Development of Shock Diffuser for Pulse Detonation Turbine Engines

K. Yoshinaga[1], T. Ofuka[1], A. Ochi[1], T. Yatsufusa[1], T. Endo[1], S. Taki[1],
S. Aoki[2], and Y. Umeda[2]
[1]Hiroshima University, 1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8527, Japan
[2]Toho Gas Co., Ltd., 507-2 Shinpo-Machi, Tokai, Aichi 476-8501, Japan

Corresponding author, K. Yoshinaga: tolucky@hiroshima-u.ac.jp

Introduction

The pulse detonation engine (PDE) is attractive not only for propulsion applications but also for power generation on the ground because of its high theoretical thermal efficiency (Endo 2004). The pulse detonation turbine engine (PDTE) is a PDE which drives a gas turbine for power generation as shown in Fig. 1. An important issue in the development of the PDTE is the interface between the combustor and the turbine. For high turbine efficiency and safety, the pressure at the turbine inlet should be smoothed in time enough. In the case of the PDTE, shock waves are necessarily disgorged from the combustor. Therefore, these shock waves should be smoothed before the turbine inlet. In this paper, we describe the newly-developed shock diffuser, which deforms a strong shock wave into a series of weaker shock waves.

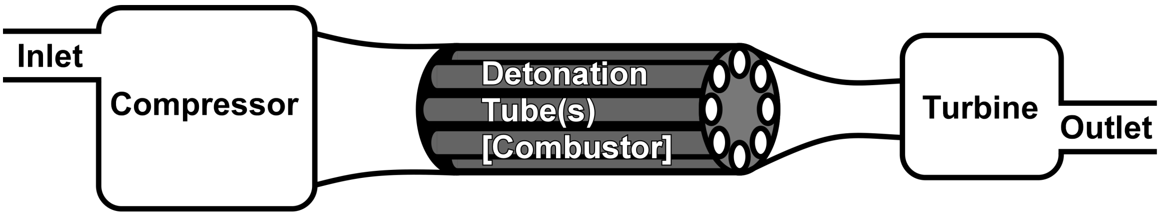

Fig. 1 Conceptual PDTE system.

Principle of the Shock Diffuser

In ordinary gases, the sound speed becomes higher when the pressure becomes higher. Accordingly, a compression wave, the wave front of which is a gradual pressure increase, becomes deformed into a shock wave, the wave front of which is a sharp pressure increase, as it propagates one-dimensionally. Therefore, some multi-dimensional effects should be utilized for the shock diffuser. Figure 2 schematically shows the principle of the shock diffuser. A strong shock wave in a duct is geometrically divided into several small-wave-front shock waves. After that, these small-wave-front shock waves are weakened by wave-front expansion (geometrical effect), and then, merged together with different phases in a duct. As a result, a strong shock wave is deformed into a series of weaker shock waves. It should be noted that this shock-diffusing effect is essentially temporary because of the nature of the sound speed described above.

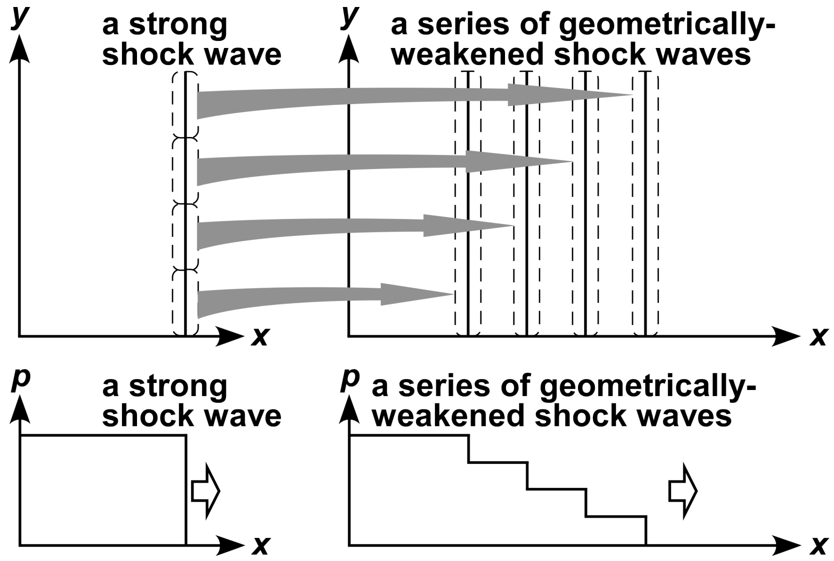

Fig. 2 The principle of the shock diffuser.

Experiments

Figure 3 shows the prototype of the shock diffuser we constructed. The shock diffuser is attached to the exit of a detonation tube. A strong shock wave is disgorged from the detonation tube into the diffuser tube. As the strong shock wave propagates in the diffuser tube, weaker shock waves seep through the “V” slit of the diffuser tube into the space between the diffuser tube and the confinement chamber, and propagate toward the outlet of the shock diffuser. The “V” slit of the diffuser tube is set in the shock diffuser as shown in Fig. 3. The surviving shock wave in the diffuser tube is finally reflected by the multi-step reflector. Each step of the multi-step reflector reflects the corresponding portion of the surviving shock wave. The reflected shock waves propagate toward the outlet of the shock diffuser.

In the experiments, the detonation tube was partially filled with the mixture of white gasoline and air. The remainder of the detonation tube and the inside of the shock diffuser were initially filled with air. In the experiments, the pressure histories at P2 and P3 shown in Fig. 3 were measured, where P2 was located in the air-filled portion.

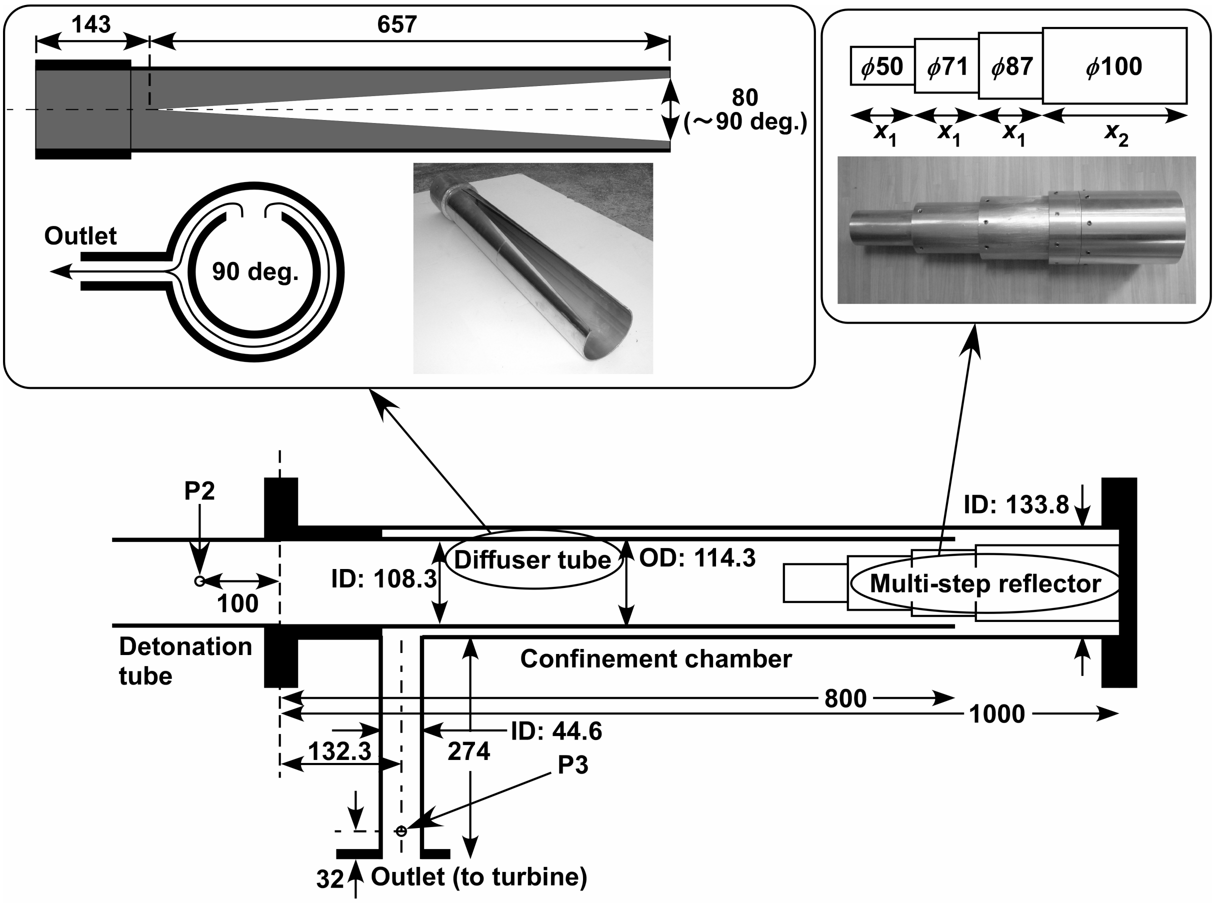

Fig. 3 The prototype of the shock diffuser.

Figure 4 shows representative pressure histories, where some of them were vertically shifted for the viewability. In Fig. 4, "P2_NT_NR" means the pressure history at P2 with no diffuser tube and no multi-step reflector, namely, when only the confinement chamber was used, and "P3_NT_NR" means the pressure history at P3 with no diffuser tube and no multi-step reflector. The difference between these two pressure histories shows the effects of the confinement chamber. In Fig. 4, "P3_T90_NR" means the pressure history at P3 with the diffuser tube set at 90 deg., as shown in Fig. 3, and no multi-step reflector, and "P3_T90_R90_260" means the pressure history at P3 with the diffuser tube set at 90 deg. and the multi-step reflector of x_1=90 mm and x_2=260 mm. The difference between the two pressure histories, "P3_NT_NR" and "P3_T90_NR", shows the effects of the diffuser tube. By means of the diffuser tube, the shock wave at about 1.6 ms on "P3_NT_NR" was diffused. However, the diffuser tube could not diffuse the shock wave at about 3.8 ms on "P3_T90_NR". The difference between the two pressure histories, "P3_T90_NR" and "P3_T90_R90_260", shows the effects of the multi-step reflector. By means of the multi-step reflector, the shock wave at about 3.8 ms on "P3_T90_NR" was diffused. Finally, the difference between the two pressure histories, "P2_NT_NR" and "P3_T90_R90_260", shows the effects of the entire shock diffuser, which were remarkable.

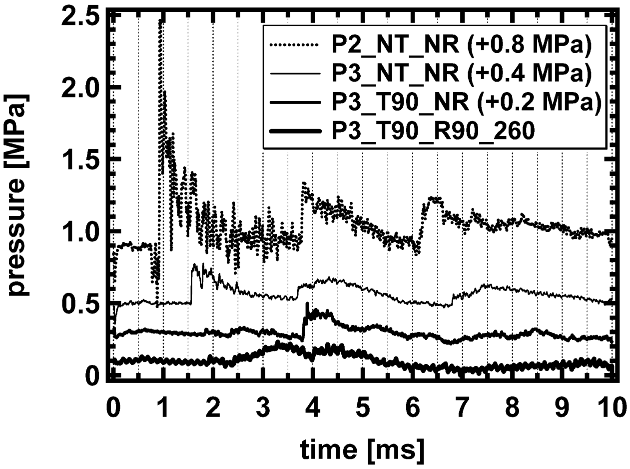

Fig. 4 Pressure histories.

Conclusions

For high-efficiency pulse detonation turbine engines, we developed the prototype of the shock diffuser, which is an important element of the interface between the combustor and the turbine. In order to investigate the effects of the shock diffuser, we carried out experiments where a detonation tube partially filled with the mixture of white gasoline and air was used. The experimental results clearly showed that the prototype of the shock diffuser was effective.

References

T. Endo, T. Yatsufusa, S. Taki, and J. Kasahara 2004 "Thermodynamic analysis of the performance of a pulse detonation turbine engine" Science and Technology of Energetic Materials 65 (4): 103-110 (in Japanese).