Numerical Simulation of Detonation inside the Electrochemical Pulse Engine

Ilia V. Semenov[1] , Vladimir V. Markov[2] , Stanislaw Wojcicki[3]
[1]Institute for Computer Aided Design, RAS, Moscow, Russia
[2]V. A. Steklov Mathematical Institute, RAS, Moscow, Russia
[3]Washington State University, Pullman WA, USA

Corresponding author, I. V. Semenov: semenov@icad.org.ru

Introduction

The creation of new types of internal combustion engines based on new principles is important for both theory and practice. A relatively new scheme is an electrochemical pulsejet. In this device the electrical discharge appears in the combustion chamber when the flame front impinges on special electrodes that are attached to a pre-charged energy storage capacitor. Electrodes with the Rogowski profile eliminate electric field enhancement near the electrode edges. A "collar" (ring-type) discharge creates converging shock waves in the combustible mixture, leading to a fast burning process with detonation, high pressure, and an increase in the compression ratio. The energy of combustion of one cycle is thereby much higher than the electrical energy delivered by the electrical discharge. Some previous experimental and theoretical investigations carried out by the authors [1-4] have been devoted to small scale device. Now the new full-scale model proposed by S. Wojcicki is under theoretical consideration.

Mathematical model and numerical method

It is necessary to emphasize the very interesting and complicated effects that take place during performance of engine which is under consideration. Among them are electrical discharge, converging shocks and detonation waves, propagation of combustion and detonations inside the vessels of complex shape. It is due to these that all transport effects, details of the chemical kinetic mechanism have to be taken into account for adequate simulation of real processes. Two-dimensional axisymmetric unsteady Navier-Stokes equations are used to describe the flow. The heat conductivity and diffusion are both taken into account. The well known concept by Academician O.M. Belotserkovskii about direct numerical modeling of turbulence [5] is employed. Energy input due to electrical spark is considered as the instant increase of internal energy inside the ring corresponding to real "collar" discharge system. The original numerical method based on finite volume scheme is used. For integration of stiff chemical kinetic system the Gear’s scheme is applied. The developed computational package permits to use different kinds of most common fuels. The package is implemented on massively parallel machines.

Results and discussion

The results concerning the numerical modeling of the engine whose combustion chamber is presented on Fig. 1 are given below. Hydrogen is taken as a fuel. The following elementary stages of the hydrogen oxidation reversible reaction are taken into account:

$$H+O_2 \Leftrightarrow OH+O, \quad O+H_2 \Leftrightarrow OH+H, \quad O+H_2O \Leftrightarrow OH+OH,$$
$$OH+H_2 \Leftrightarrow H_2O+H, \quad H+OH+M \Leftrightarrow H_2O+M, \quad H+O_2+M \Leftrightarrow HO_2+M,$$
$$HO_2+O \Leftrightarrow OH+O_2, \quad HO_2+H \Leftrightarrow OH+OH, \quad HO_2+H \Leftrightarrow H_2+O_2,$$
$$HO_2+OH \Leftrightarrow H_2O+O_2, \quad H+O+M \Leftrightarrow OH+M, \quad O+O+M \Leftrightarrow O_2+M,$$
$$H+H+M \Leftrightarrow H_2+M, \quad H_2O_2+OH \Leftrightarrow H_2O+HO_2, \quad H_2O_2+O_2 \Leftrightarrow HO_2+HO_2,$$
$$H_2O_2+M \Leftrightarrow OH+OH+M, \quad H_2O_2+H \Leftrightarrow HO_2+H_2$$

where M denotes a third particle.

The very important problem is initiation of the combustion in the hydrogen-air mixture at rest by electrical discharge with different energies E_0. The calculations show that there exists a minimal energy E_0 capable of initiating a detonation wave in the device. This value depends on the mixture composition. For example: E_0=30J for mixture 1 ($2H_2+O_2+3.76N_2$) and E_0=59.5J for mixture 2 ($2H_2+O_2+4.3N_2$).

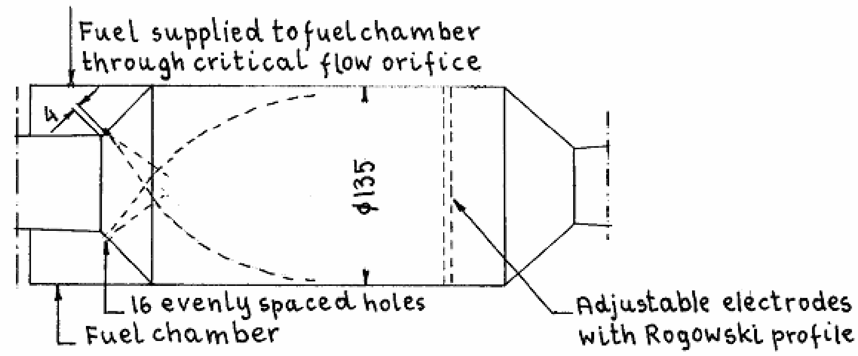

Figure 1. The schema of the combustion chamber.

The calculations are made for several initial conditions, several types of combustible mixtures and implosion modes. Output from the model includes impulse, thrust values and engine efficiency. The graph and the pictures demonstrate the results. An application of implosion schemes to RAM Accelerators is discussed.

The numerical investigation shows the new gasdynamics problems concerning the engine operation: Initiation of detonation by circular electrical discharge (critical energy); Effective formation of fuel-air mixture in the combustion chamber; Determination of the optimal system parameters; Adaptation to flight conditions.

Acknowledgments

This work is supported by Program of the Mathematical Branch of the Russian Academy of Sciences on fundamental researches: “Numerical and Informational Problems of Complex Goals Solution”, Russian Foundation for Basic Research Grant #03-01-00700-a, The Russian President Grant for Young Scientists and Leading Scientific Research Schools support #НШ-70.2003.1

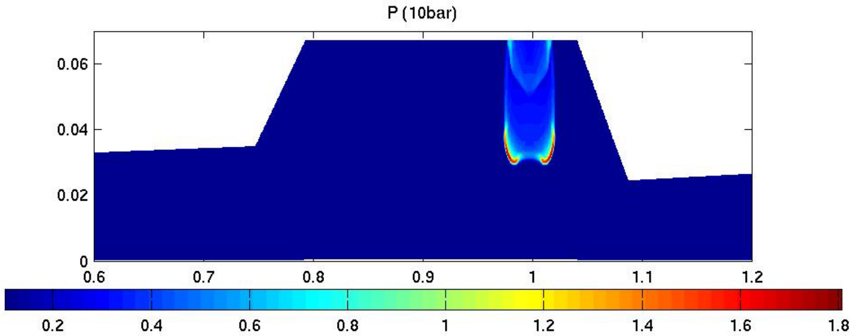

Figure 2. Pressure in the combustion chamber at 20 mcs after discharge.

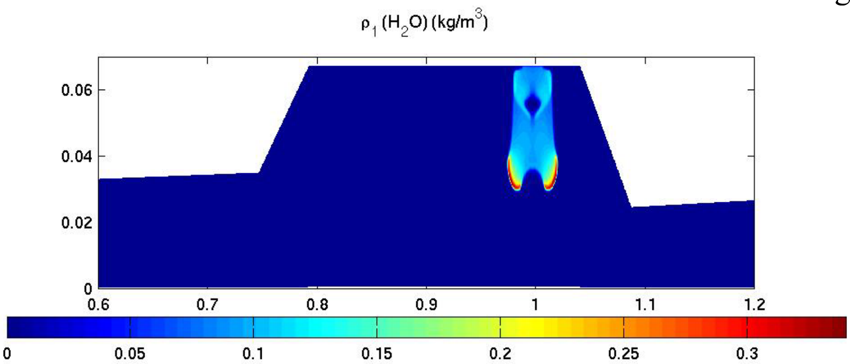

Figure 3. Density of the water in the combustion chamber at 20 mcs after discharge.

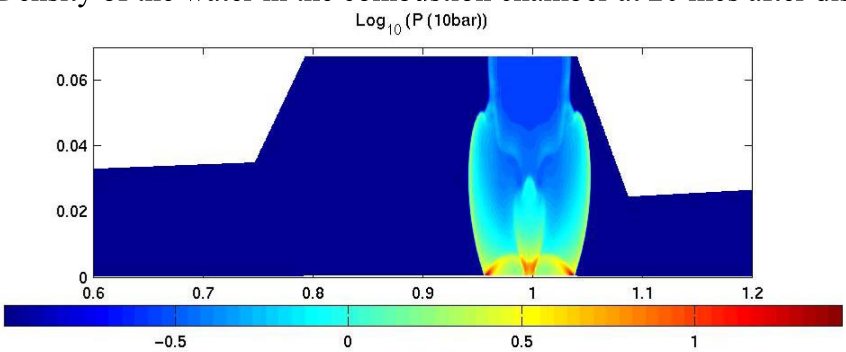

Figure 4. Decimal logarithm of the pressure in the combustion chamber at 40 mcs after discharge.

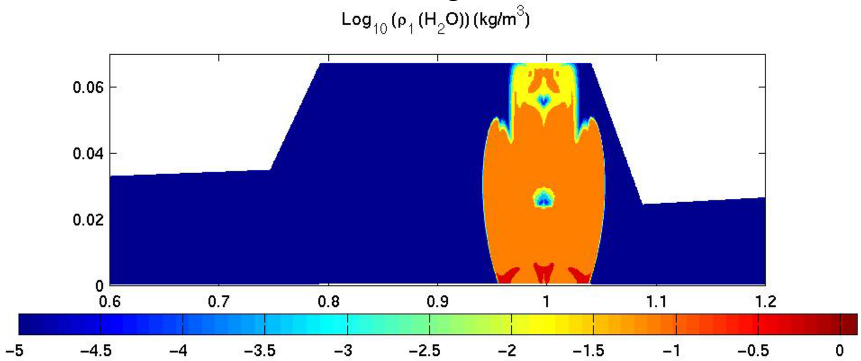

Figure 5. Decimal logarithm of the density of the water in the combustion chamber at 40 mcs after discharge.

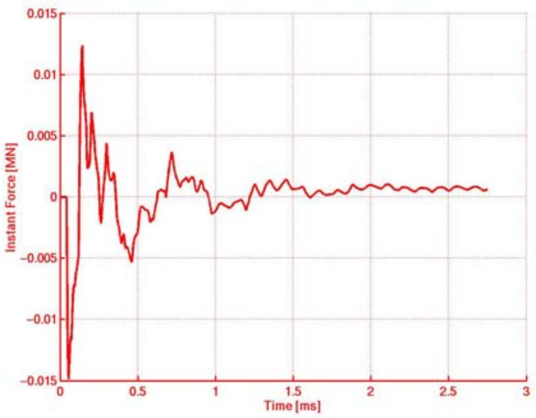

Figure 6. Instant force depending on time after discharge.

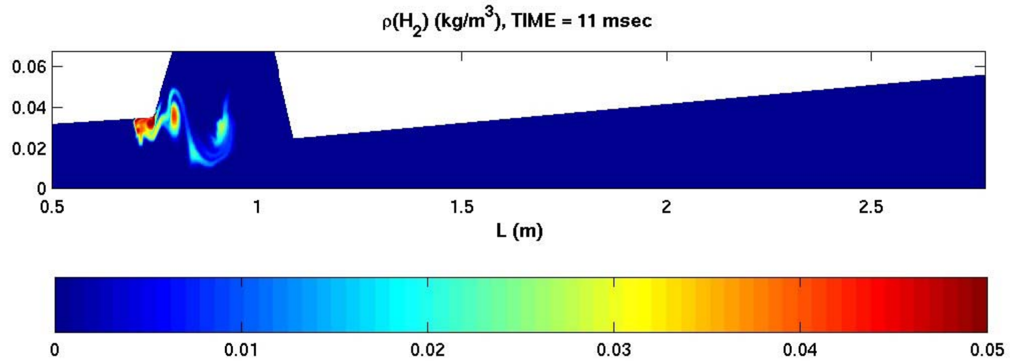

Figure 7. Injection the hydrogen fuel into the combustion chamber.

References

1. D. Ponizy, S. Wojcicki 1984 "On modeling of pulse combustor" *Archivum combustionis* 4 (3/4): 161.

2. V.P. Korobeinikov, S. Wojcicki 1995 "Theoretical modeling of detonation pulse engine with application to ram accelerator" Proc. of 2nd Intern. Workshop on Ram Accelerators, RAMAC II, Univ. of Washington, Seattle, WA USA, Session 8, 35.

3. S. Wojcicki 1996 "Engineering System Design and Analysis" 1 ASME (PD-VOL.73).

4. V.P. Korobeinikov, V.V. Markov, I.V. Semenov, D.D. Pedrow, S. Wojcicki 2001 "On modeling of a pulse detonation engine" ELEKS-KM Publishers. High speed deflagration and detonation: Fundamentals and Control, Eds. Roy G., Frolov S., Netzur D., Borisov A. Moscow, 289.

5. O.M. Belotserkovskii 1999 *Turbulence and Instabilities,* Moscow: MIPT.