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EXPERIMENTAL STUDY ON EFFECT OF VIBRATION CAUSED IN AUDIO EQUIPMENTS TO SOUND QUALITY AND SUMMING LOCALIZATION

Kiminobu Nishimura*[1], and Ryuhkei Ina[2]

[1]School of Engineering, Kinki University
1 Takaya Umenobe, Higashi-Hiroshima City, 739-2116 Japan
[2]KRYPTON Co, Ltd.
1156-1 Kanemori, Machida, 194-0012 Japan
nisimura@hiro.kindai.ac.jp (e-mail address of lead author)

Abstract
Acoustic phantom and sound quality of reproduced sound of stereophonic equipment suffer from effects of vibration on equipments, signal and power cables, a jitter of digital audio system and *etc*. Several kinds of vibration occurred in stereophonic equipments will cause deterioration of high order acoustic and sensational information. In this report, we propose a new method on treatment of vibration in stereophonic equipments to suppress higher harmonics of vibration and electric and/or acoustic signals. The effects of suppression of harmonics have checked up and compared with changes of the source images and sound quality by listening test.

INTRODUCTION

Recently, according to progressive development of digital signal processing techniques, like multi-channel signal, multi-bit data, higher sampling rate etc., it leads to huge information of acoustic signal. These techniques realize the feeling of being at a live performance with moving phantoms of summing localization by linking up with pictures or movies. Furthermore, they promoted miniaturize, lightweight and low price of acoustic representation system, and as a result, these equipments are in common use. But, as most of the above phantoms are recognized under the influence of pictures, the realization of the sense of distance and/or direction is open to question without pictures.

Acoustic phantoms and sound quality of reproduced sound of stereophonic equipment suffer from effects of the equipments, signal and power transmission cables, a jitter of digital audio system and *etc*. [1],[2],[3]. Then, the high order acoustic and sensational information like the distribution of acoustic sources and circumstances of recording place may deteriorate due to the above distortion factors [4]. Generally, various methods are proposed to improve the sound quality from various viewpoints, but it seems prejudiced about individual favorite sound after repeating trial and error because of unknown detail relationship between physical feature of equipments and human recognition of acoustic phantom or sound quality. So, it seems too difficult to make sure which method is proper or not.

At the recording site of acoustic signal, since the above spatial information is also recorded together with main acoustic signal through microphones in a very tiny level, the background noise and harmonic distortion generated in a stereophonic equipment and other originated noises cover that spatial information and make them blurred one at reproduce of stereophonic signal.

On the other hand, the sense of hearing of human can recognize source locations and their kinds [5]. The ability of acoustic phantom recognition is advanced one, which seems difficult to realize easily by using measuring system and signal processing technology. Because, the sense of hearing of human to recognize an acoustic source location and its identification seems due to minute difference of acoustic signal buried under electric noise. When one aims estimation of acoustic source location, the quality of acoustic signal in electric circuit will control its results.

In this study, we first zero in on not pursuit of individual favorite sound quality but discovering the cause of human acoustic source or phantom recognition in three-dimensional source location to clarify the relationship among mechanical and electrical characteristics and human recognition.

MEASURING METHODS

Here, we restrict the problem to recognition of phantom location reproduced by stereophonic equipment and its sound quality related to their vibration control method. Then, we have check up and compare the changes of recognition for summing localization and sound quality of stereophonic replay sound by comparing listening test and the change of physical factors especially amount of harmonics of acoustic and vibration. Here, following three physical factors were picked out as disturbance on summing-localization recognition under sinusoidal input, 1) amount of harmonic distortion of speaker, 2) amount of harmonic distortion of vibration on chassis of amplifier and 3) vibration of plate electrode of vacuum tube. Test sound signal were reproduced from CD's on the market for hearing test by using well-designed high-definition audio system, which can realize spatial location of sound source phantoms. In the listening test, above-mentioned physical factors are changed by using control method of mechanical vibration. For the differences in above-mentioned physical factors, the subjects hear and illustrate the difference of summing localization of phantoms and fill a questionnaire on words of its sound quality.

Measurement of Harmonics on Speaker

To evaluate the effect of vibration control, we measured vibration velocity on a speaker enclosure and sound pressure level of radiated sound signal with laser Doppler vibrograph and microphone. The experimental arrangement is shown in Fig. 1. Speaker was put on a speaker stand under several vibration control materials between them; 1) without control systems, 2) supported by sponge-gum, 3-A) supported by ordinary conical spikes, 3-B) supported by double spike type 1, 3-C) supported by double spike type 1 with silicone oil and 3-D) supported by double spike type 2 with silicone oil. Vibration velocity of enclosure and center of speaker units were measured by laser Doppler vibrograph (Onosokki, LV-1610). Radiated acoustic signal and its higher harmonics were measured by an FFT analyser (Onosokki, CF5220) through a microphone (Victor Japan, MU-80). Every 1kHz sinusoidal signal from 1kHz to 10kHz were employed as test signal and replayed by a CD player.

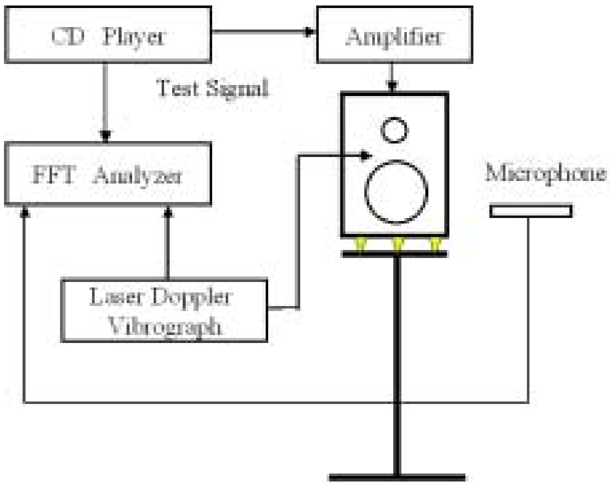


Figure 1 – Experimental arrangement of vibration measurement of a speaker with and without vibration control by using a laser Doppler system

Measurement of Harmonics on Chassis of Amplifier

To investigate the effect of vibration control on the chassis of amplifier, the frequency characteristics of vibration velocity on the chassis and that of electric output signal were measured by laser Doppler vibrograph and FFT analyser. The double spike type 2 with silicone oil was employed as vibration control unit. The effect of vibration control was compared with no vibration control case.

Measurement of Harmonics on Plate Electrode of Vacuum Tube

Frequency spectrum of vibration velocity of plate electrode in a vacuum tube and electric signal output of the amplifier were measured by laser Doppler vibrograph and FFT analyzer under sinusoidal input. Improvements in vibration of plate electrode and higher harmonics in electric signal were compared by difference between their frequency spectrum for with and without vibration control. Photo 1 shows applying the laser on plate electrode enclosed in a vacuum tube. The measurement was carried out about 30 minutes after changing the vibration control system because of stabilization of its thermal inertia under sinusoidal input.

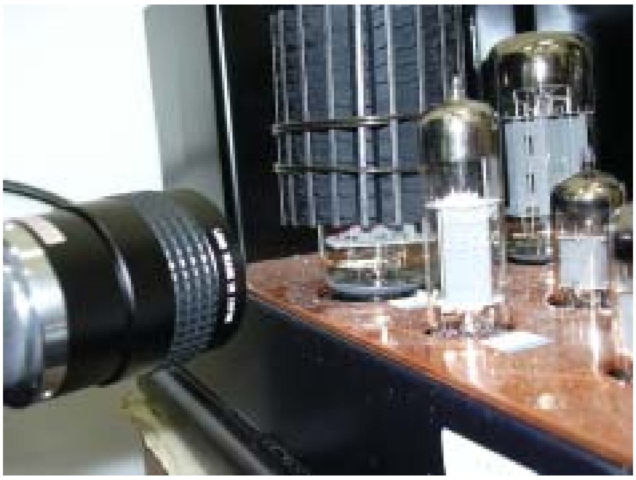
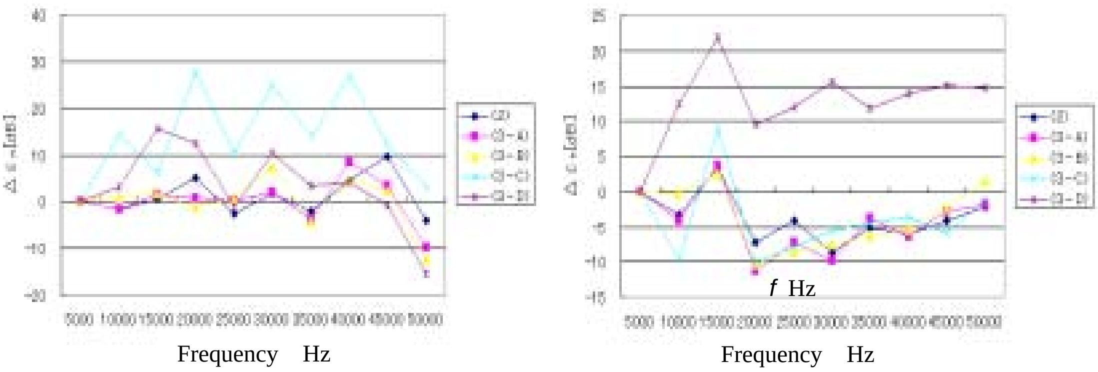


Figure 2 – Experimental situation of measuring vibration on plate electrode in a vacuum tube under vibration control unit by using a laser Doppler system

EFFECTS OF VIBRATION CONTROL ON PHYSICAL FEATURES

Effect of Vibration Control on Speaker

Figure 3(a) shows comparisons of higher harmonics in vibration velocity on tweeter among each supporting system under 5kHz sinusoidal input. The Δε denotes the difference between improvement in S/N of each harmonics to input signal level with and without vibration control. So, positive Δε denotes suppression of higher harmonics. Comparisons of higher harmonics in radiated sound are shown in figure 3(b). As shown in Fig. 3(b), the double spike type 2 is effective to suppress the higher harmonic distortion.



(a) Difference in vibration velocity *(b) Difference in acoustic signal*

Figure 3 – Difference of harmonics level between with and without vibration control under sinusoidal input of 5 kHz.

Effect of Vibration Control on Chassis

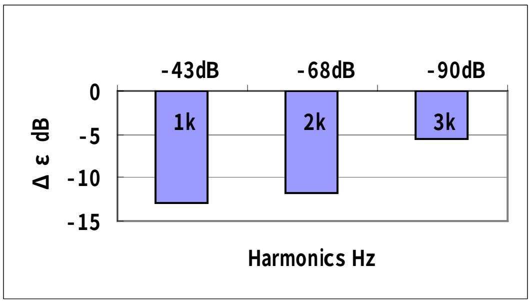
Table 1 shows comparisons of higher harmonics contained in electric signal output of amplifier with and without vibration control under sinusoidal input of 1 kHz. Vibration control with double spike type 2 seems effective to suppress higher harmonics. On the other hand, vibration velocity level on chassis for input signal was more suppressed by vibration control than that without control.

Table 1 – Comparison on higher harmonics contained in electric signal output of amplifier for with and without vibration control under sinusoidal input of 1 kHz.

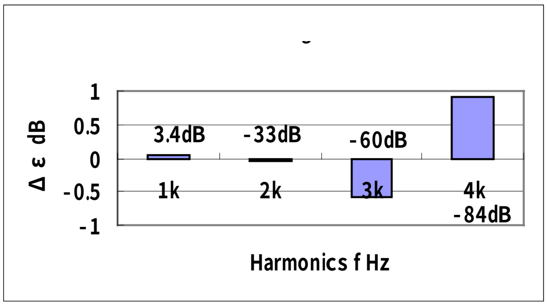
	Signal to higher harmonic's ratio under 1kHz input [dB]			
	2kHz	3kHz	4kHz	5kHz
without control	-73.2	-71.9	-93.4	-88.0
with double spike type 2	-73.5	-75.5	-	-

Effect of Vibration Suppression on Plate Electrode in Vacuum Tube

Figure 4 shows difference in signal and higher harmonics contained in (a) vibration velocity of plate electrode in a vacuum tube of amplifier and (b) electric signal output of amplifier with and without vibration control by tube radiator under sinusoidal input of 1 kHz. There were remarkable differences in vibration velocity level of plate electrode in Fig. 4(a). On the other hand, there were very small amount of difference in electric signal less than 1 dB in Fig. 4(b). In the frequency spectrum, the 2nd harmonics was suppressed remarkably and 3rd one was missed with tube radiator.



(a) Difference in vibration level



(b) Difference in signal level

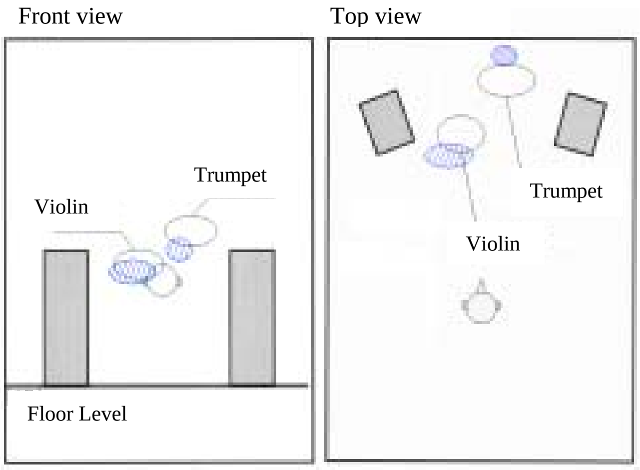
Figure 4 –Power spectrum of vibration velocity on the plate electrode in a vacuum tube under 1 kHz sinusoidal input

LISTENING TEST ON SOUND QUALITY AND PHANTOMS

As mentioned above, the vibration control seems effective to suppress higher harmonics and background noise. So, to evaluate the effect of physical changes on stereophonic equipments to the reproduced sound, we carried out listening test. Several types of music CD on the market, which can illustrate well the spatial distribution of sound sources were employed as test signals. Two loudspeakers were arranged in the standard stereophonic arrangement with base angle about 60 degrees and stereo base distance 1.6m. The listening tests were carried out in a well dead listening room with good quality of sound absorption and its reverberation time was about 0.15sec. From 3 to 6 healthy students of laboratory were employed as subjects. The subject illustrates the distribution and stretch of phantoms to specified instruments appeared in the test music on the front and top view sheets as shown in Fig. 5. And he also answers a questionnaire on words of sound quality (words were selected from references [6],[7]).

Effect of Vibration Control on Distribution of Phantoms

Figure 5 shows an example of images on reproduced acoustic phantoms. This figure illustrates the difference in location and stretch of phantoms on violin and trumpet in an orchestra performance for vibration control of speakers with use of double spike type 2. Then, there were clear distinctions about the acoustic phantoms reproduced by summing localization. By vibration control, the phantoms come to sharp and clear one. And the difference between their locations was more emphasized.



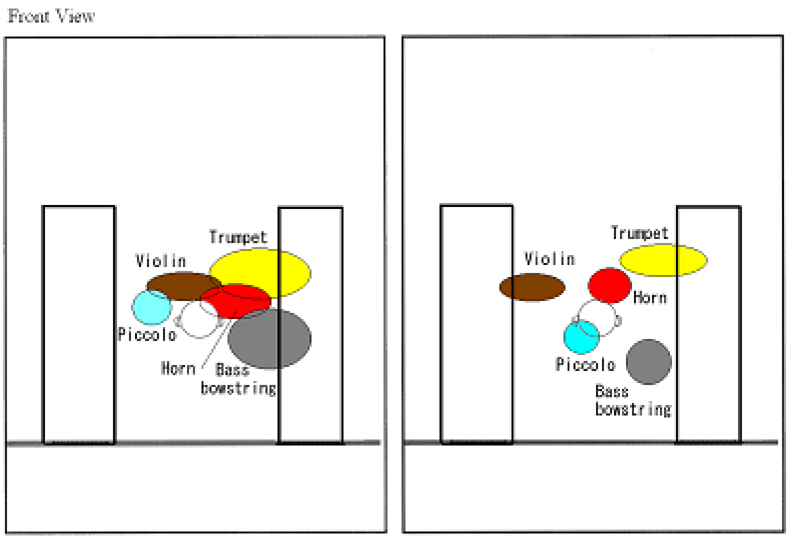
(a) Front view of phantoms (b) Top view of phantoms

Figure 5 —Comparisons of reproduced acoustic phantoms with and without vibration control of speaker support. White circles illustrate phantoms without vibration control

Figure 6 shows also difference in location and stretch of acoustic phantoms on several instruments in an orchestra performance for tube radiator. In Fig. 6, suppression of vibration on the plate electrode and the higher harmonics distortion in electric signal seems effective to make the acoustic phantoms clear and sharp ones.

Effect of Vibration Control on Judgement of Sound Quality

Listening test was carried out by filling a questionnaire on words of sound quality with use of the same system as mentioned in previous section. Each evaluation word was scored 5 step points from 1 to 5. In this test, the judgement for Case 3-A with ordinary conical spikes was set to standard of sound quality whose judgement points were mid value 3. Table 2 shows the words of questionnaire and numeric results of judgement. In this table, small values mean improvement of sound quality.



(a) Without tube radiator *(b) With tube radiator*

Figure 6 –Comparison of acoustic phantoms with and without tube radiator for orchestra performance

Table 2 – Comparison on sound quality of stereophonic replay among the difference in speaker supporting system.

Words	Improvement from 3-A by		
	3-B	3-C	3-D
Clearness of Higher Tone	2.5	2.5	2.1
Clearness of Lower Tone	2.7	2.7	2.5
Understanding of Sound	3	3	2.8
Distinctness of Tone	2.4	2.5	2.2
Sense of Distance	2.4	2.1	2.5
Forcefulness of Sound	2.9	2.9	2.6
Expanse of Sound Field	2.8	2.7	2.5
Three-Dimensional Sound	2.8	2.4	2.4
Smoothness of Higher Tone	2.5	2.4	2.1
Smoothness of Lower Tone	2.8	2.6	2.5
Lightness of Sound	2.9	2.6	2.6
Brightness of Sound	3	2.5	2.5
Calmness of Higher Tone	2.8	2.7	2.1
Calmness of Lower Tone	2.8	2.7	2.2
Shrillness of Tone	3.1	2.9	2.6

Comparing the result in Table 2 with Fig. 3, the less higher harmonics distortion in stereophonic equipments provides higher quality of reproduced sound. Then, the vibration control seems effective to improve the sound quality and 3-dimentional representations by stereophonic equipments.

CONCLUSIONS

In this study, human listening ability to recognize phantoms as summing localization for stereophonic sound transmission process will change owing to the distortion originate in higher harmonics and S/N. By comparing the results on change in physical feature and reproduced sound quality and acoustic phantoms with and without vibration control, following results are obtained:

1) The double spike supporting system for speaker suppresses the obstacle vibration like higher harmonics and improves the S/N and summing localization.
2) Tube radiator suppresses vibration of plate electrode and effective for stereophonic representation to improve the summing localization and sound quality.

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