

An Experimental Study of Rotating Detonation Engine

Piotr Wolanski¹, Jan Kindracki¹, Toshi Fujiwara²,
Yasuyuki Oka³, Katsuyuki Shima-uchi³

¹Warsaw University of Technology, Poland,

²ATES Corporation, Japan,

³Mitsubishi Heavy Industries LTD,
Nagoya Guidance & Propulsion System Works, Japan.

Corresponding author, P. Wolanski: wolanski@itc.pw.edu.pl

Extended abstract

Research into development of pulse detonation engine (PDE) was initiated by J.A. Nicholls et al, University of Michigan [1]; however only recently more works were focused onto this kind of engine. Also in fifties through early sixties of last century, Voitsekhovskii, Mitrofanov and Topchiyan, [2, 3] performed experiments on continuously rotating detonation. More recently, Wolanski, Fujiwara and Mitsubishi group [4] applied for a patent on the Rotating Detonation Engine (RDE). In 2004 a paper on continuously rotating detonation in cylindrical channel filled with oxy-acetylene mixtures was presented in St. Petersburg [5]. In the present paper, the basic principles of RDE are described and their proof is attempted where the initial-phase laboratory experiments of RDE are presented.

The principle of Rotating Detonation Engine (RDE) is based on the creation of high centrifugal force, resulting from a detonation propagating in a disk-like combustion chamber (toroidal or ring-like shape). In a typical detonation, the flow velocity immediately behind the CJ point is equal to about $\frac{1}{2}$ of the CJ propagation velocity, which is highly supersonic. Thus, after the detonation has propagated in a “ring-like chamber”, the burnt products of detonation will be subjected to a strong centrifugal force and be forced to approach the outer wall of chamber, creating a significant pressure/density gradient across the radial direction. Because if this pressure gradient (low pressure on the inner wall), we can design that the low pressure over the inner wall will stimulate the self-sustaining (sucking) supply of fresh mixture into the combustion chamber. Naturally, the new fresh mixture should have time sufficient to fill up the region where the detonation has already passed, before the next appearance of detonation front. Therefore, the frequency of chamber operation will depend on the CJ detonation velocity and the size of “ring-like combustion chamber”. Simultaneously, the burnt products of previous detonation should have time sufficient to flow out from the combustion chamber. Because of the inertia force of flowing-out burnt products, a rarefaction wave will be created inside the chamber, significantly helping evacuate the products from the chamber and refill the “ring-like chamber” with a fresh mixture. The expanding detonation products from nozzle will produce the thrust, allowing RDE to operate continuously. This is the basic principle of RDE operation. A schematic diagram of this engine is shown in Fig.1.

For the purpose of testing the above idea on RDE, a special experimental test stand was built in Institute of Heat Engineering, Warsaw University of Technology. The stand consists of a cylindrical combustion chamber connected to the fuel supply system on one end and to a dump tank on another end. The schematic diagram of test stand is shown in Fig.2a, while the photograph of combustion chamber in Fig.2b. As a combustible mixture, oxy-

acetylene mixture was used. The test stand was operated by a control system integrated into PC and by the data acquisition system. A schematic diagram of the control and data acquisition system is shown in Fig.3. Numerous experiments were conducted for a variety of mixture compositions (different stoichiometric coefficients) and different pressures (rate of mixture supply). A typical test lasted about 0.5 s where many rotations of a detonation wave inside the combustion chamber were recorded. A typical pressure record obtained by the three pressure transducers located on one section of the cylindrical combustion chamber is presented in Fig. 4. We can notice that the detonation pressure peak is slightly decreasing with time, probably due to the change of mixture supply rate and pressure in dump tank. The observed rotating detonation wave seems to have a nature of single-head or multi-head spinning detonation.

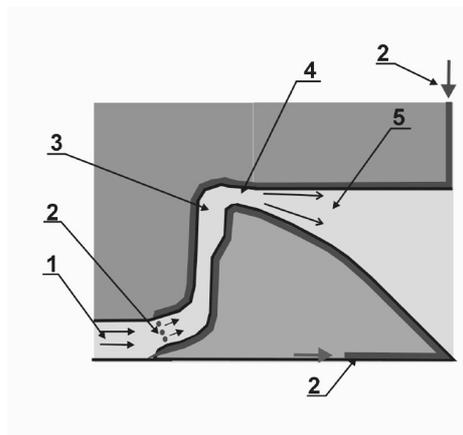
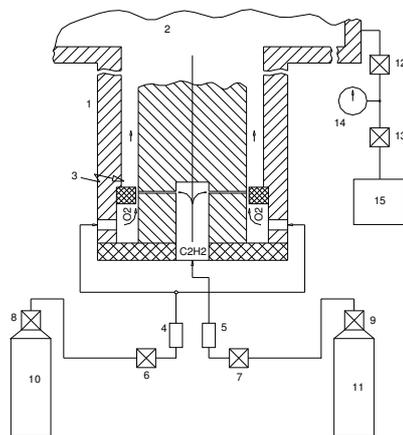
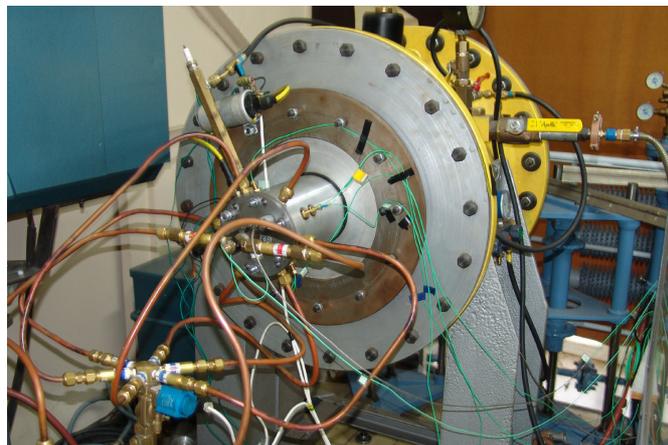


Fig.1. Schematic diagram of RDE. 1- inlet (air), 2 – fuel injection, fuel cooling of combustion chamber, 3 - “ring-like combustion chamber”, 4 – critical nozzle area (throat), 5 – expansion nozzle.

a)



b)



*Fig.2. a) Schematic diagram of research stand: 1 – detonation chamber, 2 – dump tank, 3 – spark plug, 4, 5 – flame stopper, 6,7 – electromagnetic valves, 8,9,12,13 – valves, 10 – bottle with O₂, 11 – bottle with C₂H₂, 14 – manometer, 15 – vacuum pump;
b) Photograph of detonation chamber.*

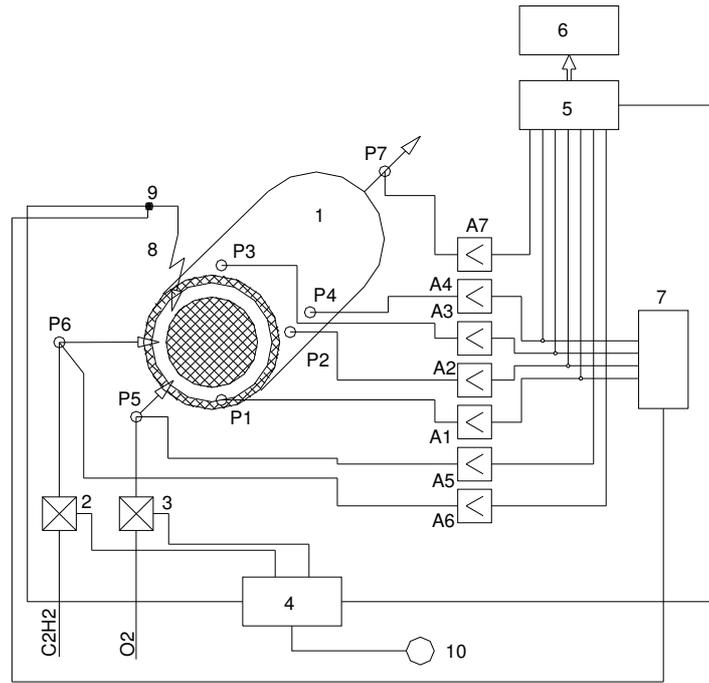


Fig. 3. Schematic diagram of measurement and control systems: $p_1 \div p_4$ – pressure transducers over chamber wall, p_4, p_5 – pressure transducers at manifold wall, p_7 – pressure transducer at dump tank wall, $A_1 \div A_7$ – amplifiers, 1 – detonations chamber, 2,3 – electromagnetic valves, 4 – control unit, 5 – data acquisition system, 6 – computer, 7 – oscilloscope, 8 – spark plug, 9 – time marker, 10 – starter.

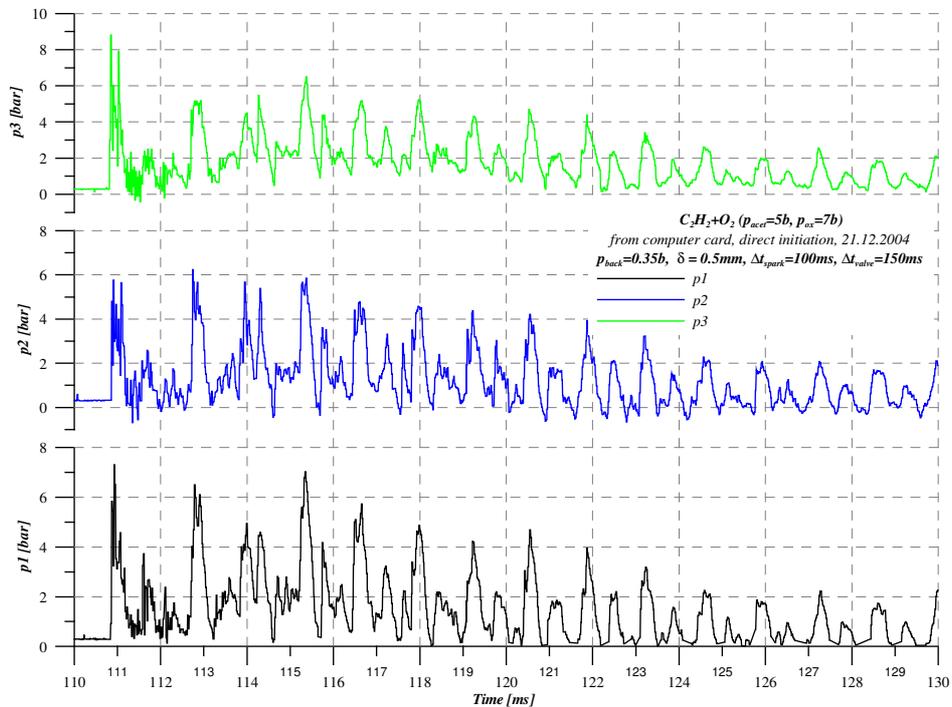


Fig.4. Histories of pressure variation at three different locations of detonation chamber.

In the patent [3] other configurations of RDE are also discussed. On similar principles, a rocket engine using rotating detonation could also be designed. Special attention could be also focused on the configurations of RDE using compressor and turbine (Fig. 5a), or a fan directly propelled by an integrated Fan-RDE (Fig. 5b.). Such configurations could significantly increase RDE performance.

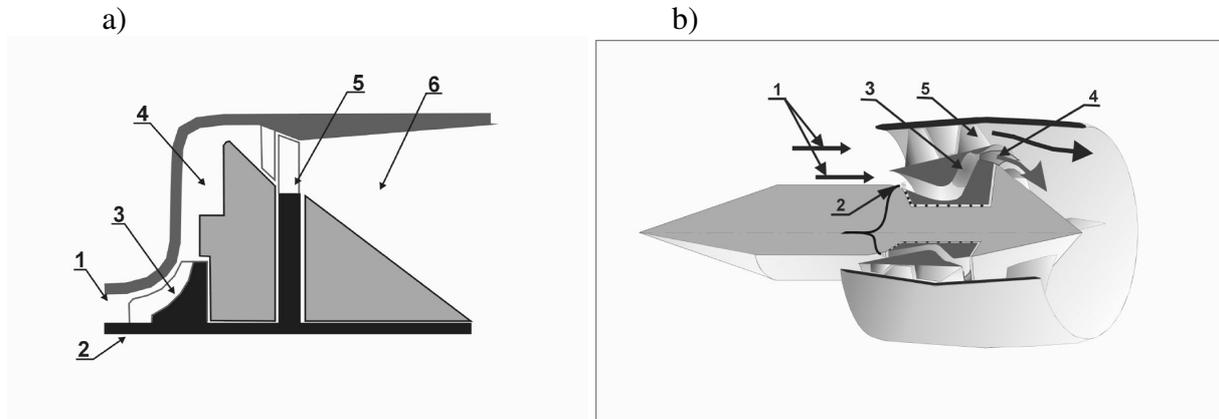


Fig.5: a) Schematic diagram of turbocharged RDE. 1 – inlet, 2 – shaft, 3 – impeller (compressor), 4- “ring-like detonation chamber”, 5 – turbine, 6 – nozzle; b) Schematic diagram of RDE with fan blades attached to rotating RDE and inlet and nozzle integrated with fuselage (missile, aircraft etc), 1-inlet, 2 – fuel injection, 3 - “ring-like detonation chamber”, 5 – fan, 6- tilted nozzle (turbine).

References

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