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Electrical behaviour of ceramic composite materials for aero-engine igniters

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Abstract

High energy igniters are extensively used in aero-engines and this study describes the specific ceramic composite materials used at the igniter tips. These ceramics favour the formation of a plasma-like process on their surfaces under an electrical field not exceeding 1 kV mm^{-1}. The elevated temperature which is reached, and the high energy released during sparks are very favourable for engine ignition, even when internal engine temperature, pressure and fuel flow are unfavourable. Currently used ceramics and possible igniter designs are described. For composite ceramics, the physical mechanisms involved during sparking are presented, together with the high temperature and pressure effect in engines. Degradation mechanisms of materials are also examined to understand the operational life of igniters when working conditions vary. Problems associated with continuous ignition and the type of surface discharge materials are also discussed.

Keywords: Ceramic; Igniter; Electrical property

1. Introduction

This study describes the design of ceramic composite materials used for spark igniters or more generally for aeronautical ignition systems. Descriptions will be focussing on specific low-tension igniters as they have been studied for years [1], and are currently used for the aero-engine ignition. The rather special characteristic of these igniters is the plasma-like process occurring on the ceramic surface during the electrical discharge under an electric field in the 0.5–1 kV mm^{-1} range. The localized high energy level (1–5 J) of “hot electrons” is very useful for gas or liquid ignition, even when the stoechiometry ratio in engines is unfavourable. To understand the role of a ceramic composite material, it is necessary to present the whole ignition systems, the various types of spark igniters and the whole assembly of spark igniters in which ceramics are used.

1.1. The ignition system

The whole ignition system includes four parts: a direct current source, a high voltage unit, an electric cable and the igniter itself. The HV ignition unit is an electronic assembly to transform the DC low-tension source (28 V) into high voltage pulses. Whereas for simple air gaps up to 30 kV are required, composite ceramic igniters require only 1–2 kV. The high voltage source must be precisely calibrated (duration of pulses, energy level, periodicity) to obtain a high energy level during sparks on the ceramic composite surface.

There are three main groups of igniters currently used in civilian or military aero-engines. Different technologies and designs are used, with various high voltage sources and a large range of delivered energy. This review describes three typical types of igniter designs.

1.2. Air-gap igniters

Fig. 1 presents the air-gap igniter end. It is similar to standard spark plugs for automotive internal-combustion engines.

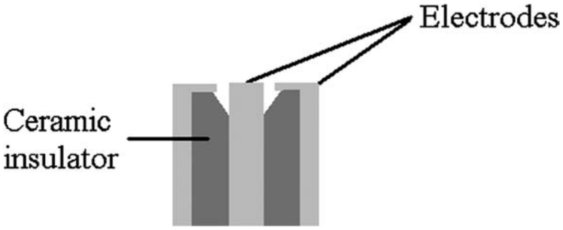

Fig. 1. Air-gap igniter.

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These igniters have two coaxial electrodes with an 0.2–1 mm air gap. The electrical insulation uses a ceramic insulator (alumina ceramic) and a glass sealing between metal and ceramic. The spark across the air gap requires at least 15 kV, but the breakdown voltage increases drastically with pressure, up to 30 kV for 15 bars. Therefore, these igniters cannot always meet ignition needs in combustion chambers when the atmosphere pressure exceeds 15 bars. Whereas these igniters present the largest lifespan under operation, their use is not generalized in all aeronautical engines, because of the electromagnetic disturbances from high voltage pulses.

1.3. Surface discharge igniters

High energy surface discharge igniters (H.E. Igniter) are devices used to initiate combustion with a low voltage source. Early surface discharge igniters were developed in the forties for aircraft engines in Germany.

The story of the utilisation of H.E. Igniters is linked to the history of gas turbine ignition. In general, problems encountered in the early days of gas turbine ignition included:

- fouling and shorting of high voltage igniters by combustion products;
- inability of low energy spark plugs to ignite droplets of the less volatile kerosene fuels;
- disturbance and insulation problems when carrying high voltage power sources on board aircrafts.

These requirements mean that at present, low voltage H.E. Igniters are always used.

There are two main categories of H.E. Igniters, the first one having a thin layer of semiconductor or resistor coated on an insulating material acting as the surface discharge material. The alternative is to use a specific ceramic material at the igniter tip, which is a source of a plasma-like process.

1.4. Surface diffused or coated igniter

This range of novel devices was investigated years ago and the first successful solution was found for Rolls Royce Dart Engines, which used a primitive form of the high energy igniter. This device named Aquadag, was a colloidal dispersion of graphite powder in an aqueous media, deposited onto the ceramic between electrodes, and dried to form an adherent film. The problem of erosion of such a surface discharge material was overcome by the deposition of soot from the combustion products and the soot layer acted effectively to allow sparks. Nevertheless, problems with igniter life resulting from spark plug erosion were encountered as soon as more efficient combustion chambers were developed, where the necessary carbon layer did not withstand working conditions.

Subsequently some new ceramics have been investigated as surface discharge materials to prevent erosion at high temperature and improve ignition efficiency at any pressure or fuel to air ratio. These ceramics include various combinations of materials such as oxides of aluminum, copper, iron or titanium. More recently, improvements were also obtained with doping an insulating ceramic surface, such as alumina, by various metals (e.g. copper).

As for igniters with a simple air-gap between metal and electrodes, the whole assembly has two coaxial electrodes close to the semi-conducting surface of the ceramic (Fig. 2). Metal and ceramics parts are sealed by a glass layer. The main difference between an air gap igniter and a semi-diffused igniter is the existence of a significant surface conductivity.

This material favours the decrease of the breakdown voltage down to 1.5 kV. Voltage is almost independent of the atmosphere pressure, within the common range of the atmosphere pressure encountered in engines (up to 15 bars). Nevertheless, the major disadvantage of these igniters is their lifespan, which is considerably reduced because of the wear and of the fast chemical erosion of the conducting layer.

The most recent type of igniter uses composite ceramic materials. They are often named semiconductors, even if this terminology is incorrect because the physical mechanisms involved are somewhat different. Such igniters are often used for the ignition of a large range of aero-engines. These ceramic materials, insulating materials, metal parts and the whole igniter design are at present under constant development.

1.5. Igniters ceramic composites

The igniter design described in Fig. 3 is commonly used. Two coaxial electrodes are connected to the composite ceramic material at the igniter tip. Underneath, an insulating ceramic holds the assembly and a glass seal is used for metal to ceramic bonding. In general, the breakdown voltage is about 1 kV for a gap between electrodes of about 1.5 mm.

The significant physico-chemical strength of some ceramics at high temperature reduces the phenomenon of wear and increases the lifespan of igniters. Besides, the breakdown voltage and the electrical discharge characteristics at high pressure are important characteristics, which can be maintained within

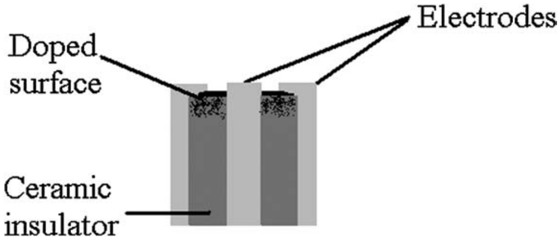

Fig. 2. Semi-diffused igniter.

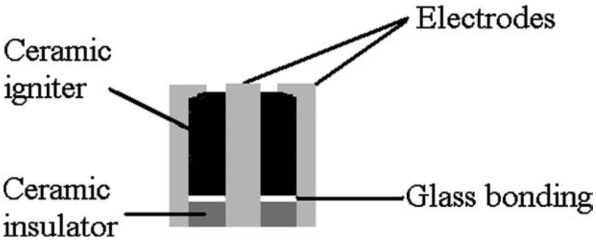

Fig. 3. Ceramic gap igniter.