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A method for radiation of a large-amplitude single shock pulse with sharp width into free space

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1. Introduction

It has been considered that use of an impulsive sound is useful in acoustic measurements because of its high resolution on time axis and rapidity and feasibility for the measurement. The sound source for this purpose, however, involves many problems to be solved. It should be required that the generated pulse is specified by a short wave length for improvement of resolution and high amplitude for improvement of signal-noise ratio, furthermore, a good reproducibility. A spark gap and an electro-magnetic induction type have been used as the sound source for generation of sound with a simple time-profile like as a single pulse of one period sinusoidal waveform, but these had a defect that the control of the waveform at the source is difficult. In this paper, we intend to describe a sound source utilizing actively the waveform distortion due to the non-linearity in air in order to radiate a sound pulse of sharp width with large amplitude into free space. It is confirmed that this sound pulse satisfies the necessary conditions described above.

2. Method

In the linear theory, the radiated waveform $p(r, t)$ obtained at the distance r on axis of a circular piston with a radius a mounted in infinite baffle is written as

$$p(r, t) = \rho c [u(t - r/c) - u(t - \sqrt{r^2 + a^2}/c)], \quad (1)$$

where $u(t)$ is the velocity waveform of a circular piston. The first term of the right hand side in Eq. (1) represents a plane wave from the surface of the piston and the second term represents the waveform from the circumference of the piston. The former has the same waveform as the latter except the inverse phase. Now, we use a single sound pulse with sinusoidal form for $u(t)$, and then we discuss the propagation behaviour of the single pulse in the radiated field. If the width of $u(t)$ is shorter than time difference between these two

Fig. 1 Schematic diagram of experimental apparatus.

terms in Eq. (1), they are separated each other, and keep the each amplitude constant. This appears in the near field of the source. On the other hand, the second term in the far field is superposed to the first term with time lag corresponding to the path difference between these two pulses, and the resultant waveform appears in the form of time differentiation of the $u(t)$,¹⁻³⁾ as the distance from the source increases. If we plan to realize an extremely sharp pulse with finite amplitude in free space, we would be able to utilize $u(t)$ including a sharp shock front in its time profile, because $u(t)$ is differentiated on axis in the far field, and therefore a sharp single pulse could appear. In order to realize this process, the following method is convenient for a practical application. A sound generator is composed of a driver unit located at the end of a straight pipe with a certain length and a horn also located at the other end of the pipe, as shown in Fig. 1. The diameter of the horn is not needed to be so large in this case. When the driver unit is driven by a sinusoidal signal of high amplitude, the finite amplitude pulse is generated in the pipe. Propagating through the pipe, the waveform is distorted due to the nonlinear effect in air and the shock front is formed at last. The length of the shock formation for various amplitude and width are shown in Fig. 6 in Ref. 4). If the generated wave has one period of the sinusoidal waveform with the negative first half period, one shock front is formed at the center of the waveform. As the thickness of the shock front is regarded as sufficiently thin, the peak level of the shock in free space must be kept almost the same level as the each pulse given in Eq. (1), if the time difference between two waves in Eq. (1) is longer than the time corresponding to the thickness of the shock front. Therefore, it is desired for generation of large amplitude shock with sharp width that the thickness

of the shock front in $u(t)$ is sufficiently thin. In practically, however, the height of the shock may decrease due to nonlinear absorption. Although, there is a problem whether Eq. (1) may be applied to the nonlinear phenomena described above or not, it may be expected that this process is able to obtain large amplitude sharp pulse with the higher efficiency than the direct radiation from the horn speaker without the nonlinear propagation through the pipe.

3. Results

Experimental apparatus is composed of a driver unit (JBL 2441), an exponential horn (JBL 2311) with the diameter of the mouth of 10 cm, and a circular pipe with the length of 2.2 m connecting between both the driver and the horn. When a sinusoidal electric signal with the width of 0.5 ms generated by a function oscillator was applied to the driver unit, the sound waveform shown in Fig. 2 was observed at the point of 20 cm apart the sound source, and the peak pressure of the wave was about 25 mbar in this case. Propagating through the distance of about 2 m in the pipe, the wave was distorted and became a shock wave as shown in Fig. 3. When this shock wave was radiated from the horn into free space, the waveform shown in Fig. 4

Fig. 2 Observed waveform in pipe at the distance of 20 cm from the source.

Fig. 3 Observed waveform in pipe at the distance of 220 cm from the source.

Fig. 4 Observed waveform in free field at the distance of 50 cm on-axis from the mouth of the horn.

Fig. 5 Frequency spectra of the waveforms of Fig. 2 (solid line), Fig. 3 (dashed line) and Fig. 4 (dotted line).

was observed by the microphone (B&K 4135) placed at the distance of 50 cm on axis from the mouth of the horn. This waveform radiated in free space has a sharp width of about $50 \mu\text{s}$ and a high peak pressure of about 5.5 mbar. However, the accuracy of these values may be not so exact because of the limitations of the frequency and the dynamic ranges of the microphone used in this experiment. The horn is not always necessary in this experiment though the reflection at the mouth is reduced more or less. Spectra of these waveforms shown above are given in Fig. 5. The spectrum of the wave radiated into free space is amplified around the high frequency range in comparison with the spectrum of the wave before propagation in the pipe. As the result, the method of the generation of an impulsive sound described above can be realized by a relatively simple equipment and is useful for acoustic measurements as the radiated wave has a smooth frequency spectrum in a broad frequency range.

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References

- 1) A. Nakamura and R. Takeuchi, "Generation of sound pulses with finite amplitude in free air," Jpn. J. Appl. Phys. **8**, 507-517 (1969).
- 2) A. Nakamura and R. Takeuchi, "Reflection and transmission of acoustic shock wave at a boundary," Acustica **26**, 42-50 (1972).
- 3) T. Otani and M. Takeda, "Acoustic farfield of short impulsive sounds radiated from baffled pistons," Jpn. J. Appl. Phys. **20**, Suppl. 20-3, 29-34 (1981).
- 4) T. Nakamura and A. Nakamura, "New method for generation of finite amplitude sound pulse by the use of loudspeaker," J. Acoust. Soc. Jpn. (E) **3**, 47-49 (1982).