DETERMINATION OF THE TOTAL EFFICIENCY OF DIRECT INJECTION SI ENGINE WORKING ON STRATIFIED CHARGE

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Abstract

The paper presents determination of the total efficiency of GDI Engine working on stratified charge. For the determination of the total efficiency of a Gasoline Direct Injection engine, test bed investigations were carried out with the aim to determine the speed and load characteristics of the investigated engine. On this basis, the total efficiency of a GDI engine can be determined. The results of the performed analysis were given in two-dimensional diagrams. Characteristics of full power and torque in dependence on rotational speed, characteristics of torque for increasingly smaller partial powers in function of rotational speed, characteristics of partial loads r in function of rotational speed, relation of fuel consumption per hour and per unit for full value of rated power in dependence on rotational speed, load characteristics of fuel consumption in function of torque at constant rotational speeds, relation of fuel consumption in function of rotational speed and relation of total efficiency η_0 in function of rotational speed are presented in the paper.

Keywords: *GDI engine, total efficiency, stratified charge*

1. Introduction

Engine constructors aim, at increasing the value of total efficiency, and not only one of the constituting partial efficiencies. Hence, a thorough analysis of the abovementioned factors is crucial, for its real value is justified.

Another positive aspect for designing is the possibility of a computer simulation of the mechanism occurring in the cylinder and the elaboration of mathematical models that allow a quick calculation of the parameters we are interested in. The application of such calculation methods helps in the determination of preliminary structural assumptions and makes it possible to design arbitrary shapes of co-working parts in order to choose the best solutions.

The aim of the present work is to prove an increase in the general efficiency of a GDI (Gasoline Direct Injection) engine and its dependence on the quality of stratified mixture and the loading range. This combination of computer methods and model investigations with test bed investigations yields an exact description of the processes occurring inside the cylinder and makes it possible to achieve a considerable decrease in production costs and to modify the elements of a gasoline engine.

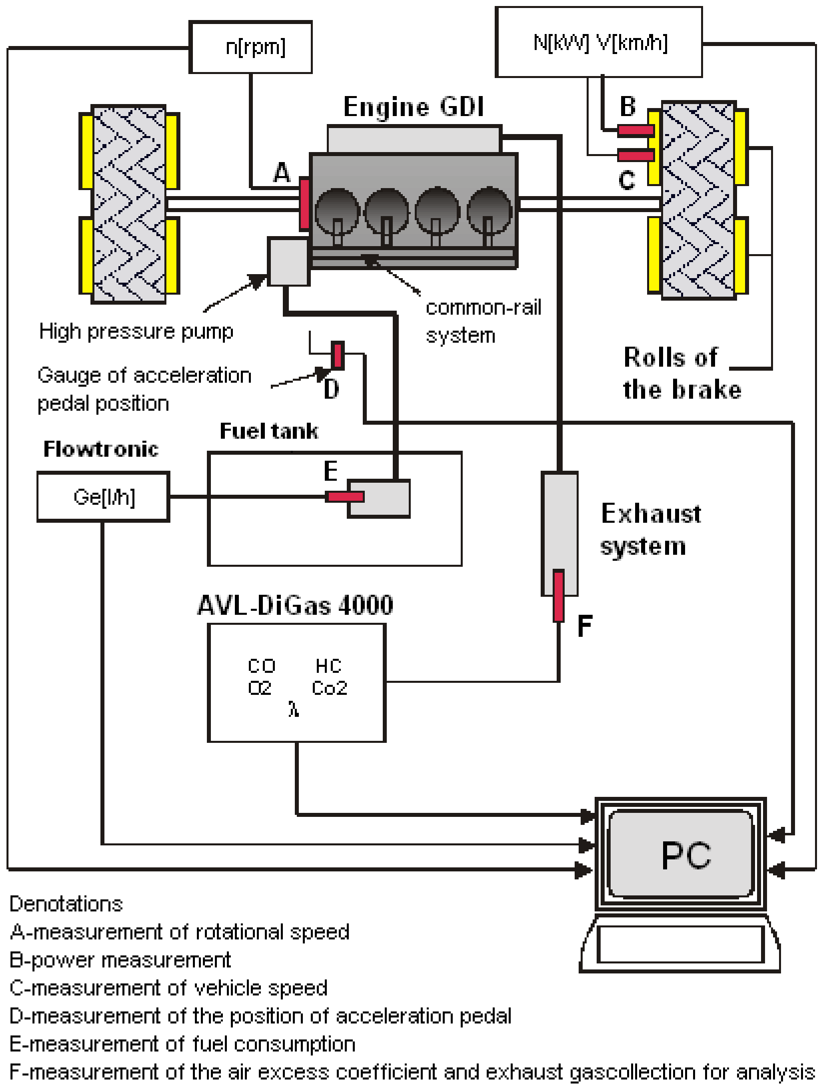

Fig.1. Scheme of the test bed

2. Test bed investigations of the 4G93 GDI engine

A roller chassis test bed, equipped with an electrically controlled water brake, whose maximal moment was 180 [Nm], was adopted for the determination of speed and load characteristics of an 1834-cm^3 Mitsubishi 4G93GDI engine.

The system was equipped with meters of vehicle speed V [km/h] and power on wheels [kW].

The system for fuel consumption measurement was equipped with a Flowtronic apparatus, measuring fuel consumption per hour Ge [l/h], connected to the fuel pump located in the fuel tank.

The AVL DiGas 4000 system for the measurement of toxic component content in the exhaust gases was connected to the exhaust system using a sound. The measurements considered the content of CO, CO_2, O_2, and HC, and the coefficient of air excess λ.

The system for the measurement of the engine's rotational speed was equipped with a crankshaft angle encoder (Angle Encoder 364 made by AVL) on a pulley.

Additionally, a positioner was used allowing an exact determination of the accelerator position.

All the measurement systems were integrated with the central measurement computer mounted on the test bed to allow a precise determination of all possible data for a given rotational speed and load of the investigated engine.

The scheme of the measurement test bed used for the determination of speed and load characteristics of the investigated engine is provided in Fig.1.

2.1. Speed characteristics

In the two-dimensional diagrams below, speed characteristics of the investigated Mitsubishi GDI engine are presented. Fig.2 shows the full power characteristics representing the relation between the engine's effective power and torque.

In Fig.3 and Fig.4 the moment and power relations for increasingly smaller partial powers are shown respectively for the full value, 3/4, 1/2 and 1/4 of the rated power in function of the crankshaft's rotational speed.

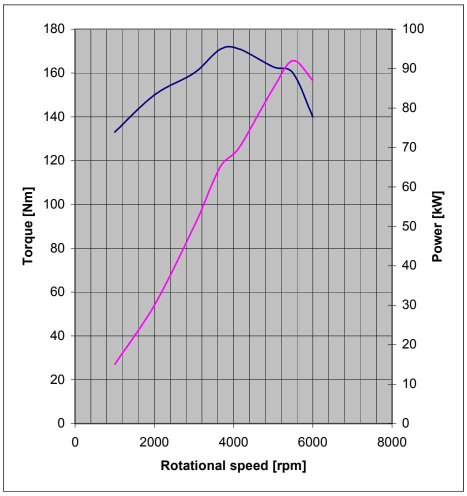

Fig. 2. Characteristics of full power representing the relation between the engine's effective power and torque in dependence on rotational speed

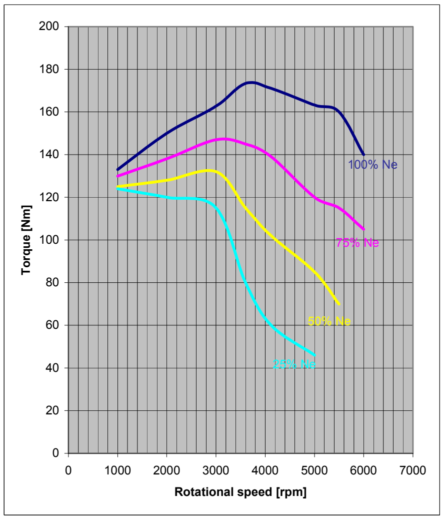

Fig. 3. Characteristics of torque for increasingly smaller partial powers respectively for full value, 3/4, 1/2 and 1/4 of rated power in function of rotational speed

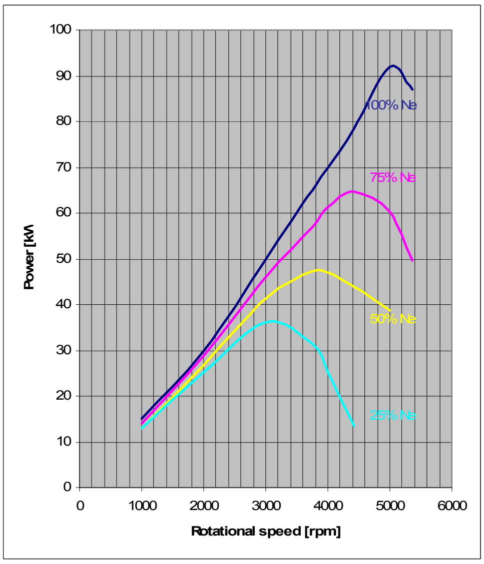

Fig .4. Characteristics of partial loads respectively for full value, 3/4, 1/2 and 1/4 of rated power in function of rotational speed

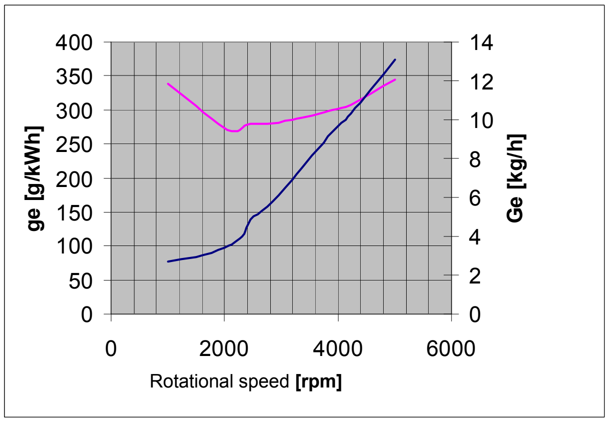

Fig. 5 Relation of fuel consumption per hour and per unit for full value of rated power in dependence on rotational speed

Next, in Fig.5-8**,** characteristics of partial powers representing the relation between the engine's effective power, torque, and fuel consumption per hour and per unit are presented respectively for the full value, 3/4, 1/2 and 1/4 of the rated power in function of the crankshaft's rotational speed.

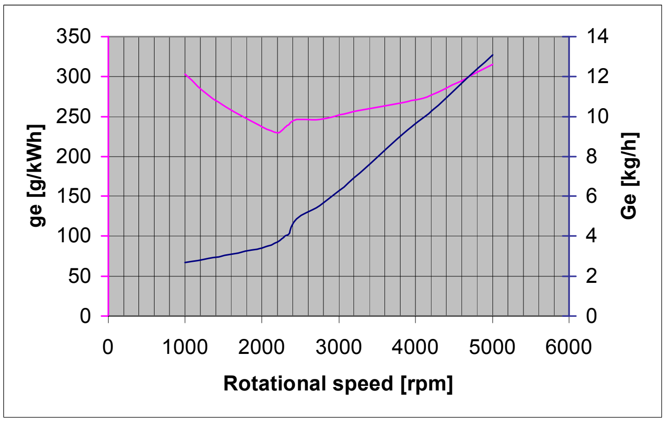

Fig. 6. Relation of fuel consumption per hour and per unit for 3/4 of rated power in dependence on rotational speed

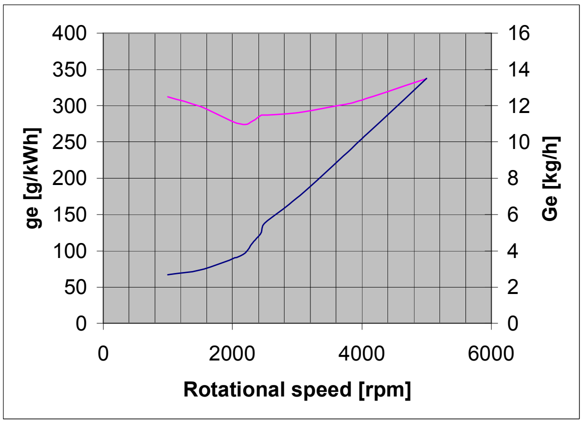

Fig. 7. Relation of fuel consumption per hour and per unit for 3/4 of rated power in dependence on rotational speed

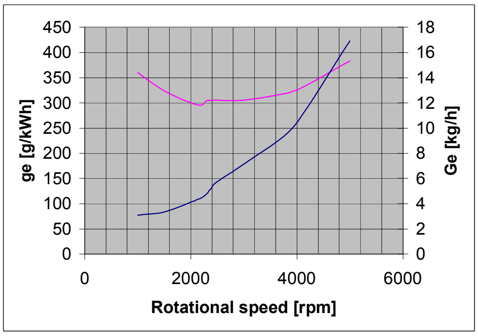

Fig. 8. Relation of fuel consumption per hour and per unit for 1/4 of rated power in dependence on rotational speed

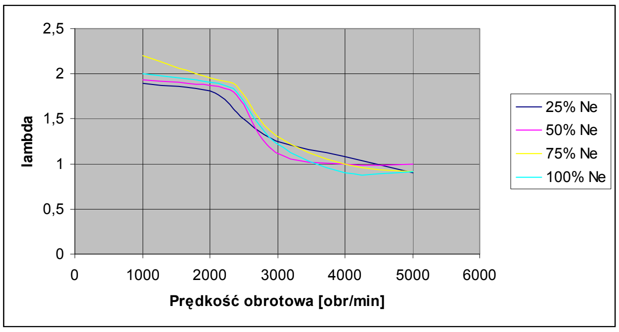

Fig. 9. Relation of the coefficient of air excess respectively for full value, 3/4, 1/2 and 1/4 of rated power in function of rotational speed

The test bed investigations resulted in a number of speed characteristics. In Fig.2**,** the full power characteristics of the 4G93GDI engine are presented, showing the relation between the engine's effective power and torque in dependence on its rotational speed. According to the test bed investigations, the value of maximal engine power is 95 [kW] at 5500 [rpm], whereas the value of maximal engine torque is approximately 175 [Nm] at 3750 [rpm]. The engine shows significant elasticity already within the speed range of 2500 [rpm] to 5500 [rpm].

As for the full power characteristics concerning the relation of fuel consumption per hour and per unit in dependence on the engine's rotational speed (Fig.5), an evident drop in fuel consumption per unit is noticeable. It lasts until the speed of 2500 [rpm] is reached and is followed by a rapid increase. This is caused by the engine being switched from working on a stratified mixture (heterogeneous - approximately $\lambda = 1,6\div2,1$) to working on a homogeneous mixture ($\lambda \cong 1$).

Additionally, Fig.9 shows the relation of the coefficient of air excess in dependence on the engine's rotational speed.

2.1. Load characteristics

The subsequent two-dimensional diagrams show the load characteristics of the investigated Mitsubishi 4G93GDI engine. Fig.10-11 present load characteristics and a graphic relation of fuel consumption per unit and per hour in function of torque for constant rotational speeds of 2000 and 1500 [rpm].

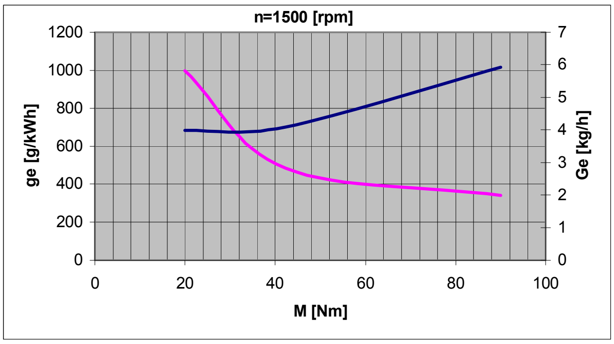

Fig. 10. Load characteristics presenting the relation of fuel consumption per unit and per hour in function of torque at constant rotational speed n=1500 [rpm]

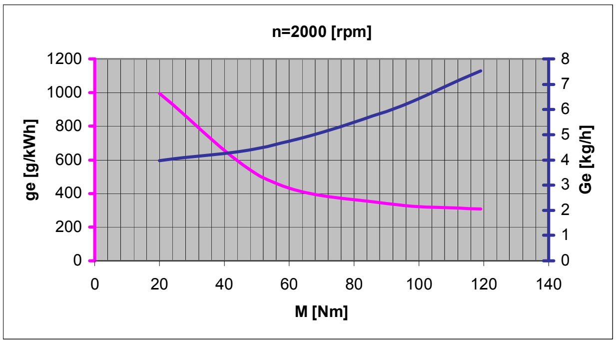

Fig. 11. Load characteristics presenting the relation of fuel consumption per unit and per hour in function of torque at constant rotational speed n=2000 [rpm]

2.2 Determination of the total efficiency of a GDI engine based on test bed investigation results

In order to determine the total efficiency of the 1834-cm^3 Mitsubishi 4G93GDI engine, use was made of the speed characteristics obtained during the test bed investigations of the relation of fuel consumption per unit in function of the engine's rotational speed.

With regard to a considerable decrease in fuel consumption per hour and per unit between the rotational speeds of 750 and 2700 [rpm], which was caused by the engine working in the mode of stratified fuel-air mixture ($\lambda \cong 1,5\text{-}2,1$) depending on the engine's rotational speed and load), the diagrams had to be complemented by additional characteristics of fuel consumption per unit. With this aim in mind, diagrams of fuel consumption per unit within the same range of rotational speed (750–2700 [rpm]) were drawn in the same way as for the engine working on a homogeneous mixture ($\lambda \cong 1$). In consequence, the value of fuel consumption per unit does not show the characteristic jump from one mode of work to the other.

Fig.12-19 show some traces of changes in the GDI engine's fuel consumption per unit and its total efficiency in function of its rotational speed.

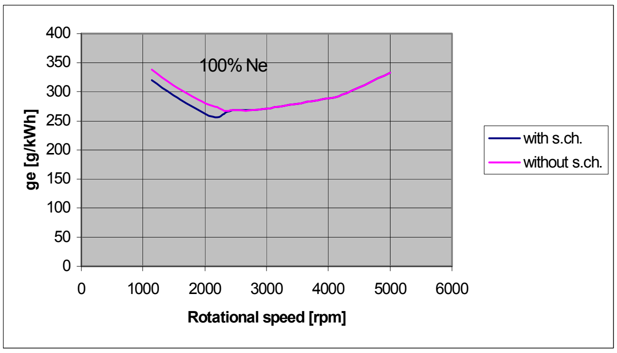

Fig. 12. Relation of fuel consumption per unit in function of rotational speed at full power

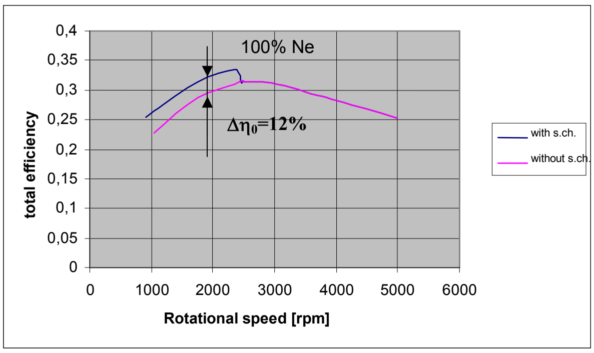

Fig. 13. Relation of total efficiency η_0 in function of rotational speed at full power

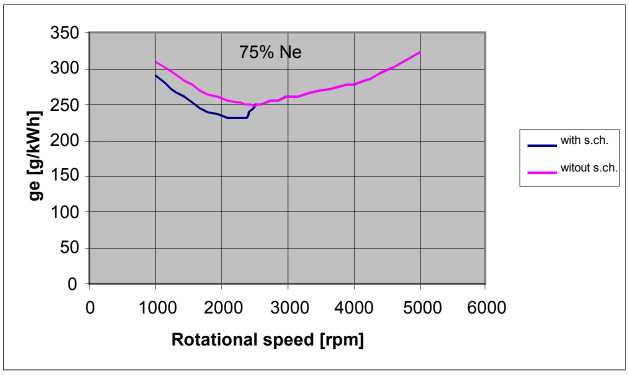

Fig. 14. Relation of fuel consumption per unit in function of rotational speed at 3/4 of rated power

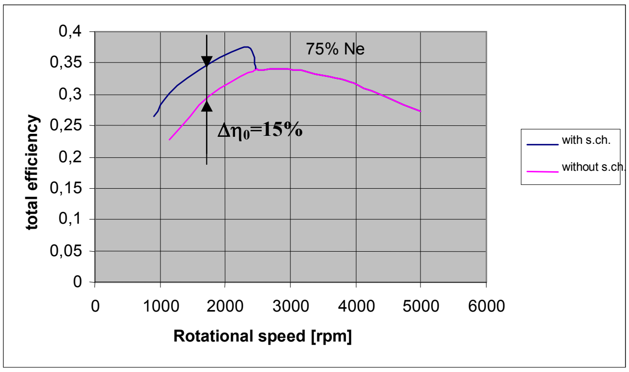

Fig. 15. Relation of total efficiency η_0 in function of rotational speed at 3/4 of rated power

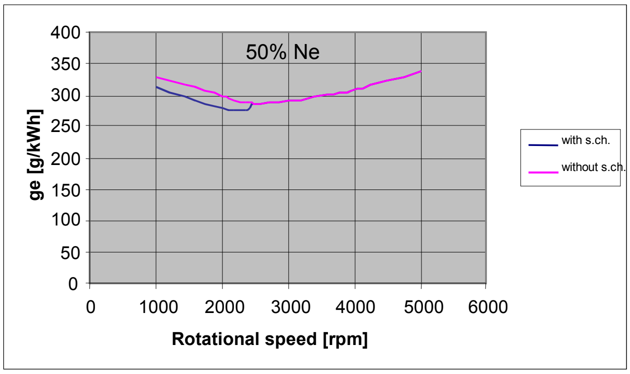

Fig. 16. Relation of fuel consumption per unit in function of rotational speed at 1/2 of rated power

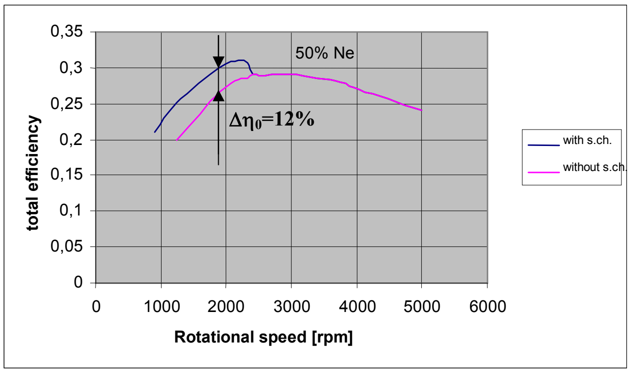

Fig. 17. Relation of total efficiency η_0 in function of rotational speed at 1/2 of rated power

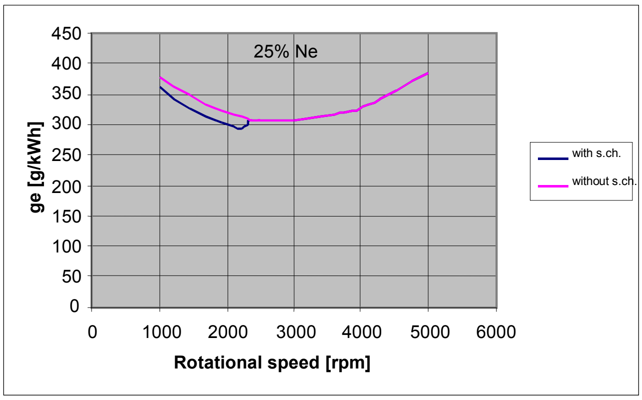

Fig. 18. Relation of fuel consumption per unit in function of rotational speed at 1/4 of rated power

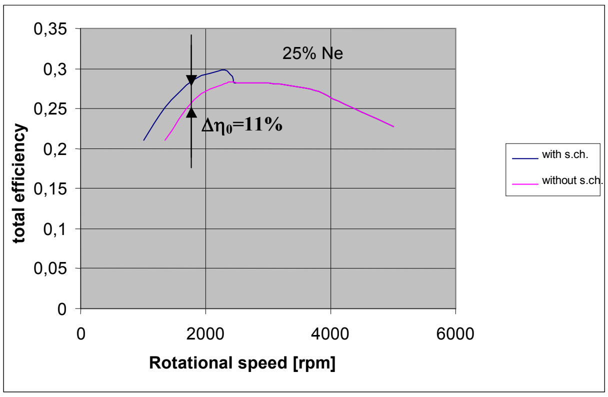

Fig. 19. Relation of total efficiency η_0 in function of rotational speed at 1/4 of rated power

3. Conclusion

The test bed investigations we carried out, whose aim was to demonstrate an increase in the total efficiency of a GDI engine, allow us to arrive at the following conclusions:

1. A considerable increase of approximately 17% has been noticed in the total efficiency of the investigated gasoline direct injection engine at the determined rotational speed when the engine worked on stratified mixtures (injection during the compression stroke). As a result, fuel consumption per unit and per hour decreases by approximately 17%.
2. The air excess coefficient value during work on a heterogeneous mixture increases to $\lambda \cong 2{,}2$.
3. Stratification of the charge depends, first of all, on the engine's rotational speed and load, and remains at this level to approximately 2700 [rpm].

4. A characteristic moment of transition from the engine working on a heterogeneous mixture to it working on a homogeneous mixture is noticeable in the form of a rapid jump of fuel consumption per unit by approximately 60 [g/kWh] on all characteristics of partial powers (i.e. for the full value, 3/4, 1/2 and 1/4 of the rated power).
5. When the engine works in the idle gear, a decrease in the rotational speed to approximately 600 [rpm] is noticeable. As a result, fuel consumption decreases in the idle gear.
6. The range of rotational speeds where the total efficiency increases is 600-2700 [rpm] depending on the engine's working conditions.

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