Estimation for vibration mode of membrane by NAH method

Nabilah Ibrahim, Hideo Shibayama and Toru Itakura

Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, 135-8548 Tokyo, Japan
m107068@sic.shibaura-it.ac.jp

Near Field Acoustic Holography (NAH) is the method of measuring sound information on the radiant surface in the near field as a hologram. By use the technique, we can visualize the vibration of the radiant surface. Thus, we can easily understand the object of the acoustic conditions in acoustic image processing. We made the measurements on one side of the drum using an array microphone while the driven source is attached to the other side. In measurements, the array microphone is scanned in parallel with the membrane. Merit of this measurement is not touched on the vibrating membrane surface. This paper describes the estimated results of the vibration mode on the vibration membrane of the drum. And we can apply it to the vibration-controlling field for detecting the sound structure on the membrane.

1. Introduction

NAH is capable of completely describing the acoustic field generated by a structure. However, its limitations with respect to the frequency area that brings the meaning of natural frequency. Natural frequencies are the frequencies that belong to the object when it is tend to vibrate. Using the selected natural frequencies of the membrane, the natural vibration mode on the vibration membrane of the drum is estimated. This natural frequency is estimated by the natural acoustic spectrum method. Four difference acoustic conditions had been measured to the drum. We carried out 2 different sound pressure measures for space between the array microphone and the membrane surface to visualize the differences for the vibrating membrane related to the space. And all these measurements have been done in an anechoic chamber.

The goal of this paper is to understand the object of the acoustic conditions as applied to an engineering structure. In the following sections, the basic theory and measurement process of this technique are discussed. Then, the results of the experiments and application of this technique are summarized.

2. Near-field Acoustic Holography

2.1 Theory

Sound pressure in the domain where the evanescent wave exists in near-field acoustic field is expressed.

$$p(k_x, k_y, k_z) = Ae^{-k'_z z} e^{i(k_x x + k_y y)}$$

• (1)

Here, kx, ky, kz are the x, y, z direction of wave number. And, A is constant and independent to the frequency. Satisfied that evanescent waves, under the condition that is travel in z direction, causing the waves continuing damping. And the exponential function in z direction becomes 1. As a result, the sound pressure is only in two-dimensional plane function. And, in this domain of complex amplitude, function of x and y can be written as $P(k_x, k_y)$. Sound pressure around the membrane is expressed

$$p(x,y) = \frac{1}{4\pi^2}\int_{-\infty}^{\infty} dk_x \int_{-\infty}^{\infty} dk_y P(k_x, k_y) e^{i(k_x x + k_y y)}$$

• (2)

2.2 Measurement

Fig 1 Array microphone and side of Drum

Considered here, we are set the frequency for below than 10kHz. Based on the calculation that the space between each microphone of the array microphone is less than the half wavelength, we structured the array microphone with 13 electrets microphones. The space between each microphone is setting 1.5cm. During the measurement, the array microphone is moved on a step-motor for every 1.5cm and the sound pressure is measured.

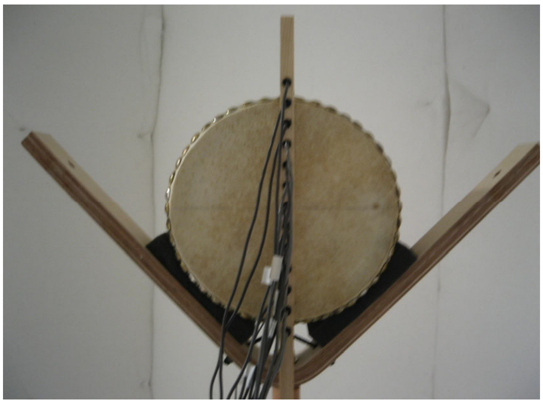


Fig 2 Front of Drum

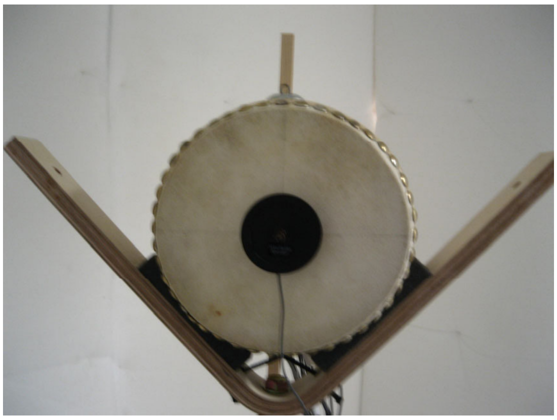


Fig 3 Rear of Drum

Figures 1, 2 and 3 show the side, front and rear pictures of drum that have been setting along with array microphone. The membrane is in circle shape and its diameter is 16cm. The acoustical measured side is set on the other side for the driving surface. And the membrane is in parallel direction that the observation point is (x,y,z) coordinated. An origin is set the center of the membrane surface of the drum. The measurement distances between the drum and the array microphone are 0.1cm and 0.2 cm. The height of the drum and array microphone is 98cm on floor where the floor is fully covered with absorbs material and this experiment took place in anechoic chamber.

By applying the resonance and solid body transform, the driven source is transfer by TSP signal for the duration of 40msec .And sampling frequency is 20 kHz.

Table 1 Processing Condition

Sampling frequency	20[kHz]
Number of addition averages	11Times
Point number of FFT	16384[Point]
Measurement time	22seconds

2.3 Results
Selection of Natural Frequencies

To select the frequency range to obtain the holography figure, a few of acoustic spectrum of a drum have to be analyzed to produce the natural frequency. In this experiment, four conditions of acoustic spectrum had been estimated. First, we took the condition when the membrane is droved from rear and front sides with a shaker. Then, also took the condition when the membrane is hit from rear and front sides without shaker by a stick.

Below are the listings results of the four conditions of the acoustic spectrum.

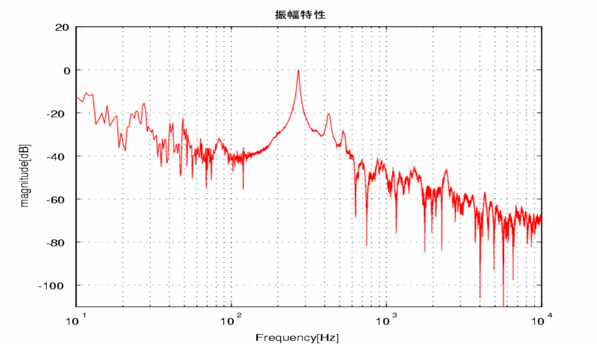


Fig 4 Acoustic Spectrum at back hit

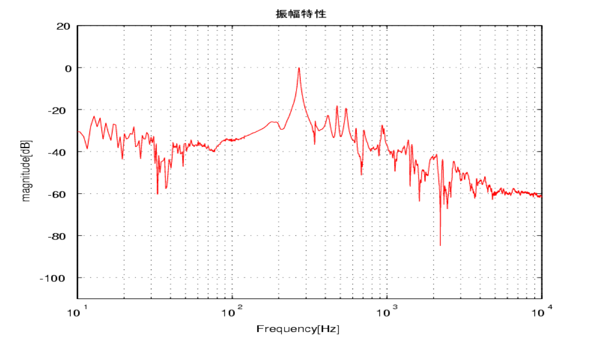


Fig 5 Acoustic Spectrum at front hit

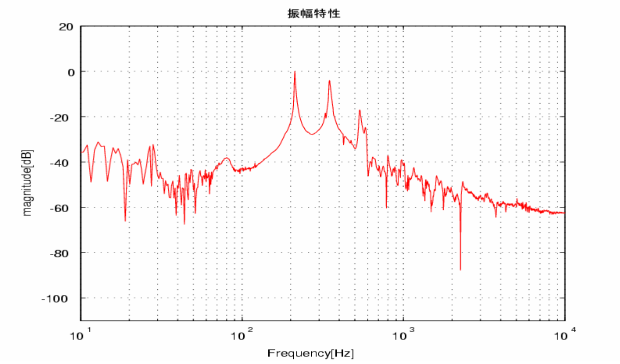


Fig 6 Acoustic Spectrum at back hit and without shaker

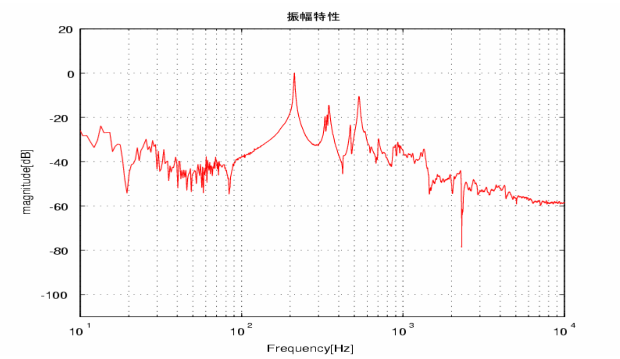


Fig 7 Acoustic Spectrum at surface hit and without shaker

Acoustic Spectrum

Estimation for the natural frequencies of vibrating membrane from 4 spectrum results above is shown in Fig. 8, and this is the brief conclusion of natural frequency of the membrane drum. The centerline is the mean of each peak frequency. We choose the mean frequencies as natural frequency of the vibration membrane of drum.

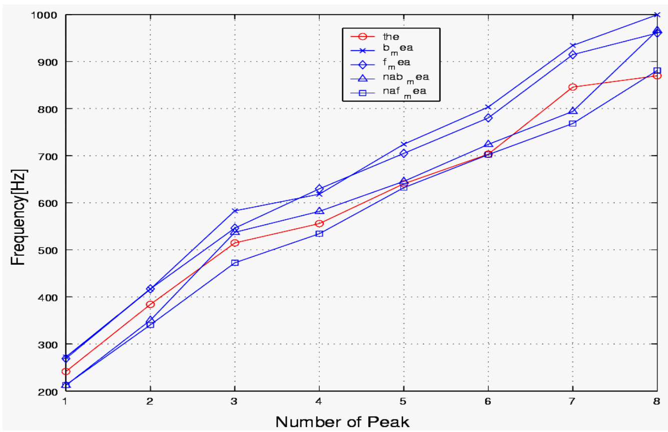


Fig. 8 Natural Frequency of Membrane

Table 2 shows the natural frequencies that we had chose from the mean of each frequency in satisfying the acoustic spectrums. And we applied them into holography process. From acoustic measurement results, the higher frequency to the fundamental frequency ratio is 1:1.53:2.14:2.27:2.66:2.95:3.43:3.67. And, in calculation results, the higher frequency to the fundamental frequency ratio for membrane is 1:1.59:2.13:2.30:2.65:2.91:3.50:3.60.

From the comparison between these ratios, it is a good agreement with the measurement and calculation results. Satisfy these frequencies, holography figures are shown.

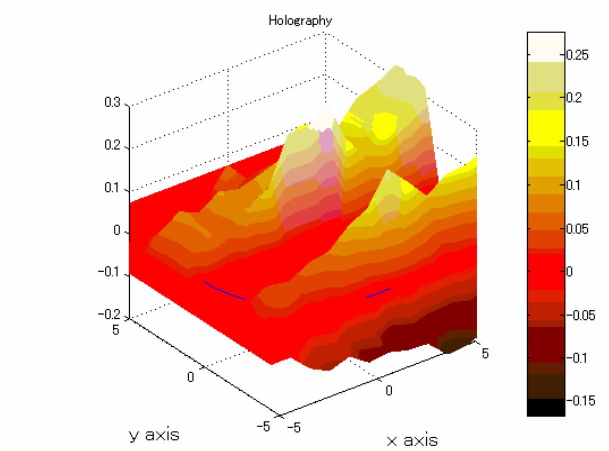
Table 2 Natural frequency of Membrane

Ratio	Freq	Mode
1	272.3	(0,1)
1.3	354.8	–
1.53	416.9	(1,1)
1.97	537	–
2.14	582.1	(2,1)
2.27	616.6	(0,2)
2.57	699.8	–
2.66	724.4	(3,1)
2.95	803.5	(1,2)
3.24	881	–
3.43	933.3	(2,2)
3.67	1000	(0,3)

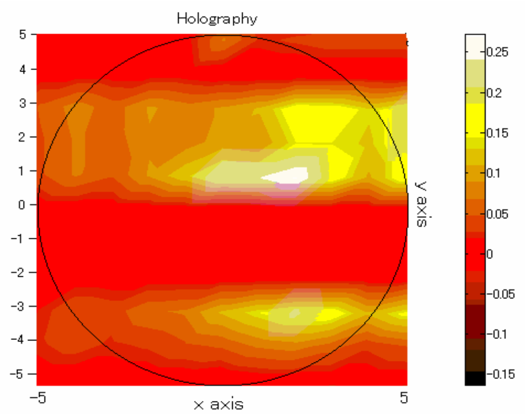
Holography at Selected Frequency

In this section, we show the holography figures at the natural frequency of membrane according to the measurement condition. These results are holography results at the distance of 0.2cm between drum and array microphone. The circle line means the drum size that used during the measurement. For easy understanding, for each reconstruction figure mode, we produced 4 types of figures that are; (a) 3-Dimensions image (b) image from above measurement (c) image from x-axis of measurement and (d) image from y-axis of measurement.

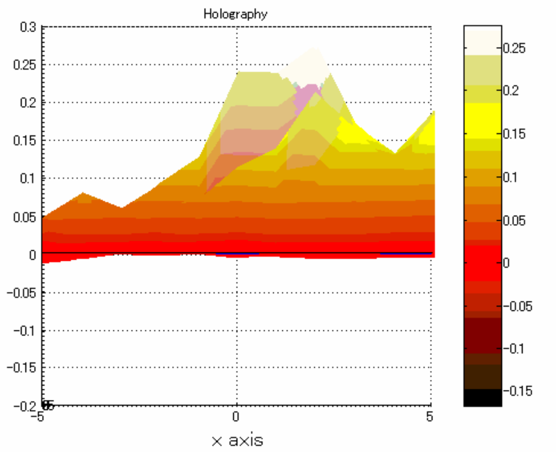
Holography results at the Distance of 0.2cm



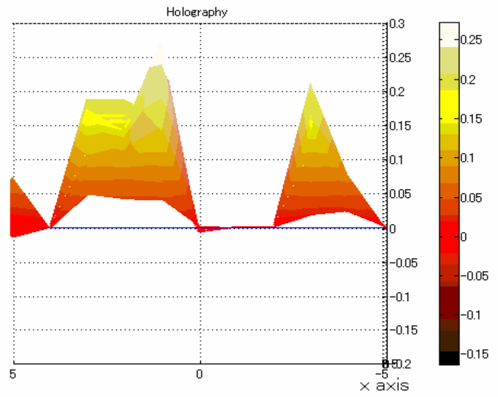
(a) 3-Dimensions image



(b) Image from above measurement

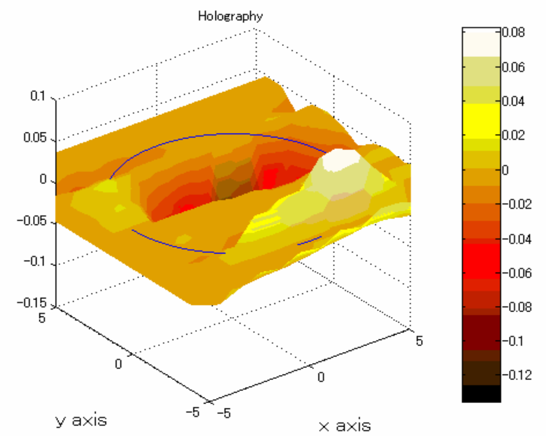


(c) Image from x-axis of measurement

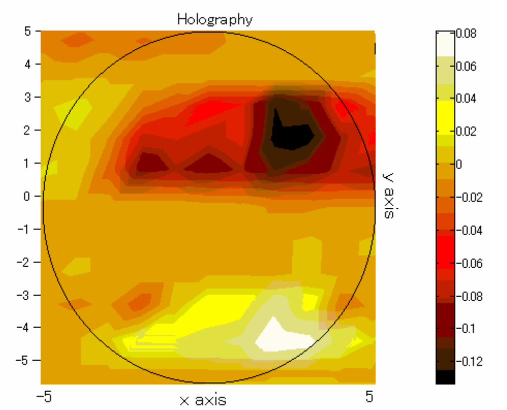


(d) Image from y-axis of measurement

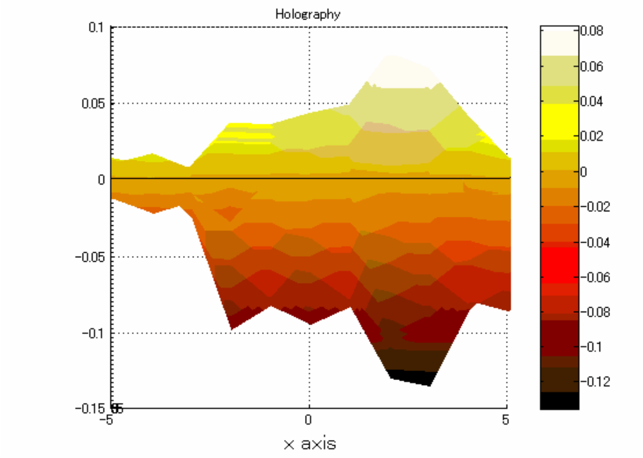
Fig 9 Mode (0, 1) at 268Hz



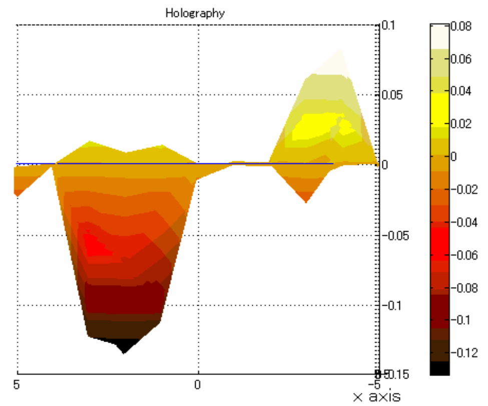
(a) 3-Dimensions image



(b) Image from above measurement



(c) Image from x-axis of measurement

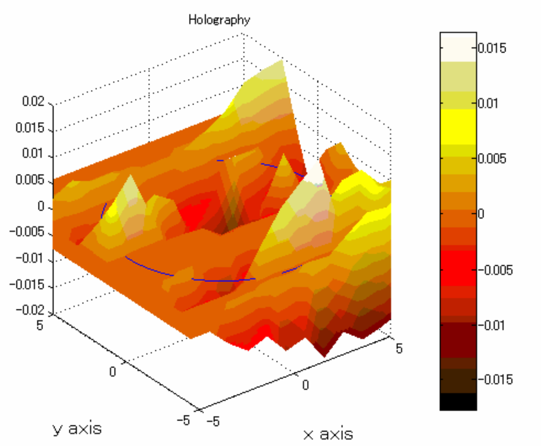


(d) Image from y-axis of measurement

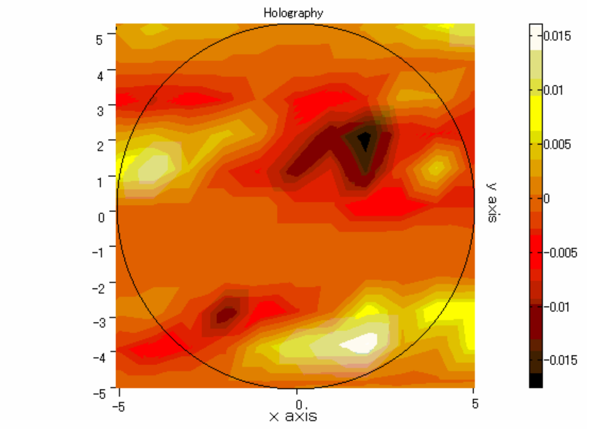
<u>Fig 10 Mode (1, 1) at 593Hz</u>

Figures 9 and 10 show the vibration mode of drum at 268Hz and 593Hz. At 268Hz, the vibration mode (0, 1) is produced. And same phase is reconstructed at measurement plane. At 593Hz, the vibration mode (1, 1) is produced. Here, the symmetry at y-axis is clearly visualized where the figures are rightly divided into 2 phase that are plus and minus area. We also can state that there are one high peak and one low peak at this vibration mode.

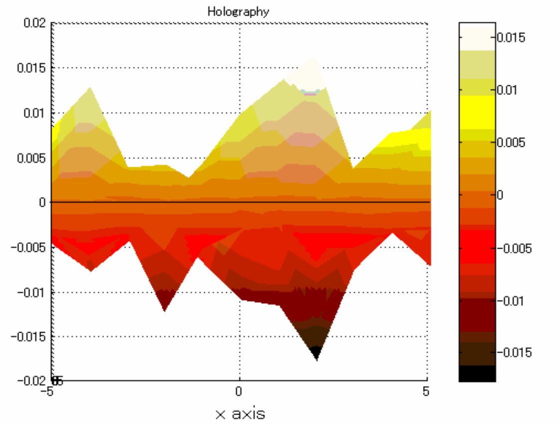
Figures 11 and 12 show the vibration mode of drum at 884Hz and 931Hz. At 884Hz, the vibration mode (2, 1) is produced. This vibration mode shows 2 high peaks and 2 low peaks. At 931Hz, the vibration mode (0, 2) is produced. At this frequency, high peaks surround the low peak in the center of the measurement object.



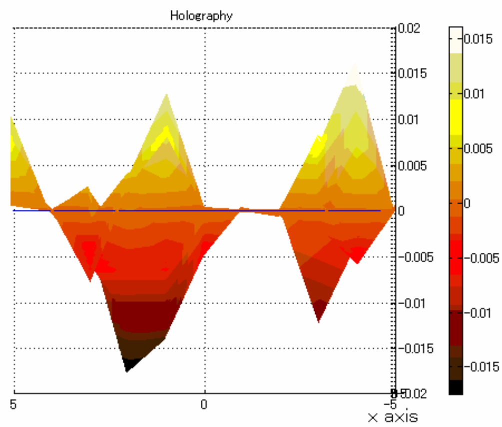
(a) 3-Dimensions image



(b) Image from above measurement

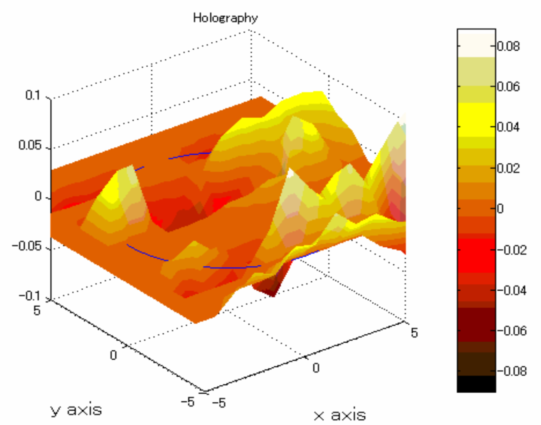


(c) Image from x-axis of measurement

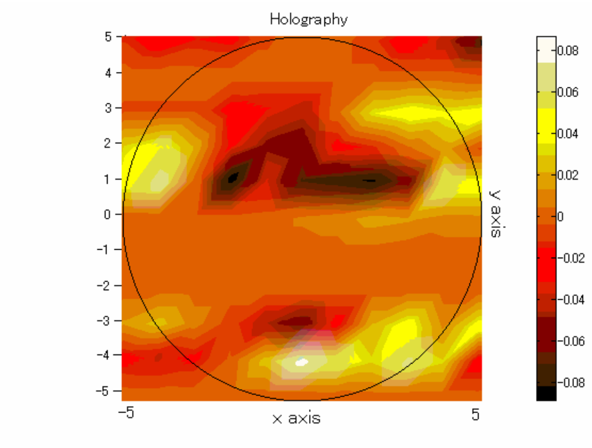


(d) Image from y-axis of measurement

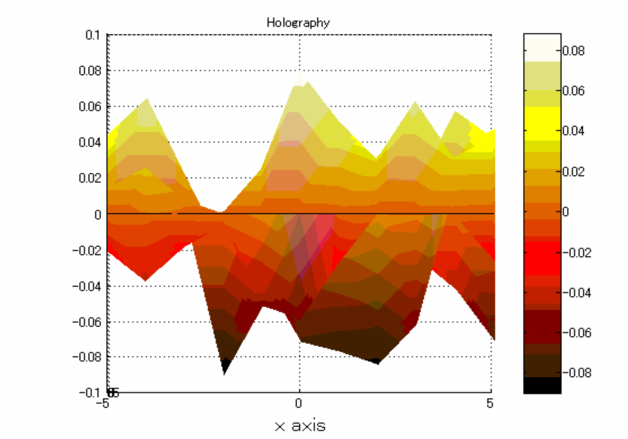
<u>Fig11 Mode (2, 1) at 884Hz</u>



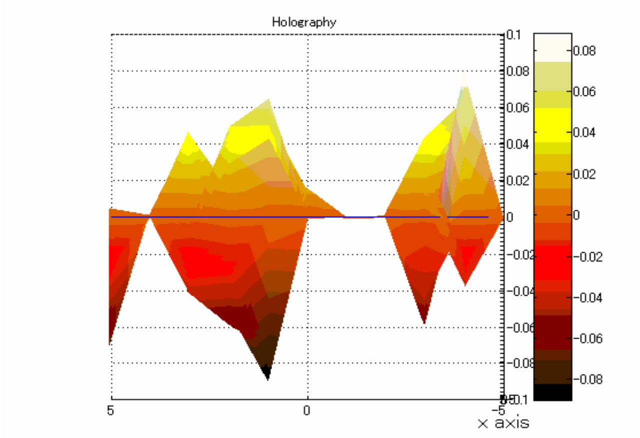
(a) 3-Dimensions image



(b) Image from above measurement



(c) Image from x-axis of measurement



(d) Image from y-axis of measurement

Fig12 Mode (0, 2) at 931Hz

2.4 Discussion

From the holography figures at natural frequencies above, 4 figures of vibration mode of membrane are produced.

And Table 3 shows the conclusion of frequencies that match to the holography condition and the vibration modes.

Table 3 Natural frequency of Membrane that match to holography condition

Freq	Mode
268	(0,1)
593	(1,1)
884	(2,1)
931	(0,2)

From Table 3, at 268Hz, vibration mode (0, 1) is produced. And at 593Hz, vibration mode (1, 1) is produced. At 884Hz, vibration mode (2, 1) is produced. And at 931Hz, vibration mode (0, 2) is produced. All these vibration modes are produced at the measurement distance of 0.2cm, respectively.

3. Summary

We had calculated the vibration figuration of membrane by no-touch to drum using Near-field Acoustic Holography method. Natural frequency on vibration surface was calculated from the acoustic spectrum, since there are similarly to the natural frequency of membrane. We also summarize the mode of vibration figurations are good agreement with the mode of membrane. From the space between the drum and array microphone, each space of vibration mode on selected natural frequency also has been estimated. Here, the space of 0.2cm showed the best result or good agreement to the mode of membrane. This also means that in the distance of 0.2 cm, the evanescent wave exists through the domain of near-field acoustic field. Moreover, for the distance other than 0.2 cm, the vibration modes also produced.

From this conclusion, the applications of this technique are clearly understood in vibration controlling or acoustic controlling industries. Even though this technique is not new, but this paper result had once again proved that this technique is useful in certain industries stated above.

From now on, we make the progress to produce the vibration intensity using the same measurement object at these natural frequencies. The goal is to observe the power and the direction of vibration membrane and then make the comparison to the holography figure of the vibration mode.

References

[1] E.G Williams (Translated by S.Yoshikawa) • Sound Radiation and Nearfield Acoustical Holography• 1998.

[2] K.Kido •Acoustic Engineering (音響工学)•、Corona Publishing Co. Ltd, Showa 57 (昭和 57).

[3] N.Maasaki K.Inomoto •Vibration Analysis of Japanese Drum (和太鼓の振動分析)•、電子情報通信学会 1999.

[4] N.Takai, •Matlab Introduction (Matlab 入門)• 2002.

[5] K.Kido •Digital Fourier Analysis (ディジタルフーリエ解析)•, Corona Publishing Co. Ltd, 2007.

[6] Richard W.Bono and David L.Brown, Susan M.Dumbacher, •Comparison of Nearfield Acoustic Holography and Dual Microphone Intensity Measurements• The Modal Shop, Inc. University of Cincinnati, SDRL.

[7] H. Kawai, Y. Koike, K. Nakamura_ and S. Ueha •An estimation of vibration intensity from the measured vibration locus at one point• , Acoust. Sci. & Tech. 23, 5 (2002).