Detonation initiation in PDE[']

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1 Introduction

The paper contains the results of theoretical investigations of deflagration to detonation transition (DDT) processes in combustible gaseous mixtures and transmission of detonation into large chambers. In particular, the paper investigates the effect of cavities incorporated in PDD and the implosion shock waves on the onset of detonation in gases.

Development of modern technology needs more and more powerful energy converters for propulsion issues. Converting chemical energy of fuel into propulsion energy of the vehicle is limited by the rates of chemical energy release in combustion. The rates of energy release in detonation modes of combustion of gases are three orders of magnitude higher than in deflagration combustion modes that could make the use of detonation combustion modes more efficient for creating high power energy converters. The rate of combustible mixture supply is usually lower thus requiring the pulsed operation mode of such an energy converter.

The specific impulse of PDE is higher as compared with specific impulse of RAM jet even operating under similar conditions and having the same fuel and oxidant average mass flow rate. The rough estimate provides the

following ratio: $\frac{I_{PDE}}{I_{RAM}} \approx \sqrt{\gamma} = \sqrt{\frac{c_p}{c_v}}$. Besides, the power of engine could be increased by increasing essentially

the mass flow rate of fuel and oxidant due to the increased opportunity of energy conversion rate.

The control of detonation onset in large chambers is of major importance in pulse detonating devices. The advantages of detonation mode of energy conversion over constant pressure combustion bring to the necessity of promoting the onset of detonation and shortening the pre-detonation length.

The DDT and further transmission of detonation wave into the large combustion chamber turned out to be the key factor characterizing the Pulse Detonation Engine (PDE) operating cycle. Thus, the problem of DDT control in gaseous mixtures became very acute.

The onset of detonation in large chambers could be promoted in two ways.

First way is promoting DDT in the whole chamber using different turbulizing elements, such as Schelkin spiral, orifice plates, or wider cavities [1]. The method is very effective, mostly using wider cavities [2], but the predetonation length turns to be big for wide chambers [3].

Second way is promoting onset of detonation in narrow chambers, which needs much shorter pre-detonation length, and then transmitting the detonation to a wider chamber. The method is effective in terms of shortening the predetonation length, but there is a great probability the transmission of detonation could fail under certain conditions.

The present paper is aimed at theoretical investigations of different methods for promoting detonation onset in wide chambers. Wilcox Ka-omega model [4] is used together with: 1) compressibility effects, 2) low Reynolds

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correction, 3) lagged eddy viscosity model. Standard wall functions are used as boundary conditions. The lagged turbulence viscosity model was used, which was shown [5] to give better results for non-stationary turbulence processes or for stationary processes with shock waves.

2 **Results of numerical simulations**

Numerical investigations of the DDT process and transmitting the detonation to a wider chamber were performed for a model hydrogen-air mixture, because chemical kinetics for these types of mixtures was well developed. Mixtures containing hydrogen in stoicheometric relationship with hydrogen, and lean mixtures were regarded. Fig. 1 illustrates the successive stages of the DDT process in a narrow tube (diameter 20mm) for stoicheometric hydrogen-air mixture. The upper part of the figure shows pressure maps, and the lower – temperature maps. The mapping colors for all the successive diagrams are shown in Fig. 2.



Figure 2. Mapping colors for pressure (a) and temperature (b).

It is seen from the figure, that the onset of detonation takes place near the wall in the pocket of unburned mixture.

The narrow tube is connected to a wider chamber 200mm diameter. The length of narrow section is 400 mm, the length of wide chamber is 100 mm. The detonation is easily transmitted for the case of stoicheometric mixture $H_2: O_2: N_2 = 2:1:5$. The successive stages of the transmission process are shown in Fig. 3.

Fig. 4 illustrates the successive stages of the detonation wave transmission for lean hydrogen – air mixture $(H_2: O_2: N_2 = 1, 5: 1: 5)$. It is seen from the figure that on entering the wide chamber combustion zone lags behind the leading shock on the sides, but remains attached to the front in the center. In some time a transverse wave appears, which reinitiates detonation.



Figure 3. Transmission of detonation in hydrogen – air mixture $H_2: O_2: N_2 = 2:1:5$.

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Fig. 5 illustrates detonation wave in nitrogen diluted stoicheometric mixture $(H_2: O_2: N_2 = 2:1:7)$ entering the wide chamber. As it is seen transmission of detonation fails: decoupling of flame and shock wave is never changed for reinitiation.



Figure 4. Transmission of detonation in hydrogen – air mixture $H_2: O_2: N_2 = 1, 5: 1: 5$.



Figure 5. Decay of detonation in hydrogen – air mixture $H_2: O_2: N_2 = 2:1:7$.

Placement of an obstacle ahead of the tube exit in the chamber was always considered to be a promoting factor for reinitiation of detonation in reflected shock waves, A disk was placed in the chamber at a distance of 10 mm from the wall leaving gaps of 10 mm each with the side walls. The attempts to transmit detonation in lean mixture(Fig. 6) failed for the present structure, though without the obstacle detonation was reinitiated.



Figure 6. Decay of detonation wave entering the chamber with an obstacle $H_2: O_2: N_2 = 1,5:1:5$.

The results of investigations show that diverging flows create less favorable conditions for onset of detonation. Thus the idea to use converging flows for transmission of detonation [6] deserves high appreciation. For all the regarded concentrations of hydrogen we tried the DDT in the narrow gap between two cylinders and further transmission of detonation in the internal cylinder, which resulted in a successful transmission of the

detonation in all the cases under consideration (Figs. 7 - 9). The width of the chamber was 200 mm as in all previous cases.



Figure 7. Implosion method for transmitting the detonation wave $H_2: O_2: N_2 = 1,5:1:5$.



Figure 8. Implosion method for transmitting the detonation wave $H_2: O_2: N_2 = 2:1:7$.



Figure 9. Implosion method for transmitting the detonation wave $H_2: O_2: N_2 = 2:1:5$.

3 Conclusions

The results of investigations show that for successful onset of the detonation with mild initiator it is necessary to come to a DDT in a narrow gap with a successive transmission of detonation into a wider section by implosion.

To promote DDT wider cavities should be used in the narrow gap.

The future research should be aimed at investigating the conditions for successful DDT in a gap and further transmission of detonation into a wider chamber using converging detonation waves for hydrocarbon - air mixtures, and studying the effects of fluid turbulent flow and its velocity in the wide chamber on the onset of detonation.

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