Influence of Microphone Characteristics on Measurement of Near-field of Parametric Acoustic Array
近距離場のパラメトリック差音計測における マイクロホン特性の影響

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1. Introduction

Parametric loudspeakers, one of the airborne applications of parametric arrays [1], have a sharper directivity than conventional loudspeakers with the same aperture size. In recent years, parametric loudspeakers have also been considered for the application to personal use [2] and the realization of private sound spaces [3,4].

In developing parametric loudspeaker systems, we need to evaluate the reproduced sound field using theoretical prediction and measurement. Especially for personal use, it is necessary to evaluate the sound pressure in the near-field of ultrasonic emitters. However, the actual sound pressure of the demodulated signal (parametric sound) in the near field is low. Still, the measurement tends to overestimate the sound pressure compared to the theoretical prediction, so it is hard to evaluate it properly. This unexpected measured result is due to the pseudo sound caused by the acoustic radiation pressure acting on the diaphragm of a microphone placed in a modulated finite-amplitude sound field and the spuriousness caused by nonlinearities of the microphone element and the connected electronic circuit [5]. Although several acoustic filters have been proposed to prevent these undesired effects on measurements [6–9], these filters themselves disturb the sound field. Therefore, a quantitative evaluation of the spurious results is necessary.

In this study, we experimentally investigated the demodulated sound measurement of parametric loudspeakers in the near field. In particular, we discuss the influences of microphone characteristics and the placement, comparing the measured values with the theoretical ones.

2. Method

We used a hexagonal ultrasonic emitter, which was consisted of 127 closed-packed ultrasonic sensors with a diameter of 1 cm. The diameters of the circumscribed and inscribed circles of the hexagonal emitter were 13 cm and 11.2 cm, respectively. The emitter radiated single-sideband-modulated finite-amplitude ultrasounds of a carrier frequency of 40 kHz.

1/4- and 1/2-inch condenser microphones (GRAS, 40BF, and Brüel & Kjær, 4190) measured primary sounds and demodulated signal components. A microphone was placed at the incident angle of sound to the diaphragm θ_{inc}=0° and 90° (**Fig. 1**). We calibrated these microphones with a pistonphone before measurements, and the free-field correction considering diffraction by a microphone described later was performed.

The output signal of the microphone was sent to an oscilloscope through a preamplifier, and when we measured parametric sound, a low pass filter followed the preamplifier. The fast Fourier transform function of the oscilloscope extracted the primary frequency and the demodulated difference frequency components from the output signal of the microphone.

The sound pressure measured along the sound axis of the emitter was compared to the theoretical value. The theoretical values were obtained by numerically solving the Khokhlov-Zaboiotskaya-Kuznetsov equation [10].

3. Results and discussion

Figure 2 shows the measured and theoretical values of an experiment for radiated sound frequencies of 40 and 42 kHz. The measured and theoretical values are in good agreement for the primary sound components at 40 and 42 kHz. On the other hand, the measured sound pressure of the demodulated sound at 2 kHz is larger than the theoretical value. This tendency was more pronounced in the near field of the emitter. In particular, the differences are significant at 0.13 and 0.4 m, and the measured values at θ_{inc}=0° and 90° are about 30 dB and 10 dB larger than the theoretical values, respectively. In addition, the difference is small at 0.1 and 0.2 m. The region indicating the overestimation of parametric sound coincides with the peak position of the measured primary sounds. Therefore, the high amplitudes of primary sounds had a significant effect on the demodulated sound

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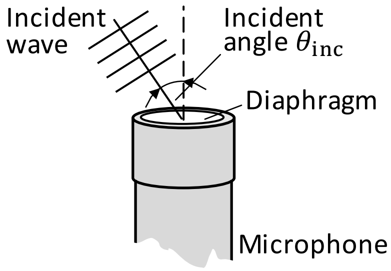

Fig. 1 Incident angle of sound wave to microphone diaphragm.

measurement.

Microphone size does not much affect the measured sound pressure at the difference frequency. Instead, the angle of incidence has a more significant effect. For example, at 0.4 m, the measured sound pressure at θ_{inc} =0° is about 20 dB larger than that at 90°. The nonlinear response of a microphone may cause this increase. A microphone placed in a sound field disturbs the original sound field by reflection and diffraction from the microphone. This phenomenon adds the diffracted sound pressure amplitude P_{diff} to the free-field pressure amplitude P_{free}, and the sound pressure amplitude $P_{\mathrm{free}}+P_{\mathrm{diff}}$ contributes to the microphone. Depending on the wavelength and the microphone size, this effect is generally more prominent at the normal incident of θ_{inc}=0°. For example, for a sound of 40 kHz, the 1/4-inch microphone used in this study gives $D=|(P_{\mathrm{free}}+P_{\mathrm{diff}})/P_{\mathrm{free}}|$ =4.06 (12.18 dB) at θ_{inc}=0° and D=1.15 (1.22 dB) at 90°. This increased sound pressure increases the nonlinear effect of the microphone and receiver system, resulting in the generation of spuriousness in observed signals.

Another factor that causes the parametric sound measurement to show a considerable value is pseudo sound generated by the acoustic radiation pressure acting on the microphone. We estimate this value at a distance of 0.4 m. The diffraction-corrected free-field sound pressure of the primary sounds at 40 and 42 kHz are approximately 133.6 dB (97.7 Pa) for both. The radiation pressure component acting on the microphone at θ_{inc}=0° is 76.6 dB (0.67 Pa) by taking the primary sound pressure and the correction for diffraction into account. The value for 90° incidence at which incident parallel to the microphone diaphragm may be smaller than that for 0°. Since this value is sufficiently small compared to the measured values, the radiation pressure is considered to be negligible in this measurement.

4. Conclusion

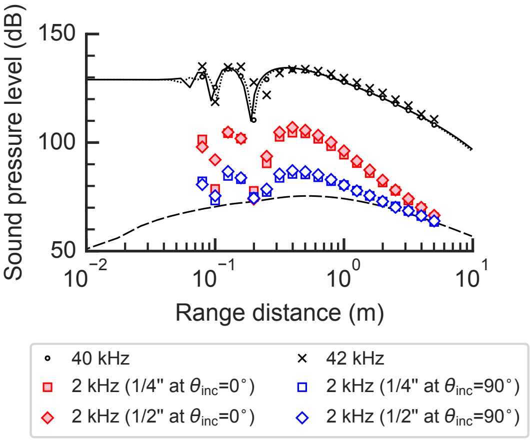

Fig. 2 Measured and theoretically predicted sound fields. Symbols indicate measured values. Solid, dotted, and dashed lines indicate primary sounds at 40 and 42 kHz and demodulated sounds at 2 kHz.

This study compared the measured values with the theoretical ones for demodulated parametric sound in the near field of ultrasound emitter to consider the accurate estimation of a parametric loudspeaker. The experiment evaluated the demodulated signal with a larger amplitude than the theory. Rather than the microphone's size, the sound incident angle to the microphone significantly affected the measurement. The normal incident to the microphone significantly increased measured sound pressure in the near field.

The nonlinear effect of a receiving microphone may cause this effect. If the nonlinearity of a microphone is obtained in prior, it will be possible to correct this discrepancy.

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