SOME INSIGHTS INTO DIESEL LOCOMOTIVES MISFIRES FOR THE APPLICATION OF AN OBD SYSTEM

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Abstract

The paper presents the overview of diesel locomotives which are using in Poland with the description of their technical parameters and the influence of a misfire phenomenon for the ecological parameters. We take into consideration the subject of on-board diagnostic of compression-ignition engines (diesel engines) from the future norms point of view and show the directions of the changes in European regulations in the area of compression-ignition engines emission, what confirms the necessity of continuous inspection of misfires. The paper presents the different methods of misfire detection which can be applied in the compression-ignition engine, both the methods used in present produced engines and being in the experiment phase also. We present each of this method showing it failure, virtues and difficulties in practical implementation for diesel locomotive engines.

1. Introduction

An combustion traction vehicle is a rail vehicle driven by the compression-ignition engine, which main task is to pull or push the cars and to direct passengers or load transport (fig. 1). The participation of combustion traction vehicles (including locomotives) in rail transport in different countries depends on historical and strategic conditions, a technology level, geographical position and energy resources of the country (fig. 2).

If one does not take into consideration economical estimations, combustion traction has some advantages in comparison with the electric traction:

– it supplies independent of outside resources, what can be important in unusual cases (natural calamity) where an diesel locomotive can completely replace an electric locomotive,

– the possibility of applying some innovations in a locomotive power transmission system, of different methods of energy conversion and of different kinds of electrical transmission,
– the possibility of diesel locomotive operation in hard weather conditions, which are usually a big difficulty for electric locomotives work,
– the bigger efficiency of combustion traction ($\eta_o = 0{,}26$) than electric traction ($\eta_o = 0{,}21$) [5].

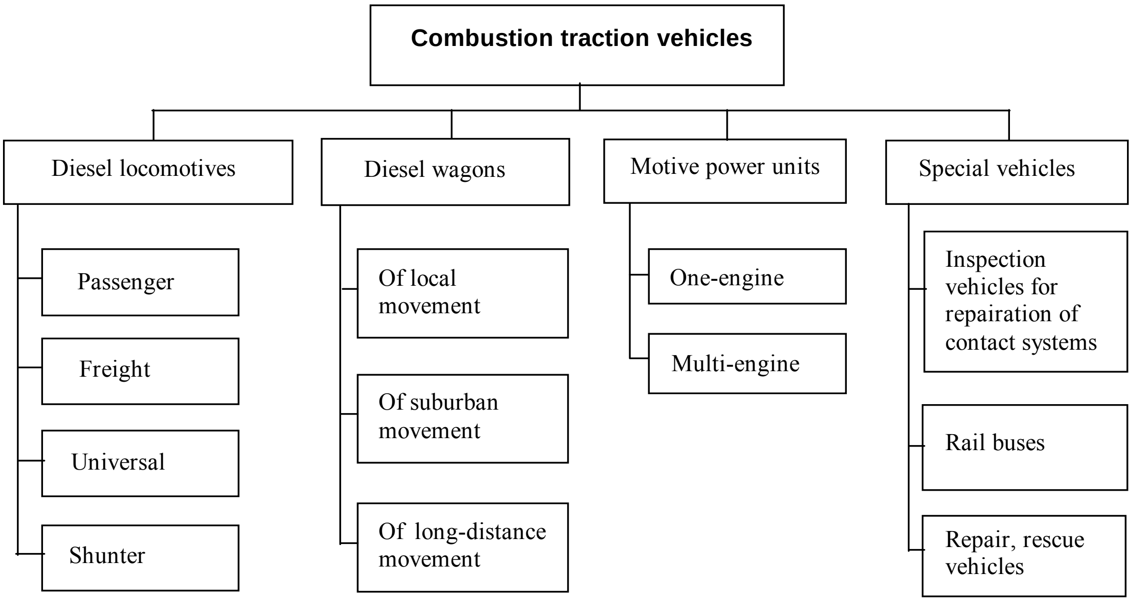

Fig. 1. *Types of combustion traction vehicles [5]*

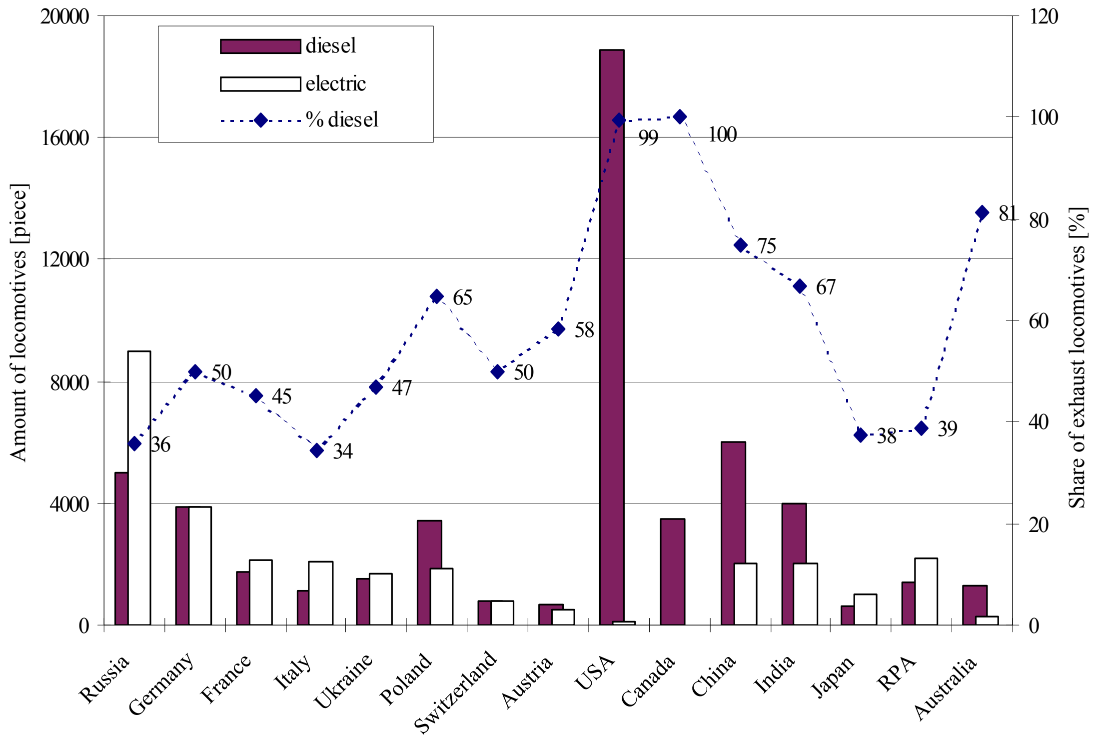

Fig. 2. *Shares of diesel and electric locomotives in the railway traction for individual countries [9]*

The diesel locomotive is a combustion traction vehicle, which does not have a compartment to a passengers and load transport. In most European countries the combustion traction take part in only a part of all rail transport, and it basic usage is lines with little traffic density, in auxiliary operations (including shunting).

Polish State Railways uses now 12 series of diesel locomotives with engine power is from 110 kW till 2200 kW (table 1). Each year the number of diesel locomotives (in Poland and in other European countries) decreases because of replacing this traction by the electric locomotives.

Most of diesel locomotives engines used in Poland are 4-stroke and piston engines with compression ignition and V-type cylinder system (table 2). Some of engines are 2-stroke, where one can obtain the bigger power in the same volume in comparison with 4-stroke engines. But the 2-stroke engines have the bigger fuel consumption per unit, which relates to losses in combustion process and load change. The settlement requirements in railway stock forces application of V-type cylinder system engines. The bifurcation angles are correspondingly 60^o and 90^o. Only in some old solutions one can find the in line vertical cylinder system (e.g. in an engine 12LDA28 for a locomotive ST43).

Table 1

Types of diesel locomotives used in Poland [4, 5, 7]

	Series production	**Power [kW]**	**Engine type (all compression ignition)**	**Number of units**	**Year of use**	**Kind of transmission**	**Assignment**
1	SM03, Poland	110	4-stroke (2DSR 150)	40	1959	Mechanical	Shunting
2	SM30, Poland	257	4- stroke (3DVSRa – 350)	167	1957	Electrical	Shunting
3	SM31, Poland	883	4-stroke (a8C22W)	156	1976	Electrical	Shunting
4	SM40, Hungary	441	4-stroke (XVI JV170/240)	-	1958	Electrical	Shunting
5	SM41, Hungary	441	4-stroke (XVI J170/240)	11	1961	Electrical	Shunting
6	SM42, Poland	588	4-stroke, (a8C22)	1087	1965	Electrical	Shunting
7	SM48, Soviet Union	883	4-stroke	127	1976	Electrical	Shunting
8	SP30, Soviet Union	257	4-stroke	85		Electrical	Passenger traffic
9	SP32, Romania	956	4-stroke (M820SR)	143	1987	Electrical	Passenger traffic and shunting
10	SP42, Poland	588	4-stroke, (a8C22)	254	1970	Electrical	Passenger traffic and shunting
11	SP45, Poland	1250	4-stroke (2112SSF)	53	1970	Electrical	Passenger traffic
12	SP47, Poland	2206	4-stroke (2116SSF)	2	1975	Electrical	Passenger traffic
13	ST43, Hungary	1544	4-stroke (12LDA28)	346	1965	Electrical	Freight traffic
14	ST44, Soviet Union	1471	2-stroke (14D40)	750	1966	Electrical	Freight traffic
15	SU45, Poland	1250	4-stroke (2112SSF)	190	1970	Electrical	Passenger and freight traffic
16	SU46, Poland	1655	4-stroke (2112SSF)	48	1976	Electrical	Passenger and freight traffic

Table 2

Technical data on selected diesel locomotives engines used in Poland [5]

Engine type	Power [kW]	Rotational speed $N_{e,\,max}$ [1/min]	Engine capacity V_{ss} [dm^3]	Cylinders number/ cylinder system	Kind of ignition	p_e [MPa]	$c_{śr}$ [m/s]	Consumption per unit [g/kWh]	
								fuel g_e	oil g_o
2DSR150	110	1500	19,09	6/R	CI	0,46	9,0	258	6,8
3DVSRa-350	257	1500	38,17	12/V (60^o)	CI	0,47	9,0	245	6,8
a8C22W	882	1000	82,0	8/V (50^o)	CI	1,32	9,0	224	4,8
XVIJV170/240	441	1100	88,34	16/V (40^o)	CI	0,55	9,0	238	4,1
a8C22	588	1000	82,10	8/R	CI	0,88	9,0	224	4,8
PD1M	883	750	158,7	6/R	CI	-	10,25	224	5,4
M820SR	956	1500	159,2	12/V (60^o)	CI	1,32	10,25	217,5	-
12LDA28	1544	750	265,8	12/2R	CI	1,04	9,0	235	2,7
14D40	1470	750	150,6	12/V (45^o)	CI	0,81	7,5	228	2,7
2112SSF	1250	1500	95,6	12/V (90^o)	CI	1,07	11,5	223	2,7
2116SSF	2206	1500	127,46	16/V (90^o)	CI	1,38	11,5	217	-

p_e – averaged effective pressure, $c_{śr}$ – averaged piston speed, R – in-line cylinder engine system (2R – 2-in-line), V – V-type cylinder engine system, CI – compression ignition,

2. The ecological characteristics of diesel locomotives

The influence of diesel locomotives on natural environment depends on the sort of their work. The sorts of work decide on fuel consumption per unit and this way on the level of combustion pollution. The contribution of diesel locomotive work in shunting traffic for idle run is 51,6% of all time work, 33% of time work corresponds to 10% of nominal effective power, other contributions are negligible [4].

In ecological evaluation combustion traction appears very disadvantageous in comparison with electrical traction (fig. 3). The damages in natural environment caused by combustion rail vehicles in Poland during the load transport are 4 times bigger of damages caused by electrical rail vehicles, 1,8 times bigger than for inland navigation, but 5 times smaller of damages caused by trucks with compression-ignition engines [4].

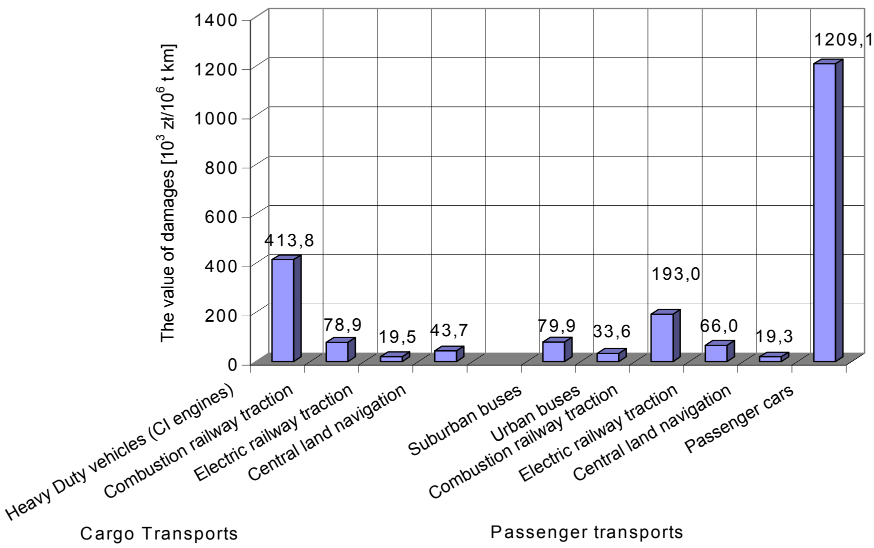

***Fig. 3**. Comparing of the values of damages which are inflicted on the environment by different means of transport [4]*

The value of destructive compounds in exhaust gases from off-road sources, where one finds diesel locomotives, has the significant contribution in comparison with road vehicles. For example in USA in 2000 year the off-road emission of hydrocarbons (HC), nitric oxides (NO_x), carbon monoxides (CO) and particulate matters (PM) in comparison to the values of this emissions from road vehicles was correspondingly 97%, 68%, 59% and 191% (fig. 4) [10].

Off-road emission sources in USA in 2000 year were responsible for atmospheric pollution in the amount of 3677 thousand kg of hydrocarbons, 5461 thousand kg of nitric oxides, 29514 thousand kg of carbon monoxides and 459 thousand kg of particulate matters. It shows that the emission from traction rail vehicles like diesel locomotives can not be neglect, because it is the cause of a big atmospheric pollution.

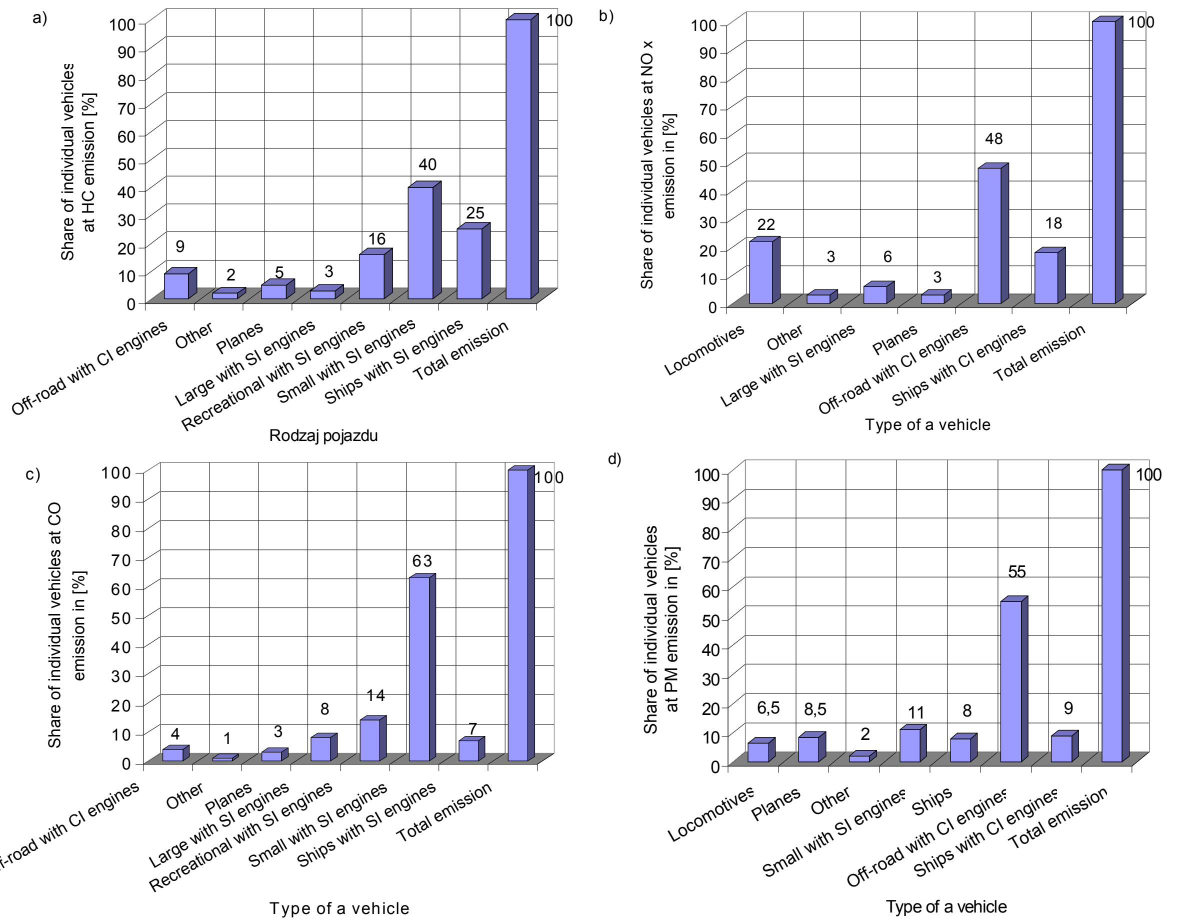

Fig. 4. *Influence of off-road motor sources in USA (in 2000) on emission: a) hydrocarbons, b) nitrogen oxides, c) carbon monoxides, d) particulate matter [10]*

3. Misfire detection from the point of view of future regulations on combustion gases emission

In compression-ignition engine the organization of atomized liquid fuel combustion is one of the most complicated technical task. The reason is in complicated structure of the fuel blend creation process inside the combustion chamber. The fuel is injected into a cylinder and next it heats, evaporates and mixes with an air in such a way that the mixture composition and it temperature are vary in time and space. One should also take into account the high-value and high-variable pressure in combustion chamber. On the assumption that the chemical reaction speed depends on temperature and reacting substance concentration, the speed and progress of reactions of fuel combustion process have the local property and compression ignition is possible in many places of combustion chamber. The right organization of the fuel atomization process in a cylinder and a combustion process of the fuel blend influence the parameters achieved by the engine. It have also an effect on appearing of the compression ignition sources in the combustion chamber. The effective misfire detection in the given cylinder of combustion engine and misfire counteraction is possible by using of on-board diagnostics system (OBD).

In 1996 in USA one introduced the standard called On-Board Diagnostics II (OBD II), which describes standardization in the area of new diagnostic procedures in automotive vehicles. The OBD II standard imposes on car producers the obligation of on-board diagnostics systems creation. In turn, basing on directives 98/69/EC and 1999/102/EC, since 01.01.200 in European Union countries has been forced European On-Board Diagnostics system EOBD. The EOBD system must be installed in all new passenger and delivery vehicles (LDV – *Light Duty Vehicle*) with spark-ignition engines (fig. 5).

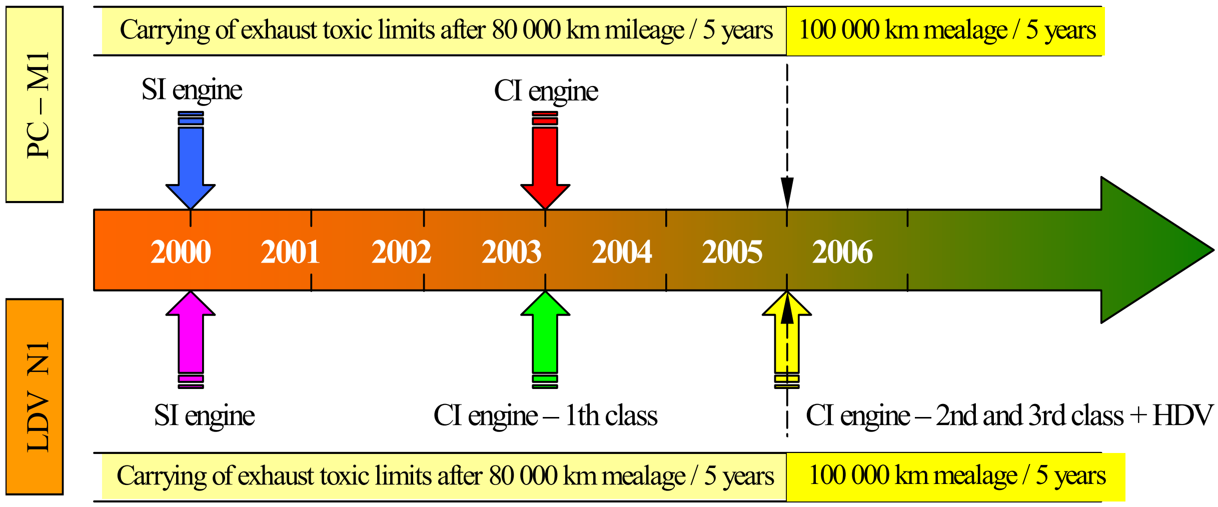

Fig. 5. *The project of the application of EOBD norms for passenger cars, Light Duty Vehicles (LDV) and Heavy Duty Vehicles (HDV) in European Union countries [8]*

Basing on the standard EURO III one plans since 01.01.2003 introduce EOBD system as the optional equipment of compression-ignition engines (passenger cars in M1 category and trucks in N1 category) and since 1.01.2005 also for tricks in N1 category in class II and III. For this reason we expect that in non long future the OBD system will be used in HDV vehicles with off-road application and with compression-ignition engines. Because the diesel locomotives belong to HDV vehicles class one should consider the application in diesel locomotives the OBD systems.

4. Misfire detection by the analysis of the instantaneous value of angular velocity (or position) of engine crankshaft

One of the common method of misfires detection in engines under continuous production is an analysis of the instantaneous value of an angular velocity of the engine crankshaft [2]. The lack of combustion in one engine working cycle gives a decrement of the torque and next the decrement in the instantaneous value of an angular velocity of the engine crankshaft (fig. 6).

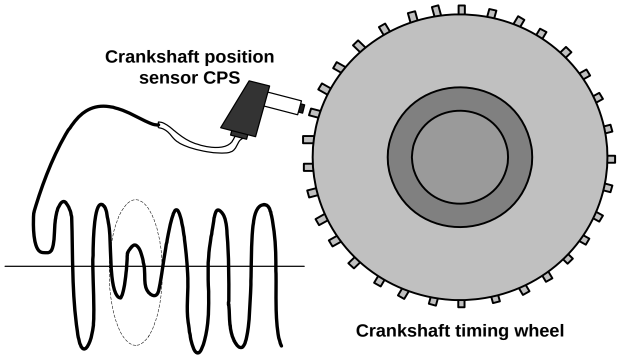

Fig 6. Recognition system for misfire detection on the basis of changes in crankshaft speed [15]

This method must be resistant to the disturbance which are caused by:

- tolerance of the wheel with sensor cuts realization,
- crankshaft torsion vibration,
- vibration which appear in engine cycles after misfire phenomenon,
- dynamical changes of velocity and vehicle loading which are transferred into combustion engine crankshaft,
- the influence of non uniformity of trip trajectory to engine crankshaft angular velocity.

Misfire detection system can be divided into functional blocks (fig. 7).

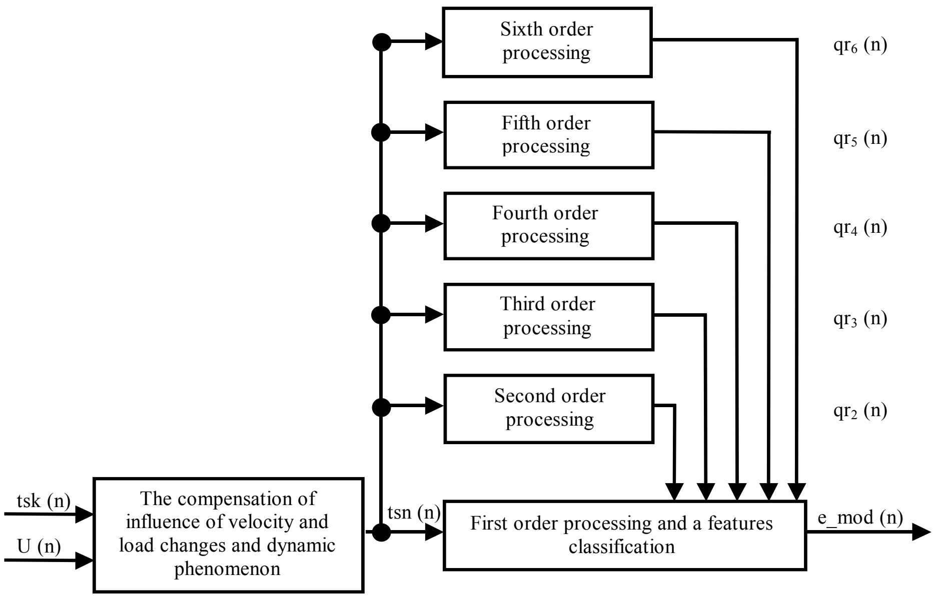

***Fig. 7.** The general diagram of a modulation method [2]*

The input block effects both compensation of the sensor wheel tolerances as well as cancellation of the effect of the torsion oscillations of the crankshaft. The corrected signal is then processed further with the use of various methods, depending on the working conditions of the engine. For low rotational velocity and heavy engine loads a different algorithm is used in comparison with high rotational velocity and light loads. The both algorithms use the general methods of feature extraction from the signal, which are next appropriately classified. Another block is to analyze the engine working conditions, and stops the method which is in the given conditions inapplicable.

Difficulties with proper misfire detection in the conditions of high values of engine crankshaft rotational velocity and low load values arise due to the transfer of crankshaft rotational velocity distortions originating from the combustion absence to many consecutive engine cycles and to the deteriorating of the registered signal quality. The lower quality of registered signal is a result of signal to noise ratio decrease, what can be due to quantization error. To improve the signal to noise ratio one can apply the following solutions:

- the usage of the digital band-pass filtering,
- the usage of the order analysis utilizing frequency analysis and basing on the crankshaft current rotational velocity value.

During order analysis one finds that the continual misfires in one cylinder will cause the occurrence of the effect with the dominant frequency in the measurement data related to the shaft revolutions (first order effect). With the application of discrete Fourier transform (DFT) a complex transform is obtained and basing on phase characteristic it is possible to identify a cylinder. However, this method proves ineffective in detecting single misfires.

Processing the rotational velocity signal bases on modulation and order analysis methods (fig. 7). The first block cancels the effect of the velocity and load fluctuations. Further processing is conducted for each order of the signal separately, whereby classification is performed by the block of the first order. In order to extract signal features one uses the number of blocks corresponding directly to the order of the analysis that the system is to conduct (depending on the number of the cylinders in the engine). The clock generates the reference signal, which is multiplied with the time signal. The result of this operation is subjected to low-pass filtering with the use of the digital filter of finite impulse response. The shadowed blocks are used for detecting single misfires and are present only in the block of the first order (fig. 8).

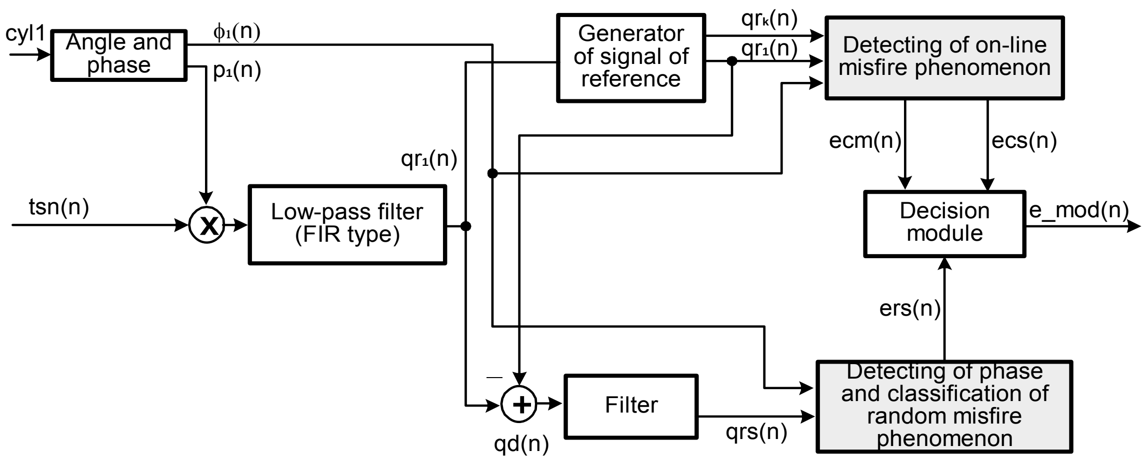

Fig. 8. *The diagram of the first order processing module [2]*

5. Misfire detection using analysis of instantaneous engine exhaust gas pressure

During each work cycle of combustion engine the outlet valve opens once to exchange the charge in the combustion chamber. The pressure in the outlet duct increases owing to the abrupt release of combustion products and to the motion of the piston while the exhaust valve is open. The pressure fluctuations depend on the combustion features and outlet duct properties.

In the event of a misfire the exhaust-gas pressure falls rapidly on account of the absence of combustion and the resultant lower pressure in the cylinder [6].

The frequency of the exhaust-gas pressure signal is a function of the number of cylinders and instantaneous rotational velocity of the engine. The spectrum of the pressure signal in the outlet duct differs considerable for the engine working properly and for the occurrence of misfires [14].

The pressure is measured with the pressure transducer connected to the outlet duct through a short flexible connector and a three-joint pipe. In contrast in the case of sensors mounted on the engine block a cooling circuit is not necessary. Owing to that fact, an inexpensive pressure transducer can be used. The requested transmission band range for the registered signal depends on the dynamics of the processes in the outlet manifold. The cut-off frequency of the sensor should be at least 200 Hz. Of much importance are also the construction and quality of the sensor connector as well as its signal distortion damping properties. The sensor can be feasibly mounted in the part of the exhaust system between the outlet manifold and the catalyst reactor. It is not advisable to position the measurement point behind the catalyst for the latter distorts pressure pulsation which make impossible the analyze of the combustion process on the basis of the signal logged there. The best results have been achieved mounting the sensor with a 165-mm-long connector. The highest temperature of the diaphragm of the sensor in this case is 85 °C [14].

In the case of the ignition absence, the pressure in the cylinder is approximately three to four times lower than in the case of regular ignition and regular combustion. As the pressure in the cylinder in such a case is lower than in outlet duct, it is followed by a reverse movement of the exhaust gas from the outlet manifold to the cylinder where the misfire has occurred. This may explain a significant fall of the pressure in the outlet duct. The wave form of the spreading pressure depend on the dynamic properties of the outlet circuit. Dumping depends on the length of the outlet pipe from the engine to the catalyst, its cross-section, position and the number of connections. The outlet system forms an oscillation unit with its own characteristic resonance frequencies, for which the dumping falls down considerably, leading to the phenomenon of standing wave.

The pressure sensor is not connected to the outlet system directly at the outlet valves but in some distance from them. If the cylinder with faulty combustion is identified on the basis of the pressure signal, all occurring delays have to be taken into consideration. Bearing this in mind it is possible to establish the opening time of the valve responsible for the shape of the signal at the given measurement point for various working conditions of the engine. For the purpose of detecting and localizing misfires various methods of signal processing and recognition strategies can be employed.

6. Misfire detection using measurement and analysis of the ionization signal in the combustion chamber

Measurement of the ionization current provides the information about the quality of the combustion. This way it is possible to establish many parameters of that process (such as estimated pressure in the combustion chamber, Air-to-Fuel ratio at the beginning of combustion, fuel admixtures, and similar). In particular low value of ionization signal indicates the absence of combustion in the cylinder, which information may be taken into a misfire detection.

The result of chemical reactions which proceed in engine combustion chamber during the fuel combustion process is a creation of free electrons (chemical ionization). The chemical ionization occurs during an exothermic reaction, when release energy is high enough to ionize at least one reaction product. The ionization process in the flame is as following [3]:

$$CH + O \rightarrow CHO^{+} + e^{-} \tag{1}$$

As a result of charge exchange the ion H_3O^+ is created [3]:

$$CHO^{+} + H_2O \rightarrow H_3O^{+} + e^{-} \tag{2}$$

The number of this ions is comparatively high in comparison with the number of CHO^+ ions, because reaction (2) course is speeder of reaction (1). The process of additional free electron creation appear under influence of temperature increase in combustion chamber (thermal ionization) and can be described by the following reaction [3]:

$$M + E_{ion} \leftrightarrow M^{+} + e^{-} \tag{3}$$

where:

- M – the given kind of particle,
- M^+ – the positive ion,
- E_{ion} – ionization energy.

Ions created by chemical and thermal ionization [3] in a short time join once more with electrons and create more stabilize particles (4). Their recombination speed is however different.

$$H_3O^{+} + e^{-} \leftrightarrow H_2O + H \tag{4}$$

The electric field created by the direct current generator by using the positive electrode (ionization sensor) will attract electrons created in combustion chamber, what gives the passage of a current. The surface of the piston and of the cylinder wall has the negative charge.

For the spark-ignition engine the measurement of the ionization current is very simple and do not need any special engine modification. In this case the existing sparking plug can be used as the measurement probe. The measurement follows the period of generation of spark by the sparking plug for fuel blind combustion when the energy in the ignition system is unloaded and the combustion take place in the chamber. In the compression-ignition engine the ionization sensor is placed in mounting of heater plug. It consists of metal core (conductor), steel screen, fixing nut and two rings, whose task is to isolate the core from steel screen (fig. 9).

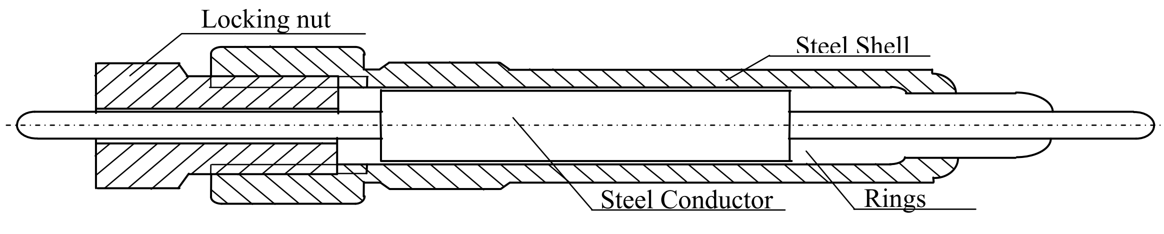

Fig. 9. *The view of the ionization sensor for a compression-ignition engine [3]*

In order to a full misfire phenomenon estimation one needs to join a ionization current measurement with a pressure measurement in the combustion chamber. Before the start of the combustion the voltage is applied to the ionization sensor (fig. 10).

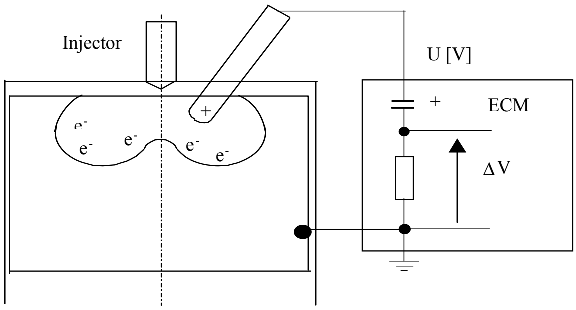

Fig. 10. *The system for the measurement of ionization current for a compression- ignition engine [3]*

Before the start of the combustion process the capacitor covers are under the voltage U what gives the positive charge on ionization sensor. In the moment of combustion process start in combustion engine cylinder appear the passage of a current from the sensor, through the combustion chamber, to the grounded surface of piston and cylinder. The absolute value of the current intensity depends on sensor construction and the voltage. It is about 1÷10 μA/V (for sensor voltage). The value of current intensity which passage through the ionization sensor circuit is measured by engine Electronic Control Module (ECM) with the usage of the resistor, which creates a voltage signal, called also a ionization signal. The signal is proportional to a ionization sensor voltage and a ionization intensity in it neighborhood.

The combustion beginning which is obtained basing on the ionization current measurement is equivalent to a moment when the first derivative of a ionization signal reaches the assumed threshold level. The value of the threshold should be near zero. The ionization signal is processed by a low-pass filter (fig. 11) what gives minimization of the errors in combustion start point detection (hence in the misfire detection also). The process of free electrons creation begins with the combustion start. The detection of this moment has a little delay which is the result of electronic equipment properties.

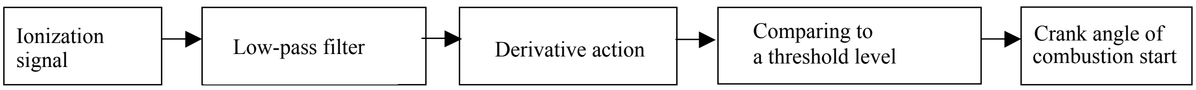

Fig. 11. *The definition of combustion start which is determined on the basis of the measurement of the ionization current [3]*

In the phase of flame front the ionization signal has a high amplitude owing to the intense ionization occurring in the flame. Various kinds of ions are generated in the flame. They differ in terms of their durability (from the moment of their creation to their recombination). The flame only for a short period of time is near the ionization sensor – the spark plug. This time the maximum, single and smooth signal peak appears. What remains afterwards are ionized product of chemical reactions (fig. 12).

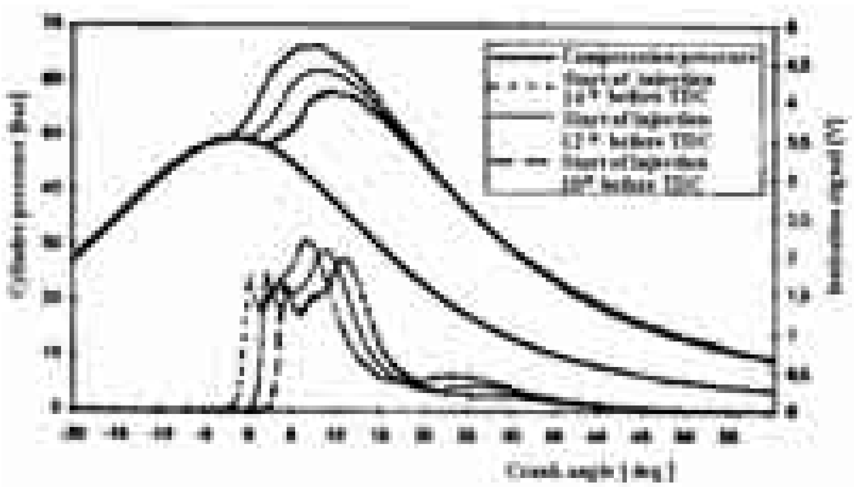

Fig.12. *The example of the compression pressure route in an engine cylinder and the ionization signal for a compression-ignition engine with the direct injection (n=1500 1/min, M_o = 64 Nm) [3]*

The post flame signal phase is chiefly created from H_3O^+ and CO^- ions and their hydrates. In high temperatures, presuming a balance, a presence of electrons should also be expected.

Ionization in the space being in the post flame phase is the sum of the remainder of ionization created in the flame and ionization triggered by the temperature and the pressure. The ionization signal alters mainly, in considerable correlation with changes of the temperature. As pressure and temperature are closely interconnected, the ionization signal in this phase follows the changes of the pressure. The smallest value of ionization current appear in the idle run of the engine.

In order to extract from the logged signal the required features one must undergo analog and digital processing. With the use of analog processing the signal offset is removed from the signal. The information about combustion is hold chiefly in low frequency offsets. The signal frequency is limited by using of the given filer. The signal is processed to extract its features: its peak value and integral in a given measurement window. In order to avoid disturbances from the ignition, the measurement window is chosen in such a way as to start after the disappearance of the electric ark on the plug. On the other hand, the window should be sufficiently long as to record even late combustion. Optimal is to use the window of the length of around 360 degrees of the crankshaft revolution.

7. Misfire detection using measurement and analysis of torque

Another method of misfire detection is a measurement of an instantaneous torque. Although such measurement is rarely implemented in the engines manufactured at present, modern measurement techniques make it possible to be introduced in mass production [13]. The torque measurement can be conducted with the use of various sensors and various physical phenomena.

Instantaneous torque value measurement methods and sensors are as follow:

- **Piezoelectric sensors** – this method takes advantage of the piezoelectric effect – the generation of a charge under the influence of a force deforming the crystal structure of the active element. The piezoelectric methods require the use of conditioning systems with high impedance and do not lend themselves to static measurements. They display low sensitivity to temperature changes (they can work in temperatures up to 500°C). They permit measurements of signals of relatively high frequencies;
- **Magnetic sensors** – this method measures changes in the magnetic susceptibility of the crankshaft under the influence of the load. The torque working on the shaft causes a torsion deflection and tensions in the shaft as well as proportional alteration of the measured feature (magnetic susceptibility). Measurement with this method relies heavily on temperature and the changes of width of the air-gap;
- **Measurement elements stuck onto the engine crankshaft** – they are made from materials of magnetic properties with strongly depending on mechanical tensions. To define the flow changes in the air-gap, additional sensors are used;
- **Analysis of instantaneous angular velocity of the engine crankshaft** – a correlation has been found between torque and square difference of angular velocity in chosen positions of the crankshaft [12].
- **Measurement of the crankshaft torsion deflection** with the use of two measurement discs placed at its ends. This method is relatively inexpensive and simple in implementation. The crankshaft torsion detected with this method is directly proportional to the torque carried by the shaft.

The torque is a superposition of two factors: the pressure caused by combustion and the dynamics of the other rotational elements in the engine. A misfire detection with using of this method is impeded in some conditions of the engine performance. This occurs in high engine velocity and heavy loads. With high rotational velocities a decisive influence over the dynamics of the system has the inertia of rotating masses and it may explain the decrease in torque resulting from misfires. Moreover, with small engine loads the influence of effective torque on the pressure in the combustion chamber gives the results similar to those obtained for high rotational velocity.

The oscillatory character of the torque response resulting from a misfire may be very similar to other shapes of torque logged in normal conditions of exploitation, for example triggered by the change of gear. Also this temporary state may disguise the response in the event of another absence of combustion within a short span of time from the first one. With the rotational velocity of the engine at 4000 revolutions per minute it is very difficult to detect the decrease of the torque triggered by a misfire.

8. Misfire detection using analysis of combustion chamber pressure

The value of pressure in the combustion chamber remains directly related to the quality of combustion. The intrusive pressure sensors commonly used so far were riddled with serious drawbacks such as low durability and their use limited by the high cost. Although there has been a marked technological progress in this field, resulting in both the lowered prices and decreased size of such sensors, further progress in this area is likely to be inhibited by considerable limitations arising from the excessively difficult working conditions of the sensor fitted directly in the combustion chamber. For this reason there is an effort being made in order to develop methods of indirect measurement of pressure in the combustion chamber through the measurement of tensions in existing engine elements, for example, in screws fastening the engine head to the engine block. Owing to integration with the existing elements the costs of such solutions are lowered, which increases the likelihood of such ideas being practically implemented in mass production. However, the signal quality obtained through the indirect measurement of tension in the engine elements is often inferior to the required quality. A solution may be offered by integrating the measurement sensors with the plug (spark plug in the spark-ignition engine or glow plug in compression-ignition engines). As a result an additional hole in the engine head is not necessary, yet a direct access to the ignition chamber is provided. Unfortunately, the developmental work in this area have not yet given a solution which would be introduced in the mass production.

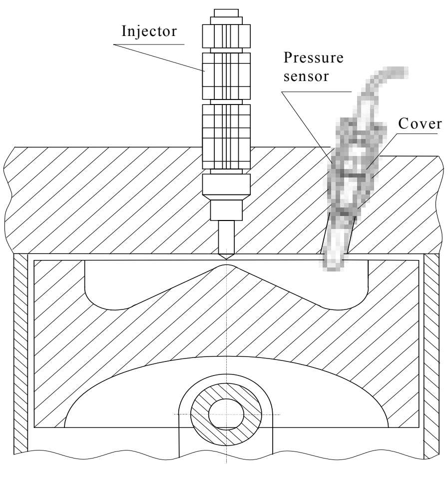

Fig. 13. The pressure sensor for a compression-ignition engine which is mounted in the cover of a glow plug

Maintained, however, are efforts aiming at developing sensors and pressure measurement methods that would satisfy the given requirements. One of possible solutions is a measurement of tensions arising in the engine head with the help of a piezoelectric sensor mounted in a glow plug boss (fig. 13). The sensor should give a linear response to the changes of pressure in the combustion chamber in the measurement window (from -50 to +70° TDC). Essential here is the relative measurement and not the absolute value, so minor changes of gain and offset are admissible provided and they do not exceed a certain specified value. The sensor mounted in the plug boss is subjected to the effect of the pressure in the combustion chamber and owing to the flexible structure of the engine head is conveyed onto the sensor.

The advantages of using the piezoelectric sensor to quick-varying pressure analysis in the combustion chamber:

- direct access to the combustion chamber is not required,
- the possibility of work till temperature 500 ^{o}C,

- owing to the fact that it is mounted outside the combustion chamber, measurement is unaffected by many possible causes of errors resulting from extreme thermal conditions in the combustion chamber and high pressure (for example, in the engine transition phases),
- the high sensibility for pressure variations in combustion chamber.

The disadvantages are high costs, short life and sensibility for electromagnetic interference.

9. Misfire detection using optical method

One of the ways of obtaining information about the processes occurring in the combustion chamber are optical methods [11]. This category includes the investigating optical methods consisting in registering or assessing the electromagnetic emission within the range of visible and thermal radiation. Vision methods are applied for the direct observation of such processes as the creation of air-fuel mixture, the charge movement inside the combustion chamber and the combustion progression (compression ignition, flame development).

These methods include sterography and video endoscopy, which at present are the most commonly used. An example of the utilization of stereoscopic photography is its application in investigating the flow of gases in the spark-ignition engine. In order to gain information about the movement of the gases within the engine cylinder, a measuring system has been devised [2], furnished with a camera for rapid photo shots and cooperating with the system of five mirrors.

The photos describe the traces left in combustion by the molecules of sodium added to the fuel (fig. 14). Owing to the choice of a proper mixture the progression of gases could be observed before and during combustion, what makes this method potentially useful for misfire detection (in research).

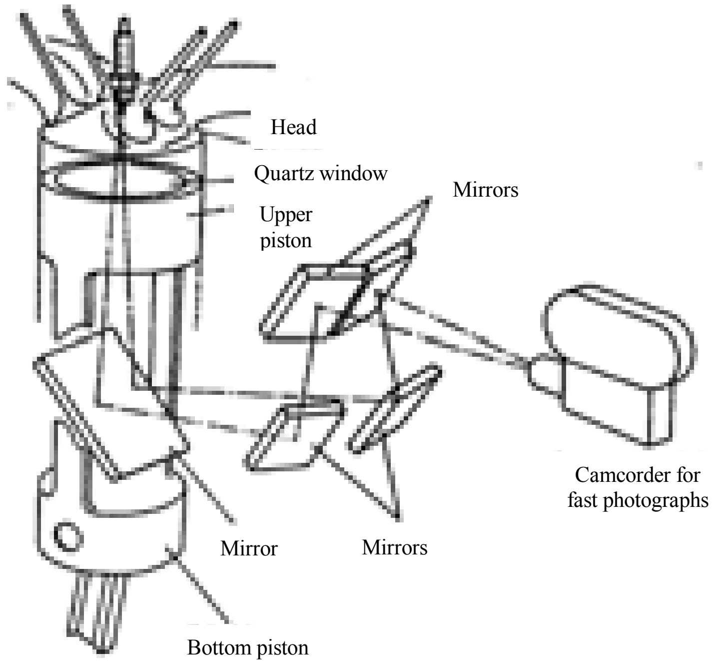

Fig. 14. *The diagram of the measurement system using in stereophotography [11]*

The application of endoscopic methods enabled complete and continuous visualization of the processes ongoing inside the engine. Endoscopy combined with video technology allowed real time observation and recording of the cyclic processes, which constitutes a novelty in the process of researching internal combustion engines. However, the method of conducting observation for processes occurring in the engine relies on their periodicity, the photographs are taken in certain positions of the crankshaft over a number of consecutive engine cycles. Thus its applicability for investigating misfires is limited to laboratory conditions.

The mid-eighties showed the first reports on taking advantage of fiber optics in researching internal combustion engines. The intensity measurement is the easiest way of obtaining the analog electric signal; yet it is susceptible to disturbances and distortions resulting from temperature changes and pollution. Assessing the change in the wavelength is complicated and requires that the measurement channel be furnished with additional optical elements. Nonetheless the frequency measurement provides a very accurate and stable signal carrying the information about combustion. Owing to their specific properties, fibers may also be used for quick-varying pressure measurements. This is achieved by utilizing intensity changes of the reflected light transported through the fibers or by direct signal phase modulation inside the fiber subjected to the activity of pressure. The application of fiber optics eliminate the disadvantages of piezoelectric sensors.

10. Conclusion

The misfire detection methods presented here differ from one another in terms of difficulties in their implementation as well as the costs of their introduction into automobile mass production. The method founded upon measurement of the instantaneous rotational velocity is relatively the most inexpensive one. It is common in application in currently manufactured motor vehicles equipped with OBD II system. The similar disadvantages are typical to method of torque measurement and analysis. However, it is vulnerable to distortions and disturbances in all working conditions of the engine. The optical methods are utilized chiefly in laboratory research; however, their simplified and refined implementations may find practical application in the future. Only the application of the sensors with a fiber optics gives the real possibility to use it to the misfire detection evaluation in compression-ignition engines in practice, e.g. in on-board misfire diagnostic in diesel locomotives. The method basing on the measurement of the ionization current is a new method and appears to be holding quite a prospect. Interesting and promising seems also the method using pressure measurement in the outlet duct, yet its application would entail additional pressure sensors, which would reduce the likelihood of its successful adoption on a larger scale. The spectrum of combustion diagnostics methods appears to be relatively wide, so the automobile manufacturers are to encounter new problems in a satisfying way.

Notations and abbreviations

CO	carbon monoxide
DFT	Discrete Fourier Transform
ECM	Electronic Control Module
EOBD	European On-board Diagnostics
η_o	general efficiency
HC	Hydrocarbons
HDV	Heavy Duty Vehicle
LDV	Light Duty Vehicle
M1	passenger vehicles with set number less than 10
N1	trucks with maximum full mass not bigger than 3500 kg
	Class I – vehicles with a full mass not bigger than 1250 kg, class II – vehicles with a full mass in the range $1250 < m \leq 1700$ kg, class III – vehicles with a full mass over 1700 kg

NO_x	nitric oxide
OBD	On-Board Diagnostics – the set of software and hardware procedures and tests which allow the continual detection in move of vehicles systems failures
OBD II	On-Board Diagnostics II – norm applied in USA by EPA for detection of emission critical damages of vehicles during early developing stage
PM	Particulate Matter
TDC	Top dead center

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