

Detonation Initiation at the Focusing of Shock Waves in Combustible Gaseous Mixture

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Abstract

The detonation initiation under the focusing conditions in a hydrogen - air mixture was experimentally investigated. It has been found that the mild ignition inside reflector cavity can lead to detonation initiation. Schlieren pictures of the process were obtained and the dependence of the distance of initiation on the incident shock wave Mach number was established.

Introduction

The phenomenon of shock waves focusing in the inert medium on a reflector located in a shock tube has been extensively studied during last 20 years. This phenomenon is less investigated in the case of combustible gaseous mixtures. The regions with high pressure and temperature resulting from a collision of a shock wave with a reflector can give birth to different modes of reaction front propagation. The possibility of realization of mild (combustion) and strong (detonation) modes of ignition in the highly sensitive oxyhydrogen mixture dependencies on the Mach number of the incident shock wave [1]. The existence of two modes of ignition was shown for stoichiometric hydrocarbon-air mixtures in [2]. The experimental featuring the focusing in hydrogen-air mixtures [3] revealed the different ignition mode that is characterized by the high pressure spikes behind the reflected shock wave. The values of the Mach numbers for this mode of the ignition fall in the range between Mach numbers for mild and strong ignition. In the present work the process of detonation initiation due to the focusing of the shock waves of different intensities was investigated.

Experimental

The experiments were carried out using a shock tube of 54 mm x 54 mm in cross section, low pressure section of 6.25 m in length and high pressure section of 3.15 m in length. The laser schlieren high-speed photography was used simultaneously with the pressure recording by transducers located on the top and bottom walls of the tube. Lean hydrogen – air mixture (15% vol. H_2) at initial pressure 26.3-40 kPa was used in the experiments. The symmetrical wedge reflector with apex angle of 90° was used for the focusing of shock waves. The Mach number was calculated by processing the instants of the incident shock wave arrival on the pressure transducers with the accuracy about 2%.

Results

The experiments show that at Mach numbers of the incident shock wave $M \geq 2.52$ the detonation is initiated in the volume adjacent to the reflector apex. At the beginning of propagation the detonation appears as a cylindrical wave, and after leaving of the reflector cavity transforms into the plane detonation wave. The parameters of this wave correspond well to the parameters of detonation propagating in the mixture compressed by initial shock wave. This case can be classified as an analog of direct detonation initiation by the high energy pulse. Decreasing

the Mach number of the incident shock wave to the value of $M = 2.47$ leads just to the combustion mode behind the reflected shock wave. Detonation in this case is initiating at the some distance L from the edge

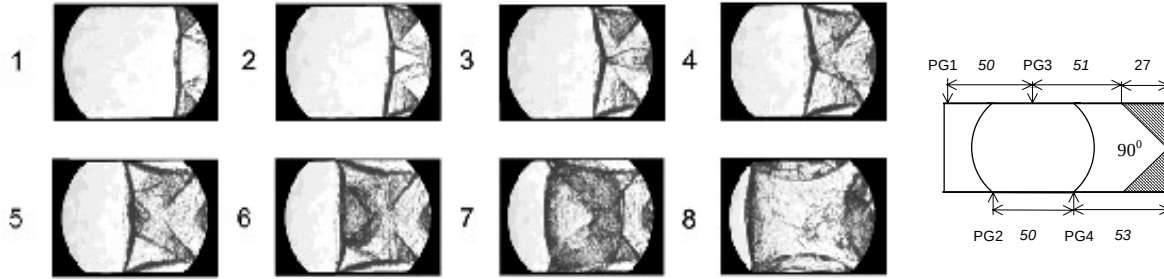


Fig.1 Schlieren pictures and the scheme of the test section. Incident shock wave Mach number $M = 2.47$. Time between frames $10 \mu s$.

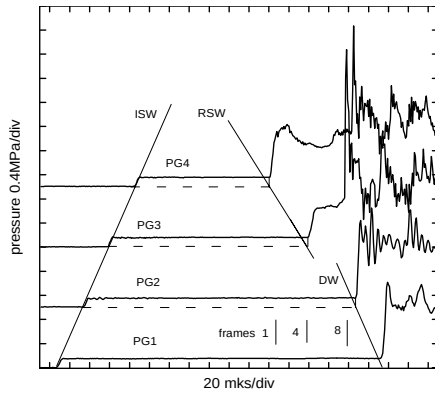


Fig.2 Pressure records for the case presented at Fig.1

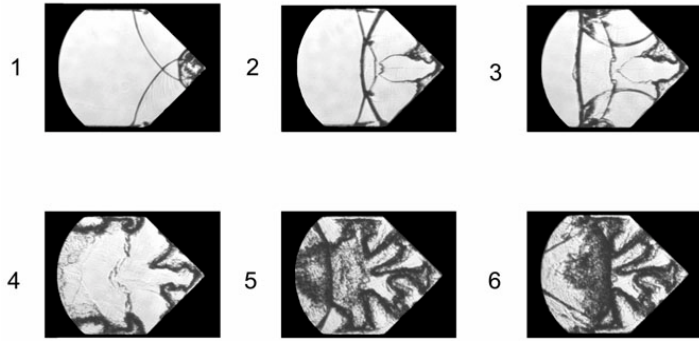


Fig.3 Schlieren pictures at the focusing of the incident shock wave with $M = 2.45$. Time between frames 1-2: $40 \mu s$, 2-3: $30 \mu s$, 3-4: $90 \mu s$, 4-5: $170 \mu s$, 5-6: $10 \mu s$.

of the reflector, as shown in Fig. 1. Pressure profiles recorded on the top and bottom walls of the tube are pictured in Fig. 2. From Fig. 1 one can see the presence of a system of weak shocks behind the reflected shock wave. Some of these shock waves give rise to ignition and mixture burnout. Specific feature of this process is that combustion starts in upper and bottom walls of the tube behind the reflected shock wave. Detonation wave arises in frames 4, 5 in Fig.1 at centerline at the distance of about 50 mm from the reflector edge after the collision of two weak shocks accompanied by combustion. After that the detonation wave propagating outwards the reflector is forming. Simultaneously, a shock wave, which moves along partially burnt mixture in the direction of the reflector, is generated.

At $M = 2.45$ the detonation is initiated at larger distance from the reflector. As it is seen from the photo in Fig.3 (frames 1,2) the ignition takes place inside reflector cavity and combustion front forms. Frames 3,4 show the appearance and development of combustion zones in the vicinity of tube walls behind the reflected shock wave. Approximately since $170 \mu s$ (frames 5,6) the shock wave that moves to the reflector is detected. Also seen in these frames is the significant growth of the combustion zones. The shock wave propagating to the reflector can be considered a quasi-retonation wave in partially burnout mixture. Near the walls, where the reaction is complete, this wave is oblique. The proper distance L for this case can be estimated using $x-t$ diagram assuming that the initiation takes place near the front of the reflected shock wave. The assessment for the case presented in Fig. 3 shows that the detonation is initiated at $L = 140 \text{ mm}$ from reflector edge.

Figure 4 demonstrates the pressure profiles at the distance of 224 mm from PG1 for the cases corresponding to detonation initiation both in the reflector apex at $M = 2.52 \div 2.55$ and at different distances L from the reflector at $M = 2.34 \div 2.47$. The dependence of L on the Mach number of the incident shock wave is plotted in Fig. 5.

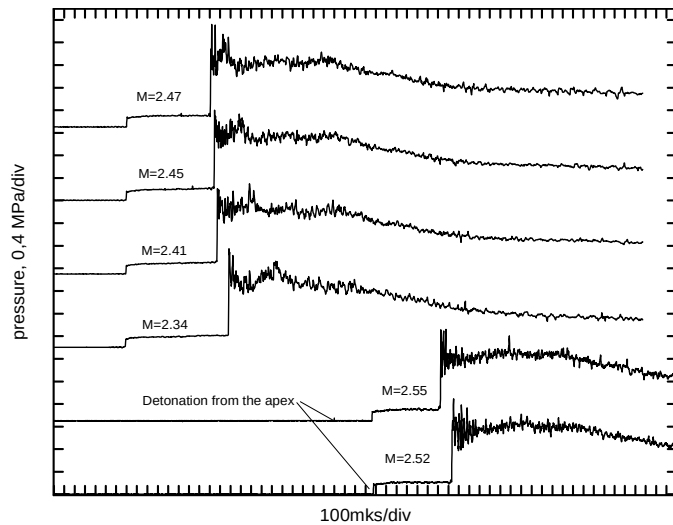


Fig. 4 Pressure records of the gauge located at a distance of 224 mm from PG1 for detonation initiation at the apex of the reflector ($M=2.52 \div 2.55$) and outside ($M=2.34 \div 2.47$).

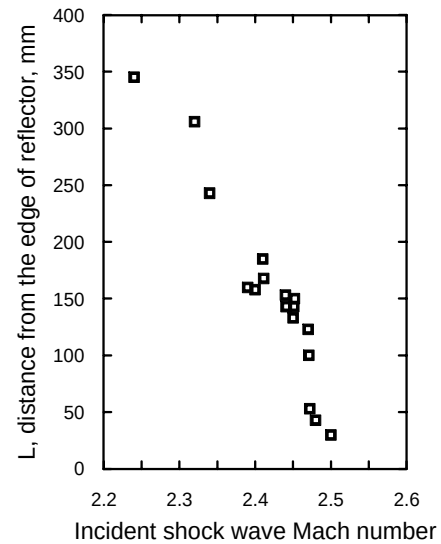


Fig. 5 Distance of detonation initiation vs of the incident shock wave Mach number

Conclusions

The experiments performed demonstrate the possibility of detonation initiation outside the reflector cavity due to self-ignition near/behind the reflected shock wave. The self-ignition is promoted by additional compression and preheating by turbulent multi-front combustion behind the reflected shock wave. It is possible to define a set of attributes peculiar to the given kind of initiation, namely:

- presence of an area of pre-heated mixture behind the incident shock wave,
- presence of a zone of turbulent combustion inside the reflector cavity,
- presence of zones of combustion behind the reflected shock wave outside the reflector cavity developing in time and capable to meet at the center of a tube.

The considered processes can be treated as DDT under focusing conditions.

Acknowledgments

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