Passive Control of an Impulsive Wave Using a Cavity/Helical Vane System

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In many engineering practices, frequently an impulsive wave is a consequence of discharge of a shock wave from the exit of a tube, leading to an annoying noise like a sonic boom. The impulsive noise has often been a major factor to limit the performance of flow devices as well as to affect hazardous influences on human being. The current paper describes a new control method for the reduction of impulsive wave. An experiment using a simple shock tube was carried out to examine the effect of a cavity/helical vane system on the impulsive wave strength. The resulting impulsive wave was influenced by the detailed configuration of the helical vane inside the cavity which is located at the vicinity of the exit of a tube. The effect of the helical vane was compared with no helical vane tests to ensure validation of this kind of control strategy. The results showed that the strength of the impulsive wave could be significantly reduced by the current passive control using the cavity/helical vane system.

Keywords: unsteady flow, compressible internal flow, impulsive wave, shock wave, passive control, shock wave discharge.

INTRODUCTION

Unsteady compressible gas flow through a duct is often encountered in many engineering applications and has been investigated by many researchers. When a pressure wave generated inside a duct is discharged from an open end of the duct, an impulsive wave, which can be frequently characterized by high sound pressure level and short duration, forms at the vicinity of the exit of the duct. Inside the duct the pressure fluctuations occur due to successive reflections of the pressure waves from the exit and the entrance of the duct.

Discharge problem of a shock wave from an open end of a duct has been associated with a variety of
unsteady internal flow devices, for example, gun muzzles\cite{1}, diesel engine exhaust mufflers\cite{2}, dynamic pressure exchangers\cite{3}, pulse combustors\cite{4}, pulse jet filters\cite{5} etc. Very often the impulsive wave has been a major problem that restricts the performance of flow devices. Moreover it causes human being and structures to be faced with a serious noise as well. The characteristics of an impulsive wave resulting from a shock discharge should be understood to find an appropriate control strategy.

A similar impulse wave phenomenon\cite{6,7} can also be found in high-speed railway train/tunnel systems which are under development at many countries in recent years. When a high-speed train enters a tunnel, a compression wave is formed ahead of the train and propagates toward the exit of the tunnel. A part of the compression wave is reflected back from the exit of the tunnel as an expansion wave. A complex wave interaction occurs inside the tunnel due to successive reflections of the pressure waves at the exit and the entry to the tunnel.

A part of the compression wave is discharged from the exit of the tunnel and gives rise to an impulsive noise like a sonic boom. The impulsive noise was not an important issue in the past when the speed of the train was not high. But with the increase in the speed of trains in recent years, the impulse noise has become a serious environmental problem. It is thus highly requiring a proper reduction against the impulsive wave.

A great deal of research has devoted to linear acoustics of an infinitesimal amplitude wave, usually with negligible nonlinear effects and the wave directivity. Rudinger\cite{8,9} investigated the shock wave discharge and reflection phenomena from the exit of a tube. He pointed out that the shock wave does not perfectly reflect from an open end of a tube, and explained the wave phenomenon using an imaginary exit of the tube. Recently some reports have been made on the blast wave resulting from a strong shock discharged from a tube exit\cite{10,11}. However, the impulsive wave that can often be found in many engineering practices has a character of a typical weak shock wave below Mach number $M_{\infty} = 1.2$. In this case, the impulsive wave may not be explained by both the linear acoustics and blast wave theories.

With regard to the weak shock wave discharge problem, more recently the authors have carried out some experiments using an open ended shock tube and TVD numerical calculations\cite{12,13}. The impulsive wave generated by a weak shock discharge was characterized in terms of peak pressure, open-end correction, directivity, and attenuation with the propagating distance. It is, however, actually difficult for us to get a real noise level directly from an impulsive wave, because until now there has been no rule of thumb for an assessment of impulsive noise.

In general a noise level is associated with the amplitude as well as frequency component of the wave under consideration. It should, however, be noted that for a single impulsive wave, the peak pressure of impulsive wave would be a more important factor to do with an actual noise level\cite{14}. It is necessarily desirable that any control of the impulsive wave should be directed to reduce its peak pressure. To the authors' knowledge, no control strategy has yet been made for this kind of impulsive wave.

The objective of the current work is to develop a new control strategy for the impulsive wave. An experiment using a simple shock tube was carried out to examine the effect of a cavity/helical vane system that has on the impulsive wave strength. The resulting impulsive wave was influenced by the detailed configuration of the helical vane inside the cavity which is located at the vicinity of the exit of a tube. The effect of the helical vane was compared with no helical vane tests to ensure validation of this kind of control strategy. The results showed that the strength of the impulsive wave could be reduced by the current passive control using the cavity/helical vane system.

**EXPERIMENTAL FACILITY AND MEASUREMENT**

A simple open-ended shock tube has a diameter of $D$ and a total length of about 3.8 m (the length of driven section: 2.13 m, as shown in Fig.1). Some of the calibrated pressure transducers were mounted flush on the wall of the shock tube. A cellophane diaphragm of 0.03 mm thick, being manually ruptured, is used to separate the low-pressure section from the high-pressure section. A cavity having a dimension of length $L$ and height $H$ was installed at the exit of the shock tube. The resulting length of the driven section of the shock tube was somewhat varied depending on the length of the cavity. A helical vane was made of a steel plate of 0.6 mm thick having a twist angle of $\lambda$ and a pitch of $t_p$, and was set up inside the cavity and allowed the flow passage to be helical inside the cavity. The height of the helical vane was held constant so that the flow passage of no vane part outside the cavity coincided with that of the driven section of the shock tube.