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RESEARCH OF THE IGNITION ADVANCE ANGLE CHARACTERISTICS ON THE EXAMPLE OF A GERMAN GX 390 COMBUSTION ENGINE

Contemporary motor vehicles are equipped with efficient and eco-friendly engines. It is possible to control electronically such parameters as the ignition advance angle, whose computational model takes into account multiple variables. These characteristics are often determined by empirical studies and then programmed in the controller. Due to the adaptability of these systems to the operating conditions, manufacturers often do not anticipate their regulation, resulting in the lack of publication of the above-mentioned characteristics so called "ignition map". Combustion engines are found both in vehicles and in machines and non-road vehicles for which homologation standards are less restrictive. The article presents the methods of recording and reproducing the ignition timing characteristics of the German GX390 engine designed for non-road mobile machines according to operating conditions. Results obtained in tests may be used to as inputs to modify systems controlling combustion engines.

INTRODUCTION

The efficiency of the processing processes depends on the efficiency of the working mechanisms used, the drives and the processed raw materials. Among non-road mobile machinery such as i.e.: chipping, shredder, industrial drilling equipment, generators, water pumps, hoisting cranes, a device for snow removal, etc. internal combustion engines are used as a drive [10]. Mostly these are a spark-ignition engine which is subject to European approval regula-tions 2016/1628/EU [6]. These regulations are liberal and do not force manufacturers to adopt innovative designs for ignition systems and fuel supply.

The ignition system is one of the two basic components responsible for the quality of exhaust gases [7, 11] and drive efficiency [5]. Its purpose is to generate an electric spark between the spark plug electrodes in the correct position of the piston while the engine is running. Over the years, it has been observed that the optimum moment in which a spark ignites and the moment the piston reaches the Top Turn Point (TTP) is variable and depends on many factors. The rotation speed and engine load can be indicated as the main ones [1, 8]. In the automotive industry already several decades ago the ignition advance angle mechanisms have been replaced by electronic circuits.

On the other hand, in non-roadmatic motors, structures without ignition timing changeover systems meet the approval standards [6, 10]. The lack of such solutions can limit their efficiency and affect emissions. This article presents methods of controlling the ignition advance angle and the method of measuring the ignition angle. The results of the research of the ignition system of the new German GX390 combustion engine for the drive non-road moving machines are presented.

1. REVIEW OF CONSTRUCTION

The design of the ignition system over the years has undergone a structural change, and with them, the systems of ignition angle. Eliminated mechanical systems for electronic systems that have the following advantages:

- a large number of variables included;
- flexible characteristics;
- no loss of settings due to wear.

This has led to the widespread use of such solutions in the automotive industry. However, they have not been adopted in non-road mobile machines.

1.1. Mechanical adjustment of the ignition advance angle

Ignition angle regulation that depends on rotation speed uses centrifugal regulators (fig. 1) whereas the one depending on the load vacuum regulators (fig. 2). There were systems using one and the other method of regulation simultaneously. The disadvantage of this type of system was limited characteristics and loss of settings due to wear. Later, these structures were replaced by electronic ignition advance angle control.

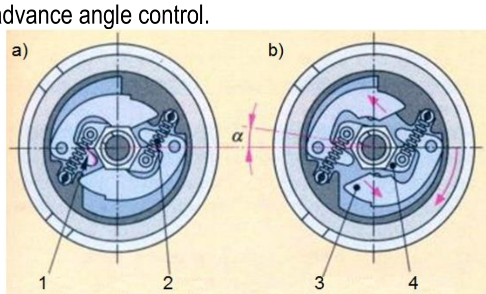

Fig. 1. *Construction of the centrifugal ignition angle regulator: a) rest position: 1-envelope, 2-return spring; b) operating position: 3-counterweight, 4-carrier [9]*

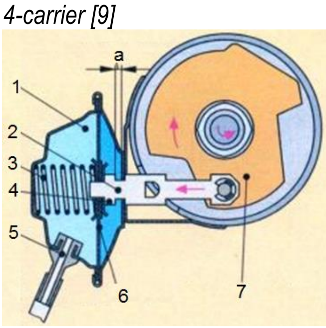

Fig. 2. *Construction of a vacuum ignition timing regulator: 1- vacuum box, 2-wire, 3-compression spring, 4-bumpers, 5-connection to the inlet pipe below the throttle, 6- membrane, 7- movable plate interrupter, a- adjustment path [9]*

1.2. Electronic ignition timing adjustment

The electronic ignition timing adjustment system allows it to be adjusted according to the rotational speed and engine load. Such control provides a wide range of potential ignition timing characteristics and require no adjustment. In addition, the system equipped with a knock sensor, engine temperature, suction air temperature, etc., takes into account the parameters [2] in the control algorithm. An example of the ignition advance angle algorithm α_{wz} is shown in (1) [4].

$$\alpha_{wz} = \beta_{L,\omega} + a + b + c + d + e + f + g \qquad (1)$$

where:

$\beta_{L,\omega}$ - the value of the ignition advance angle from the load map and the speed of rotation (fig 3);

a - correction of the ignition advance angle as a function of the cylinders;

b - correction of the ignition advance angle as a function of the suction air temperature;

c - correction of the ignition advance angle as a function of the coolant temperature;

d - Ignition advance angle correction due to occurring knock combustion;

e - ignition advance angle correction by the speed controller;

f - ignition angle correction when the "Launch Control" function is activated;

g - correction of the ignition angle as a function of the throttle position and pressure in the suction manifold.

2. RESEARCH OBJECT

The German GX39 four-stroke engine was designed to drive non-road mobile machines with a power output of 9.6 kW (13 HP) at a rotational speed of 3600 rpm. The engine complies with the latest homologation standards applicable in the European Union. The available ignition system information is missing from the above mentioned drive unit. Ignition timing data has been determined to obtain input data for the engine modification. The ignition system is shown in figures 4 and 5.

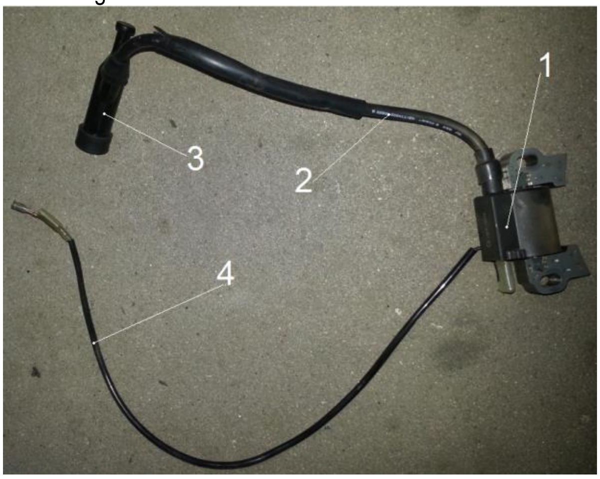

Fig. 4. German GX39 engine ignition system where: 1- Ignition coil with control module, 2-wire high voltage, 3- spark plug, 4-wire ignition signal

																RPM (rpm)
35,0	35,0	35,0	31,0	29,0	27,0	26,0	21,0	18,0	14,0	14,0	14,0	10,0	10,0	10,0	10,0	7500
29,0	29,0	29,0	26,0	24,0	23,5	19,5	16,0	18,5	14,5	13,5	13,5	10,0	10,0	10,0	10,0	7000
23,0	23,0	23,0	21,0	19,0	20,0	13,0	11,0	19,0	15,0	13,0	13,0	10,0	10,0	10,0	10,0	6500
21,0	21,0	21,0	19,5	18,0	18,0	13,0	11,5	17,0	12,5	10,5	10,5	10,0	10,0	10,0	10,0	6000
19,0	19,0	19,0	18,0	17,0	16,0	13,0	12,0	15,0	10,0	8,0	8,0	10,0	10,0	10,0	10,0	5500
18,5	18,5	18,5	18,0	16,5	16,0	12,5	11,0	12,5	8,0	6,0	6,0	10,0	10,0	10,0	10,0	5000
18,0	18,0	18,0	18,0	16,0	16,0	12,0	10,0	10,0	6,0	4,0	4,0	10,0	10,0	10,0	10,0	4500
16,5	16,5	16,5	16,0	14,5	15,0	11,0	7,5	9,0	6,0	4,0	4,0	10,0	10,0	10,0	10,0	4000
15,0	15,0	15,0	14,0	13,0	14,0	10,0	5,0	8,0	6,0	4,0	4,0	10,0	10,0	10,0	10,0	3500
15,0	15,0	15,0	13,5	12,5	13,0	8,0	4,0	5,5	4,5	2,5	2,5	10,0	10,0	10,0	10,0	3000
15,0	15,0	15,0	13,0	12,0	12,0	6,0	3,0	3,0	3,0	1,0	1,0	10,0	10,0	10,0	10,0	2500
11,0	11,0	11,0	11,0	9,0	9,0	5,0	2,0	1,0	0,0	-2,0	-2,0	10,0	10,0	10,0	10,0	2000
8,0	8,0	15,0	19,0	12,0	10,0	4,0	0,0	-2,0	-2,0	-4,0	-4,0	10,0	10,0	10,0	10,0	1500
5,0	5,0	12,0	12,0	5,0	4,0	0,0	-3,0	-3,0	-3,0	-6,0	-6,0	10,0	10,0	10,0	10,0	1250
5,0	5,0	5,0	5,0	5,0	4,0	0,0	-4,0	-4,0	-4,0	-6,0	-6,0	10,0	10,0	10,0	10,0	1000
5,0	5,0	5,0	5,0	5,0	4,0	0,0	-4,0	-4,0	-4,0	-6,0	-6,0	10,0	10,0	10,0	10,0	750
20	25	31	36	41	47	52	57	63	68	73	79	84	89	95	100	

MAP sensor load (kPa)

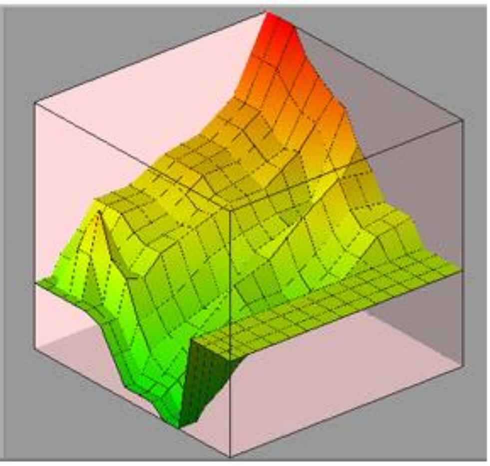

Fig. 3. Example of ignition advance angle characteristic depending on load and engine rotational speed

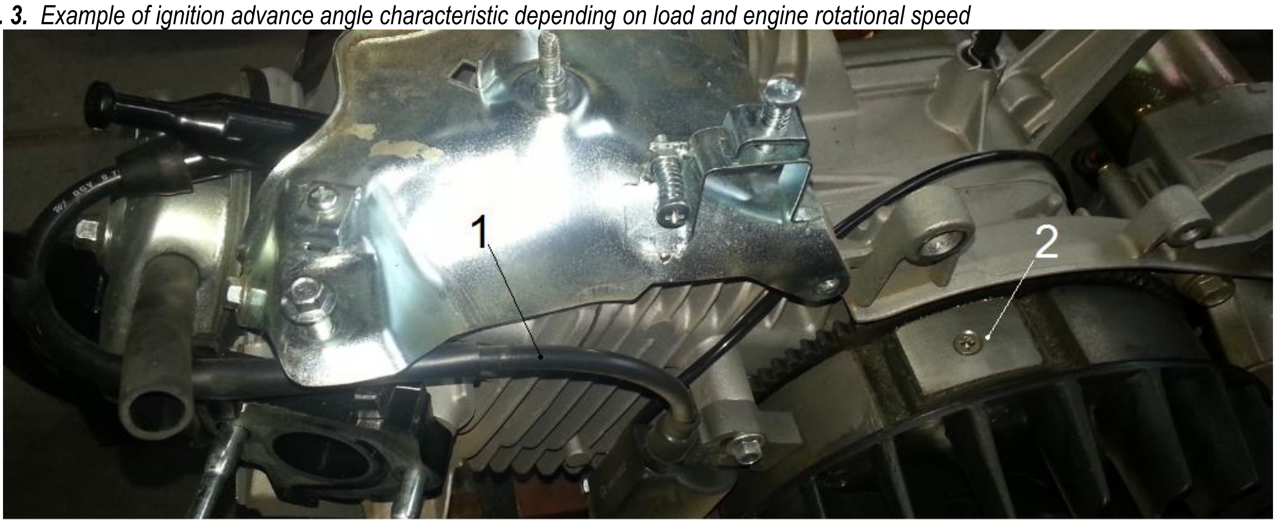

Fig. 5. German engine GX390 engine ignition system where: 1- high-voltage induction and spark-ignition assembly, 2- flywheel magnet inducing high-voltage coil

3. RMETHODOLOGY OF RESEARCH

3.1. Stroboscopic method of measuring ignition advance angle

Ignition timing systems are mainly used for diagnostic or regulation [3]. The proposed methodology is intended to gather system characteristics according to operating conditions.

The internal combustion engine has at least one reference point indicating the position of the upper turning point "A". The strobe enables to determine the moving point of the ignition point "B" or, as in the case of the test object, indicates the mark on the impulse plate, which characterizes the ignition timing (figures 6 and 7).

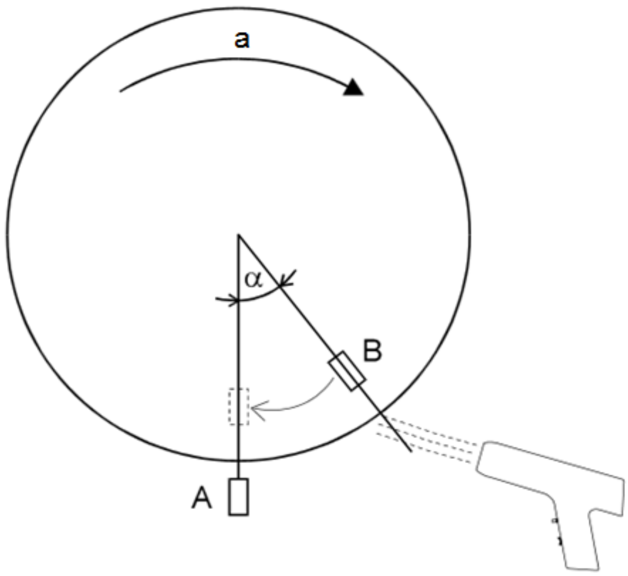

Fig. 6. Method of determining the ignition advance angle by the stroboscope method: α- ignition advance angle, a- direction of rotation of the crankshaft [12]

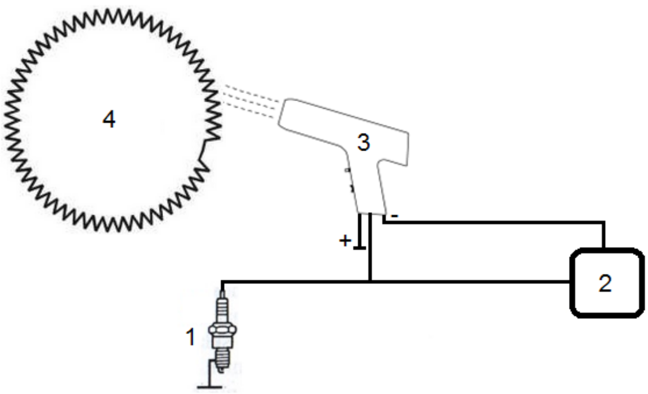

Fig. 7. Diagram of the ignition angle with flash strobe: 1- spark plug, 2- coil, 3- strobe lamp, 4- impulse wheel "60-2"

3.2. Oscilloscope method of measuring ignition advance angle

Determining the ignition angle of the examined combustion engine with an oscilloscope requires that it must be equipped with an inductive sensor and an impulse disc (fig. 8). Recording the impulse of the impulse wheel and the ignition timing enables to determine the value of the ignition angle in degrees (figures 9 and 10).

Fig. 8. German spark ignition engine GX390 equipped with: 1- induction sensor, 2 impulse wheel

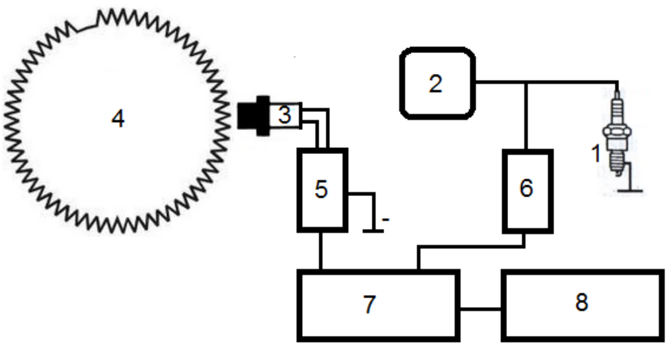

Fig. 9. Diagram of the ignition advance angle with an oscilloscope: 1- spark plug, 2-coil ignition, 3- induction speed sensor, 4- impulse wheel "60-2", 5- high-voltage measuring probe, 6- capacitive measuring probe, 7- oscilloscope, 8- PC with software

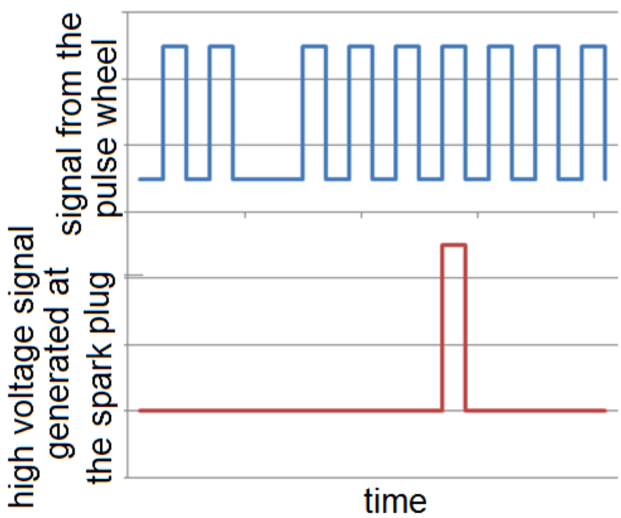

Fig. 10. Pulse signal characteristic of inductive sensor (blue), signal from high voltage probe indicating generated high voltage (red)

4. RESULTS OF THE STUDY

Recording the ignition advance value using the above methods allows to reproduce the characteristics of this parameter depending on the variable being implemented. The variable in this research was a change in the rotational speed or load of the engine. The results of the stroboscope test gave a value of 30° regardless of operating conditions and introduced variables. Oscilloscope studies were performed using the DSC Hantek 3064, and the results are shown in figures 11 and 12. The oscillograms show the characteristic of the impulse wheel (blue) and the characteristic of the induced high voltage (yellow).

The highest peak (yellow) represents the point of the spark jump that indicates the ignition point of the air-fuel mixture and, with respect to the blue peaks characterizing the teeth on the impulse wheel, determine the ignition advance angle. Bearing in mind that the first peak on the impulse wheel after the break is a zero impulse indicating the upper turning point, it is determined that the ignition occurs when the impulse wheel is on the fifth tooth, the indication equals 30°.

5. ANALYSIS OF RESULTS

Measurement of ignition angle with strobe and oscilloscope showed that the ignition advance angle is 30°. Interpretation based on the strobe and oscilloscope indicated the fifth pulse of the pulse from the upper turning point irrespective of the engine rotational speed. This indicates that in spite of the technologies available described in Chapter 2, the manufacturer did not apply the mechanisms responsible for controlling the ignition advance angle. This approach shows that it is possible to improve the parameters of this motor by introducing a control system with this parameter. In the case of the modernization of the structure with an integrated ignition and ignition system, the use of the ignition angle is mainly connected with the changes in the software. The introduction of such a modernization can affect aspects such as economics and the ecology of exploitation.

SUMMARY

The German GX39 engine ignition system for driving the non-road mobile machinery has shown that the engine is equipped with

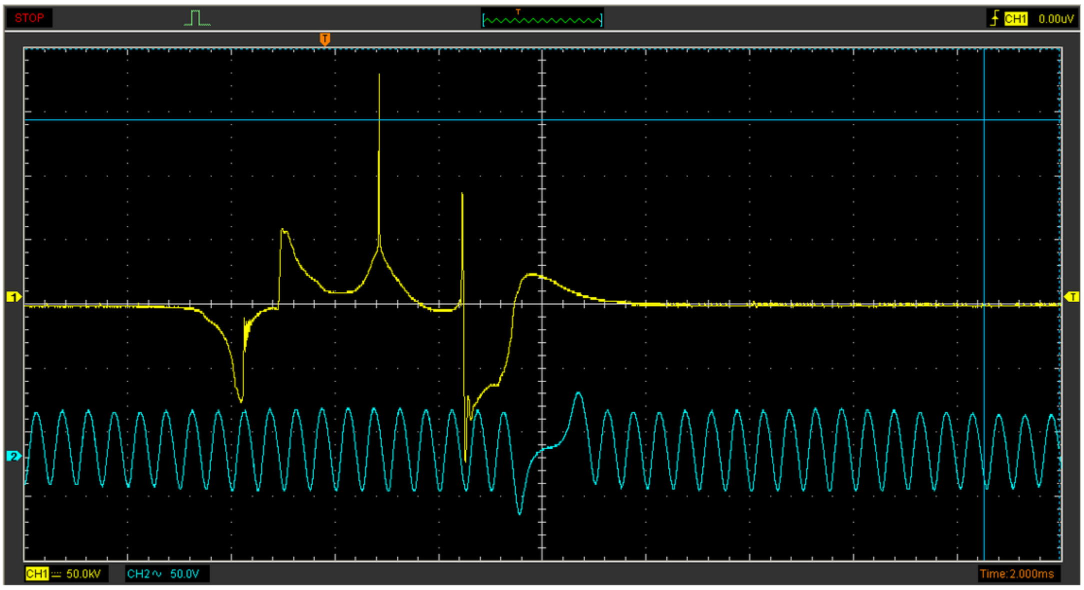

Fig. 11. *Oscillograph characterized by pulse wheel (blue), induced high voltage (yellow) at idle speed without load*

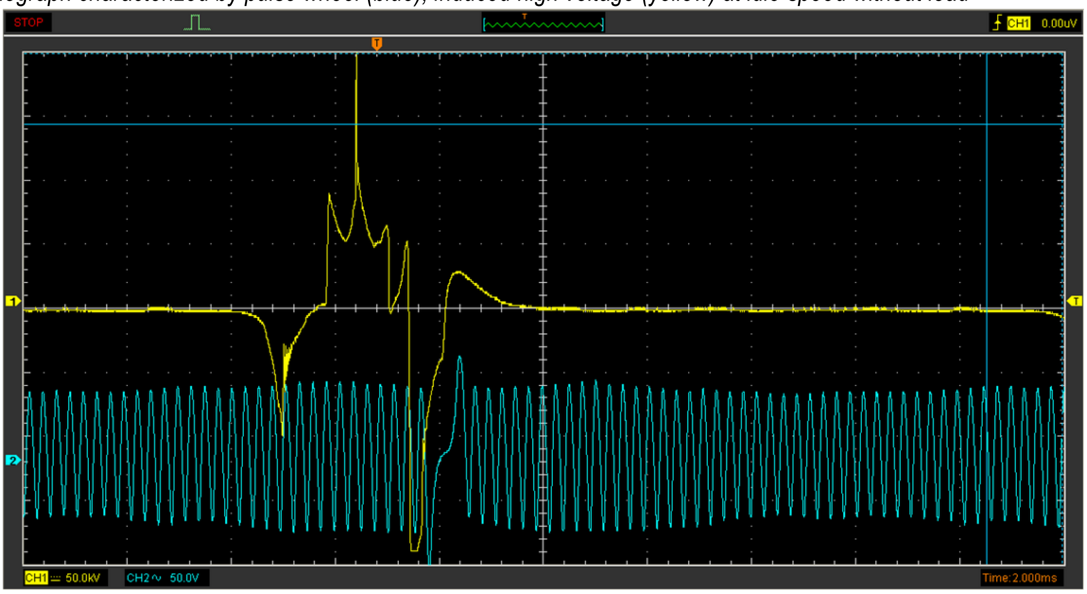

Fig. 12. *Oscillograph characterized by pulse wheel (blue), induced high voltage (yellow) characteristics at a rotational speed of 3800 rpm with load*

a ignition timing control system without ignition timing. Its value is constant and, depending on the operating conditions equals 30°. The system used in the engine manufactured in 2016 is technologically out-dated. The results will be used as inputs to the modification process of the construction, which will be equipped with an electronic ignition system with an ignition advance control algorithm that is ideally similar to modern vehicles.

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Badania charakterystyk kąta wyprzedzenia zapłony na przykładzie silnika German GX 390

Współczesne pojazdy samochodowe są wyposażone w efektywne i proekologiczne jednostki napędowe. Przyczynia się do tego elektroniczne sterowanie takim parametrem jak np. kąt wyprzedzenia zapłonu, którego model obliczeniowy uwzględnia wiele zmiennych. Charakterystyki te bardzo często są wyznaczane podczas badań empirycznych, a następnie programowane w sterowniku. Ze względu na adaptacyjność tych układów do warunków eksploatacji producenci często nie przewidują ich regulacji, co skutkuje brakiem publikacji wyżej wymienionych charakterystyk tzw. „map zapłonu". Silniki spalinowe spotyka się zarówno w pojazdach jak i w maszynach i urządzeniach pozadrogowych dla których normy homologacyjne są mniej restrykcyjne. W artykule przedstawiono metody rejestracji oraz odtwarzania charakterystyk kąta wyprzedzenia zapłonu silnika German GX390 przeznaczonego do pozadrogowych maszyn ruchomych w zależności od warunków eksploatacji. Wyniki uzyskane z badań mogą posłużyć jako dane wyjściowe w procesach modyfikacji układów sterowania silnikami spalinowymi.

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