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THE DESİGN AND İMPLEMENTATİON OF LASER İGNİTİON SYSTEM FORTWOSLOT AND FOUR SLOT EV BURNERS

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ABSTRACT

EV Burners are of the type undergoing periodically ignited constant-volume combustion. In contrast to conventional firing techniques, wherein constant-pressure combustions occur substantially, a constant-volume combustion entails an explosive combustion with an accompanying pressure wave. A particular advantage of constant-volume combustions is that the pertinent starting components have a stoichiometric relationship and can be virtually completely consumed.

Shock wave burner includes equipment for periodically injecting fuel-oxidant mixture into a constant-volume combustion chamber, a laser pulse device for directing an intermittent beam of laser radiation pulses into the chamber so as to repeatedly ignite fuel-oxidant mixture supplied thereto, and equipment for synchronizing the frequency of injection of the fuel-oxidant mixture into the chamber with the pulse frequency of the laser beam.

A photon ignition system for igniting the air/fuel spray Within a Combustion chamber of a gas turbine engine is comprised of a photon source has an output wavelength characteristic suitable for being absorbed by the hydrocarbon fuel droplets within the fuel spray. An ultraviolet flash having spectral characteristics which are selected to be strongly absorbed by hydrocarbon fuel

INTRODUCTION

Laser igniters are a promising area for ignition systems and have a number of advantages over the conventional ignition methods, such as the ability to control the ignition location, ignition timing and ignition energy. The fact that it is non-intrusive is also a great advantage. However, a lot of research is needed,[1,2] primarily in the areas of evolution in high-speed streams, engine-like conditions and beam quality, before it is possible to release the laser igniter on a large scale commercially. Because of the advantages, it is expected that laser igniters will be the dominant ignition source in many applications, including gas turbines, in the future

The source of radiant energy may be a laser having a pulsed radiant output having a wavelength which lies within the ultraviolet (UV) portion of the electromagnetic spectrum, the UV being that portion of the spectrum which is most completely absorbed by the hydrocarbon molecules which comprise fuel. The radiant output is coupled to the combustion chamber by a photon transmission means. The radiation is transmitted and focused using optical collecting lenswhich focusses the beam at a selected region within the air/fuel mixture, the mixture being provided,[3,4] typically, as a premixed mixture of air and fuel. The region of the fuel mixture is selected to be at an optimum position within the spark in order to provide the best ignition characteristics. The photon ignition system comprises the photon source and the focusing means which are amenable to packaging in a small, lightweight module which is capable of being mounted on an EV burner. The use of the invention advantageously provides for positioning the focal point of the radiation at a region in space which is determined to be an optimum region for the ignition of the fuel spray and, thus, requires a minimum amount of ignition system energy. This overcomes the problem of the prior art wherein the spark ignitor is positioned at the combustor liner wall where the fuel spray is generally not desired, the cooling of the liner forcing the fuel spray away from the ignitor. The problem of the higher ignitor energy required to achieve reliable ignition under this circumstance, which in turn shortens the useful life of the ignitor, is also thus overcome. The radiation through an existing combustor lining primary air hole such that no special ignitor hole, which requires special liner cooling treatment, is necessary. In addition, the shank of the ignitor which tends to obstruct the air flow through the combustor outer air passage is eliminated, thereby providing for an unobstructed outer air passage and the elimination of disruptive turbulence. The photon ignition system of the present invention also overcomes the problem related to the relatively large inductive losses experienced by the electrical ignition power between the sources of ignitor power. In the photon ignition system of the present invention the losses are greatly reduced inasmuch as there are minimal inductive loss effects involved; the losses are instead relatively small optical losses experienced by the radiation as it traverses through the air gap. Furthermore, the relatively fixed ignition firing rate of approximately three sparks per second due to the characteristics of the capacitive network is overcome in that the photon ignition system may have a photon source operated at a variable pulse rate. Due to the elimination of the spark ignitor the photon ignition system of the present invention has no devices which are rapidly consumed or degraded during operation, thereby resulting in a reduced maintenance schedule and the costs associated therewith. The overall reliability of the ignition system and, hence, the engine, is therefore also greatly improved.

EXPERIMENTAL SET UP

The present work aims to study the effect of using laser ionization beam on the ignition time of EV burners, the fuel used during the experiment is LPG gaseous fuel. **(Fig.1)**

Figure1: LASER ionization system

To ensure accurate settings of the experiments together with reliable data collection, a Vertical arrangement of the burner is chosen to eliminate buoyancy effects on the developed turbulent flames.

The schematic of the experimental set-up is illustrated in **(Fig2).** This set-up essentially consists of:

1- Fuel and air supply system.
2- The EV burners and combustor.
3- Electric spark ignition system.
4- Laser ignition system.
5- Acoustic measuring system.

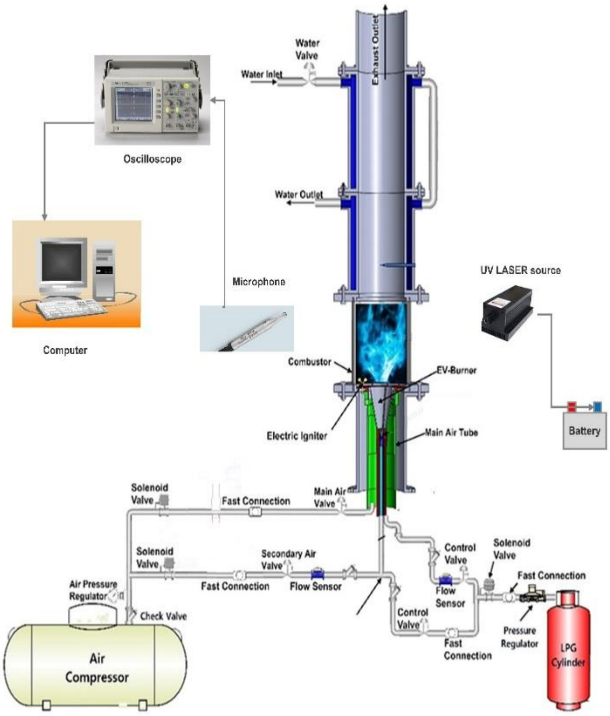


Figure2: Schematic diagram of system set-up

Fuel and air supply system

In order to admit accurate flow rates of both the gaseous fuel and the co-flowing air, measurements were made using rotameters manufactured by Dwyer Instruments Inc. Since all the rotameters used were calibrated for air at standard pressure and temperature, the flow-rate readings taken were corrected according to the calibration equations supplied by the manufacturer for the flow pressure. Solenoid valves were used and controlled by Lab View program. The rotameters of different ranges were used to measure the fuel flow rate according to their range. However, only one rotameter was enough to measure the air flow rate.

<u>Four Slot burner:</u> (Fig 3)

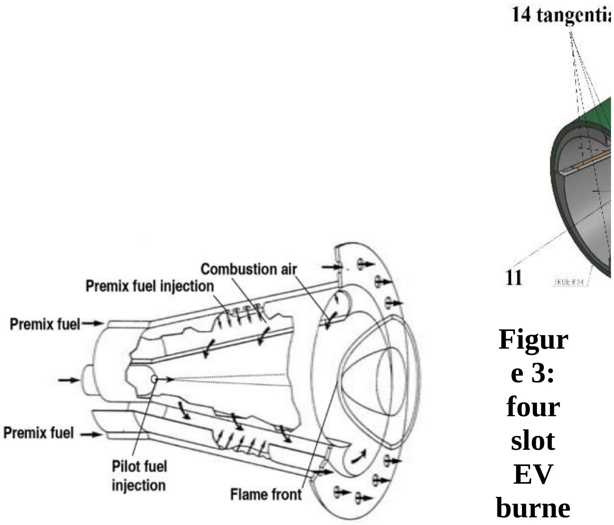


Figure 3: four slot EV burner.

- <u>EV Burner:</u>
  (a) <u>Conical Passage with 4-Slots</u>
  (b) <u>Air Passages</u>

Four circumferential air slots displaced (formed by quarter cones with four slots between them).Air is forced to enter into the cone circumferentially.

(c) <u>Fuel Admission:</u>

At each of burner slots, main fuel is injected through equidistantly holes located along the entry of each air passage between the apex and the burner exit.

Two Slot burner:

To perform the objectives of this study, the design of the test rig should facilitate the following:

- Co-axial jets burner.
- Double concentric tubes (centric and outer), two fluid supplies to the passages of the air jets to enable separately easy control of the air mass flow rate.
- Separated fuel supply to the first annular line to facilitate easy control of the fuel mass flow rate.
- Precise control of the fuel mass flow.
- Accurate vertically support of burners to avoid changes in jets direction.

The tested burner as shown in **(Fig.4)** consists of an air jet surrounded by a fuel jet which is also surrounded by an outer air jet. The burner is made of two cast iron pipes as detailed on the figure.

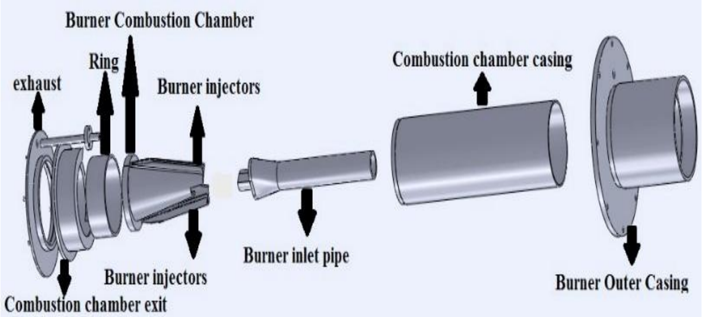


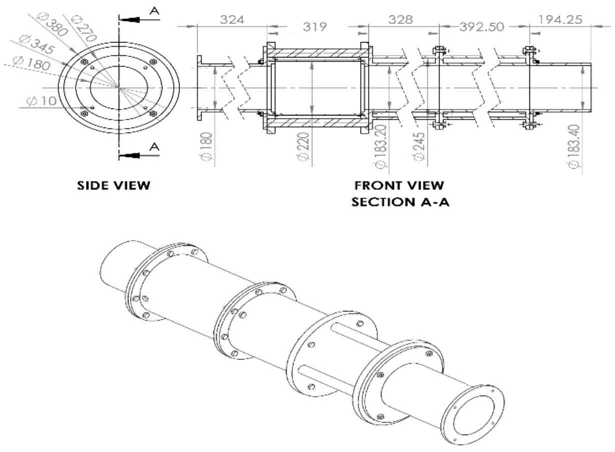
Figure4: Assembly of EV burner components

The EV-10 shown in **(Fig.5)** consists of two shifted half cones with two slots between them, such that air is forced to enter into the cone circumferentially. The resulting swirling airflow generates a recirculation zone along the centerline at the EV-10 outlet.

The main fuel is injected through 62 boreholes, 0.7 mm diameter each, that are distributed equidistantly along the two air slots.

The main fuel is mixed with the swirling air resulting in a nearly premixed combustion.

Figure 5: Two slot EV burner.



<u>**Combustor**</u> **(Fig.6)**

The combustor is a vertically cylindrical air-cooled flame tube of 230 mm inside diameter and 300 mm long with 18

bore holes 8 mm diameter to access probe of Thermocouple to measure in flame temperature. During the combustion process, these openings are closed with 8 mm screws of stainless steel 316. The Combustor Manufactured of thick steel pipe of 5 mm thickness. a water-cooled resonance tube of the same diameter and 1050 mm in length is attached to this combustion chamber with one bore hole 8 mm diameter

Figure 6: Combustor

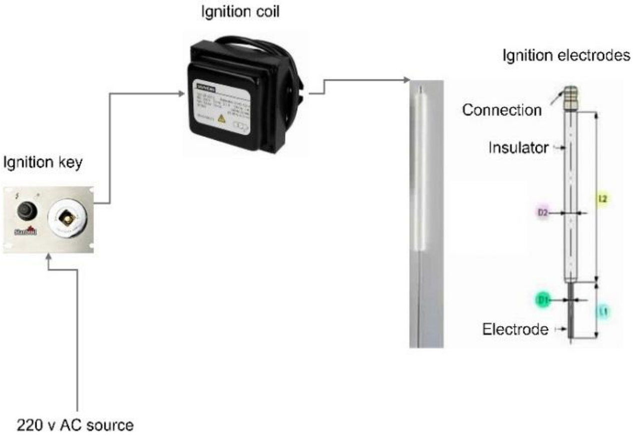
Electric spark Ignition System

The spark igniter is the most convenient and satisfactory igniter in gas turbines. The main parts of a spark plug are the electrodes, which is the area where the spark is created. The features of a spark plug are the deposition of ignition energy in a short duration (up to 100 milliseconds) and the concentrated region (up to a few millimeters) of the spark. As the frequency, duration and amount of energy can be controlled. The temperature of the spark is around 60,000 K and therefore heats the gases rapidly.

The ignition system of an EV-burner generates electric sparks at air gap between two electrodes to ignite the fuel-air mixture in the combustion chamber. The ignition system is an array of components that work together in the process of starting the combustion. Fig. 7

Figure 7: Electric spark Ignition System

The electric spark ignition system consists of:



1- Ignition key
startsthe burner ignition system, it allows the low voltage electricity from the electrical source to flow into the ignition coil.
2- Ignition coil (Transformer)
The ignition coil is a transformer that converts the low voltage into high voltage. The coil increases the voltage from 220 volts to 10,000 volts. It consists of primary and secondary winding circuits.
3- Ignition electrodes Fig.8

Two cable connected between Transformer and twoelectrodes 8 mm diameter adjusted on top the burner with air gap

Figure 8: Ignition electrodes of EV burner

Laser Ignition System:

In order to form an ionized air between the electric igniter electrodes a low power UV laser is used.**(Fig.9)**The diode laser specifications, 405nm, 20mW Compact CW diode laser with TEC temperature control Emission wavelength: 375nm Optical output power: 20mW Beam diameter: 1.1mm (1/e²) +/- 0.2mm M²: <1.15, (1,05 typical) CW in ACC and APC mode Analogue modulation: >1.5MHz Electronic Shutter: >150kHz .

Figure 8: 405 nm UV laser diode

Microphone setup

A condenser microphone is used to measure the acoustics oscillations downstream flow. It is mounted at the position which is able to record clearly these oscillations. The used microphone is GRAS- type 26AC- S7. It is a ¼″ preamplifier with a 3-m lightweight cable terminating in a 7-pin LEMO series 1B plug and used for high-frequency measurements and high-pressure measurements with wide frequency range, low noise level and very small size. The cable is only 2.5 mm in diameter and withstands temperatures from -40°C to +150°C. The typical capacitance of ¼″ microphone capsule is 6.5 pF. The electrical circuit in this type of microphones is built on a ceramic substrate using selected low-noise components to gain very low self-noise. The electrical self-noise is very low that system noise is mainly determined by the microphone capsule’s thermal noise. The dimensions of the microphone are as follows: 6.35mm diameter and 48mm length while the microphone weight is 4g in addition to 46g for cable and plug. As the size of the microphone is decreased, the useful frequency range of the microphone is increased. The frequency range, which can be obtained, is determined in part by the size of the microphone. The frequency range (±0.2 dB) is 2Hz- 200 kHz. It has a flat pressure frequency response in its entire frequency range. The frequency response of the microphone is determined by the diaphragm tension, the diaphragm mass, and the acoustical damping in the airgap between the diaphragm and the back plate see **Fig.10**. When the sound pressure in the sound field fluctuates, the distances between the diaphragm and the back plate will change, and consequently change the capacitance of the diaphragm/back plate capacitor. As the charge on the capacitor is kept constant, the change in capacitance will generate an output voltage on the output terminal of the microphone. The acoustical performance of a microphone is determined by the physical dimensions such as diaphragm area, the distance between the diaphragm and the back plate, the stiffness and mass of the suspended diaphragm, and the internal volume of the microphone casing.

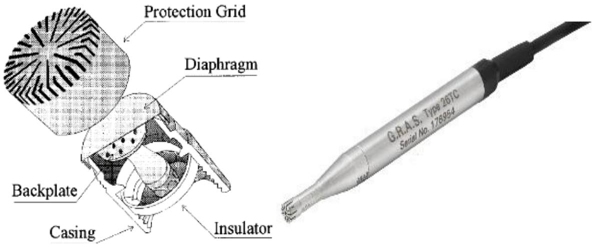


Figure 10: Basic elements of a condenser microphone

It is calibrated by using a Brüel& Kjaer pistonphone type-4228 at reference frequency 250 Hz and nominal gain of 124dB and the sensitivity was 1.152mV/pa. This type of microphones has proven to be superior with respect to temperature stability, long-term stability, and insensitivity to rough handling. It is designed and produced to ensure well-defined and accurate measurements. The operating temperature is in range of -20°C- +60°C at relative humidity of 0- 90%. The diaphragm and the back plate form the parallel plates of an air capacitor. This capacitor is polarized with a charge from an external voltage supply (externally polarized type) or by an electric charge injected directly into an insulating material on the back plate (pre-polarized type). The supply can vary between 28 VDC and 120 VDC single-sided or ±14VDC and ±60 VDC dual sided.

Signal record:

The output signal from the condenser microphone measured and recorded using Agilent 3000 Series oscilloscope **(Fig.11)** with up to1 GSa/s sample rate, Up to 4 kpts memory, Automatic voltage and time measurements (20) and cursor measurements, Advanced triggering (edge, pulse width, and video). Math function waveforms: add, subtract, multiply, FFT, USB ports (1 host with rear panel module, 1 device) for easy printing, saving, and sharing of waveforms, setups, screen BMP files, and CSV data files, Internal storage for 10 waveforms and 10 setups. Special digital filter and waveform recorder.Built- in 5- digit hardware frequency counter.

The oscilloscope’s sampling and acquisition modes according to The Nyquist sampling theorem states that for a limited bandwidth (band- limited) signal with maximum frequency f_{MAX}, the equally spaced sampling frequency f_S must be greater than twice the maximum frequency f_{MAX}, in order to have the signal be uniquely reconstructed without aliasing.

$f_{MAX} = f_S/2 =$ Nyquist frequency (f_N) = folding frequency

Aliasing occurs when signals are under- sampled ($f_S < 2f_{MAX}$). Aliasing is the signal distortion caused by low frequencies falsely reconstructed from an insufficient number of sample points.

Figure 11: Agilent 3000 Series oscilloscope

The oscilloscope can operate in normal, average, or peak detect acquisition modes.

The trigger determines when captured data should be stored and displayed. When a trigger is set up properly, it can convert unstable displays or blank screens into meaningful waveforms. When the oscilloscope starts to acquire a waveform, it collects enough data so that it can draw the waveform to the left of the trigger point. The oscilloscope continues to acquire data while waiting for the trigger condition to occur. After it detects a trigger, the oscilloscope continues to acquire enough data so that it can draw the waveform to the right of the trigger point.

RESULTS AND DISCUSSION

The electric spark ignition used in EV burner has several problems are associated with the use of a spark ignitor.**(Fig. 12)** One problem is related to the ignitor's position at a peripheral portion of the combustor which is not an optimum position to ignite the air/fuel mixture. Thus, the spark of the ignitor may fail to ignite or to completely ignite the air/ fuel spray within the combustor. Secondly, due to the nature of the operation of the ignitor, the device is subject to degradation and erosion by the action of the spark traveling thereacross. This ignitor degradation results in a requirement that the ignitor be replaced at regular intervals, thus the user of the ignitor incurs the cost associated with a replacement ignitor and the labor involved in its installation.Thirdly, due to the requirement that the ignitor shank extend through the combustor inner liner and into the chamber, the ignitor shank obstructs the air flow through a combustor outer air passage, resulting in a disturbance of the airflow and the generation of turbulence in the outer air passage. The peripheral position of the ignitor at the liner wall is also not optimum in that air required for cooling of the liner forces the spray away from the ignitor. **(Fig.13)**

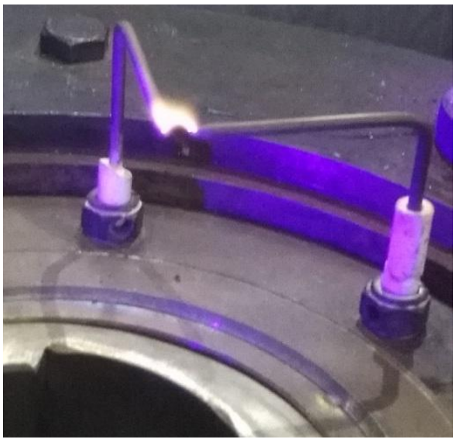


Figure 12: Electric spark ignition

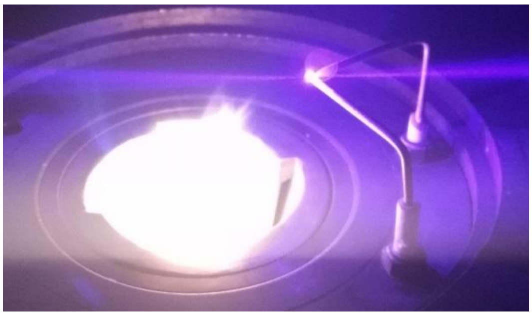


Figure 13: Ignition start using electric spark igniter

In order to achieve ignition under such a non-optimum condition the power into the ignitor is typically increased resulting in a proportional decrease in ignitor life. A still further disadvantage of a spark ignitor system is related to the electrical losses experienced in the ignition system between the source of ignitor power and the ignitor. The source of ignitor power is typically a capacitive device which charges to the breakdown volt age of the ignitor and subsequently discharges across the ignitor electrodes, resulting in the spark. This discharge energy is conveyed by electrical cables which have an inductive loss associated therewith. This inductive loss experienced by the discharge energy may typically be as great as 80 to 90 percent. The nature of such a capacitive power source further results in a relatively constant spark frequency of approximately three sparks per second. This frequency, under some engine operating conditions, may not be an optimum frequency.

To limit the ignition failures LASER ionization of air gap are searched and developed, to which can be ranked laserignition systems.**(Fig.14)** The advantages of LASER igniter with gliding traditional arc are, as follow:

Figure 14: Air gap ionization

- Higher power of ignition energy, Spark energy in traditional high-energetic igniters varied in the range 4 ÷ 16J (spark frequency: 3 ÷ 30 per second) **[5]**. The ignitiontime of LASER igniter is faster, it can be matched adequately to the given fuel and operation condition of the burner.
- higher ignition efficiency in comparison to the traditional spark ignition system, Because of higher ionization density in air gap the ignition of fuel is much more effective.
- large volume of the "Laser igniter" and lack of necessity of very precise location of the ignition source in the outlet of the burner,**(Fig.15)** Low spark energy and its small volume requires very precise location of discharge electrodes. Moreover, this kind of ignition system is sensitive on the feeding condition of the burner.

Laser with electric arc **(Fig. 16)** takes up larger volume and therefore is much more resistant on disturbances and rapid changes in the burner surroundings.

- the possibility operation in more difficult conditions (lean mixtures, high flow velocities), As a consequence of Laser ignition and its large volume is high ignition efficiency of the fuel-air mixture in the conditions in which the spark ignition of fuel is impossible. This factor is very important from practical and environmental point of view.

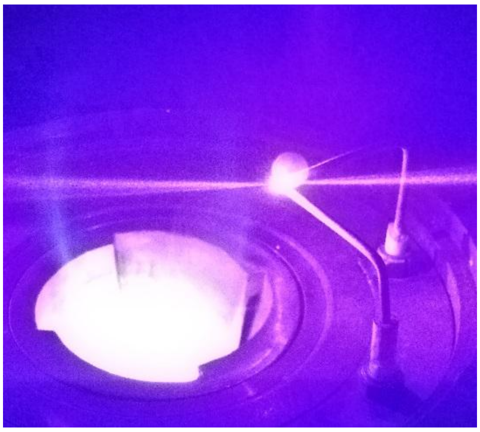


Figure 15: Ignition start using LASER igniter

- Automation possibility and full control of the Laser ignition process. The practical application can yield benefits, however the prosecution of the research in technical scale is needed to eliminate eventual problems for the cooperation with other devices or working systems and to choice proper conditions of the operation.

Figure 16: Ignition using LASER igniter in combination with electric spark igniter

The ignition duration using laser ignition compared with the ignition with electric spark ignition shown in **(Fig.17).**
The results clearly show that laser ignition main merit that the ignition time decreases by 80% percent compared with the spark ignition

Figure 17: The variation in ignition duration between laser ignition and spark ignition

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