PROTOTYPE OF THE SPARK PLUG FOR IGNITION OF NATURAL GAS-AIR MIXTURE

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Abstract

This paper presents issues concerning the selection of spark plugs for engines fuelled with natural gas. There are discussed the specific conditions for proper ignition and combustion of natural gas in SI engine. The new model of spark plug for ignition of natural gas-air mixture was designed and manufactured in collaboration with Iskra Zakłady Precyzyjne Sp. z o.o. from Kielce. The way of assessing of the performance of the new spark plug after test operation in a bus after 10 thousand km, 15 thousand km and 30 thousand km is presented. These tests allow preparing mass production of spark plugs for professional ignition system for SI engines fuelled with natural gas. New spark plugs will provide a longer service life compared to previously used. They also make it possible to eliminate the extinction of the arc between the electrodes and an electrical misfire in subsequent cycles of engine operation. As a consequence, fuel consumption reduction and reduction of emissions of unburned hydrocarbons into the atmosphere is expected. A positive effect of the application of new spark plugs can be also longer engine service life. The introduction of the new spark plugs contributes to fulfil the strategy elaborated by EU which foresees the effective use of alternative fuels, especially natural gas which is good alternative for gasoline and diesel oil because of possibility of fulfilment of European emission and noise standards.

Keywords*: spark plug, ignition mechanism, natural gas, spark plug tests, durability*

1. Introduction

The growing requirements of the European Union to protect the environment have made gas fuels the most common alternative for fuelling cars and buses. EU directives put special emphasis on reduction of emission of harmful substances emitted by IC engines in urban areas (large cities, industrial areas). In order to force manufacturers of vehicles to introduce new solutions which are friendly to the environment, the assessment of toxic gases emitted into the atmosphere by "cold engine" will be introduced. It is well known that such an assessment does not correspond to the normal emissions tests of "hot engine" but it is dedicated to introduce new technical solutions, especially to improve ignition and exhaust systems of produced vehicles as well as to improve the quality of fuels. Update research confirms that fuelling with natural gas gives possibility to obtain low engine emission and low level of noise.

Due to lack of infrastructure to fill up a vehicle tanks with gas fuel, the use of vehicles fuelled with natural gas is limited to the urban and local transport. Therefore, in our country, the biggest

group of vehicles fuelled with natural gas is buses and service vehicles used by the technicians from gas companies. These vehicles are equipped with engines with fuel systems which enable fuelling only with gaseous fuel. Such fuel systems are used in some SI engines prepared on a base of diesel engine for local and urban buses. Very important element required for proper operation of SI engine which gives the possibility of effective ignition of air-gas mixture is a spark plug which should be also durable and not expensive.

2. Spark ignition of the air-fuel mixture

In spark ignition engines the electric discharge between the electrodes of the spark plug starts the combustion process before the end of the compression stroke. During a typical spark discharge difference of electric potential between electrodes of the spark plug grows until it reaches a sufficiently high value. The value of it significantly influences the shape of the electrodes, the size gap between the electrodes which influence the pressure and the presence of ionizing radiation necessary to initiate the process of ionization in the subsequent spark discharges.

Under the influence of the electric field the positive ions of gas begin to move toward the negative electrode and negative ions and free electrons in the direction of the positive electrode.

As the voltage on the electrodes rise the movement of ions becomes more intense, until the next collision which leads to the creation of new ions. It causes an avalanche ionization of gas particles between the electrodes, which takes the form of rapid spark discharge. As a result, the gas loses insulating properties, impedance gap between the electrodes decreases dramatically, and the current is growing rapidly. Ionized gas surrounding the avalanche path warms up to such an extent that it starts to glow, which is visible in the form of sparks. This part of the discharge is called a capacitive discharge and creates a front of spark, while the voltage at which the spark begins is called the breakdown voltage. Then, after reducing the resistance of gas the voltage between the electrodes sharply decreases to such an extent that allows the continuation of discharge in the form of a discharge arc. During this time, the transfer of energy stored mostly in the inductance of the ignition system takes place forming tail-end of spark. This phase is characterized by a small degree of ionization, as well as the large energy loss. This part is called discharge.

When the current is reduced the bow is broken and the spark disappears. The movement of the compressed air-fuel mixture between electrodes causes sparks quenching and new discharges. The actual discharge is a series of sparks, which does not affect the ignition of the mixture. To initiate the process of ignition of the mixture the energy of the front of the spark is sufficient, due to the intense gas ionization in this area. However, during cold start ignition of the rich and not a homogeneous mixture the tail-end of spark causes ignition. The thermal influence of it causes the evaporation of a fuel and improves the conditions to ignite the mixture. The theory of ignition influences the construction of spark plugs.

To ensure proper selection of a spark plug to the engine, the producers of them mark them with a code of designation which gives information about the parameters of the spark plug. The phenomena occurring in the different phases of ignition have a devastating influence on the spark plug electrodes, causing their wear, so the types of materials of electrodes as well as their shape and a size of gap between them is very important. For example, based on the research the shape of electrode was changed, giving it the shape of “U”. This helps to increase the area of ionization and make faster the process of ignition of fuel-air mixture. Steady improvements of gas installations up to the next generation of installation for direct injection of liquid gas into the engine cylinder force the improvement of ignition systems and especially of spark plugs.

3. Requirements for spark plugs for ignition of natural gas-air mixtures

The proper ignition of the natural gas-air mixture as well as durability demands required to apply special spark plugs. The most important factors in constructing the spark plug are:

- increase of the resistance of the mixture (about 30%),
- higher average temperature in the combustion chamber (combustion of natural gas is slower than the combustion process of gasoline-air mixture, what gives lower maximum temperature, but the combustion process takes more time and average temperature in the combustion chamber is higher). It causes higher thermal stress of spark plugs.

More difficult process of ionization of the gas between electrodes demands higher voltage peak for ignition of the mixture. The higher voltage peak is necessary because of higher resistance of the gas-air mixture. It is also applied the smaller gap between electrodes in comparison with spark plugs for gasoline-air mixtures. In order to reduce the negative effects of the increased thermal stress the heat value of spark plugs is high. Thanks to this the wear of electrodes are reduced and a lifetime of spark plug is longer.

To make a selection of a spark plug easier the heat value of it was introduced. This value is expressed in numeric form that determines the capacity of dissipation of the heat being transferred from the combustion chamber to the spark plug. The higher the heat value, the heat dissipation capacity of the spark plug is higher. The spark plug may be thermally charged, without danger of self-ignition of the mixture from a hot part of the spark plug. Such spark plugs are popularly called “cold”. The disadvantage of these spark plugs is the increased tendency to gather the pollution on the surface of electrodes. It reduces the energy of spark. Cold spark plugs are used in engines with high compression ratio and in the engines a high average temperature in the cylinder is expected.

The smaller the heat value of the spark plug the faster is heating of it. This makes possibility of self-ignition of the air-fuel mixture. The advantage of such spark plugs is a faster self-cleaning process. Such spark plugs (called “hot”) are used in engines with low compression ratio and low power, where there is a lower average temperature in the cylinder. The heat value of the spark plug is affected mainly by the shape and dimensions of the cone insulator: the larger the size of the cone of the insulator, which is exposed to hot exhaust, the spark plug is easier to be heated.

4. Prototype spark plug for the engine fuelled with natural gas

As a result of research it was designed and constructed a spark plug for the engine fuelled with natural gas. The new spark plug construction was elaborated with Iskra Zakłady Precyzyjne Sp. z o.o. from Kielce. The spark plug is marked: TWG100RS. It is shown in Fig. 1-3.
The Spark plug which was designed for CNG engines have the following parameters:

- electrode distance 0.5 mm,
- side electrode is connected by resistance welding to the spark plug body,
- resistance of the centre electrode is 6 ± 3 kOhm,
- used materials:
  - central electrode - NiCr2MnSi + Cu,
  - side electrode - NiCr2MnSi,
  - body - 11SMn30,
  - insulator - Al2O3.

5. Tests of new spark plug

New spark plug was made in accordance with Polish standard PN-85/S-76035 “Spark plugs. Requirements and tests”. For verification it was installed in buses fuelled with natural gas. The buses “Jelcz” operate in four public transport companies. They are exploited in different conditions and give possibility to test new spark plugs for different load of the engines. The analysis and evaluation will be done after driving 10 thousand, 15 thousand and 30 thousand km. After each of this millage the examination of spark plugs according to the previously cited standard will be carried out including analysis of their wear.

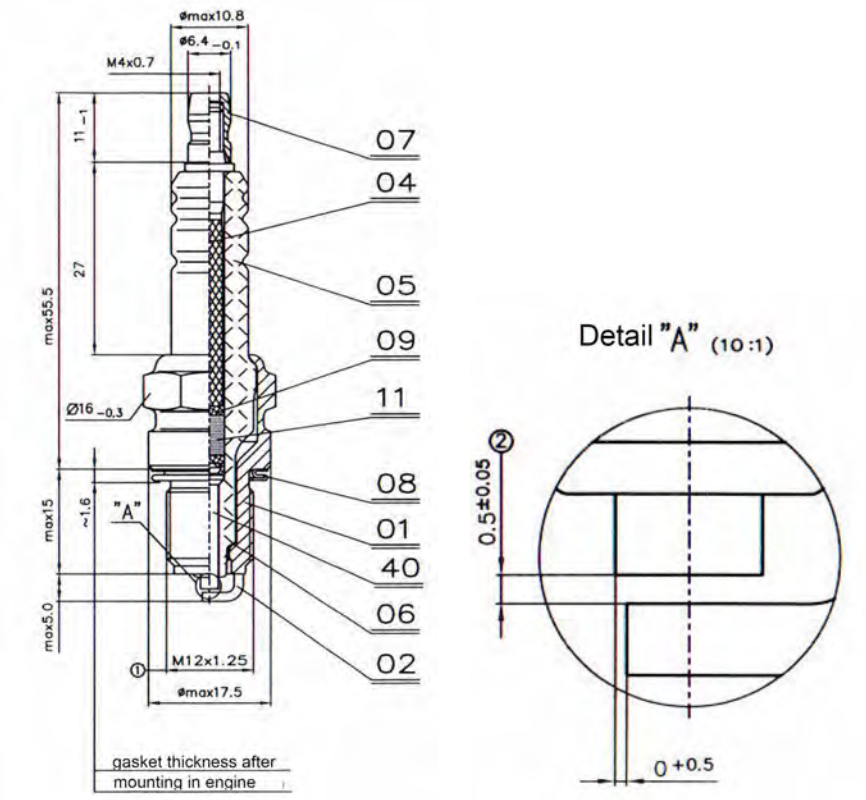

Fig. 1. The construction of the new spark plug for engines fuelled with CNG (ac cording to Iskra Zakłady Precyzyjne Sp. z o.o. from Kielce documentation): 01 – body, 02 – side electrode, 04 – contact pin, 05 – insulator, 06 – internal gasket, 07 – contact nut, 08 – outer gasket, 09 – glass-hermetic conductive material, 11 – glass-hermetic resistance material, 40 – central electrode

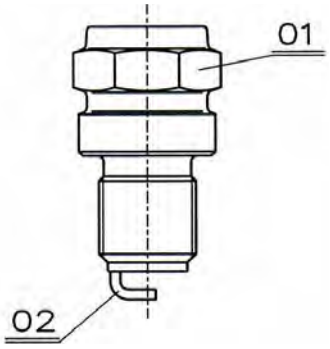

Fig. 2. The construction of the connection of side electrode to the the body by resistance welding (according to Iskra Zakłady Precyzyjne Sp. z o.o. from Kielce documentation): 01 – body, 02 – side electrode

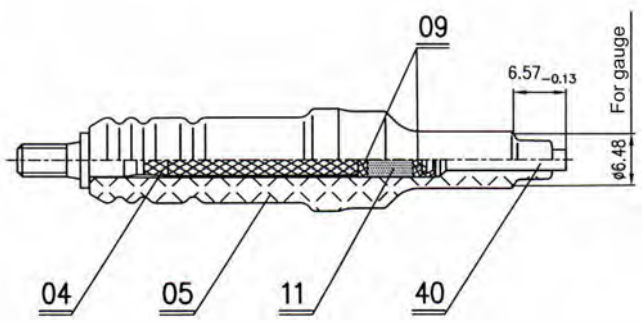

Fig. 3. The construction of the centre electrode (accordi ng to Iskra Zak łady Precyzyjne Sp. z o.o. fr om Kielce documentation): 04 – contact pin, 05 – insulator, gasket, 09 – glass-hermetic conductive material, 11 – glass-hermetic resistance material, 40 – centre electrode

This assessment includes:

- external visual inspection: spark plug insulator surface should be clean, enamel on insulator should have no infiltration, stains and cracks, the surface of the body of spark plug should not have mechanical defects negatively affecting the work of it, and should be protected from corrosion, dimensions shall be in accordance with the relevant standards,
- control of resistance to high temperature: there shouldn't be cracks on the part of the spark plug especially on the threaded part, and a spark plug shouldn't indicate a reduced capacity to work for heating up to temperature: 850 ± 20°C for 3 minutes, 700 ± 20°C within 10 minutes, or to temperature determined by heat value of the spark plug,
- check the strength to withstand of changes of temperature: spark plug should withstand cyclic temperature changes from 20 to 300°C and also withstand of low temperature (-40°C). The spark plug shouldn't be damaged or loosened because of temperature,
- check the strength of the body of the spark plug: the spark plug screwed and tightened with the appropriate torque (e.g. For spark plug, F and FE it is 50 Nm) shouldn't show deformation on the body and the seal between the insulator and the body must be good,
- check the strength of a tip of spark plug: tip embedded in the insulator should not be damaged by the force rising up to 300 N acting along the axis, torque - 0.5 Nm acting in a plane perpendicular to the axis of the spark plug, the lateral force – 400 N acting perpendicular to the axis of the spark plug,
- check the strength of the attachment of the side electrode: the electrode should be so secured (welded to the body) to curve through an angle of 90 degrees and bend again to the original position does not cause cracks or snap of electrodes,
- control leakage at ambient temperature: a spark plug should be tight at a differential pressure of 2 MPa after tightening with the appropriate torque (eg. For spark plug F and FE it is 35 Nm),
- control leakage at 200°C: after screwing and tightening with appropriate torque the spark plug should withstand a differential pressure of 4 MPa,
- check the spark plug insulator resistance to 250°C: the resistance should be not less than 1,000 MΩ or when heated up to 550°C of not less than 5 MΩ. The resistance is measured between the body and the tip of central electrode for 500 V DC,
- control of electric strength: after high voltage application the puncture of the spark plug should not occur.

For the new spark plug following tests will be also carried out:

- push-out the insulator from the body. An attempt is made to verify the strength of the metal body of the spark plug and the quality of the clip between metal and the ceramic body (insulator). The spark plug screwed to the mounting plate is kept immersed in oil 10W/40 for a period of 500 hours. Then, after drying the spark plug must withstand the pressure 6000 psi (about 414 bar). Permissible movement of ceramic insulator against the metal body is less than 0.025 mm. The test is Italian standard,
- corrosion resistance in salt spray. The corrosion resistance shall be checked in an environment of 5% salt mist for a period of 200 to 240 hours. After the test the rust points on the metal surface are not allowed. The test fulfils Italian and American standards.

6. Summary

These tests allow preparing mass production of spark plugs for professional ignition system for SI engines fuelled with natural gas. New spark plugs will provide a longer service life compared to previously used. They also make it possible to eliminate the extinction of the arc between the electrodes and an electrical misfire in subsequent cycles of engine operation. As a consequence, fuel consumption reduction and reduction of emissions of unburned hydrocarbons into the atmosphere is expected. A positive effect of the application of new spark plugs can be also longer engine service life.

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