. *Transportation Research*, Part D: *Transport and Environment*. 2018. Vol. 63. P. 37-48.
14. Samaras, C. & Tsokolis, D. & Toffolo, S. et al. Improving fuel consumption and CO_2 emissions calculations in urban areas by coupling a dynamic micro traffic model with an instantaneous emissions model. *Transportation Research*, Part D: *Transport and Environment*. 2018. Vol. 65. P.772-783.

15. Fonseca, N. & Casanova, J. & Valdés, M. Influence of the stop/start system on CO_2 emissions of a diesel vehicle in urban traffic. *Transportation Research.* Part D: *Transport and Environment*. 2011. Vol. 16. No. 2. P. 194-200.
16. D'Annibale, A. & Di Ilio, A. & Trozzi, M. & Bonaventura, L. The Use of Infrared Thermography for Maintenance Purposes in the Production Process of Components for Automotive. *Alternators Procedia CIRP*. 2015. Vol. 38. P. 143-146.
17. Ming Tan, C. & Chiu, J. & Liu, R. & Zhang, G. Reliability screening through electrical testing for press-fit alternator power diode in automotive application. *Microelectronics Reliability*. 2005. Vol. 45. Nos. 9-11. P. 1723-1727.
18. Commission Implementing Regulation (EU) No 427/2014 of 25 April 2014 establishing a procedure for the approval and certification of innovative technologies for reducing CO_2 emissions from light commercial vehicles pursuant to Regulation (EU) No 510/2011 of the European Parliament and of the Council.
19. Commission Implementing Regulation (EU) No 725/2011 of 25 July 2011 establishing a procedure for the approval and certification of innovative technologies for reducing CO_2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council.
20. *ISO 8854. Road vehicles – Alternators with regulators – Test methods and general requirements*. Reference number ISO 8854:2012(E).
21. Commission Implementing Decision of 25 July 2011 on the approval of the battery charging Webasto solar roof as an innovative technology for reducing CO_2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council.

Received 11.12.2019; accepted in revised form 13.05.2021