A Study on the Interactions of a Detonation Wave with a Combustion Wave

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1 Introduction

It is important to investigate the interactions of detonation waves for safety engineering, as well as for research and developments of PDE (Pulse Detonation Engines) and SCRAM Jet engine. Interactions of a detonation wave or a combustion wave with a shock wave are studied. Botros, Ng et al. investigated on a head-on collision between a detonation and a shock wave[1,2]. Terao et al. observed interactions between combustion and shock waves[3]. Numerical simulations of interactions of flamelets with shock waves are carried out by Taki[4]. Experiments and numerical simulation on the interactions between a detonation wave and structures have been performed by Ohyagi et al[5,6]. However, the interaction phenomenon of two detonation waves or of a detonation wave with a combustion wave had not been performed yet. The head on collision of two planar waves such as shock wave is the same as that between a planar wave and solid wall, which can be studied analytically. In contrast, the head on collision of two detonation waves is different from that of shock waves, because there are influences such as 3-dimensional structure of the detonation wave and Taylor expansion wave behind of that. The interactions of a detonation wave with a combustion wave is interested in complex phenomenon containing the collisions between detonation wave , shock waves and flame, since accelerating combustion wave produces some shock waves ahead. They were carried out two experimental studies of the interaction phenomenon of detonation waves, the head on collision of detonations and between a detonation wave and a combustion wave. A combustion wave and a detonation wave were produced by igniter with the delay circuit. Experiments were performed using rectangle detonation tubes with pressure transducers, ionization probes and visualization by soot track records. The present study aims at an understanding of the interaction phenomenon by experimental observations.

2 Head on collision of detonation waves

2.1 Experimental

Figure 1 shows the schematic of experimental apparatus for the head on collision of detonation waves. A tube with rectangular cross-section 30mm x 25mm and length of 2500mm is used through which detonation waves propagate. The tube is filled with stoichiometric oxyhydrogen mixture, at initial pressures 70kPa, which is ignited simultaneously by two spark plugs. Two detonation waves are developed in the tube through the DDT process. Then they collide with each other almost in middle of the tube.

The active area of the window is 30mm x 200mm. A visualization by the soot track record has been made to find traces due to the three dimensional structure of the wave fronts. The sooted thin plates are fixed on the sidewall. The plate was sooted by kerosene flames. Pressure transducers (PCB 113A24, Piezotronics Co.Ltd.) embedded on the sidewall at four positions P1 (250mm), P2 (750mm), P3 (1250mm) and P4 (1750mm) can detect pressure variations along the tube at the center of sidewall. Ionization probes embedded on the sidewall at four positions P1 (250mm), P2 (750mm), P4 (1750mm) and P5 (2250mm) can detect ionization current variations along the tube at the center of sidewall opposite to the pressure transducers.

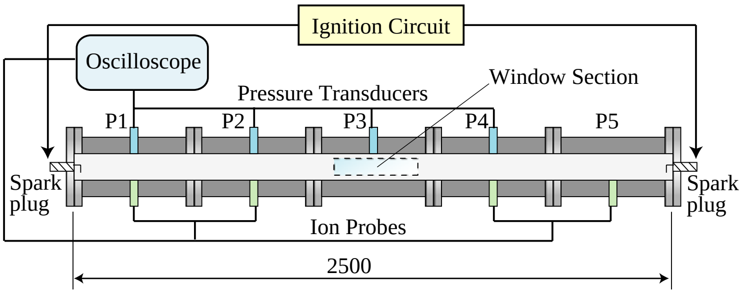

Figure 1. Schematic of experimental apparatus

2.1 Results and discussion

Figure 2 shows pressure and ionization current histories for this experimental condition. Figure 3 shows *x-t* diagram obtained from the pressure histories. Left-hand and right-hand sides tube ends indicate the position of *x* = 0mm and *x* = 2500mm. Pressure waves propagate from both tube ends by ignition. Combustion waves propagate behind the pressure waves which transit to detonation waves. At P2 and P4, steep pressure rise with peak values 27.2 and 30.1 are observed behind weak shock waves preceded. Ionization currents at P2 and P4 show that reaction fronts appear simultaneously with the steep pressure peaks so that it can be concluded that they are detonation waves. They would be over driven detonation, since pressures were over CJ value. Then, two detonation waves catch up with the preceding shock waves, and collide head-on exactly at the position of P3, which non-dimensional pressure is 51.8. After the collision, detonation waves became to be two reflected shock waves propagating in the burned gas. They propagate as transmitted shock waves and decreases in pressure and propagating velocity. Figure 4 shows the soot track record obtained by the experiment. In the soot track record, there appears a clear line of collision at P3. Unlike head on collision between a detonation wave and solid wall, the collision surface was not straight line but curvature lines by cellular fronts. The cell size of the both sides is about 1-2mm, and almost correspond to that measured by other researchers for the oxyhydrogen mixture at 70kPa.

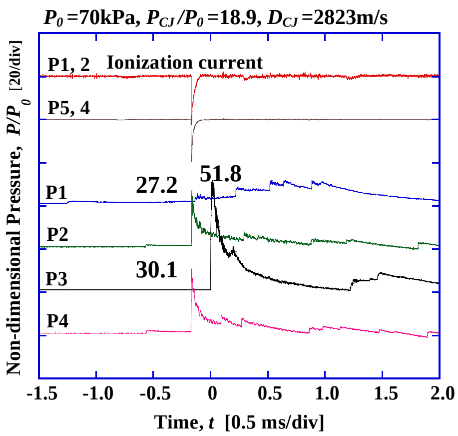

Figure 2. Pressure histories

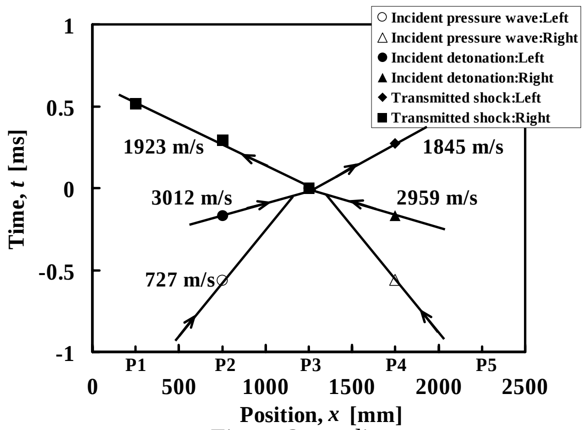

Figure 3. *x-t* diagram

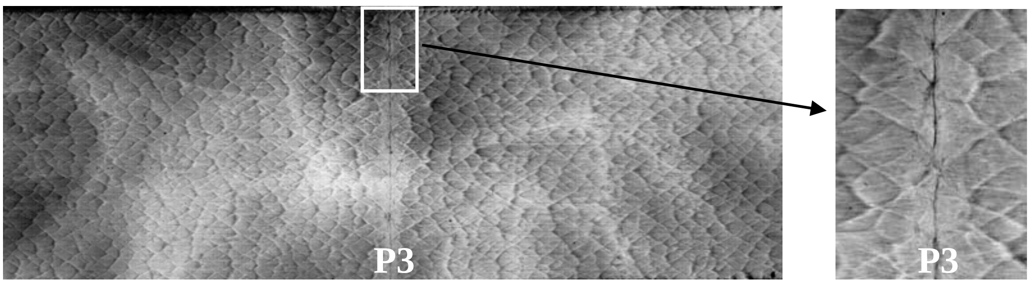

Figure 4. Soot track record (Right:closeup of the collision surface)

3 Head on collision between a detonation wave and a combustion wave

3.1 Experimental

Figure 5 shows a schematic of experimental apparatus for the interaction between a detonation wave and a combustion wave. The spiral coil with a length 500mm is inserted in the right end of tube with a length of 3000mm. The tube is filled with stoichiometric oxyhydrogen mixture, at initial pressures 20kPa. In this experiment, ignitions are not performed simultaneously, but with 4 ms delay. A combustion wave begins to propagate from left to right at first and 4 ms after the second combustion wave starts from the right end. The latter develops to a detonation due to the presence of spiral coil immediately. The two waves then collide each other near the window section. A ionization probe is added to the positions P6 (2750mm). The delay circuit can set up delay time at a step for 0.001ms from 0.001ms to 999ms.

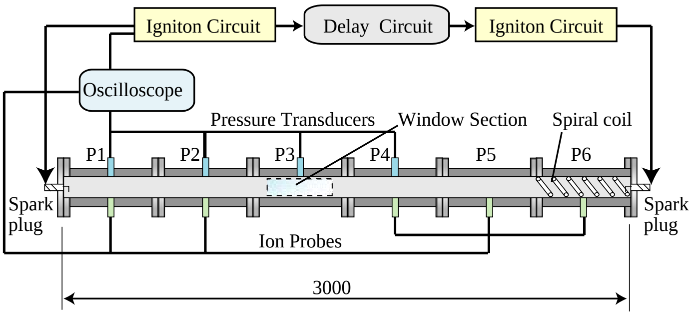

Figure 5. Schematic of experimental apparatus

3.2 Results and discussion

Figure 6 shows pressure histories by delayed ignition at initial pressure 20kPa. Figure 7 shows an *x*-*t* diagram that obtained from the pressure history. Left-hand and right-hand sides tube ends indicate the position of x = 0mm and x = 3000mm. Pressure waves propagate from both tube ends by ignition. A combustion wave propagated behind a pressure wave and a flame propagate by ignition at the left-hand side end. On the other hand, after 4ms the right spark is ignited to make a combustion wave which soon develops to a detonation by the virtue of Shchelkin spiral. Non-dimensional pressure of P3 for shock wave propagating from left-side is 3.5. After this shock wave propagates through P3, it collides with the detonation wave that propagates from right-hand side. After the detonation wave collides with the shock wave, which passes through P3 (non-dimensional pressure is 46.1), further collides with second shock wave and with a flame. Second shock wave propagates as transmitted shock wave to right, the non-dimensional pressure of P3 is 48.5. The detonation wave changes its form to a transmitted shock wave of which pressure and propagating velocity decrease. Although Ionization currents at P2 show that reaction fronts appear simultaneously with the weak pressure peaks again, it is no longer detonation wave but transmitted shock wave in the burned gas. Since the degree of ionization was different detonation wave from combustion wave, ionization reaction was induced by the transmitted shock wave in the burned gas after the collision with the flame.

Figure 8 shows a soot track record obtained by the experiment. In the soot track record, there appear two straight lines (S1,S2) and a curved line (F) which separate the different regions. In the right of S1, detonation cells are observed with its width 5 mm. In a region between S1 and S2, finer cells with 1.3 mm averaged width are observed. In just left of S2, very fine cells observed but they soon disappear near the curve F. A position of S1 is 23mm from P3 to right-hand side, S2 is 69mm to left-hand side from P3, F is 75mm from P3 to left-hand side. From the *x*-*t* diagram of Fig. 8, the position where the shock wave and the detonation wave have collided is 30mm from P3 to the right, and the detonation wave and the flame or second shock wave collided is the position of 80mm from P3 to the left. Therefore, S1 is a trace of collision of the shock wave and the detonation wave, S2 is that of the second shock wave and the detonation wave, F is a trace of a turbulent flame front when the detonation wave have interacted. The reason why the cell width has changed is that behind a shock wave a temperature and pressure become large so that a chemical reaction time decreases to reduce the cell size. In the region between S2 and F, a very high pressure might be produced due to the so-called local explosion as is observed in the pressure record of P3.

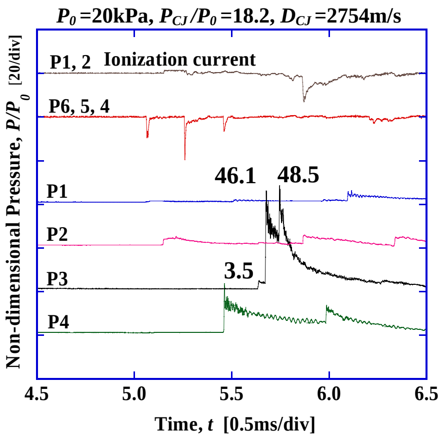

Figure 6. Pressure histories

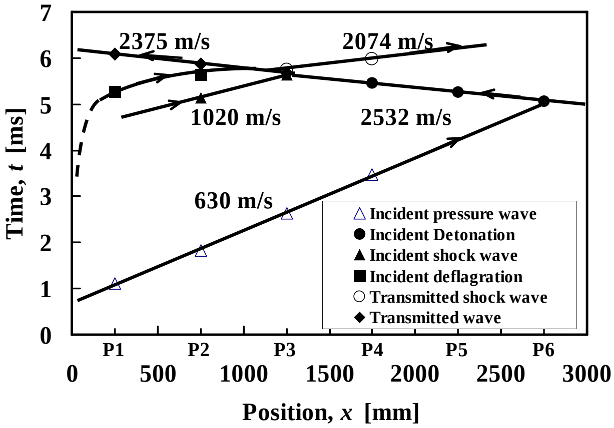

Figure 7. *x-t* diagram

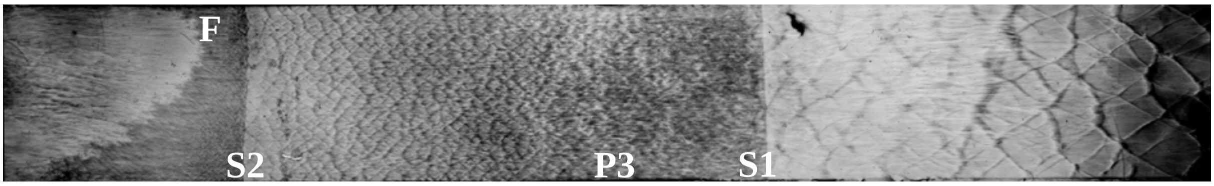

Figure 8. Soot track record

4 Conclusion

Experimental studies of the interactions of detonation waves were carried out for stoichiometric oxyhydrogen mixture. From the *x-t* diagram and soot track record, collision of detonation waves and that of a detonation wave with shock waves or a flame were observed.

References

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