Characteristics of a $60mm \times 150mm$ vertical diaphragmless shock tube

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Abstract. The propagation of shock waves in foams and highly dust-loaded gases is one of the basic topics of shock wave dynamics. To promote such experiments in the Shock Wave Research Center (SWRC) of the Institute of Fluid Science, Tohoku University a vertical diaphragmless shock tube was designed and constructed. This shock tube has a unique structure. Its $60mm \times 150mm$ low pressure channel is vertically supported, and its $200mm$ dia. high pressure chamber is horizontally supported. A quick moving aluminium piston separates the horizontal and vertical sections. The low pressure channel has a $60mm \times 1120mm$ view field so that in order to quantitatively visualize shock waves in such a wide view test section a holographic ineterferometric system with $1000mm$ dia. view field is equipped. Paper describes characteristics of this facility.

1 Introduction

Shock wave propagation in porous materials is one of basic research topics of shock dynamics (Britan et al 1999; Kitagawa et al 1999). However, in previous experiments the cross-sections of shock tubes are not large enough so that the comparison between experimental data and one-dimensional theory has a difficulty. In highly dust loaded shock tube experiments, the test section has to be vertically supported and in addition to this the replacement of diaphragms always caused leakage of dust particles in laboratory.

Supported by a Grant-in-aid for COE programme offered by the Ministry of Education and Science, Japan, a shock tube was designed and constructed at SWRC. The shock tube has a $60mm \times 150mm$ cross sectional low-pressure channel supported vertically and 200 mm dia. high pressure chamber supported horizontally. The high pressure chamber section was placed on the second floor. A relatively light weight aluminium piston is installed between the vertical channel and the horizontal chamber. Its flat surface is facing to the channel supported from behind with auxiliary high pressure gas. When the auxiliary gas is released suddenly, the piston recedes quickly allowing the high pressure driver gas flow into the low pressure channel.

This arrangement not only save the laboratory space but promote the data production with relatively higher degree of reproducibility. This paper reports preliminary results of this shock tube and also efforts of flow visualization.

2 Diaphragmless shock tube

In conventional diaphragm rupturing systems, one can precisely control the rupturing pressure of diaphragms but impossible to control the shape and open area of diaphragms. The diaphragm petals will become a throat of duct flows so that such inconsistent area irregularities created the scatter of mass flow and shock wave Mach number. In these diaphragmless system once the initial conditions are fixed the piston motion will be more consistently regulated.

Yang (1995) used a rubber membrane to separate the high-pressure driver gas from the low-pressure channel and made it recede very quickly by releasing an auxiliary high-pressure gas. Although the movement of a rubber membrane is much slower than the rupturing of plastic diaphragms, this shock tube produced shock waves with higher degree of reproducibility. This shock tube showed a good characteristics for the generation of weak shock waves at the Mach number ranging from 1.015 to 2.85 in air and its scatter is 0.25%.

This success has encouraged us to design other shock tubes that were equipped with a piston mechanism. By the way the concept of piston mechanism as a replacement of diaphragm rupturing was originated at least in Japan by Ikui et al (1976; 1978) . Oguchi et al (1976) put the piston mechanism inside the high-pressure chamber, in which the piston was facing to the low-pressure channel. However, these shock tubes were all relatively compact ones. Meguro (1995) extended the rubber membrane system to a $100mm \times 180mm$ shock tube by using a piston made of aluminium and put it facing to its high-pressure chamber. With such improvements for shock Mach number ranging from 1.5 to 5.0 in air the scatter became 0.3%. Since it is a relatively large shock tube, with previous diaphragm rupturing systems, it had been operated at most twice a day. With diaphragmless operation its productivities were also improved. It could be operated every 20 minutes keeping high degree of reproducibility. Hosseini et al (2000) recently constructed another vertical diaphragmless annular shock tube, in which a more sophisticatedly designed rubber membrane was used as a quick valve. Wonderful improvements in not only shock wave Mach numbers but their reproducibility were obtained.

3 Vectical shock tube

Figure 1 shows the schematic diagram of a $60mm \times 150mm$ vertical shock tube and in Fig. 2 its photograph. A low-pressure channel shown in Fig. 2a, made of extruded aluminium with $30mm$ wall thickness, was about $5.5m$ long and vertically supported with two pillars based on the ground floor. A high-pressure chamber shwon in Fig. 2c was horizontally supported with two pillars based on the first floor. A quick moving piston mechanism was installed between the low-pressure channel and high-pressure chamber. In order to visualize a wider area, the test section shown in Fig. 2b had a $60mm \times 1720mm$ view field and made of aluminium. Its window glasses were $20mm$ thick acrylic plates. In the case of shock wave propagation in foam, the response of longer foams is more

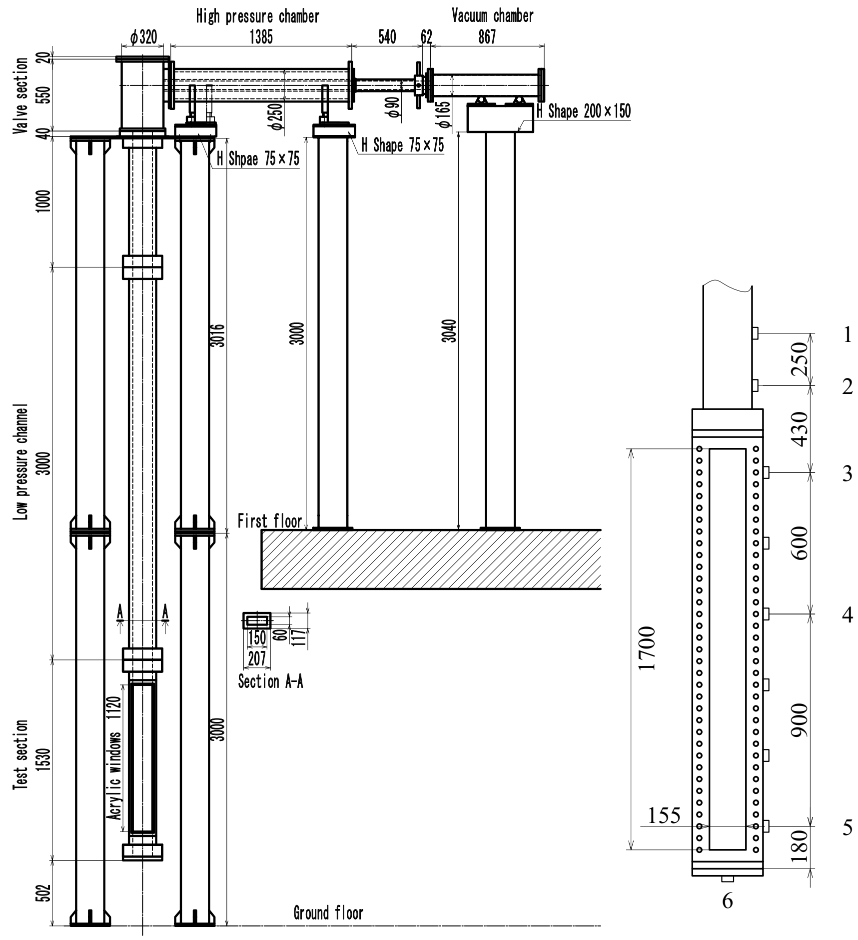


Fig. 1. Schematic diagram of the $60mm \times 150mm$ vertical shock tube. Test section and location of six pressure transducers are shown lower right.

interesting than short ones. In the case of dusty gas shock tube flows relaxation distances can be sometimes long even to one meter. Hence wide and long test sections will provide more informative data than small ones.

Figure 2d shows the quickly moving piston. The piston was initially pressed toward the low-pressure channel by auxiliary high pressures as shown in Fig. 3a. When the high pressure was released the piston started to move. Pistons had $205mm$ o.d. and were made of aluminium. Their wall thickness was $3mm$, $4mm$ and $5mm$ weighing $752g$, $1000g$ and $1330g$, respectively. Pistons were selected depending upon the shock wave Mach numbers to realize. It was well understood that the very quick start of the pistons might not be a problem but it is hard to decelerate it in a short time and to stop it without creating any serious impact damage. For this purpose the mechanism to recover the piston gently became rather complex. At the place where it impact a block of alpha gel sheet was placed which would absorb the initial impact energy. The alpha gel sheet was attached on a steal block that is approximately ten times as heavy as the piston. The steal block is also allowed to move within a 50mm distance. In this way the impact on both piston and the body of shock tube was greatly attenuated. The piston and the steal block can return to initial state by the gravity force for next experiment.

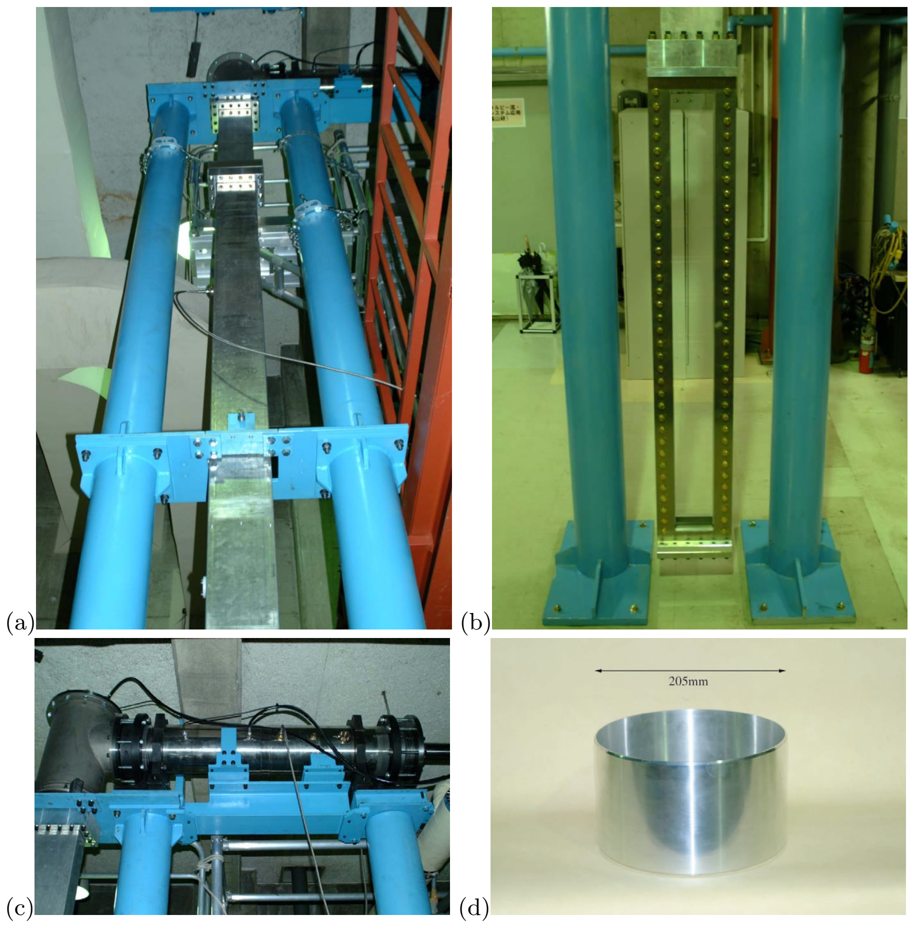
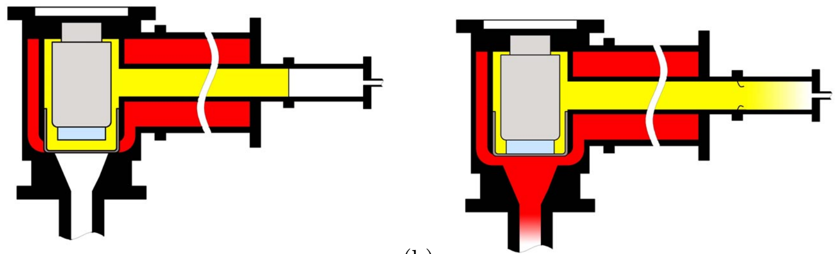


Fig. 2. 60mm × 150mm vertical diaphragmless shock tube: (a) low pressure channel; (b) test section; (c) high pressure chamber and (d) piston



(a) (b)

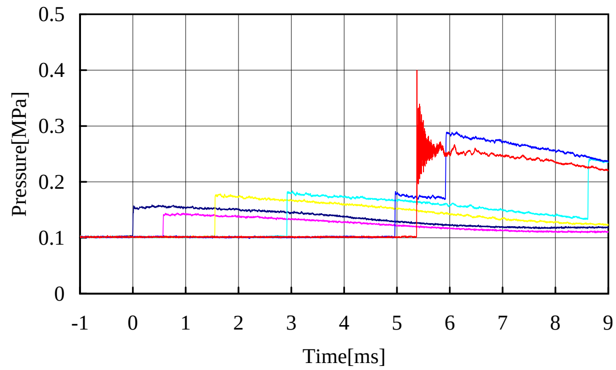
Fig. 3. Opening mechanism between high and low pressure sections: (a) Closed state, the U-shaped piston pressed by an auxiliary high-pressure section separates two sections; (b) Opening process, after a quick release of pressure in the auxiliary section the piston is lifted up by gas in the high pressure chamber and opens a channel between low and high pressure sections.

The quick release of high pressure gas in the auxiliary section was realized by rupturing a diaphragm that lies between the auxiliary section and the leak section as sketched in Fig. 3. This method has been adopted since the first diaphragmless tube was developed in the Shock Wave Research Center. In this work we tried to replace the diaphragm by an electronic valve. The electric solnoid valve had an inner diameter of two inches and its working time was about $20ms$. This working time duration was too long to obtain well shaped shock waves. Pressure histories obtained by individual pressure transducers in Fig. 1 show are sharper pressire rise is obtained when using diaphragm rupturing system using a diaphragm solenoid as shown in Fig. 4.

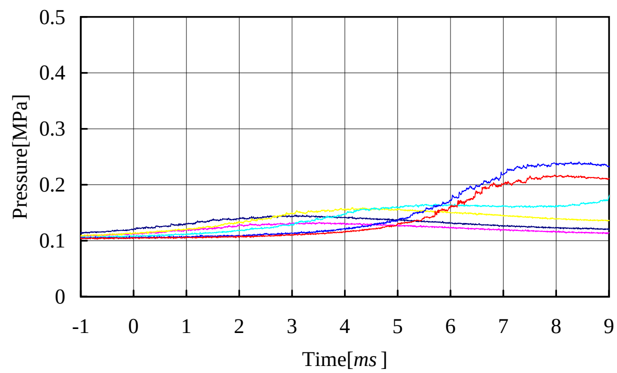
This observation confirms that the pressure in the auxiliary section should be released as quickly as we can in order to obtain a well shaped shock wave with a short formation distance in the low-pressure channel.

4 Flow visualization

In order to cover the wider view field we have equipped a pair of schlieren mirrors having $1m$ dia. and $8m$ focal length. Figure Fig. 5 shows one of the schlieren mirrors, which was mounted on the steel frame which could adjust vertical displacement and frontal inclination of the mirror. The mount was placed on a bench that was an air lifter. Supplied 50 kPa of gauge pressure air, it was lifted by $0.05mm$ from a polished steel plate and then it could be moved slowly even by one finger, which enabled the precise positioning of the mirrors. The mirror had $150mm$ thick honeycomb structure and was only 150 kg in weight. It is planned to apply these mirrors to the long test section with combination of double exposure holographic interferometry.



(a)



(b)

Fig. 4. Shock formation, (a) pressure histories using a plastic diaphragm; and (b) pressure histories using an electronic valve.

5 Future works

A relatively large vertical diaphragmless shock tube has been constructed, and shock waves were successfully created in the low-pressure channel with a limited length. However, flow conditions behind the shock waves have not been checked, and the test time of the shock tube is not clear yet. More experiments are still needed to find optimum operation conditions, for example the pressure in the auxiliary section.

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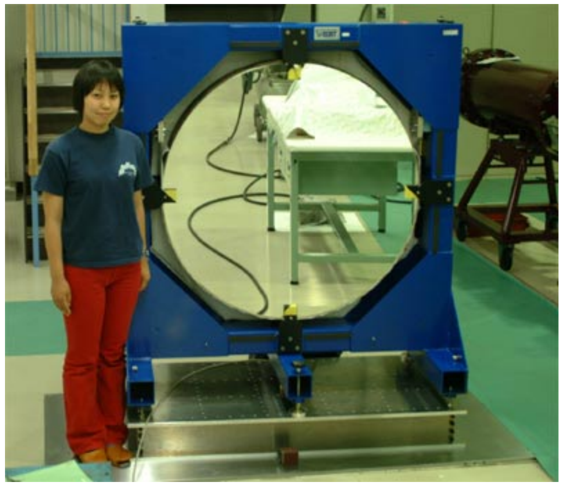

Fig. 5. A schlieren mirror with $1m$ in dia. and $8m$ in focal length

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