Experimental Research on the Rotating Detonation in Gaseous Fuels-Oxygen Mixtures

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1 Introduction

Recently the interest is focused on the development of the Rotating Detonation Engine, known also as the Continuous Detonation Wave Engine, since it offers significant improvements of thermal efficiency and simultaneously simplification of the design. In the early sixties of the last century, Voitsekhovskii, Metrofanov and Topchian performed experiments on continuously rotating detonation [1,2]. In 2004 Wolanski, Fujiwara and Mitsubishi applied for a patent for the Rotating Detonation Engine (RDE) [3].
Lately, many experimental research in this field have been conducted in different laboratories [4,5,6,7,8]. The principle of the Rotating Detonation Engine (RDE) is based on the creation of continuously propagating detonation in a disk-like combustion chamber (toroidal or ring-like shape). The fresh mixture (fuel-air or fuel oxygen mixture) is supplied from of one side and combustion products are expanding from the other side of the chamber.
In the paper, experimental research on the rotating detonation carried out at Warsaw University of Technology will be presented. The research is focused on evaluation of the geometry and the conditions in which rotating detonation is propagating in cylindrical or cylindrical-conic channels for rich fuel-oxygen mixtures. Methane, ethane, propane as a fuel was used. Pressure – time history in the manifolds and in the chamber of those tests will be presented. Thrust-time profile and detonation velocity calculated from measured pressure peaks will be shown.

2 The research stand

The research facility consists of a main parts: detonation chamber, dump tank, fuel and air fed system, measurement system and initiation system. For the thrust measurement experiment, detonation chamber with all essential systems was placed inside the cylindrical tank. The configuration allowed to simulate conditions very close to the vacuum regime. Detonation chamber was built with use of easy changeable elements (to change internal diameter of the chamber, length of the channel or shape of the inner wall of the chamber). Fuel and oxygen were injected to the chamber by two kinds of injectors: for fuel by a number of small orifices (with diameter in the range of 0.7÷1,0mm) and for oxygen by a slit with changeable width. The whole process was controlled by a specially designed control unit, which was connected with computer and a measurement system.

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The typical experiment duration time was about 150ms, but in thrust measurement experiments it was extended to the 1200ms. Duration of the tests depended on the initial pressure in the dump tank as well as on the other test parameters. The chamber was equipped with a few pressure transducers. Two of them were placed in the manifolds and the others were installed in the chamber. The detonation chamber was connected to the dump tank (was about 0.63m^3 volume). The schematic diagram and view of the research stand are shown in Fig.1, and in Fig.2 a configuration of the research facility for thrust measurement experiments is presented.

a) *b)*

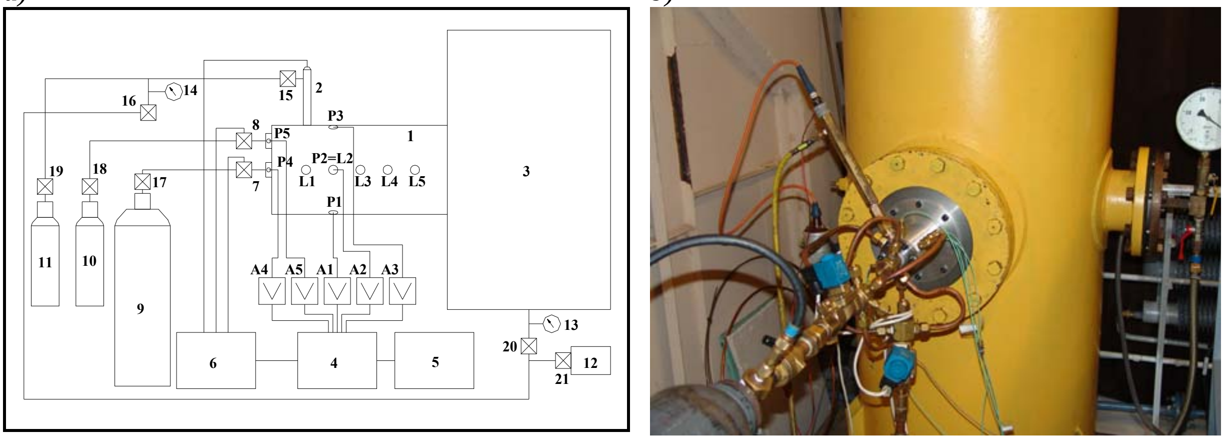

Figure 1. The research stand: a) schematic diagram: P1÷P3 – pressure transducers placed in one plane inside chamber, L1÷L5 – pressure transducers placed in one line inside the chamber, P4,P5 – pressure transducers for manifolds: fuel and air, A1÷A5 – amplifier's, 1 – detonation chamber, 2 – initiation tube, 3 – dump tank, 4 – acquisition card, 5 – computer, 6 – control system, 7,8 – electromagnetic valves, 9 – tank with the air, 10 – tank with the fuel, 11 – bottle with initiation mixture, 12 – vacuum pomp, 13,14 - manometers 15÷21 – valves; b)view of the stand.

a) *b)*

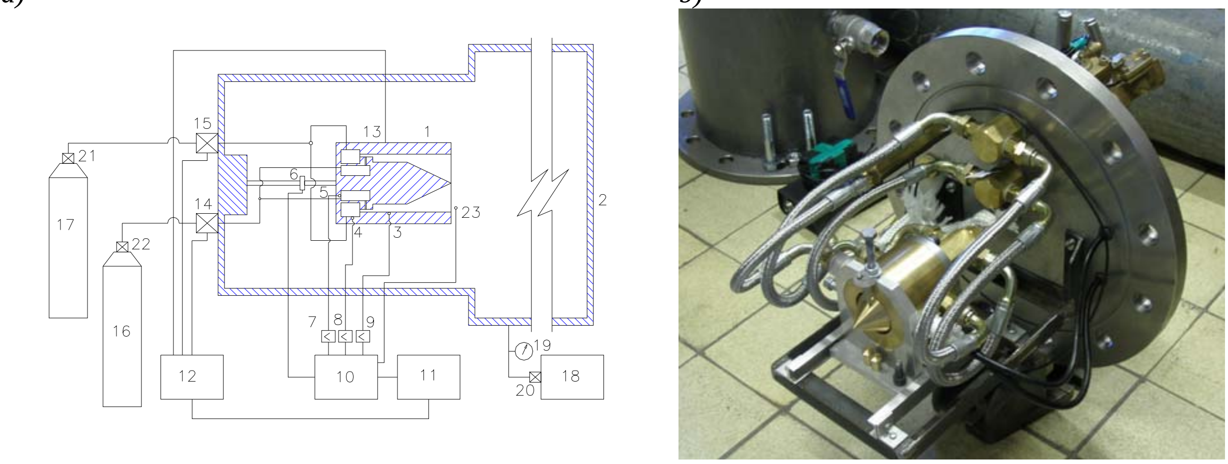

Figure 2. The research stand in thrust measurements configuration**:** 1 – detonation chamber (model of rocket engine); 2 – dump tank; 3– chamber pressure transducers; 4 – oxygen manifold pressure transducers; 5 – fuel manifold pressure transducers; 6 – thrust sensor; 7,8,9 – amplifiers; 10 – acquisition card; 11 – computer; 12 – control unit; 13 – ignitron system; 14,15 – electromagnetic valves; 16 – bottle with fuel; 17 – bottle with oxygen; 18 – vacuum pomp; 19 – manometer; 20,21,22 – valves; 23 – thermocouple.

3 Experimental results

The paper describes experiments for gaseous fuel-oxygen mixture which were carried out in three different chambers: a small chamber (outer/inner diameter was 46/38mm), the bigger one (outer/inner diameter was 150/140mm) and the model of a small rocket chamber with “aerospike” nozzle. Fig. 3

shows typical pressure records of propagation of rotating detonation in the small chamber. Fig.4 and Fig.5 show results from thrust measurement experiments (measured detonation velocity – Fig.4 and thrust-time profile – Fig.5).

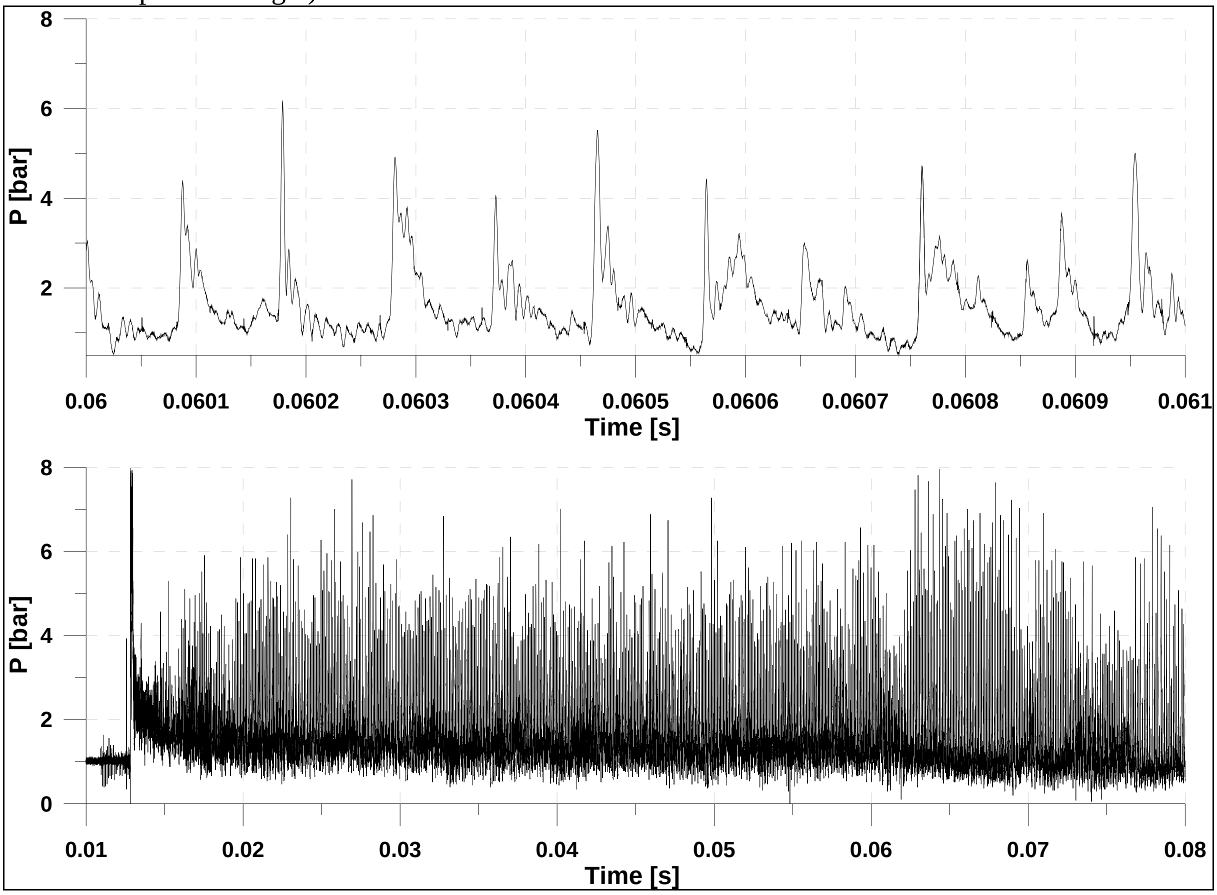

Figure 3. Pressure-time history recorded on the outer chamber wall for methane-oxygen mixture, initial pressure was 1bar (small chamber, cylindrical shape of the wall).

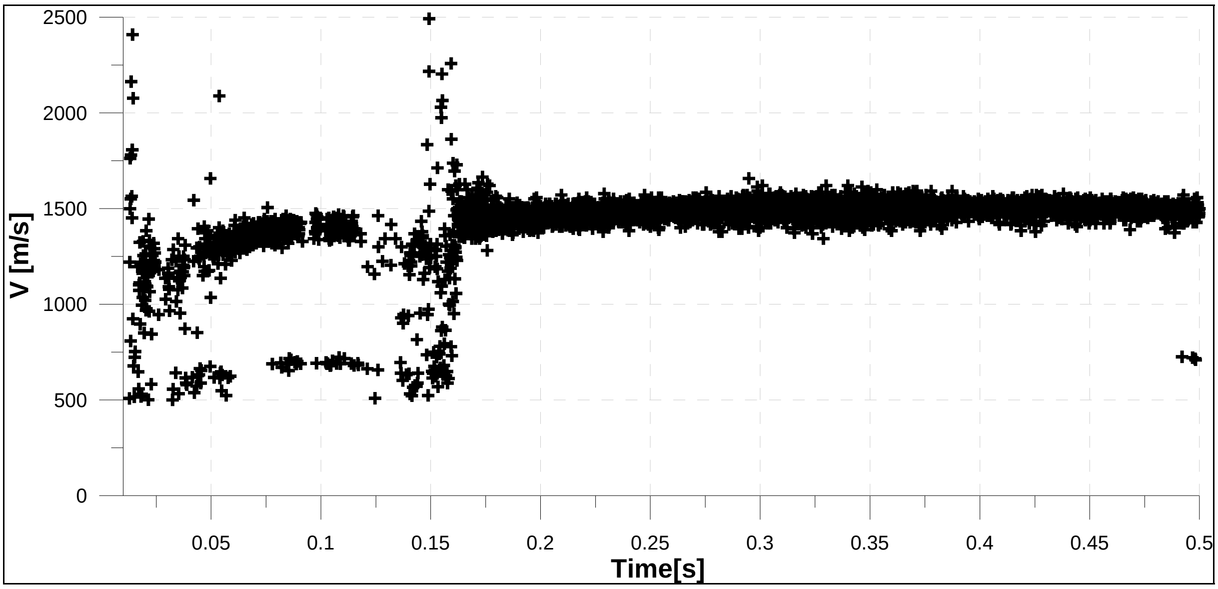

Figure 4. Detonation velocity-time history evaluated from recorded peak pressures on the outer chamber wall for methane-oxygen mixture; initial pressure was 0,1bar (small chamber with aerospike nozzle).

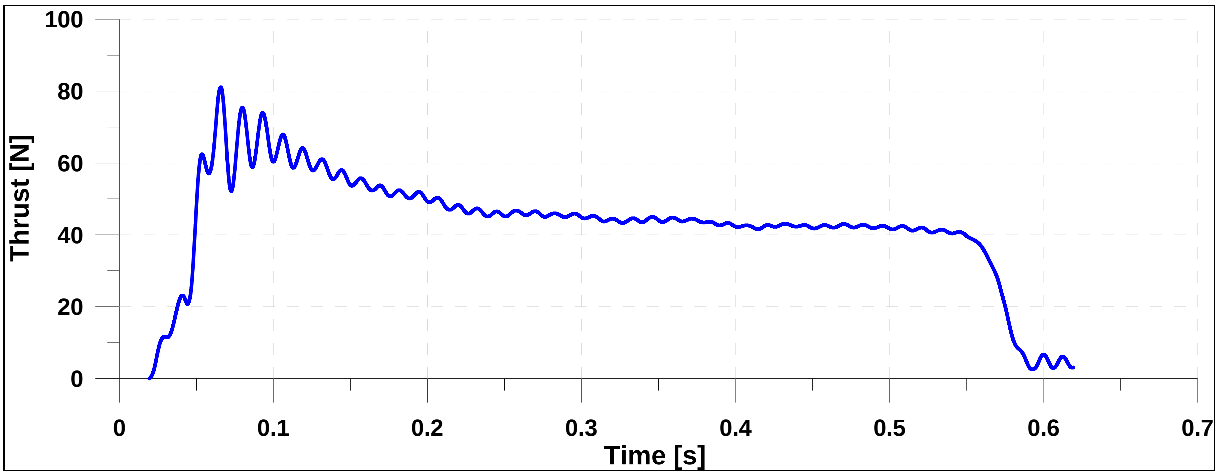

Figure 5. Thrust-time profile for methane-oxygen mixture, initial pressure was 0,1bar (small chamber with aerospike nozzle).

4 Conclusions

It was shown experimentally that rotating detonation can be established for gaseous mixtures of methane, ethane, and propane with oxygen. For each mixture detonations parameters were measured. In some cases, also thrust obtained from rocket engine equipped with aerospike nozzle was measured and specific impulse calculated. The obtained results are very promising for the application of the presented process to rocket propulsion.

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