Raman-Nath Diffraction Caused at the Focal Point of a Concave Type Transducer

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Abstract: To estimate the intensity of the sound pressure at the focal point of a concave type transducer, Raman-Nath diffraction is theoretically and experimentally discussed. Sound field including the acoustic nonlinearity is calculated by using KZK equation. Light intensity of various orders are also calculated as a function of the sound pressure. The light intensity is measured by changing the driving voltage of the transducer. Good agreements are obtained between the experimentally measured values and theoretically calculated ones.

INTRODUCTION

It is well known that the high intensity of the sound pressure can be measured by using Raman-Nath diffraction. However, there are few reports which discuss the diffraction caused at the focal point of the focused sound beam. In this report the sound pressure at the focal point is calculated by using KZK equation, and Raman-Nath theory is also applied to calculate the light intensity as a function of the sound pressure. The experiments using the concave type transducer are carried out and the observed results are compared with the theoretical ones.

THEORY

Raman-Nath theory can be applied to the focusing sound field, when the phase modulation of light passing through the ultrasonic field including the effects of nonlinearity and diffraction is estimated. The sound field near the focal point, however, can be calculated by KZK equation which includes the effects of nonlinearity, diffraction, and absorption [1]. Therefore, the effect of Raman-Nath diffraction at the focal point is also calculated.

The Raman-Nath parameter \( v \) [2], the change of the phase of light, is expressed as

\[
v = \frac{2 \alpha \delta \cdot A}{\lambda}, \quad \delta = \frac{\left( n_0 - 1 \right) \left( n_0 - 1.3 \right) \left( 1.3 n_0 + 0.4 \right)}{\left( n_0 + 0.8 n_0 + 1 \right) \rho} p
\]

where the second equation shows the Eikman's formula which express the relationship between the sound pressure \( p \) and the change of the index of refraction \( \delta \), \( n_0 \) is the index of refraction of the media, \( L \) is the length of the light path through the sound beam, \( \lambda \) is the wavelength of the light.

The light intensity of the \( k \)th order is calculated by

\[
I_k = \sum_{m=1}^{\infty} J_{2m-1} \left( \frac{2 \alpha \delta \cdot A}{\lambda} \right) \cdot \exp \left( m \phi + n \phi_0 + \frac{1}{2} \right)
\]

where \( A \) is the ratio of the sound pressure of the \( k \)th harmonic to the fundamental and \( \phi \) is the phase of the \( k \)th harmonic. The diffraction to the forward direction along the sound axis is defined as the positive order. The calculated results of light intensity of the fundamental and 1st orders are shown in Fig.1.

FIGURE 1. Relationship between calculated light intensity and sound pressure as a function of diffraction orders.
EXPERIMENTS

The experimental arrangement is shown in Fig. 2. The transducer whose radius is 15mm, and focal length is 100mm is used at a frequency of 4.4MHz. The He-Ne laser whose beam spot diameter is 1.0mm is supplied as a light source. The light intensity of the various orders are measured by changing the driving voltage of the transducer. The measured values are shown in Fig. 3. It is found that the measured values show good agreements with the calculated ones for the focused sound beam. For example, the calculated and observed ratio of the first maximum value of the +1st order to the fundamental are 0.47 and 0.45 respectively. However, the calculated value for the plane wave is 0.52. By comparing the experimental results with the calculated ones, the sound pressure at the focal point is estimated using the results of Fig. 1 and Fig. 3. The sound pressure at the focal point is also measured by the PVDF hydrophone whose diameter is 1.0mm. Figure 4 shows the relationship between the sound pressure at the focal point and the driving voltage. In this figure, the solid line shows the results observed by the hydrophone. The sound pressure measured by the light increases linearly with the increase of the driving voltage of the transducer under 1.0MPa, and show good agreements with the one measured by the hydrophone. The sound pressure can be estimated up to about 2MPa by using the light, although the hydrophone can’t be used under such a high pressure.

CONCLUSIONS

The Raman-Nath diffraction caused at the focal point is theoretically and experimentally discussed. Good agreements are obtained between the experimentally measured values and theoretically calculated ones. The sound pressure at the focal point is also estimated by the light measurements. Similar results are obtained between the values measured by the light and the hydrophone in the low pressure region. On the other hand, in the region of strong sound pressure, the hydrophone measurement cannot be applied because of the mechanical destruction. However, it is shown that the sound pressure up to 2MPa can be measured by using Raman-Nath diffraction.

REFERENCES