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IMPLOSIVE THERMAL PLASMA SOURCE FOR ENERGY CONVERSION

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Abstract. Laboratory scale thermal plasma source for magnetohydrodynamic or magnetocumulative generator was developed. The thermal plasma is created from combustible stochiometric mixture of hydrogen and oxygen by spherical implosion of convergent detonation wave. Resulting high velocity plasma is observed by capturing emitted light by hi-speed camera to determine plasma velocity and also spectroscopically in order to estimate of plasma temperatures. Construction of the implosion plasma source is discussed.

Keywords: implosion, thermal plasma, detonation wave.

1. Introduction

Combustion of fossil fuels in a process involving production of mechanical work driving a generator with rotating coils in a magnetic field is employed in processes of electricity production. In spite of past developments, the present energy generation processes are still quite complicated and characterised by high losses. In the thermal cycles the losses represent estimated 2/3 of the chemical energy available in the fossil fuel. There is therefore a demand for decreasing these losses preferably by avoiding some of the intermediate conversion steps. Promising possibility is the electricity generation in magnetohydrodynamic generators operating without mechanical moving parts allowing to increase efectivity of the energy conversion by 10 - 20 %. Known for several decades and already tested MHD idea has the weakness of insufficient number of charge carriers in the flow of combustion products through the perpendicularly oriented magnetic field. More ions have to be produced and this can be achieved only at much higher temperatures than obtainable with the currently used deflagration type of combustion. Existing MHD generators built for tests increase the ionisation by combustion in pure high-pressure highly preheated oxygen and seeding the gas with alkali metals. This is expensive and so far relegated the MHD principle to a role of economic failure. Also, the alkali metal approach is expensive due to the need of very special refractory materials necessitated by corrosive character of the additives. A more efficient form of combustion than the usual deflagration is already known. It is detonation, capable of getting nearer to the desirable ionisation goal - but difficult to exploit. Apart from the single-action military uses with explosives, attempts have been made from time to time to apply the detonations in a gas mixture.

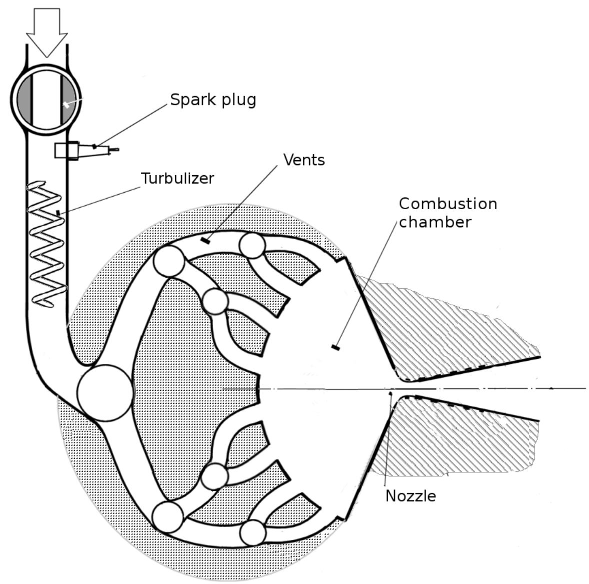

Figure 1. Schematic of the device

2. Experimental model

The idea is to obtain the extremely high temperature combustion by detonation waves focused and comming from mutually opposed directions into the common focal point. In principle, the progress to the centre is obtained from sources distributed over a spherical hollow surface. Attempts to synchronize detonation produced from separate sources are not unsuccessful - the activation energy needed to start the detonation wave directly is relatively high and the need to start large number of waves results in very high energy and power demand. A solution is to create a single detonation wave by means deflagration to detonation transition (DDT) and later bifurcate it to the several identical-length paths to the exits located on the hemisphere surface. Schematic representation of the

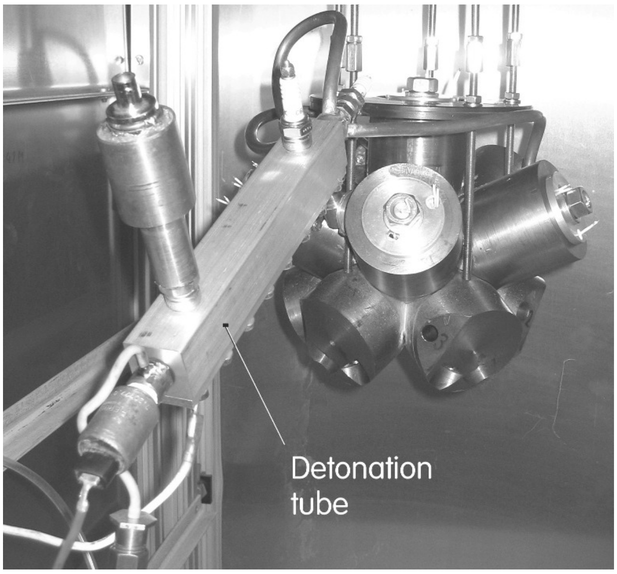

Figure 2. Experimental device

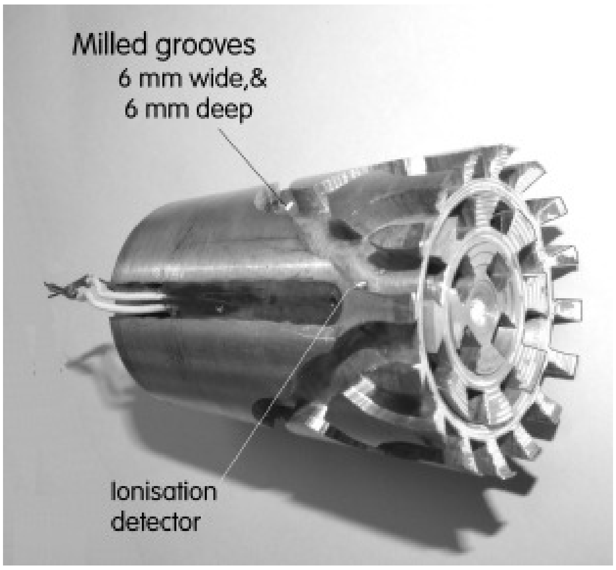

Figure 3. Assembled distributor cones.

principle is presented in Fig. 1.

The main parts shown there are detonation tube, the main body of the combustion chamber, and distributors - a system of progressively branched vents leading the detonation wave from the detonation tube into the chamber internal cavity. The detonation chamber filled with the gas mixture is activated by the spark plug at the end of detonation tube. The mixture starts burning initially in the usual deflagration regime, but generation of turbulence - by turbulator with shape discontinuities at the tube walls - causes a transition into the detonation. The detonation wave then progresses through the bifurcations which divide it and lead to exits positioned on the hemispherical surface of the combustion chamber. There the exiting waves leave the cavities and emerge at the same instant of time (this is secured by exactly the same lengths of the distributor vents) propagating as an implosion towards the common focal point. The instantaneous pressure and temperature values reach extreme magnitudes there, especially the temperature is demonstrably above 10000 K. This leads to the instantaneous ionization - practically a generation of thermal plasma moving at high velocity (commensurable with the speed of propagating detonation waves) through the nozzle. The thermal ionization together with the extreme velocity is essential to generate a high voltage pulse at MHD generator electrodes. For the purposes of this verification study it was sufficient to perform only a single detonation in a simplified model of the device - without the MHD generator. The combustion chamber in the tests was approximately hemispherical, with radius R = 47.55 mm and the apex angle was $\alpha = 180$ deg. There were three main parts of the device: Detonation tube for generation of the primary detonation wave, the distributors vents with sequential bifurcation of the detonation wave into a large number of the entries into the chamber cavity, and the actual combustion chamber

Detonation tube: The body of this detonation tube is of rectangular cross-section, as seen in its external appearance in Fig. 2. It is made of aluminium alloy. The cavity for generation and propagating of detonation wave was made by milling it as square section channel 8×8 mm and covering with top cover plate. Its axial length is 140 mm. Well recognisable in the photograph Fig. 2 is the re-filling valve, electrically operated for admission of the mixture of hydrogen and oxygen in stoichiometric ratio. As a safety measure there are several flame traps inside and in the leading tubing. Activation energy for starting the combustion process is provided by automobile spark plug with added shielding to avoid electrical interference with diagnostics. Transition from the deflagration burning into the detonation is achieved by the presence of turbulizing voids in form of a set of 5 local increases of the channel width. It was made with the same 8 mm milling tool as was used for making the internal 8 mm wide channel. At the exit from the detonation tube the flow was divided (trifurcated) into three metal (cooper) tubes of round cross section, leading to the entrance into distributors.

Distributor vents: The task of all 18 distributors together positioned on the hemispherical wall of the combustion chamber was to divide the incoming detonation wave into 168 inlets leading into the internal chamber cavity. In each distributor, the wave trajectory is progressively bifurcated into the total of 28 inlet exits, all of 6×6 mm square cross-sections. A photograph of typical assembled distributor is presented in Fig. 3, with the exits seen at the right-hand part of the picture. Also visible there are two ionisation probes with their connector leads. The distributors consisted of three cone-shaped components fitting one into another. The channels for delivering the detonation wave were made by milling. From the outer

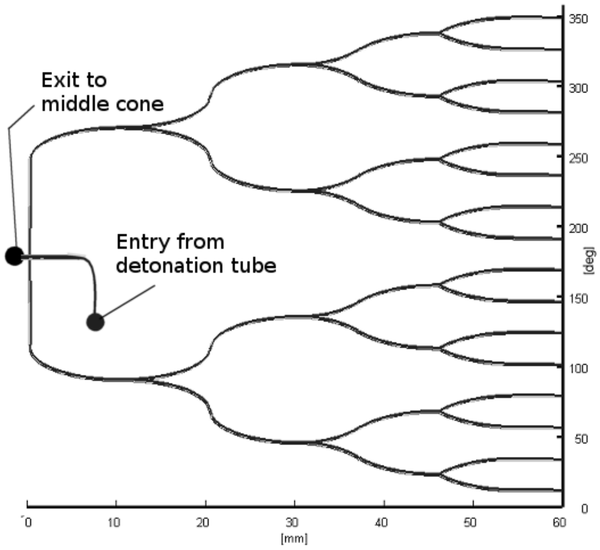

Figure 4. Plot of the enveloped vents.

side(i.e. the side from which the milling tool entered) the grooves were covered - and thus converted into the closed channels - by the conical internal hollow surface of another component fitted from outside. The milling of the channels was performed on milling machine fitted with angular division head. There were two manually input variables. One variable was the axial position distance of the tool axis in 0.1 mm steps, while the other was the angular rotation around the axis of the manufactured component. Plots of mutual values of these two variables - with data points values related to the tool centre - are presented in Fig. 4 for outher cone. Middle and iner cones are similar, they have only eight and four grooves respectively. The basic requirement for proper synchronization of the cumulative implosion is identical lengths of all wave trajectories. The axisymmetric shape of rotatable distributors provided an opportunity for precise mutual synchronization - the effective channel lengths could be varied by small angular rotation of the particular distributor.

Combustion chamber: For ease of manufacturing the hemispherical shape with the large number of distributor exits, it was decided to assemble the chamber from a number of thick-wall steel components. Their inner ends, at which these components were set into mutual contact, were each milled into a shape with five flat (planar) contact surfaces. Put together, in the first approximation the hemisphere of the chamber was assembled as a top half of a dodekahedron covering R = 47.55 mm hemisphere. Opposite to the hemisphere, in the middle of the flat base wall, pentagonal exit hole was left - in a position where in the final setup would the entrance into the MHD generator. This hole serves as a diagnostic access window (in the absence of the generator). The cylindrical outer ends of all six components (top half of dodekahedron planes) of which the chamber was assembled are seen extending out from the body in Fig. 2. They were provided each with a 6 deg hollow conical cavity of 75 mm length. It was into these conical cavities where the six distributors inserts sets were fitted.

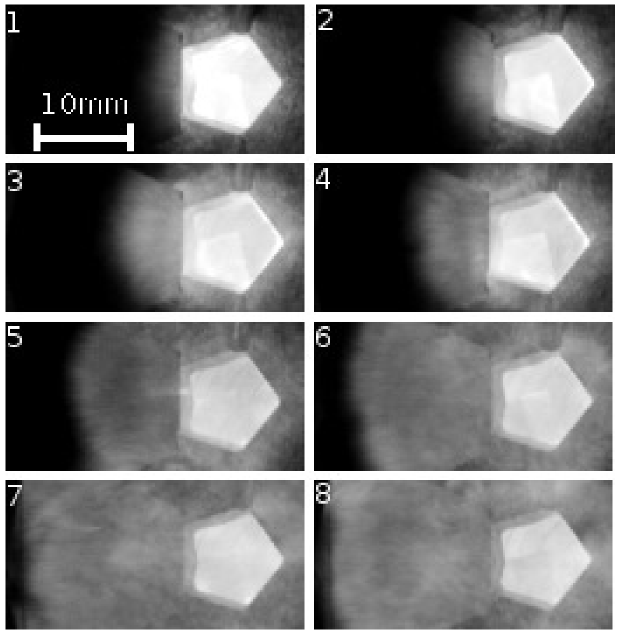

Figure 5. Time assorted camera frames.

3. Experimental results

Experiments with thermal ionisation by cumulative implosion are still in their early phase. They have, nevertheless, already demonstrated the most important fact: the capability to reach extreme temperature levels in the combustion chamber as well as the correspondingly high ionisation.

Propagation of detonation waves in the distributor cones and formation of the convergent detonation wave were monitored by an array of ionisation probes positioned near the distributor exit openings. The detonation wave itself is weakly conductive so that its passing past the probe was monitored as voltage drop on a charged electrode. The ionisation probes were made from a copper wire of diameter 0.75 mm insulated by PTFE. Active parts of the probes, protruding 2 mm into the distributor channel, had the insulation striped off. The probes were charged via 48 kΩ resistor from an 80 V DC voltage source. Main purpose of these measurements was fine synchronisation of the distributors by means of adjusting their rotary positions. This, depending on the angular adjustment, either prolonged or shortened length of auxiliary vent leading the incoming detonation wave into the first bifurcation inside the distributor. In this way, all 18 distributors could be finely tuned to microsecond range of the detonation waves entrance to hemispherical combustion chamber.

Another already performed set of experiments was measurement of velocity of the plasma ejected from the combustion chamber through its central exit. This was done by analysis of records from high-speed camera

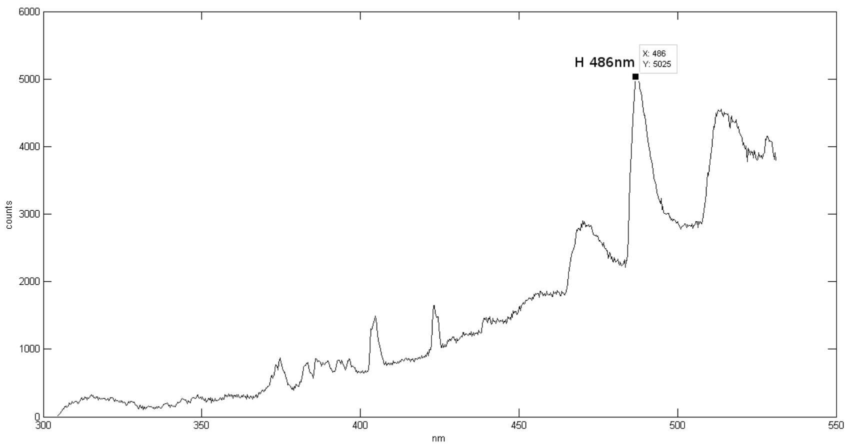

Figure 6. Emission spectra of the thermal plasma.

Phantom v7.3 capable of capturing images at 8.25 μs period, at image resolution 128×64 pixels. The camera field of view was split by an auxiliary mirror to see both the chamber exit and the expanding plasma jet in side view, both in the same frame. The problem of the frame period being nearly the same as the time needed for the plasma to expand through the almost whole camera field of view was solved by using suitable recorded frames from several shots and sorting them in the correct order. The mirror images were calibrated, leading to the length scale shown in the first frame of Fig. 5. From the distances and time scale available from the camera, the plasma front velocity was evaluated to be approximately 2 km/s. The reproducibility of the wavefronts from several shots shows that the expanding plasma is stable.

To check that the resulting plume leaving the combustion chamber exit is really thermal plasma, spectroscopic measurement was performed. The emerging light was collected by closely placed end of fused silica optical fibre 100 μm in diameter. The light was analyzed by IHR370 spectroscope. Results of representative spectroscopic analysis of the plume are in Fig. 6. In the spectra contamination peaks were found, in particular those indicating contamination by alkali metals - potassium and sodium from the electolyser used to generate the combustible gas mixture. Also seen is peak for a trace of lithium, probably from the grease used to seal distributor cones. Much more interesting was H-β line at 486 nm. This line was observable only on "succesfull" shots. When the sharp front of plasma was not observable on camera records (eg. the distributor vents did not fill evenly the chamber by the combustible mixture), the H-β line did not emerge and only alkali metals lines were present. Also the profile of the H-β line shows signs of asymmetric broadening by pressure. Presence of the H-β line was chosen as thermal ionization marker due to low possibility of coincidence with other elements lines.

4. Conclusions

Successful operation of the combustion chamber demonstrated that a promising improvement of efficiency of electricity generation by combustion of gaseous fuels is possible by increasing the degree of ionisation of the combustion product - to the level at which it is possible to employ it in no-moving-parts MHD generator. The new idea, which demonstrated this capability in a laboratory test model, is a combination of detonation combustion and the cumulative effect of waves from many directions. This paper describes design details of the tested model of 47.55 mm radius hemisphere with 168 detonation wave entrances, each of 6×6 mm size. While the model is still at an early stage of its development, it was already possible to demonstrate temperatures reaching 10000 K and the corresponding high degree of ionisation. In the overview spectra with low spectral resolution, also indication of lines of atomic iron, aluminium and manganese in the spectral region between 360 nm and 420 nm is registered. Measurement of these lines with high spectral resolution and application of Boltzmann plot will allow better specification of plasma temperature.

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