Recent advances in Spark Plug design and Technology – A Systematic Review

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Abstract - *A spark plug is used for initiation of combustion (Ignition) by passing a high voltage spark, inside the combustion chamber filled with combustible mixture of Air and fuel. The normal fuels used are Petrol, CNG, LPG, Ethanol and Kerosene.*

A general spark plug includes a center electrode, an insulating member which holds the center electrode in an axial hole, a metal shell which surrounds the periphery of the insulating member to hold the insulating member, and a ground electrode which is joined to the metal shell at a proximal end portion and which forms a spark gap at a distal end portion with the center electrode. The fuel mixture is ignited by a spark discharge occurring in the spark gap. Many international Journals and research works are happening in the field of Combustion physics and advancements in Spark plug design and development. In this journal few journals from well reputed international journals and Articles are considered for Review. The journals are reviewed and presented in a systematic way.

Spark plug has evolved since many decades, it has an glorious history of more than 120yrs. The recent trends include developments in high voltage ceramics, High temperature and Pressure resistance Electrode material development, Design of electrodes for ultra lean gasoline mixtures etc are some of the recent developments.

Keywords - Spark Plug, Combustion, physics, high temperature, ceramics, electrodes, High voltage, Brake mean effective pressure

1. INTRODUCTION

A spark plug, also known as a Sparking Plug, is a device that fits into an internal-combustion engine's cylinder head and comprises two electrodes separated by an air gap across which electricity from a high-tension ignition system discharge to generate a spark to ignite the air–fuel mixture. The electrodes must be able to survive high temperatures, as well as an electric stress of thousands of volts, and the insulator between them must be able to withstand high temperatures as well. The energy of the spark is influenced by the length of the spark gap, and the operating temperature is influenced by the shape of the insulator. Carbonization and short-circuiting of the gap can occur when running at too low a temperature; preignition can occur when working at too high a temperature. Internal combustion engines with spark ignition (SI) that run on gasoline account for most powertrains in light-duty passenger and goods transport vehicles.

Spark plugs initiate the spark production between electrodes in spark-ignited internal combustion engines, which commences the burning of compressed fuel/air mixture. A spark plug must be able to tolerate extremely demanding working conditions in the combustion chamber in terms of performance. It must withstand thermal shocks caused by a succession of cold intake air with ambient temperatures and hot exhaust gases with temperatures reaching 3000°C under high load circumstances. It is prone to chemical reactions and combustion chemical deposits. A spark plug must withstand up to 150 bar of oscillating pressure. It can withstand voltages of up to 40,000 V without charge flashover at the insulator, even when soot and carbon residues are present.

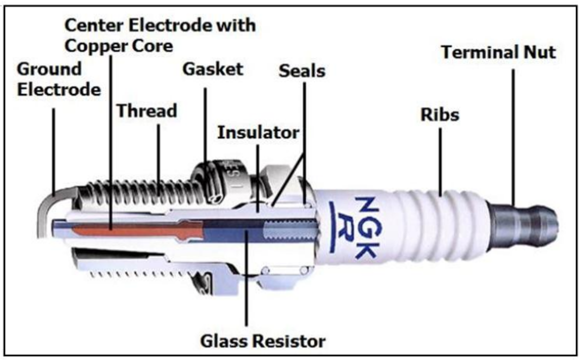

Figure 1: Spark plug design details.

The steel gas-tight terminal nut is housed in an insulator with an electrically conductive glass seal. The terminal nut is also connected to the center electrode by the glass seal. Threads for connecting to the ignition cable are present. The insulator protects the terminal nut from the shell and the center electrode by being composed of a unique ceramic substance. Aluminum oxide (Al_2O_3) is commonly used because it has strong thermal conductivity and electrical insulation. The gasket serves as a sealing device for the combustion chamber, preventing leaking from the chamber. This wears the electrode and the gap between the center and ground electrode widens. The ground electrode is attached to the shell by welding to the metal shell.

2. Literature review: Systematic Approach

Changming Gong et al, have conducted Numerical study of twin-spark plug arrangement effects on flame, combustion and emissions of a medium compression ratio direct-injection methanol engine. The effects of a twin-spark plug arrangement on the flame, combustion, and emissions of a medium compression ratio direct injection methanol engine were studied numerically. The burning and exothermic were the most reasonable compared to other twin-spark plug positions at roughly A (ratio of distance of twin-spark plug and cylinder diameter) = 0.65, according to computational results. The worst twin-spark plug configuration was A = 1.00. With increasing A, the maximum in-cylinder pressure and temperature both fell. With increasing A, the ignition delay increased. The A = 0.65 had the quickest combustion time and the highest rate of heat release. A = 1.00 had a maximum in-cylinder pressure that was around 57.5 percent lower than A = 0.25. The ignition delay of A = 1.00 was 2.4 times larger than that of A = 0.25. A = 0.67 had a 12 percent and 52.2 percent shorter combustion time than A = 0.25 and A = 1.00, respectively. Unburned methanol and soot emissions increased steadily as A grew, but at A > 0.75, unburned methanol and soot emissions surged significantly. A = 1.00 had approximately 4.6 times more unburned methanol than A = 0.25. Variations in released NOX emissions were inversely proportional to changes in unburned methanol and soot emissions. The ideal configuration of the twin-spark plug for use in a real engine was around A = 0.65. The boundary conditions for computational fulid dynamics are shown in the schematic below refer [1].

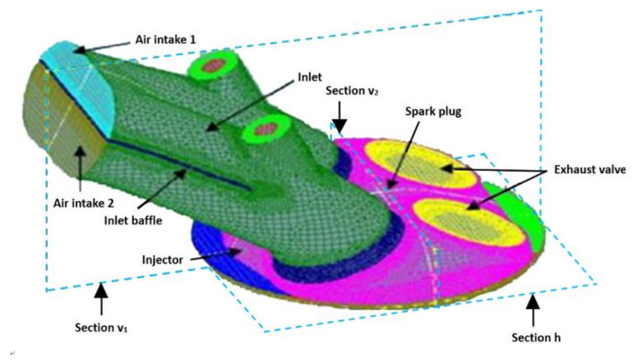

Fig 1: Boundary conditions for a CFD study [1]

E. Sher et al, has investigated that the spark discharge is preceded by a corona wind. When a high voltage (but less than the breakdown voltage) is supplied to the plug electrodes, a corona wind is produced. The corona wind drives the ignited mixture away from both electrodes, reducing heat transfer to the electrodes and thereby reducing heat loss from the ignited mixture.The new technique makes it easier to ignite lean mixes while also enhancing ignition efficiency, improving cyclic variation, and lowering HC emissions. The ignited mixture is carried out from the electrode gap at a speed of 5 m/s, which has been determined to be optimal in prior experiments, according to high-speed images of the novel system's ignition process in a constant volume bomb. Preliminary tests with a standard 4-cylinder engine have yielded encouraging results. Standard Design and New Design Views are shown in Fig 2. [2]

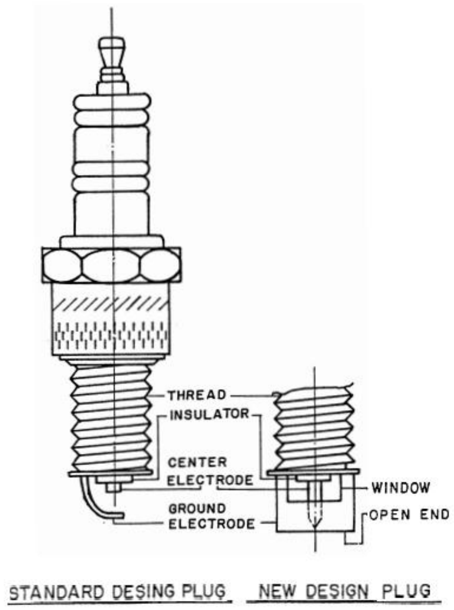

Fig 2: Standard Design and New Design Plug [2]

Lin Chen et al, has investigated that the key problems for modern natural gas engines are increasing thermal efficiency and decreasing cycle-to-cycle variability. The significance of several spark-ignition approaches in enhancing engine performance in an optical engine fueled with methane was explored in this work, as well as cycle-to-cycle changes and flame evolutions under lean combustion conditions. The experimental results show that there are close correlations between spark plug types and ignition energy with combustion stability: multi-claw spark plugs perform best in terms of combustion stability and thermal efficiency under medium ignition energy conditions, whereas different spark plug types perform nearly identically in terms of combustion performance under both low and high ignition energy conditions. High ignition energy, on the other hand, has a bigger impact on improving combustion stability when compared to spark plug types. Faster flame formation contributes to increased combustion stability, according to optical flame pictures. To quantify early flame evolutions, an empirical criterion of mass fraction burned was used to uncover the fundamental reasons. It demonstrates that a multi-claw spark plug with a high ignition energy promotes initial flame propagation, with lower cycle-to-cycle fluctuations in this combustion stage. The findings will shed light on how to improve natural gas engine performance while controlling cyclic variation using a multi-claw spark plug and high ignition energy.[3]

Ahmed A.Abdel-Rehim et al, has investigated that in today's market, there are a variety of spark plug designs to choose from. Understanding the distinctions between them will aid in the proper and effective operation of the engine.The impact of a group of four spark plugs with varied numbers of ground electrodes on engine performance, particularly combustion instability, was investigated in this study.The findings revealed that the quantity of ground strap crossing, ground strap diameters, and gap width are the key parameters influencing spark commencement, flame initiation, and kernel expansion.The plug that performed the best was one that had no ground electrode and had the least amount of heat losses and no barriers in the way of flame propagation. This spark plug type has the lowest coefficient of variation (COV) of the four primary test spark plugs.[4]

Bilge AlbayrakCeper et al, has conducted experimental investigation on the performance and exhaust emissions of a commercial hydrogen fueled spark ignition engine (HFSIE) at 50 percent and 100 percent wide open throttle (WOT) settings. The engine is a six-cylinder, four-stroke cycle, 4.9 L, port fuel injection, hydrogen-fueled SI engine with a bore of 102.1 mm, a stroke of 101.1 mm, and a compression ratio of 13.5:1 with a bore of 102.1 mm, a stroke of 101.1 mm, and a compression ratio of 13.5:1 with a bore of 102.1 mm, a stroke of 101.1 mm, and a compression ratio of 13.5: Three distinct spark plug gaps (SPG) (0.4, 0.6, and 0.8 mm), 1000–3000 rpm engine speeds, and two ignition timing values (10 and 15° CA BTDC) at 50 percent and 100 percent wide open throttle were used in the studies (WOT). SPG is a factor that affects the engine's performance depending on the engine structure. At ignition timings of 10 and 15° CA BTDC, maximum power values of 50 percent and 100 percent WOT were obtained at 0.6 mm SPG. With a 0.8 mm SPG at 50% WOT, the highest efficiency figures were attained. Maximum efficiency values were obtained with a 0.6 mm spark plug gap (SPG) at ignition timing settings of 10 and 15° CA BTDC at 100 percent WOT. For both WOT and SPGs, hydrogen resulted in a considerable reduction in NO emissions.[5]

Lucas W.S.Crispim et al, has investigated that a novel numerical technique for investigating the electric discharge produced by a vehicle spark plug in dry air. An axial symmetric 2D domain is used for this challenge. Molecular nitrogen and oxygen make up the initial gas mixture (8:2 ratio). Heat and species diffusion and convection are included in the mathematical model, as well as a discrete sub-model for energy transfer in electronic, atomic, and molecular collisions. Interspecies chemical reactions are also included. In the context of ZDPlaskin, a zero-dimensional plasma modelling tool, source terms are solved. There are 53 species and 430 processes in the plasmo-chemical kinetics model that was used. The simulation incorporates experimental properties from a real-world spark plug discharge. Within this model, the spatio-temporal evolution of species concentrations is derived. The evolution of gas temperature and species distribution is discussed, and values from the literature are compared.[6]

C Oliveira et al, has investigated that A spark discharge employing a commercial spark-plug operating in the glow phase regime was investigated using optical and electrical diagnostics. To characterise the discharge, voltage and current were monitored. By comparing real and simulated ro-vibrational spectra of the second positive system of nitrogen, the gas temperature was determined as a function of time and duty cycle. It was discovered that 1600 K Tg 2800 K. After the current pulse ended, the lowered electric field varied between 1 and 1000 Td.The electronic temperature was determined using the line intensity method between one line from the ionic argon and the other from the neutral atom, and was found to be between 17 000 and 20 000 K. The electron density was calculated using the broadening of the H line and found to be 4.0 1014 cm3 ne 1.7 1015 cm3. [7]

Kaori Doi et al, has introduced the spark plug for ion current misfire detection method in this paper. The ion current signal must be bigger than the noise signal in order to achieve high accuracy misfire detection. The setup and initial condition of the spark position are developed from an experiment and consideration of degradation in use in order to preserve the ion signal for the entire specified lifetime. Furthermore, an observation and a theoretical analysis are used to determine the cause of noise, and we show how to effectively inhibit noise. Finally, the effect of the methods discovered by these two approaches is tested using an engine, and we offer specifications for spark plugs that satisfy the criteria of high accuracy ion current sensing.[8]

Ashish.J. Chaudhary et al, has investigated that the urrent research focuses on the placement of the spark plug and how it affects the performance and emissions of a 100% raw biogas-fueled variable compression ratio engine. The influence of four spark locations protruding inside the clearing volume (viz. 0, 2, 5, and 10 mm) is investigated using various performance, combustion, and emission characteristics. For compression ratios of 8, 9, and 10, a 2 mm protrusion of the spark plug is found to be optimal. Engine efficiency and fuel economy are proven to be higher at this optimum spark plug location. In this scenario, faster combustion resulted in an earlier and higher peak cylinder pressure and burnt gas temperature. The optimality of the 2 mm protrusion location of the spark plug for all compression ratios has been proven by lower hydrocarbon and carbon monoxide emissions. As a result, current research suggests that a biogas-fueled engine's spark plug be protruded slightly to aid the combustion process, improve performance, and reduce emissions.[9]

Evers, L W et al,has investigated the he appropriateness of spark plug pressure transducers for monitoring indicated work in internal combustion engines. The response of the spark plug unit was compared to that of a reference device using three piezoelectric transducers; the comparative data came from a single-cylinder engine with both a flush mounted pressure transducer and a spark plug pressure transducer. Signals from both transducers were captured at the same time, coupled with a volume function, and output discrepancies were examined. The volume function that was used in the indicated work calculations was created around an angular reference point that was captured with the pressure data. The indicated work computed using the spark plug pressure transducer was often found to be between -3.2 and +7.6% of that predicted using the flush installed pressure transducer. The spark plug pressure transducer and its sources of inaccuracy are explored. [10]

3. CONCLUSIONS

A total of ten recent international journals published in the field of combustion physics, internal combustion engine, computational fluid dynamics and advanced sperk plug designs were systematically reviewed and documented in this current journal.As per the systematic review it is observed that spark design and materials used in spark plug are evolving rapidly to meet the global automotive demand, few important observations made are, to meet stringent emission norms and ever increasing demand for performance, the automobile manufacturers are moving towards stochiometric air fuel ratios, ultra high lamda values and peak pressure greater than 200 bar. The suitable spark plug designs have been presented and analysed by authors.

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