Wave Direction Studies in Rotating Detonation Engine

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1 Introduction

One of the problems in development of rotating detonation engines is the problem of detonation waves direction. Detonation propagating in such engines looks as follows: after the initiation usually two or more waves in opposite directions appear, after sometime the number of waves is reduced until the waves remain rotating in one direction. During such an attempt, the waves direction often changes.

It has still not been confirmed whether the direction of the wave causes the torque to rotate the engine [1-2]. This is important for rockets with a detonation engine design perspective point of view. The additional torque on a rocket would have to be taken into account. An even number of engines should be introduced (in which the directions of moments cancel each other out), or otherwise correct the flight path of the rocket.

Another reason why it is worth directing the wave is the problem of connecting the rotating detonation combustion chamber with a turbine engine. Knowledge of detonation direction in the turbine engine is crucial for the optimal design of the first stage of the turbine vanes in the engine [3-4].

Since the detonation wave itself does not carry mass, its direction is considered insignificant. In a real process, the detonation wave swirls the combustion products slightly in the direction of detonation, which raises the following questions:

1) Does the swirl transfer torque to the engine?

2) How big is this effect?

3) Is it possible to control the direction of wave motion and how?

4) How much does the swirl reduce engine performance?

This research deals with the problem of wave direction control and attempts to design a combustion chamber with a pre-determined direction.
The problem of wave direction control is addressed in the article by Knowlen and Kurosaka [5], where the wave direction was triggered by the sequential initiation of 12 spark plugs placed evenly around the

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circumference of the ring combustion chamber. Another attempt was to place the initiator together with the pre-initiator pipetangentially to the combustion chamber channel.It has been reported that this solution does not bring the expected effect.

2 Tested methods of wave motion direction

In order to check the direction of detonation waves in the combustion chamber, a test stand with 3 piezoelectric pressure sensors placed unevenly on the perimeter of the ring combustion chamber was built (Fig.1). This setting of the sensors makes it possible to unambiguously determine the direction of the waves, their number and speed. Response of the signal in order: blue, green, red, means clockwise wave direction, the signal response in order: red, green, blue, means counterclockwise wave direction (upstream). Experiments were carried out with hydrogen-air mixtures, three possible solutions: A) Synchronized initiators, B) The use of aluminum foil to block one direction, C) Eccentric chamber.

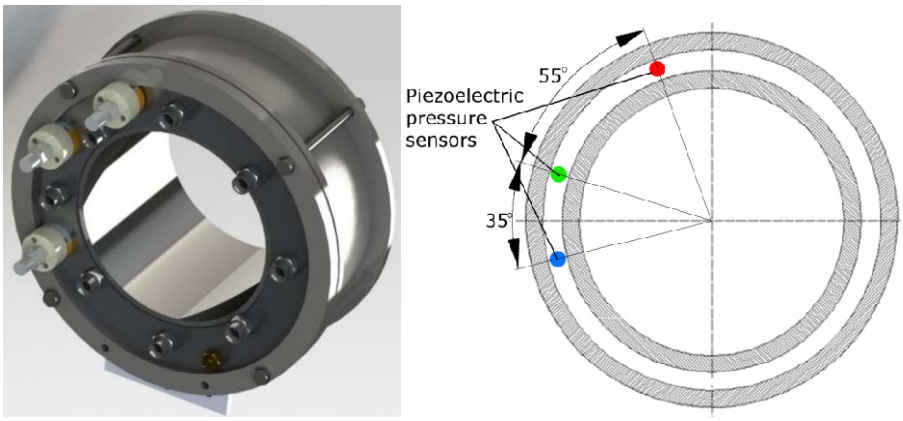

Figure 1. RDE chamber with piezoelectric pressure sensors and location of sensors on the perimeter.

A. Synchronized initiators

One of the idea was to use synchronized initiators. In this study, car spark plugs were used as initiators. The initiators were placed asymmetrically on the outer casing of the chamber. The assumption was to check whether the unsymmetrical initiations would achieve detonation in one direction (Fig. 2).

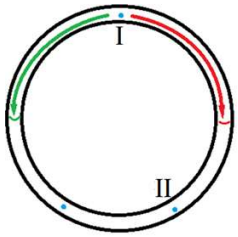

Figure 2. Location of the initiators in during experiments with synchronized spark-plugs.

The time of the waveform between initiators is about 0.12ms. Synchronization of the initiators took place before the actual experiment, by recording spark plugdischarges with a high speed camera. The recording speed of the camera was 100 000 fps . It allowed to synchronize sparks with the accuracy of 0.01ms.
Two scenarios are considered (colours according to Fig. 2):
- The red wave from initiator I is degraded by the wave from initiator II. During this time, the green wave have such a high speed and strength that it persist and become the dominant wave.

- The red wave from initiator I is amplified by the wave from initiator II. During this time, the green wave is too weak to persist and disappears.
The results of several experiments are presented in Figure 3ina form of recordingsof pressure changes obtained with piezoelectric sensors.

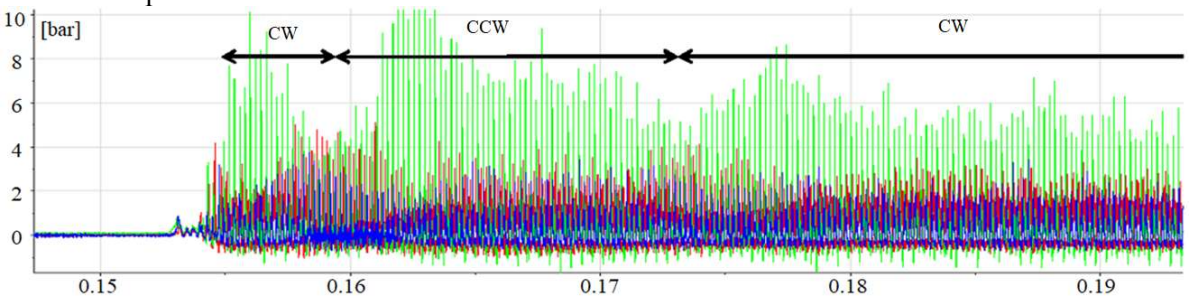

Figure 3. Pressure record in the chamber with synchronized initiators. Changing of wave direction during of experiments- Clockwise (CW) and Counter Clockwise (CCW).

As the results show in this solution, it was difficult to check the influence of the method on wave direction, because more than one initiation resulted in a large number of waves at the beginning of the process. After the process was determined in the next phase of the experiment, some waves expired and kept propagatingin one direction. Moreover, the direction seems to be accidental. It is assumed that the initiators may not have been exactly synchronized with each other. At present, it is difficult to unambiguously reject this idea based on the lack of possibility to confirm the synchronization of the initiators.

B. The use of aluminum foil to block one direction.

In this solution, a rectangular piece of aluminum foil was placed right next to the initiator (Fig.4.). Out of the two symmetrical waves initiatedby the initiator, one was reduced and the other continued the process of detonation, finally giving the direction throughout the experiment. The aluminum foil element was blown out of the chamber at the beginning of the experiment.This solution had a repeatability of 80%. Detonation induced in one direction continued until the end of the experiments (Fig.5.).

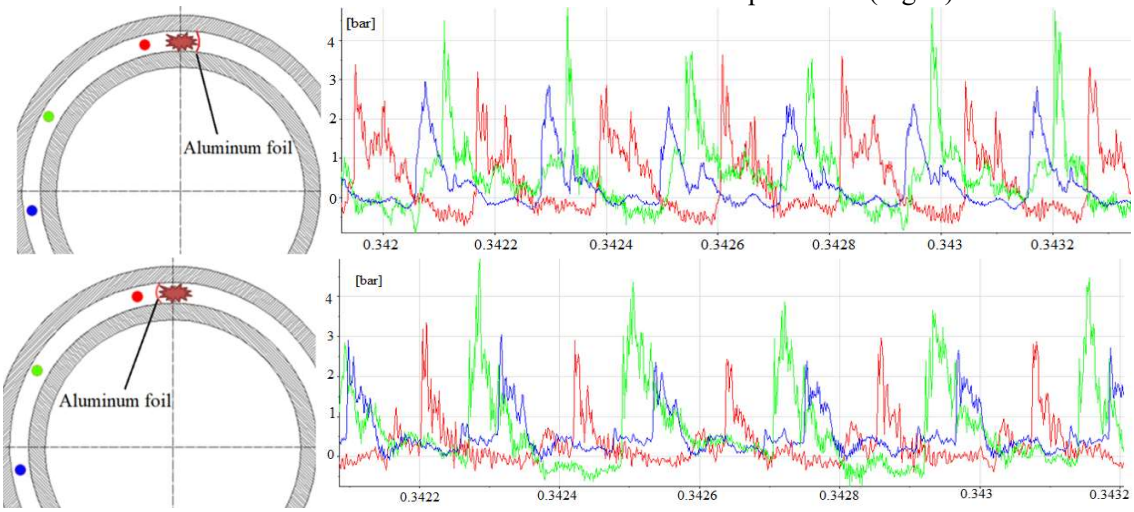

Figure 4. RDE chamber with aluminum foil, with clockwise direction of wave motion (above), and counter clock direction of wave motion (below).

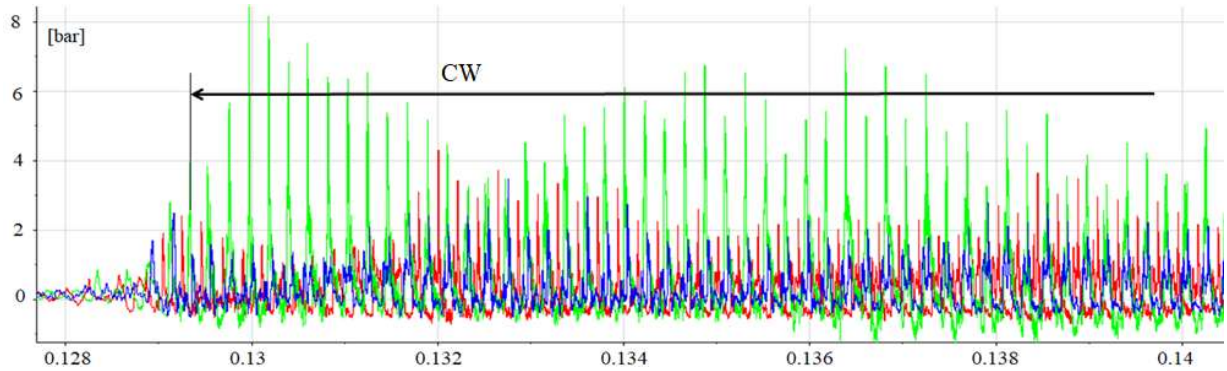

Figure 5. Direction of process sustained during whole experiment.

C. Eccentric chamber

Simple numerical calculationsof the wave passage through the wedge shaped channel were carried out in FLUENT. The channel has dimensions and initial conditions shown in Figure 6. Numerical calculations were conducted for stoichiometric hydrogen-air mixture using Navier-Stokes equations and one step chemical reaction. Based on the results (Fig.7) it was found that theDDT process propagates first in the extended channel (diffuser) direction. Moreover, wave passing through the confusor slows down and accelerates through the diffuser (Fig. 7).

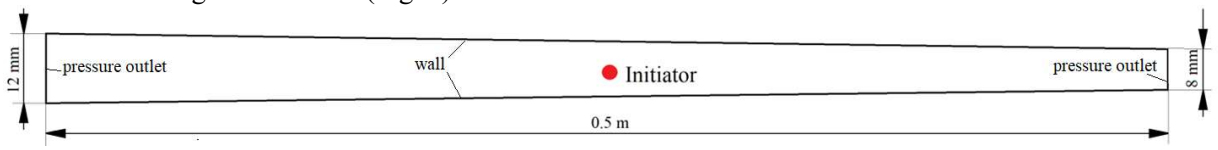

Figure 6. Dimensions of wedge-shaped channel. Initiator is in the middle of the channel.

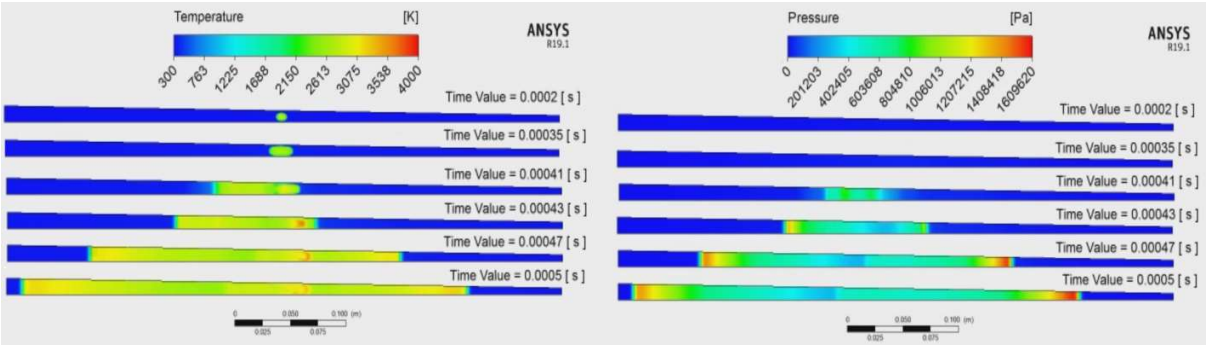

Figure 7. Numerical calculations results of wave propagation in wedge-shaped channel.

Collision of two waves weakens the slower wave. This phenomenon can be used to direct the detonation wave in the chamber.

The chamber is annular with variable height, which is obtained in such a way that the center of the inner ring is eccentrically shifted in relation to the outer ring by a certain distance "X".The numerical calculations are simplified, however, allow the mechanism of wave propagation to be noticed.

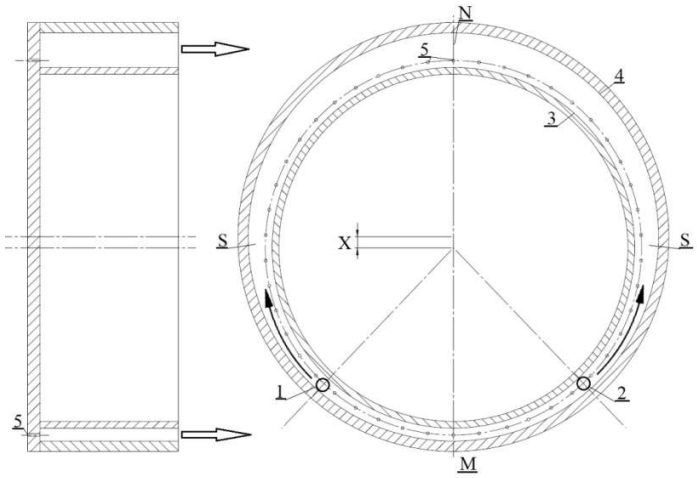

Figure 8. Detonation Chamber with Eccentric channel.

The detonation initiator is placed at a certain distance from the minimum and the maximum height of the chamber.

Several dozens of experiments were carried out by initiating initiator 1 or initiator 2. Initializing the process with the initiator No. 1 (Fig.8) causes the wave to be generated in the clockwise direction (Fig.9), and the initiation of the initiator No. 2 process causes the dominant, counter clockwise direction of the wave (waves) to be determined (Fig. 10). The minimum measured dimension "X" at which solution works was 0.3 mm. Entering a smaller dimension was associated with geometry measurement problems. The average height of annular combustion chamber was 7mm.

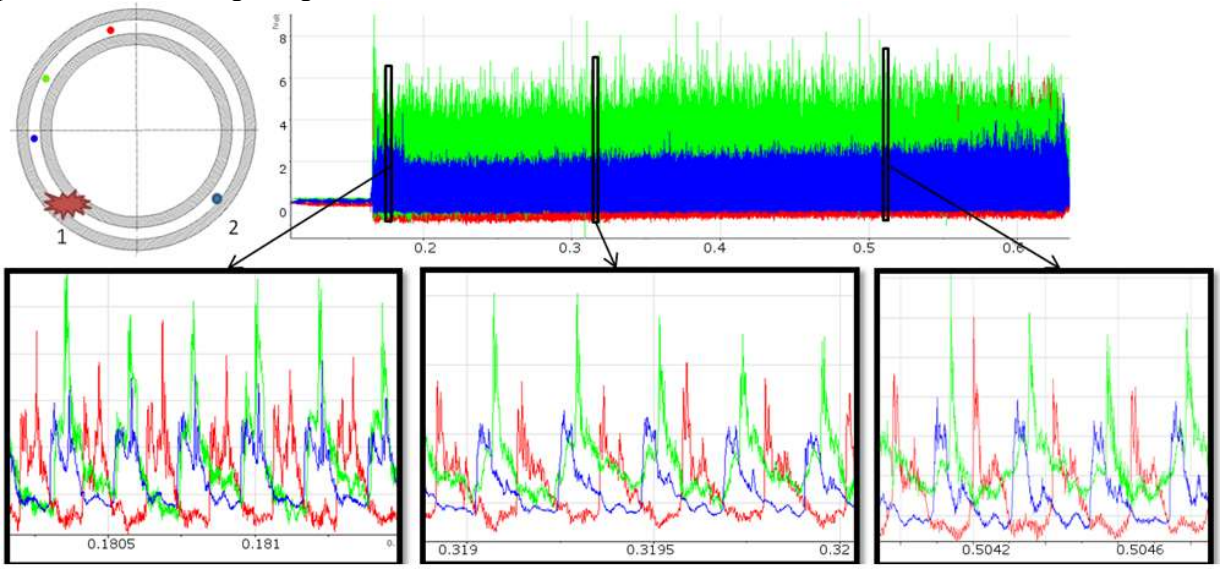

Figure 9. The example of an experiment with the use of the No. 1 initiator.

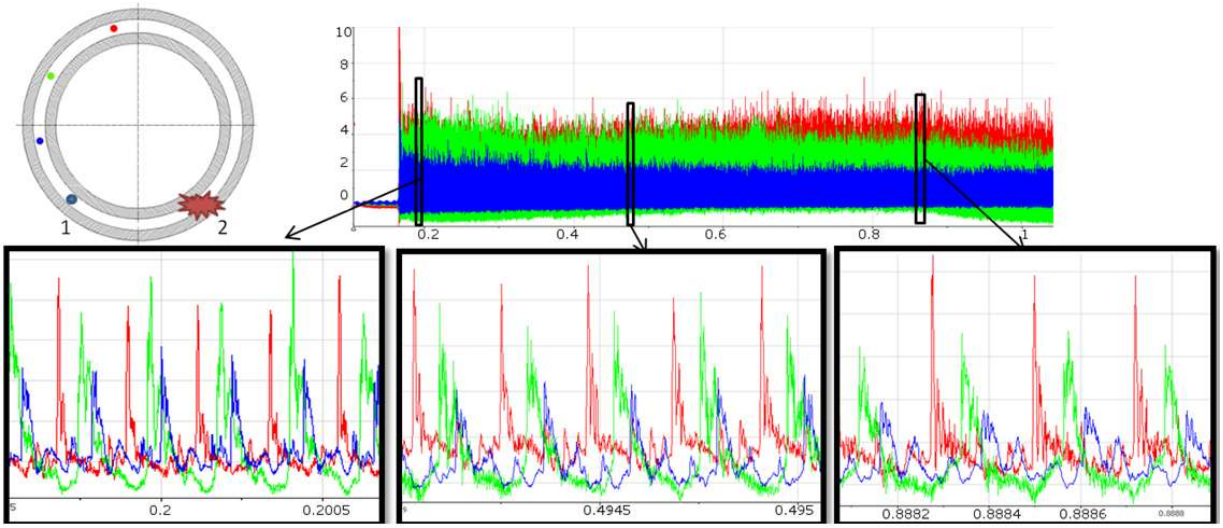

Figure 10. The example of an experiment with the use of the No. 2 initiator.

3 Conclusions

Three method were tested to find a solution for wave direction problem in RDE and results as follows:

- Synchronized initiators was not able to control directions waves propagations,
- Imposing aluminum foil next to initiator allows direction control in 80% of experiments, but is not practical.
- In Wedge-shaped channel the detonation wave starts to propagate towards extended channel.
- Introduced channel eccentricity resulted in 100% receptivity of direction of wave propagations

4 References

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