The Ignition of Hydrogen-Oxygen Mixture by Shock Wave. II. Measurement of the Pressure and the Volocity of Shock or Detonation Wave

By Momotaro SUZUKI, Hajime MIYAMA and Shiro FUJIMOTO

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In the previous paper[1] of this series, we described the results on the shock ignition of hydrogen-oxygen mixture using a shock tube of rather simple construction. Further investigation with a more complex device will be preferred to get more detailed knowledge. In this report some investigations were made to get fundamental information on the shock ignition of this mixture with a shock tube, equipped with pick-ups of barium titanate for the sake of measurements of pressure as well as of velocity of shock or detonation wave.

Experimental

A brief scheme of the measuring system is given in Fig. 1. As is shown in the figure, the shock tube made from mild steel has a square cross section with an inside lateral of 5 cm. The tube is divided into two portions, the reservoir chamber of A of 60 cm. length and the ignition test chamber C of 180 cm. length respectively. The chambers A and C are separated by several sheets of cellophane films, which can be punctured by the needle N through a side tube attached obliquely to the central axis of the shock tube.

For the measurement of pressures, five checking stations which are denoted by P_1, P_2, P_3, P_4 and P_5, are located on the wall of the test chamber. These stations are placed at a distance of 20 cm. from each other. The measuring equipment of each station is a pick-up (Fig. 2) consisting of ceramics of barium titanate whose natural frequency is something over 10 kc. A pick-up at P_0, placed near the membrane, is used for starting the sweep of the oscillograph.

1) M. Suzuki, H. Miyama and S. Fujimoto, This Bulletin, **31**, 816 (1958).

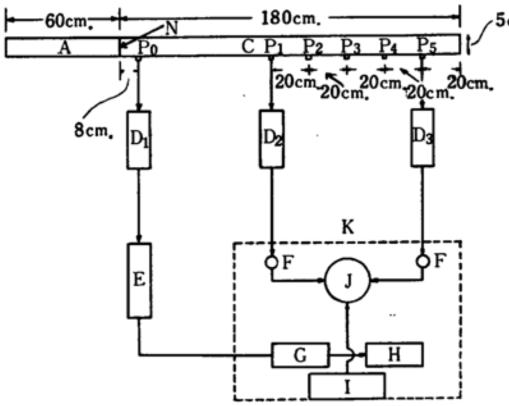

Fig. 1. Scheme of the measuring system.
A, Reservoir chamber;
C, Test chamber;
D_1, D_2 and D_3, Pre-amplifiers;
E, Trigger amplifier;
F, Signal input;
G, Sweep trigger;
H, Sweep oscillator:
I, Time-mark-oscillator;
J, Cathode-ray tube;
K, Two-element-oscillograph;
N, Needle;
$P_0 \sim P_5$; Pick-up stations.

Just as the shock wave starts at the puncturing of the diaphragm, the pick-up at P_0 operates, and accordingly the signal from this pick-up will be transmitted through the pre-amplifier D_1 to the trigger amplifier E which operates the sweep-trigger G. Then the sweep-oscillator H of the oscillograph K will start and will give a horizontal time axis on the oscillogram. As the wave further propagates and passes the pick-up stations P_1 etc., the pressure change which is caused by the wave passing there will register on the pick-ups and this transient pressure change will

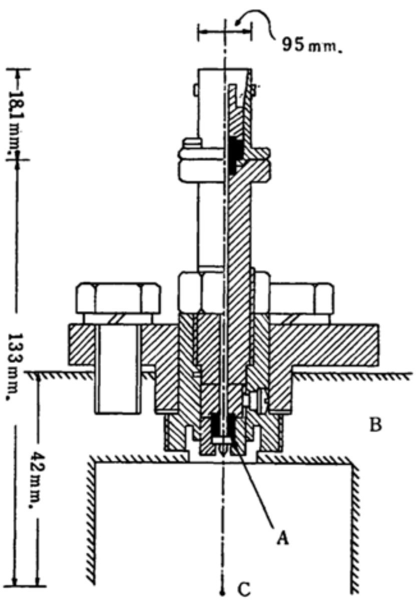

Fig. 2. Pick-up.
A, Barium titanate;
B, Wall of the shock tube;
C, Center of a cross section of the shock tube.

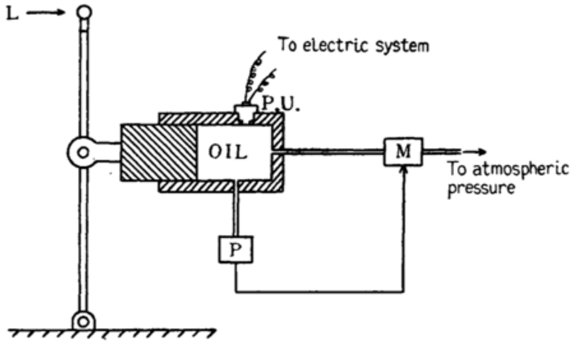

Fig. 3. Apparatus for calibrating pick-up.
P, Pressure switch;
M, Electro-magnetic valve;
L, Lever

show itself as a displacement along the vertical axis of the oscillogram whose height gives the value of the pressure change. As we have a synchronous time marking by means of oscillator I in each oscillogram, we can evaluate the time delay of these successful pressure signals and then estimate the average velocity of the wave between two subsequent stations accordingly.

The characteristics of the apparatus used are given below. The pre-amplifiers have input-impedance 5 MΩ, output-impedance 100 kΩ, gain 53 db, maxium deviation of gain −2 db between 2c./s. and 20 kc./sec., and noise ratio less than −60 db. The trigger amplifier has output-impedance 100 kΩ, gain 40 db, maximum deviation of gain −2 db between 1 kc./sec. and 20 kc./sec., trigger-output 75 V_{p-p}, trigger-delay 0.6 msec.∼1.3 msec. which on requirement can be reduced to less than 2μsec. by cutting off the circuit of the trigger-delay. The scale of the time-mark oscillator can be varied in four steps i.e. 10 msec., 1 msec., 100 μsec. and 10 μsec., and the error of scale is less than 5%. The two-element oscillograph has the following characteristics. Cathode-ray tube is the type 130 SB11 (Toshiba). The amplifier has an input-impedance ca. 2 MΩ, gain ca. 70 db, maximum deviation of gain ±3 db between DC and 500 kc./sec., input-level about 1 mV∼100 V, and continuous variable attenuator 1:1 to 1000:1. The sweep-trigger and sweep-oscillator have input-level ca. 10 mV_{p-p}, and time of duration for a single-sweep 100 msec./cm.∼10 μsec./cm.

The pick-up used for measurement was calibrated by means of the device shown in Fig. 3. The procedure of calibration is as follows. The pressure of the vessel, which is filled with low viscosity oil, will increase by pushing the lever L. When the pressure attains a certain definite value on which the pressure switch P is adjusted, electrically operate the valve M, which is suddenly opened. Accordingly, the pressure inside the vessel is reduced to atmospheric pressure during a very short period, and this pressure change is recorded through the pick-up in the oscillogram. We can calibrate the displacement of the oscillogram at a certain value of pressure by comparing this with the scale of the pressure switch which is previously standardized by an absolute manometer.

Other details about the experiment which are not described in this paper will be found in our previous papers[1,2] or elsewhere.[3]

Results and Discussion

A picture of an oscillogram of a propagating shock wave in the test chamber, which is filled only with air, is shown in Fig. 4. The picture was taken for the sake of visualizing the real behavior of a shock wave propagating in a tube filled with air without initiating any chemical reaction. The variation of the pressure P and the velocity of the shock wave with P_1/P_0 is obtained from many such pictures as this and shown in Figs. 5 and 6, where P_1 and P_0 are the pressures of the reservoir and the test chambers respectively. The values of P_0 are always atmospheric pressure. The experimental values of P are rather greater than the theoretical

2) M. Suzuki, H. Miyama and S. Fujimoto, This Bulletin, **31**, 232 (1958).

3) R. B. Morrison, "A Shock-Tube Investigation of Detonative Combustion", Engineering Research Institute, Univ. of Michigan, Ann Arbor (1955); P. F. W. Geiger and C. W. Mautz. "The Shock Tube as an Instrument for the Investigation of Transonic and Supersonic Flow Patterns", Engineering Research Institute, Univ. of Michigan, Ann Arbor (1949): P. M. Steinberg and W. E. Kaskan, "Fifth Symposium on Combustion", The Williams and Wilkins Co., Baltimore (1953), p. 664.

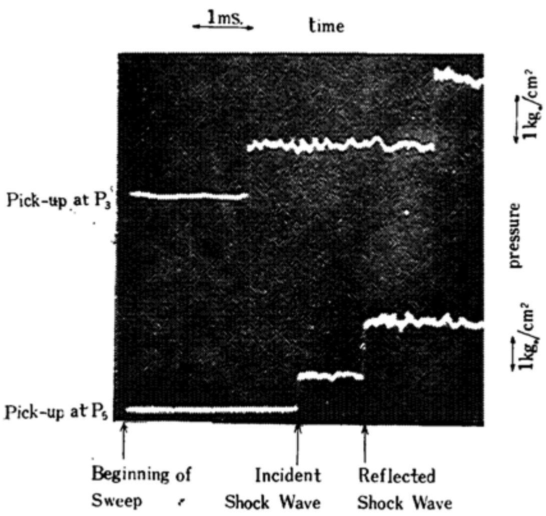

Fig. 4. A picture of oscillogram, when the test chamber is filled with air. P_0=760 mmHg, P_1/P_0=5.

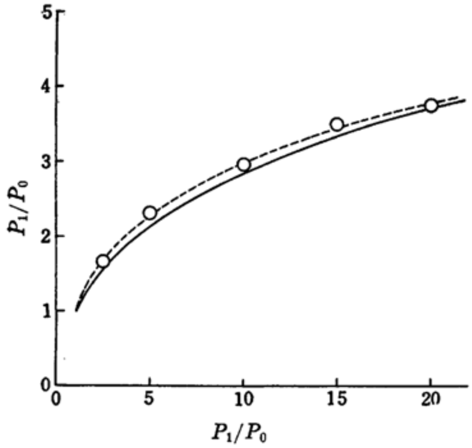

Fig. 5. Variation of the pressure of the incident shock wave with P_1/P_0
------ experimental value;
—— theoretical value.

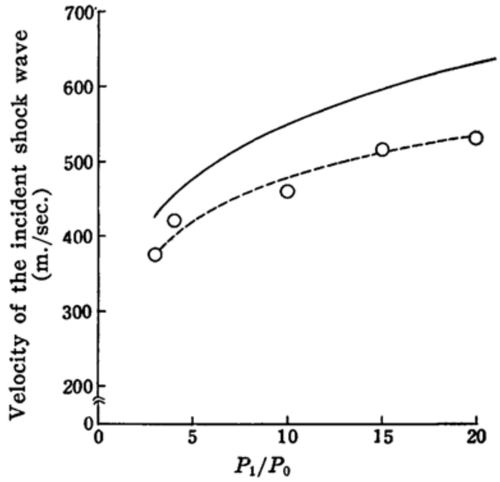

Fig. 6. Variation of the velocity of the incident shock wave with P_1/P_0.
------ experimental value;
——theoretical value.

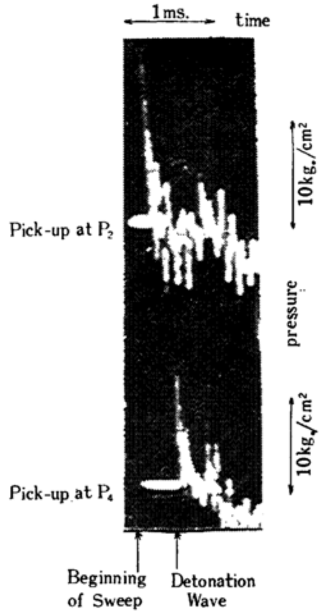

Fig. 7. A picture of oscillogram, when the test chamber is filled with $2H_2+O_2$. P_0=200 mmHg, P_1/P_0=10.1.

values as shown in Fig. 5. The discrepancies probably lie within the limit of characteristic error of the pick-up used. As may be seen in Fig. 6, the experimental values of the velocity of shock wave are smaller than those expected from the theoretical considerations, and this tendency looks more reasonable when compared with the results of any other author.[4]

In the next experiment we have carried on a series of measurements using the gaseous mixture $2H_2+O_2$ in the test chamber. Compared with the former case[1], the ignition was easier, i.e., the ignition pressure P_1 is lower, but the critical value of this pressure was more ambiguous. These results probably occur because the cross-section of this shock tube is larger, the number of sheets of cellophane films under the same pressure-difference, is more, and therefore the effect of puncturing the membrane upon the detonable

4) R. E. Duff, "The Use of Real Gases in a Shock Tube" Engineering Research Institute, Univ. of Michigan, Ann Arbor (1951).

gaseous mixture is greater than in the previous shock tube.[1]

A typical oscillogram of pick-up pressures in a series of detonation experiments where the pressure of the detonable gas mixture in the test chamber is more than 200 mmHg, is shown in Fig. 7. In this figure, the pressure of the shock wave is not observable, but only the pressure of the detonation wave can be observed. The same features are observed in oscillograms of all pick-up stations and therefore it is concluded that the detonation was initiated between the membrane and the first pick-up P_1 and that the detonation of the gaseous mixture became stable before the detonation wave arrived at the pick-up P_1.

Under a pressure of 100 mmHg, the detonation took place somewhere along the test chamber. This detonation was initiated by an incident shock wave in some cases and by a reflected one in other cases. The distinction as to whether the cause of initiation is due to the incident or the reflected shock wave, can be told from the relative position of the detonation sign and the shock sign in the oscillograms of the pick-up stations (Figs. 8 and 9).

These differences of the oscillograms between points at high pressure and at

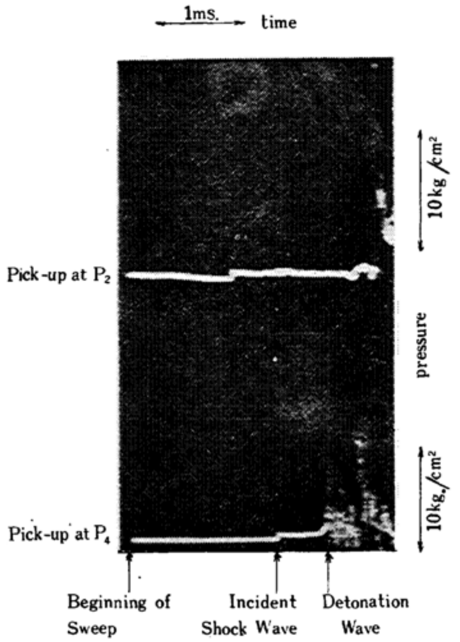

Fig. 8. A picture of oscillogram, when the test chamber is filled with $2H_2+O_2$. $P_0=100$ mmHg, $P_1/P_0=57.0$.

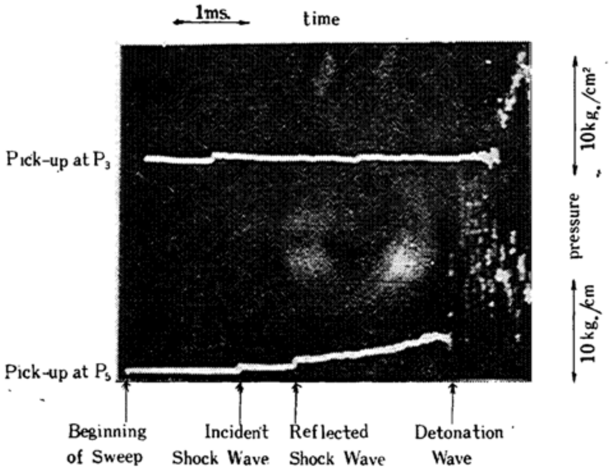

Fig. 9. A picture of oscillogram, when the test chamber is filled with $2H_2+O_2$. $P_0=100$ mmHg, $P_1/P_0=55.8$

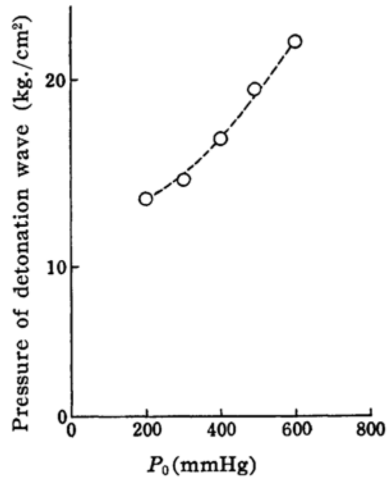

Fig. 10. Variation of the pressure of detonation wave with P_0.

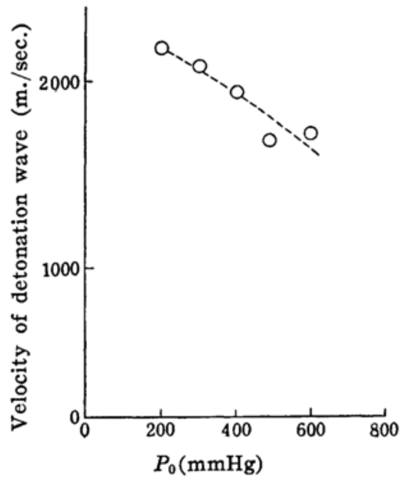

Fig. 11. Variation of the velocity of detonation wave with P_0.

low pressure is perhaps because of the difference of the disturbing effect of fractured membrane fragments in both cases. Although this effect seems to be very little in the latter case, it must be verified by a further investigation.

The variation of the pressure and the velocity of detonation wave with the pressure of the detonable gas mixture, P_0, calculated from the oscillograms, are shown in Figs. 10 and 11. These figures correspond to the cases where P_0 is higher than 200 mmHg. It will be concluded from the results of these experiments that the pressure of the detonation waves increases along with the increase of the pressure P_0, but on the other hand the velocity of waves decreases as the pressure P_0 increases.

Summary

We have carried on a series of experiments on the shock ignition of a gaseous mixture $2H_2+O_2$ by using a shock tube equipped with pick-ups, which can be used for measuring the pressure and the velocity of shock or detonation waves. The results are summarized as follows:

1) When the pressure P_0 of a gaseous mixture is higher than 200 mmHg, the ignition starts between the membrane and the first pick-up along the test chamber and the detonation becomes stable before the detonation wave arrives at the first pick-up.

2) In case P_0 is 100 mmHg, the detonation is initiated by an incident shock wave in some cases and by a reflected one in other cases.

3) When P_0 is higher than 200 mmHg, the pressure of the detonation wave initiated by shock ignition increases along with the increase of P_0 but its velocity decreases with a similar increase.

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Department of Chemistry
Defense Academy
Yokosuka