



## USE OF LANGMUIR PROBE IN DIESEL ENGINE DIAGNOSTIC RESEARCH

### Part I MEASUREMENT TECHNOLOGY

**Zbigniew Korczewski  
Jacek Rudnicki**

*Gdansk University of Technology  
ul. Narutowicza 11/12, 80-233 Gdańsk, Poland  
tel.: +48 58 3472973, fax: +48 58 3471981  
e-mail: jacekrud@pg.gda.pl*

**Adam Cenian  
Leszek Piechowski**

*The Szewalski Institute of Fluid-Flow Machinery  
Polish Academy of Sciences  
Fiszera 14 st., Gdańsk 80-231, Poland  
e-mail: lpiechowski@imp.gda.pl*

#### **Abstract**

*In the paper, the basic assumptions of diesel engine cylinder system's diagnosing method, based on observation of emerging and moving electric charges of ionized gas in the combustion workspaces, using Langmuir's probe. In the first part of the paper, only the technology of the measurement and results of the preliminary diagnostic tests of laboratory engine Farymann Diesel D10 were presented. The primary purpose of the research was confirmation of susceptibility of a control diesel engine to a completely original measurement method that enables a precise determination of the angle of fuel's self-combustion. To verify the diagnostic utility of the obtained measurement data, simultaneously, the measurement of the cylinder pressure and generated vibrations coming from injection system and engine valve train (measured on the cover of the head or its tie bolt) were carried out.*

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*The solution of the measurement of the angle of fuel's self-combustion presented in the article was applied to Polish Patent Office. The application number is P.402669, titled: „Układ monitorowania kąta samozapłonu paliwa, zwłaszcza w cylindrze silnika o zapłonie samoczynnym z zastosowaniem sondy Langmuira”. (The monitoring system of the angle of fuel's self-combustion, in the cylinder of a diesel engine using Lagmuir's probe")*

**Keywords:** *technical diagnostics, diesel engine, Langmuir's probe*

## 1.Introduction

In spite of dynamic development of diesel engine cylinder system's diagnosing methods, the basic method of the evaluation of the workspace technical condition is parametrical evaluation of the work process, based on measurements of the pressure change in cylinders, using more precise digital indicators. The development of optical-electronically technique is so enormous that the measurements, concerning low-speed marine diesel engines, are carried out almost continuously (on-line) for it is enabled by high durability of modern fiber pressure converters (Optrand) [2].

Most of presently used, more excellent digital indicators, enables the obtainment of expanded indicator graphs, i.e. the course of pressures in the cylinder (measured on or ahead of indicator valve), imposed on properly filtered course of accelerations of generated vibrations from injection system and engine valve train (measured on the cover of the head or its tie bolt) that are referred to the angle location of the crankshaft (piston GMP). They are the basic source of diagnostic information for engine's workspace.

On the basis of simultaneous measurements of pressures in cylinders, vibrations of cylinder heads and the rotational speed of crankshaft it is possible to calculate the following diagnostic parameters of the engine workspace (figure 1):

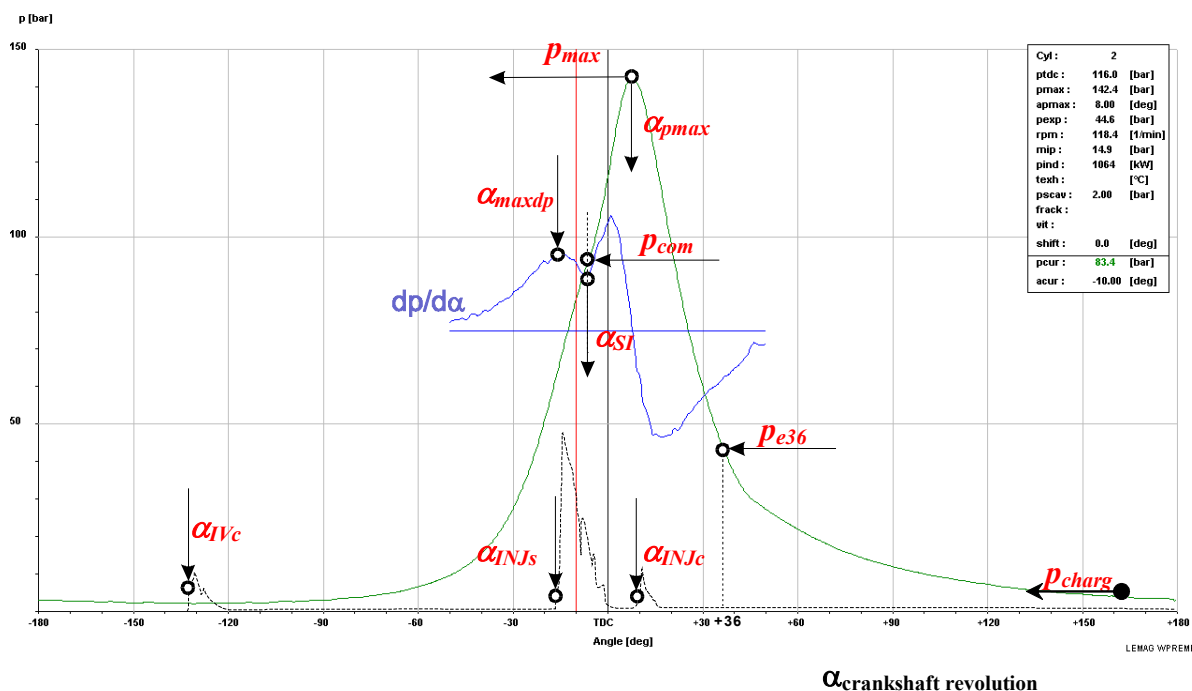


Fig. 1. Parameters characterizing expanded indicator diagram and the graph of the vibration envelope generated from the cylinder head cover:  $p_{max}$  – maximum pressure of combustion,  $p_{com}$  – maximum pressure of compression (optionally compression pressure for an angle  $10^\circ$  before TDC),  $p_{e36}$  – expansion pressure for an angle  $36^\circ$  after TDC,  $p_{charg}$  – charge air pressure,  $\alpha_{pmax}$  – angle of maximum combustion pressure,  $\alpha_{SI}$  – self-ignition angle of fuel,  $\alpha_{maxdp}$  – angle of maximum  $dp/d\alpha$ ,  $\alpha_{IVc}$  – intake valve closing angle,  $\alpha_{INJs}$  – fuel injection timing,  $\alpha_{INJc}$  – fuel injection end angle

- maximum pressure of compression and combustion -  $p_{comp}$  [bar],  $p_{max}$  [bar],
- mean indicated pressure of individual cylinders - MIP [bar]
- power indicated of individual cylinders and whole engine - PIND [kW],
- speed of pressure increase in cylinder -  $dp/d\alpha$  [bar/00WK],
- angles of opening and closing the injector -  $\alpha_{INJs}$ ,  $\alpha_{INJc}$  [00WK],
- angle of fuel's self-ignition beginning in cylinders -  $\alpha_{SI}$  [00WK],
- angles of opening and closing cylinders' valves -  $\alpha_{IVc}$  [00WK].

It enables us to perform:

- the evaluation of engine's cylinders tightness,
- the evaluation of equality of the load for individual cylinders,
- the evaluation of injection system and valve timing regulation,
- the evaluation of whole engine's achievements,
- the evaluation of engine and powertrain mechanical loss,
- the prognosis of time of engine's proper work.

The key metrological issue of the diagnostic process algorithm above is precise determination of the combustion beginning (the point of fuel's self-ignition) in the indicator graph. There are two methods of conduct:

- a) on the basis of a derivative waveform of the cylinder pressure registered [9, 3, 6],
- b) on the basis of the course of polytropic compression exponent [8].

The research carried out by the Authors of this paper enabled to suggest the original method of determination of the combustion beginning in the Diesel engine, based on entering the electrical probe, so called Langmuir's probe [1,4,5] directly to its combustion chamber. It enables the record of plasma generated in the combustion front fuel's parameters, after the initiation of air-fuel mixture self-ignition. The verification of the diagnostic method used is based on comparative analysis of measurement results acquired in simultaneous indication of cylinder and measurement of electrical signal course (voltage  $U_{wz}$ ), acquired in standard resistor  $R_{wz}=1\Omega$  included in the measurement system with Langmuir's probe.

## 2. The description of measurement system with Langmuir's probe.

The construction of Langmuir's probe is shown in Figure 2. It consists of two spaced metal electrodes positioned in space, where electrical charges can occur. The electrodes are connected to the power source  $U_{pol}$  and there's a voltage in between them and is consistent with the voltage of the power source used. If an electrical charge occurs in the space between electrodes (as electrons or ions), it causes flow of electric charge in seemingly detached electrical network.

Time of electric current flow (and its value) depends on time of electric charges occurring in the space between probe's metal electrodes. If Langmuir's probe is successfully entered to the workspace of diesel engine cylinder during the combustion process, it is expected that fuel self-ignition initiation will be accompanied by electrical charges formation. Electrical charges occurring along with combustion will be registered by Langmuir's probe.

If the moment of charge's formation (the beginning of fuel's self-ignition) with angular location of crankshaft, this time correlation enables to determine the angle of fuel self-ignition  $\alpha_{si}$ . In order to determine the time of charges formation occurring during the combustion process in relation to the course of pressure changes in the cylinder space, it is necessary to carry out simultaneous measurement of the pressure and voltage parameter of plasma generated.

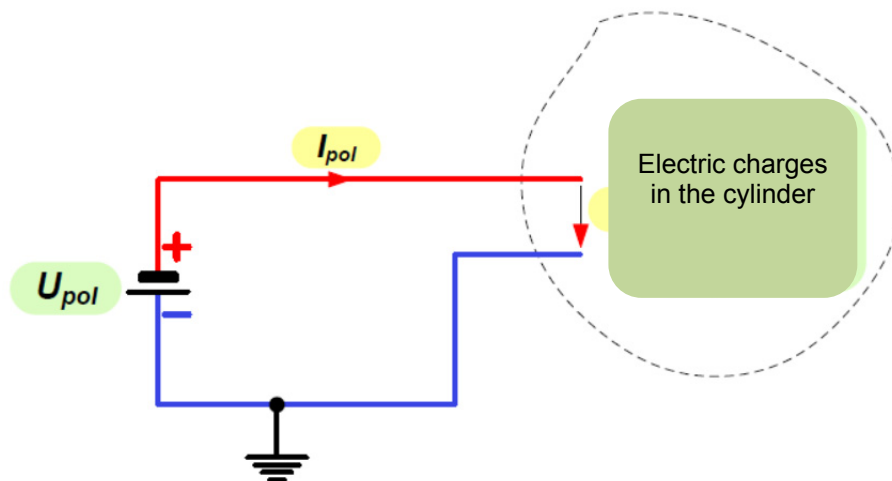


Fig.2 Structure and operation of the Langmuir probe

The operation of Langmuir's probe shown in figure 2 indicates when it is entered to the cylinder space, in the case of hydrocarbon flame initiation, in probe's electrical network an  $I_{pol}$  amperage occurs. Langmuir's probe consists of metal electrode polarized with  $U_{pol}$  voltage. An engine's trunk usually consists of a long electrode, which is why the probe should be isolated from the trunk. The simple measurement system shown in figure 3 allows an observation of  $I_{pol}$  amperage change. Oscilloscope allows both observation and registration of  $U_{wz}$  voltage change existing on  $R_{wz}$  dimmer, as a result of electric current flow with  $I_{pol}$ .

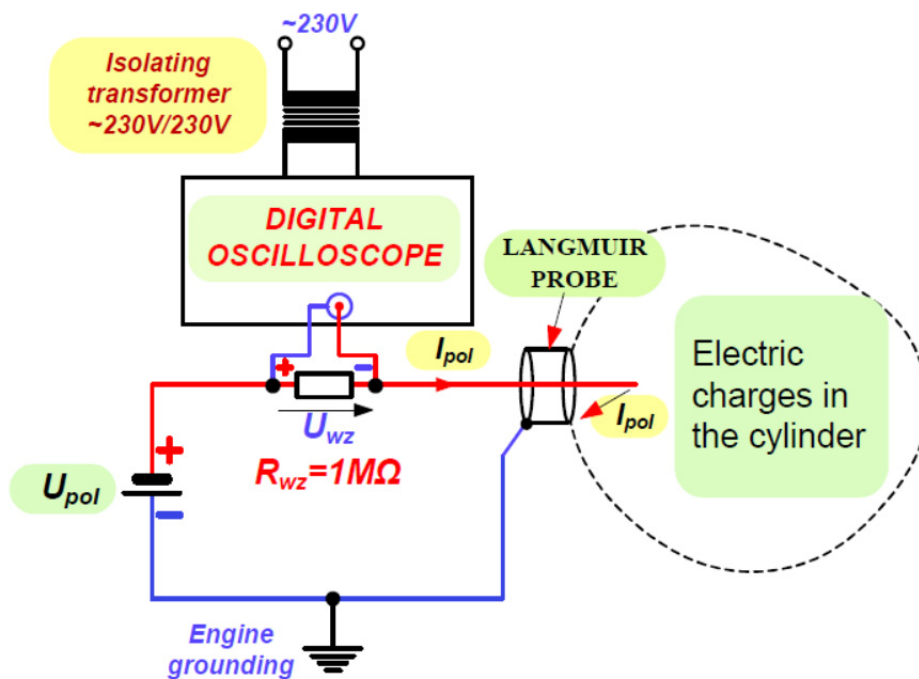


Fig.3. Langmuir probe circuit and registration setup with oscilloscope. It has to be noticed that the power source of an oscilloscope must be isolated (separated).

In passing it should be noted that it is vital to use the isolated (separated) power source for oscilloscope. Lack of this separation results in short circuit of oscilloscope's probe screen with electrical mass of diesel engine.

### 3. Technical capabilities of Langmuir's probe use in diagnostic research - the results of operating preliminary research.

The access to the serial engine cylinder space is possible only through indicator and due to that, it is imposed to manufacture Langmuir's probe in a way that enables simultaneous measurement of electrical charges and pressure in cylinder workspace. It means that an appropriate intermediate connector is required, so called adapter. It is vital to account a limit of measurement technology used that is existence of high temperatures and pressures in cylinder workspace. Furthermore, if the engine was not standard equipped in indicator valve (or it is impossible to enter the probe through indicator valve), an additional technical hole should be performed in its head.

Preliminary experimental research was carried out in laboratory conditions using one cylinder diesel engine Farymann Diesel type D10, loaded with hydraulics power system.

The research place consists of the following compounds:

- diesel engine, four-stroke, one cylinder, "Farymann Diesel" type D10, with power  $N= 5,8$  kW and nominal rotational speed  $n=1500$  rotations/minute, displacement - 765 cm<sup>3</sup>, cylinder diameter - 90 mm and compression level 1:22,
- hydraulics pump, meshed, of series No21, produced by „Waryński Hydraulika” Sp. z o.o.- Warsaw,
- hydraulics engine, meshed, of series No21, produced by „Waryński Hydraulika” Sp. z o.o. – Warsaw,
- measurement and control equipment,
- installation and fittings of hydraulics system,
- hydraulic oil tank,
- diagnostic equipment.

The whole installation is built into the foundation of multi-machine auxiliary system produced by MotorfabrikenBukh A.S. Dania.

The engine is equipped in the cast of ignition paper, a screwed cylinder head. The hole of screwed cast of ignition paper has a cut thread M14x1,25 that is used in indicator valve installation (figure 4).

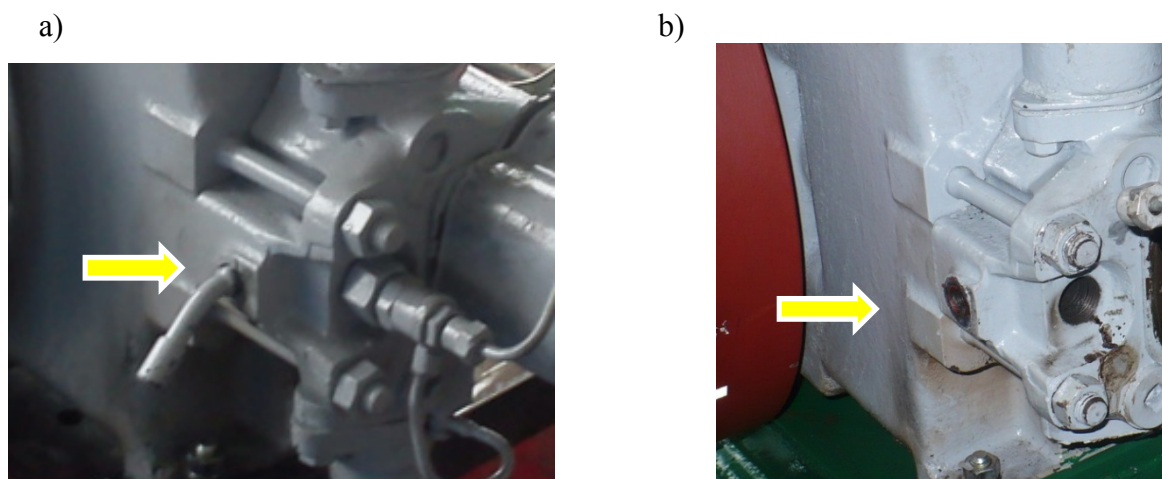


Fig. 4. The view of indicator valve installation seating in place of ignition paper - a) and b)

Figure 5 presents an applied prototype of Langmuir's probe, measurement equipment used and the method of its installation on the engine, with simultaneous application of electronic indicator. An important limitation of the technology used is a necessity of such probe's electrode leading so the required isolation from ship's trunk. It is still necessary to carry out an experimental research in order to discover the influence of exhaust gases on condition (loss) of the isolation.

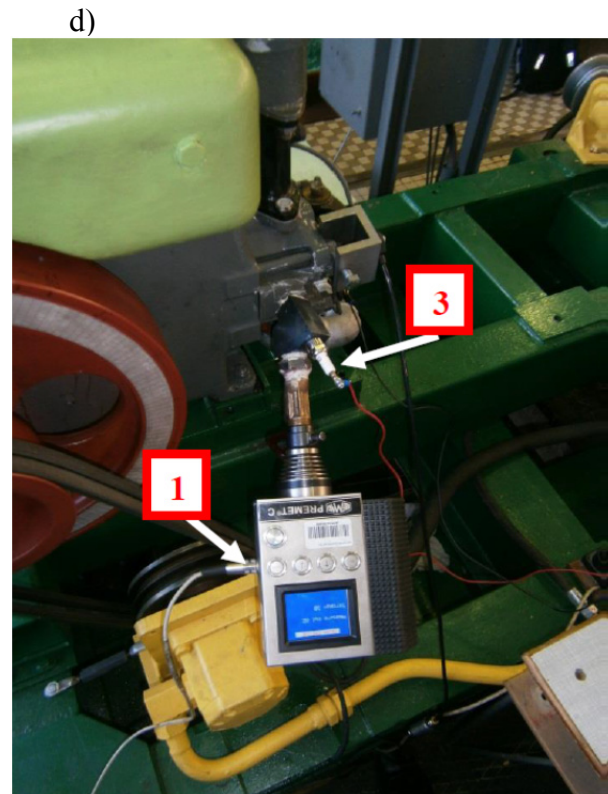
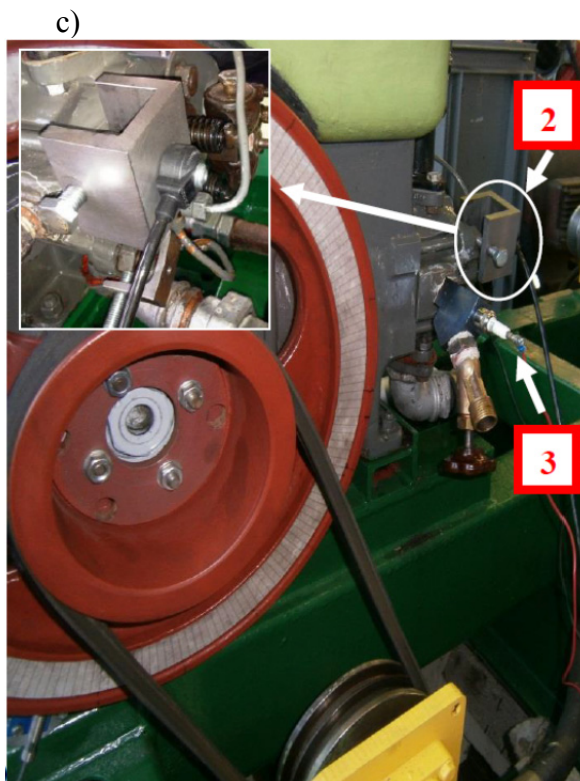
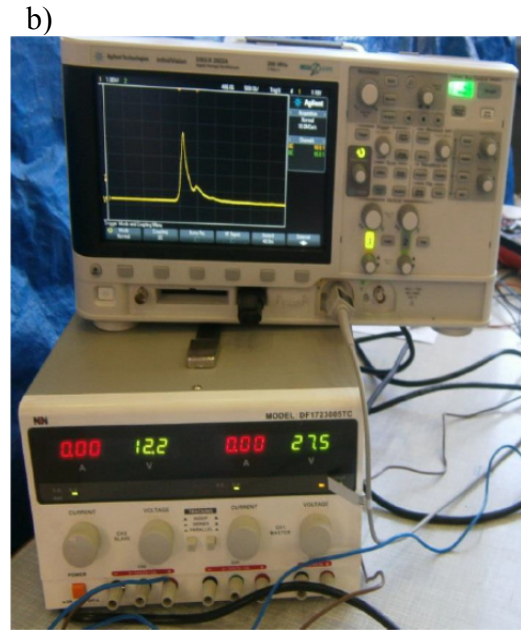


Fig. 5. Research equipment: a) the structural form Langmuir probes used in the study (on the right is shown the adapter which enables the simultaneous measurement using Langmuir probe and the electronic indicator), b) the plasma current combustion front recorder, c) mounting the electronic indicator "C LEMAG PREMET" (1), d) mounting acceleration sensor of vibration generated on the cylinder head (2) and Langmuir probe (3).

There is a strong influence of soot existing in exhaust gases, which is a good electrical conductor, can cause a short circuit in the probe's construction.

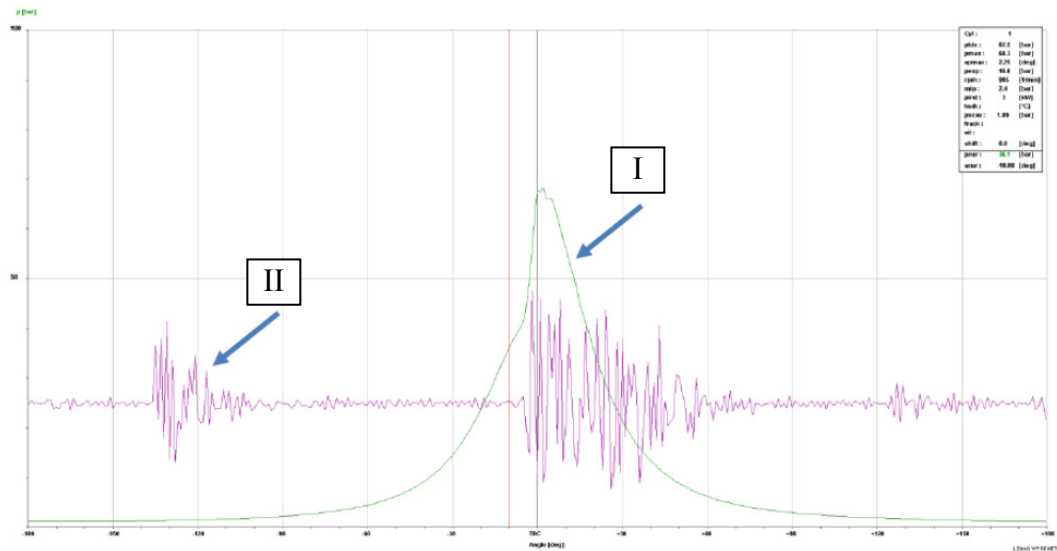
The implementation of preliminary research program, that had confirmation of theories described above as its basic purpose, required simultaneous measurement and registration of the following control parameters:

- pressure in the cylinder,
- acceleration of the generated vibration of cylinder head,

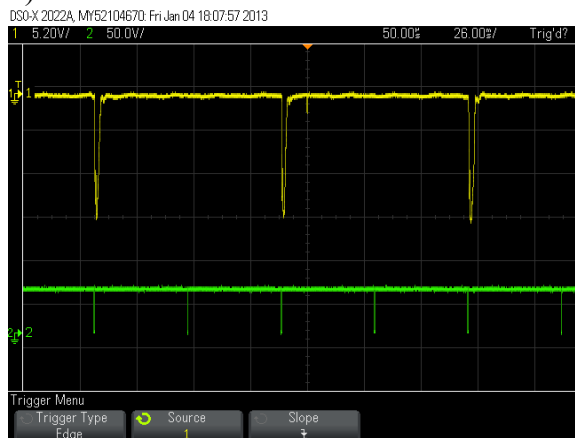
- rotational speed of the crankshaft,
- plasma potential.

The measurements were performed in the condition of established engine work in idle and an example results (presented as indicator graphs and registered oscillograms) are presented in Figure 6.

a)



b)



c)

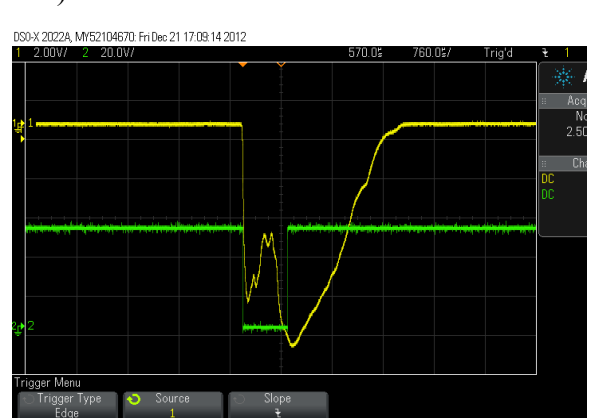


Fig. 6. Recorded signals: a) cylinder pressure (I) and cylinder head vibration (II), b) and c) electric potential of the plasma.

The analysis of registered time courses of plasma potential changes (fig. 6 b and c) indicates an occurrence of steep time signal slope, characteristic for beginning of fuel's combustion process in the cylinder of diesel engine. Its shape is analogous to the course of heat discharge in workspaces of such engines [7]. Numerical data shows that the time of signal increase is about 0.1 ms, which enables precise determination of fuel's self-ignition moment in the engine examined.

#### 4. Summary

The precise determination of angular location that accompanies fuel's self-ignition in diesel engine is a primary condition of expressing a reliable diagnosis of its workspaces and fuel reinforcement system. The observation of emerging and moving electrical charges of ionized exhaust gas using Langmuir's probe, that is entered into engine's workspace through indicator valve, brings completely new possibilities.

The preliminary research of a laboratory diesel engine using Langmuir's measurement method confirmed its high utility values and diagnostic usefulness. The object characterized in very good control susceptibility, which is a good prognosis for further diagnostic research in conditions of using biofuel.

Further works will be focused on perfecting the technology of the measurement and software in order to precise synchronization of all observed engine's control parameters registration, allowing the comparative analysis of their courses and angular location of the crankshaft.

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