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Custom-Made ITE Type Hearing Protection Device Using a Small Acoustic Filter

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Abstract

Noise induced hearing loss (NIHS), the well-known occupational disease, is caused by con-tinuous excessive noise. The prevention of NIHS is very important, because it is unrecoverable. There are some kinds of hearing protection device (HPD), and those are effective in preventing NIHS. But workers in noisy environment often resist to wearing them. Because they are ready - made products, so workers feel uncomfortable to wear. Also, they didn't maintain the conversation frequency range, so workers are hard to communicate in wearing them. To prevent hearing loss effectively, it is important that workers keep wearing HPD. Therefore, a HPD is needed to be comfortable to wear and be effective not only in hearing protection but also in preserving communication ability. So we proposed a custom - made hearing protection device in which a small acoustic filter is inserted. We designed several kinds of small acoustic filters and carried out some acoustic experiments for measuring characteristics of filters. We confirmed that acoustic transmission characteristic can be adjusted from experimental results using designed small acoustic filters. And we researched for the actual efficiency of a new developed custom - made hearing protection device using a small size acoustic filter. Also, we found out that workers are more satisfied with the new development than a former protection device from a workers' response.

Key words : noise induced hearing loss (NIHL), acoustic filter, hearing protection device (HPD)

I. INTRODUCTION

We are exposed to all kinds of noise directly or indirectly, and it causes psychological or physiological dis-eases.

A hearing disorder is a well known hazard due to noise. When hearing organ is exposed to excessive noise, some or all of hearing cells are damaged then people lose hearing ability. Noise induced hearing loss (NIHL) can be caused by a one-time exposure to loud sound as well as by repeated exposure to sounds at various loudness levels over an extended period of time. And it is classified into temporary hearing loss and permanent hearing loss. The temporary hearing loss is due to abrupt severe noise, and it can be recovered spontaneously. But if the noise lasts continuously, it causes unrecoverable permanent hearing loss. It is a sensorineural hearing deficit that begins at the higher frequencies (3,000 to 6,000 Hz) and develops gradually as a result of chronic exposure to excessive sound levels [1].

NIHL is one of the most serious occupational disease, there are over thirty million exposed to noise in Amer-ica. And it is over fifty percent of occupational disease in Korea. A hearing loss progresses by stages and the degree of loss is different according to noises. To protect hearing cells from noise, it is important to wear protec-tion devices continuously. Therefore there are many kinds of hearing protection devices (HPD). But, the former protectors have some difficulties to wear. Because they are ready-made products, so those are not fitted well and people feels uncomfortable. And it is hard to understand coworker's voice therefore workers must take off for conversation. So, we developed a custom-made hearing protection device using a small size acoustic filter for solving these inconvenience.

In this paper, we proposed a custom-made HPD using a small acoustic filter to solve the inconvenience which the former HPDs have. The small acoustic filter is applied a principle of the acoustic filter that has been used for a muffler of automobiles, guns, and etc [2]. We designed several kinds of small acoustic filters and carried out some experiments for measuring characteristics of filters.

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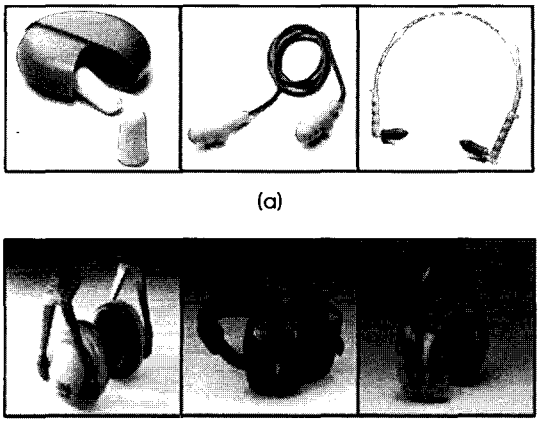
II. MATERIALS AND METHODS

A. Hearing Protection Device (HPD)

Hearing protection device is very important to wear in industrial areas where there is usually a lot of noise, especially above 85 decibels. There are various types of hearing protectors, including ear plugs and ear muffs as shown in Fig. 1. Earplugs are useful for places where there is moderate noise around 85 decibels. Formable or foam ear plugs, if placed in the ear correctly, will expand to fill the ear canal and seal against the walls. Ear plugs must be replaced on a daily basis or whenever they become soiled. Using an unclean ear plug may lead to an ear infection. Earmuffs are devices that cover the head and external ear area along with muff cup attached inside. This protective device protects ears from very loud noise. It is even more effective when worn with earplugs and reduces the intensity of the loud noise to a great extent. These devices fit against the head and enclose the entire external ears. Ear muffs are often used in conjunction with ear plugs to protect the employee from extremely loud noises, usually at or above 105 decibels. The ear muff cushion must form a seal against the head all around the ear and not rest against any part of the outer ear. Employees should be issued their own ear muffs, however, if ear muffs are used by more than one employee, the ear muffs should be cleaned frequently. Ear muffs should be wiped off with soap and water. Ear muffs should be inspected regularly for signs of wear and tea, and should defects appear, the device should be replaced.



(a)

(b)

Fig. 1. Hearing protection devices (a) earplug (b) earmuff.

B. Acoustic Filter

One reason to resist wearing a HPD is a communication problem [3], [4]. Because it is hard to understand the others as wearing a HPD, so to communicate workers must take off a HPD. As a result workers feel annoyance wearing a HPD. Therefore it is possible to understand the others wearing a HPD for using it continuously. For effective hearing protection without annoyance, we inserted a small acoustic filter in the HPD. That is applied a principle of the acoustic filter that has been used for a muffler of automobiles, guns, and etc.

There are two kinds of hearing protection device. One is an ITE (in-the-ear) type as earphone, and the other is earmuff type like headphone. We designed small acoustic filters for ITE type HPD because it is more easy to carry, convenient to use, and better looking than earmuff type. Fig. 2 shows a virtual drawing of ITE type HPD using a small acoustic filter [2].

To design a small acoustic filter which can transmit a voice, it needs to know the hearing characteristic of human. The audible range of human is generally known as 20 ~ 20,000Hz and the conversation range is 100 ~ 8000Hz. But, 95 % of sound power is distributed at the range of 125 ~ 1000Hz and the important range of dis-crimination is 500 ~ 2000Hz as show in Fig. 3. From these characteristics, we found out that the transmission band of the small acoustic filter is below 2,000Hz.

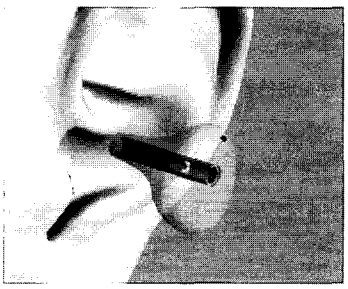


Fig. 2. Virtual ITE type hearing protector using a small acoustic filter.

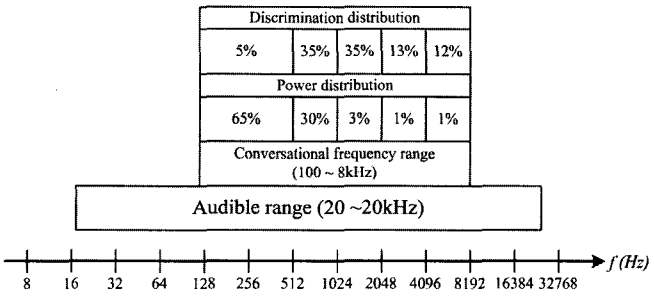


Fig. 3. Audible, conversational, and hearing frequency range of human.

The ability of a side branch to attenuate the sound energy transmitted in a pipe is the basis of a class of acous-tic filters. Depending on the input impedance of the side branch, such systems can act as low-pass, high-pass, or band-pass filters. A simple low-pass filter is produced by a constriction in a pipe, as shown in Fig. 4. This system may be thought of as

introducing an inertance in series with the pipe.

The transmission coefficient, T_π, of the filter is

$$T_\pi = \frac{4}{4\cos^2 kL + \left(\frac{S_2}{S_1}\right) + \left(\frac{S_1}{S_2}\right)^2 \sin^2 kL}$$

$$= \frac{4}{4\cos^2\left(\frac{w}{c}L\right) + \left(\frac{S_2}{S_1} + \frac{S_1}{S_2}\right)^2 \sin^2\left(\frac{w}{c}L\right)} \quad (1)$$

$$= \frac{4}{4\cos^2\left(\frac{2\pi f}{c}L\right) + \left(\frac{S_2}{S_1} + \frac{S_1}{S_2}\right)^2 \sin^2\left(\frac{2\pi f}{c}L\right)}$$

where, k is wave number (k = ω /c, c : sound velocity) and f is frequency [5].

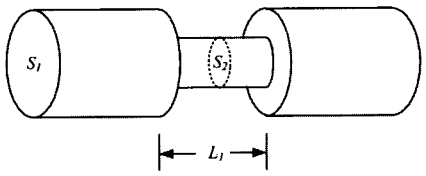


Fig. 4. An acoustic filter including a constricted section of a pipe.

Another type of small acoustic filter can be constructed by use of a small diaphragm and to magnify its effective size by using a flaring tube, a horn. One purpose of the loud-speaker horn is to spread the concentrated waves coming from the diaphragm out over a large enough area so that they can continue out from the mouth of the horn with very little reflection. Another occasionally important purpose of the horn is to concentrate the sound into a directed beam, so that most of the radiated energy is set out in one direction.

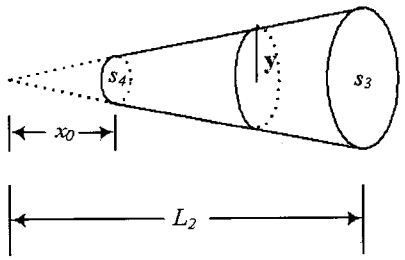


Fig. 5. Conical horn.

The transmission coefficient of corn shown in Fig. 5 is

$$T_c = \frac{1}{1+(\lambda/2\pi x_0)^2} = \frac{(2\pi v x_0)^2}{c^2+(2\pi v x_0)^2} \quad (2)$$

where, c is sound velocity and v is frequency [6].

C. Developed Filter and Custom-Made HPD

Another reason to resist wearing a HPD is unpleasant feelings wearing it. The shape of external ear is differ-ent from person, but ready-made HPDs are all same size. So, it isn't fitted well and felt uncomfortable or even pain. Therefore to make workers wear HPD continuously, it is necessary that a custom-made HPD which is made using ear impression of a specific person. The proposed HPD is made into ear impression of a specific person so that it is fitted well and improves comfortableness during wearing a device. Fig. 6 shows the making process of the custom-made HPD.

Making Process

1) Otoscopy - Examination of the external ear and eardrum
2) Making an impression - To fit the HPD on the user's ear, making an ear impression individually.
3) Trimming the impression - Cut and trim the impression for HPD
4) Making a frame for ear-mold - Coat the trimmed impression with paraffin and pour Klarsil H (Dreve)
5) Making an ear-mold - Pour Fotoplast-s/hart (Dreve) into the frame and make it hard
6) Drilling - Drilling through the ear-mold for acoustic filter and acoustic pathway
7) Trimming the ear-mold
8) Coating
9) Inserting a small acoustic filter

Small Acoustic Filter

We designed two different types of acoustic filter and those can have various characteristics as changing pa-rameters. Fig. 7 shows a diagram of a designed acoustic filter. Because filters are inserted in the HPD, the exter-nal length and diameter are fixed at 8mm and 4mm respectively. D_1, D_2, and L are changeable within the range of external size. The transmission characteristics are varied according to D_1/D_2 and L.

Fig. 8 shows small acoustic filters inserted in the HPD. Filters are made by Rapid Prototyping method and the external shape is cylindrical. The inside shape of filters is perforated as step type and horn type acoustic filter. We designed four kinds of step type filter, (F1, F2, F3, and F4) and two kinds of horn type filter (F5 and F6) shown in Fig. 7. D_1 is fixed at 3mm and the sizes of the other parameters are shown in Table 1. Fig. 9 shows a pair of custom - made HPD in which a small acoustic filter is inserted.

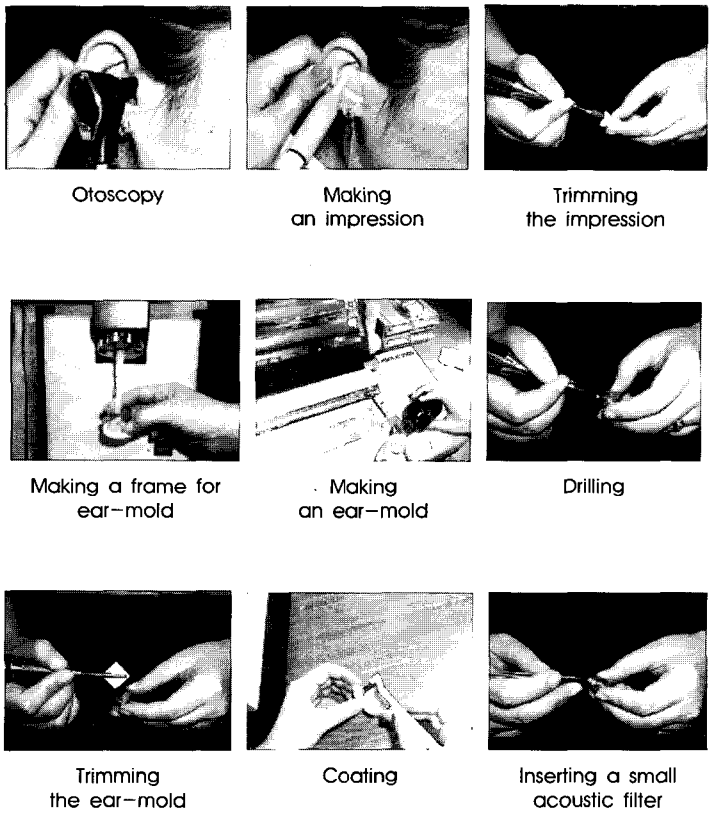


Fig. 6. Making process.

III. RESULT

A. Acoustic Transmission Characteristics of Designed Filter

We carried out two experiments to know the characteristics of the designed acoustic filters. One is about the characteristic of step type small acoustic filters and the effects of the parameters. The other is about horn type filters.

Fig. 10 shows an experiment composition for measurement and analyses of frequency response of designed small acoustic filters. The System 2 of Audio precision is used for measurement. The measurement microphone is MMK-1 of Audio precision and the frequency response of the microphone is 5 ~ 40,000Hz. The speaker is 12 inch loud-speaker (CX - 12AW200G) and

Table 1. Size of designed filters.

Filter	D_2	L
F1	1mm	5mm
F2	1mm	3mm
F3	0.5mm	5mm
F4	0.5mm	3mm
F5	0.5mm	-
F6	1mm	-

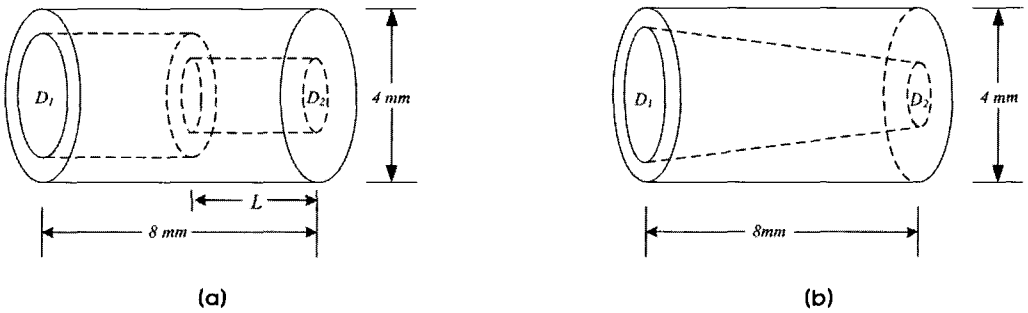
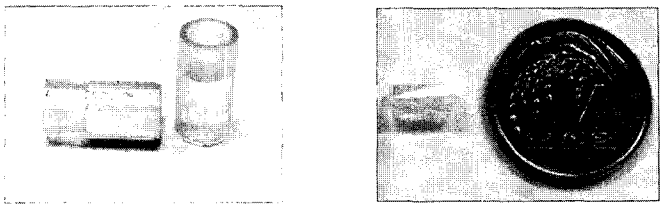


Fig. 7. The diagram of acoustic filters (a) step type (b) horn type.



(a) (b)

Fig. 8. Small acoustic filter (a) step type (b) horn type.

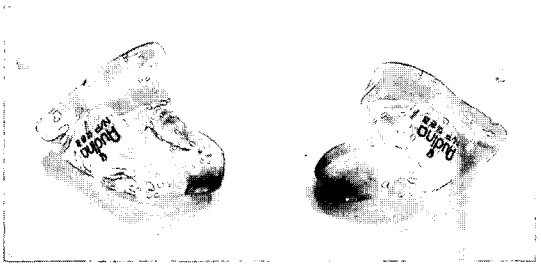


Fig. 9. Custom - made hearing protection device using a small acoustic filter.

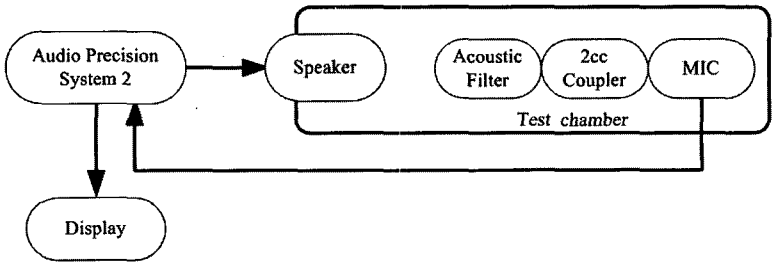


Fig. 10. Experiment composition.

frequency response of speaker is 55 ~ 15,000Hz. We measured trans-mission sounds through the designed filter and 2cc coupler. Because the outer ear canal forms a resonating tube, and by itself, reinforces energy in 3000 ~ 4000Hz frequency range by about 10 dB as shown in Fig. 11 (a). The 2cc coupler acts like an external ear canal as shown in Fig. 11 (b), so we can guess the sound reached at eardrum.

Fig. 12 shows the transmission characteristics of step type small acoustic filters. As shown in Fig. 12 (a) when L_2 is fixed, the transmission band can be controlledas the change of areas of filter. Also when m_1 (S_1/S_2) is fixed the transmission band can be controlled as L_1 as shown in Fig. 8 (b).

Fig. 13 shows the transmission characteristics of horn type small acoustic filters. As shown in Fig. 13 (a), when m_2 (S_3/S_4) is fixed the transmission band can be controlled as a length of filters. Also when L_2 is fixed the transmission band can be controlled as m_2 as shown in Fig. 13 (b). And both types of filters have same length and same ratio of areas, the transmission band of horn type filter is lower than it of step type filter, as shown Fig. 13 (c). From these results, transmission characteristics of the designed small acoustic filters are suitable for communication.

Table 1. Size of designed filters.

Filter	D2	L
F1	1mm	5mm
F2	1mm	3mm
F3	0.5mm	5mm
F4	0.5mm	3mm
F5	0.5mm	-
F6	1mm	-

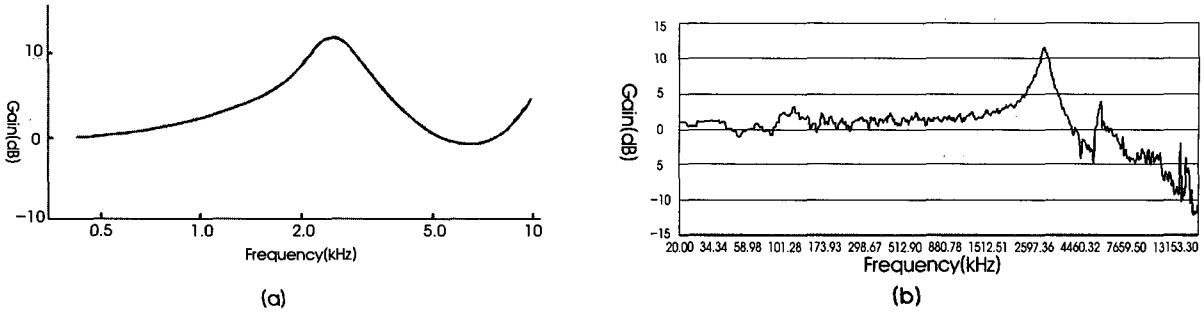


Fig. 11. Transmission characteristics (a) external ear canal (b) 2cc coupler.

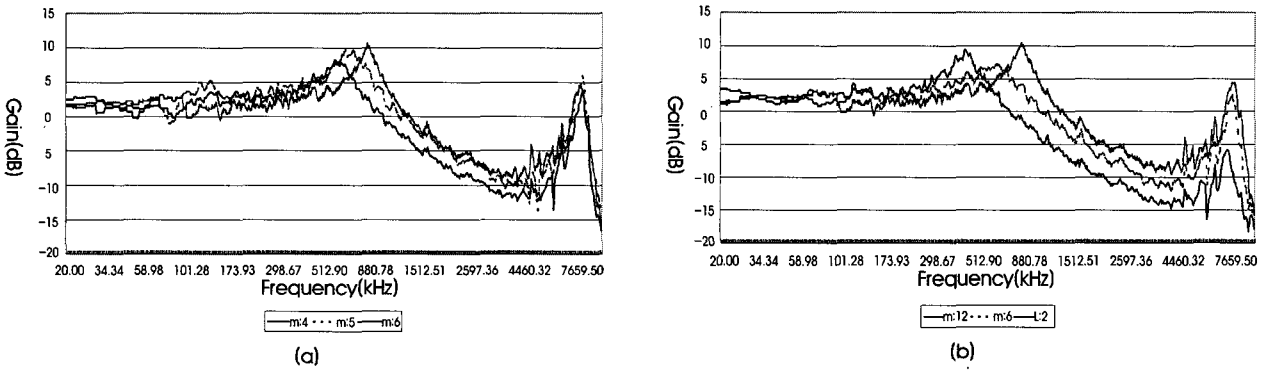


Fig. 12. Transmission characteristics of step type small acoustic filters (a) when L_1 = 2mm, the transmission characteristics according to a change of m_1, (b) when m_1 = 4, the transmission characteristics according to L_1 ($m_1=S_1/S_2$).

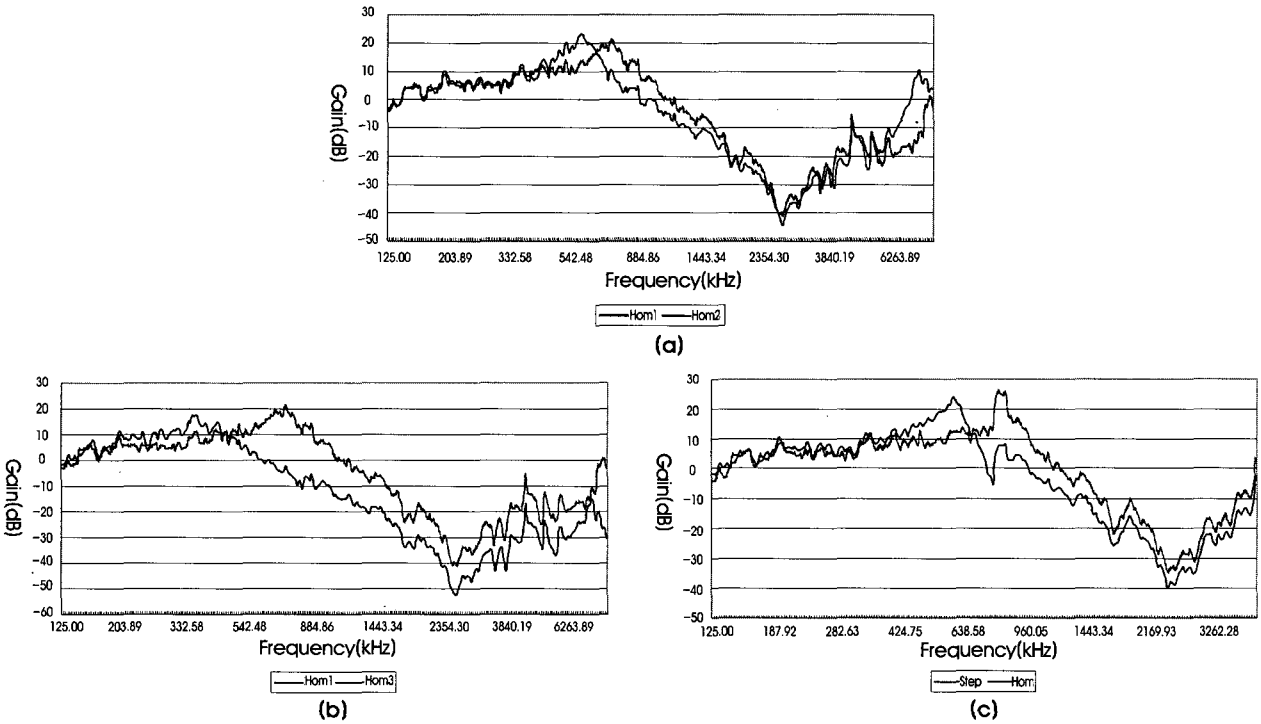


Fig. 13. Transmission characteristics of horn type small acoustic filters (a) When m2 = 0.09, the transmission characteristics according to a change of L2, (b) When L2 = 4.5mm, the transmission characteristics according to m2 (c) The transmission characteristics when m1 = m2 and the length of both type filter is same (m2=S3/S4)

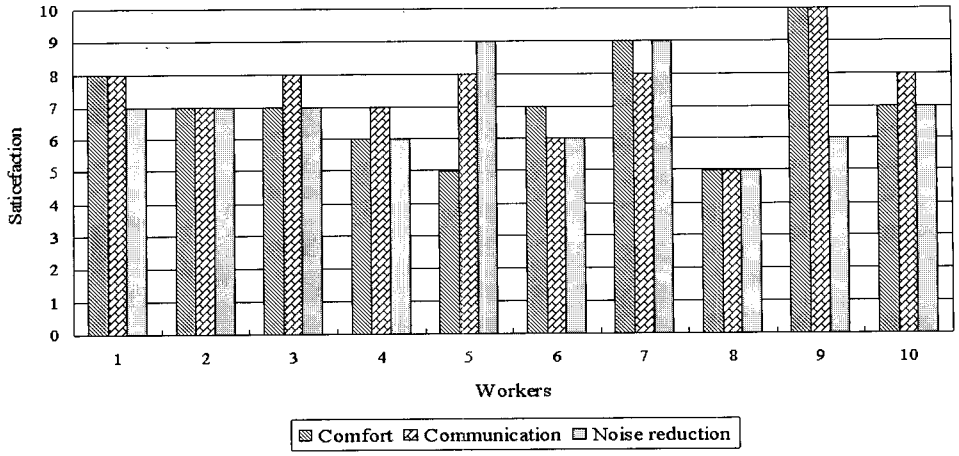


Fig. 14. Workers' response

B. Application Result of Custom-Made HPD

To prove the effectiveness of the proposed HPD, we surveyed a degree of satisfaction through workers who are working in noisy place. Machines in the work place made noise over 100dB(A) and the equivalent noise level is about 95dB(A). And the working time of the factory is over 9 hours. We offered proposed HPD to ten of the workers as objects, and surveyed their satisfaction degree through some questionnaires.

The last questionnaire is to know their opinion about continuous use of the HPD. 70% of workers wanted to keep using it as show in Fig. 16.

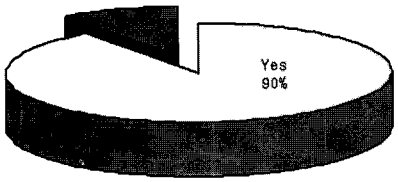


Fig. 15. Experience wearing other HPD.

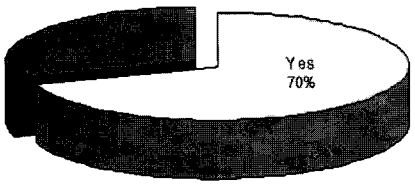


Fig. 16. Opinion about continuous use.

V. CONCLUSION

A NIHS is caused by injured hearing cells. It is not recoverable that the hearing cells injured in abrupt strong noise or lasting noises. So the prevention of hearing loss is very important. To preventing NIHS, workers in noisy environment must use a HPD. But workers resist using it, because they are ready-made products. So they arenot fitted well and workers feel uncomfortable. And it is hard to understand coworker's voice therefore they must take it off for conversation. So, we developed a custom - made HPDusing a small size acoustic filter for solving these inconvenience.

From the experiment results of various kinds of small acoustic filters, we confirm that designed filters can transmit the speech signals of 500 ~ 2000Hz which is the most important band for communication. It means the hearing protection devices using small acoustic filter can solve the communication difficulty, and it is possible to motivate wearing a hearing protection device continuously. And we researched about the actual performance of a new developed

custom - made HPD using a small size acoustic filter. From workers' response, we found out that workers are more satisfied with our development that a former protection device Therefore it is expected that the proposed HPD can motivate workers to wear a HPD continuously and be useful an effective hearing conservation.

REFERENCES

[1] Winer, F. and Ross, D., "The pressure distribution in the auditory canal in a progressive sound field", *J. Acoust. Soc. Am.*, vol. 18, no. 2, pp. 401-407, 1946.

[2] Lee, Yun-jung, *Design of an acoustic filter using external ear model for hearing protection*, Kyungpook National University, Daegu, 2005.

[3] Jennifer B. Tufts and Tom Frank, "Speech production in noise with and without hearing protection," *J. Acoust. Soc. Am.*, vol. 114, no. 2, pp. 1069-1080, 2003.

[4] A. Sérgio S. R. Miguel, "Personal hearing protection," *Safety Science*, vol. 23, no. 2/3, pp. 183-184, 1996.

[5] Lawrence E. Kinsler et al, *Fundamentals ofAcoustics*, 3rd edition, John Wiley & Sons, New York, 1982.

[6] Philip M. Morse, *Vibration and Sound, 2nd edition*, McGraw-Hill Book Company, Inc., 1948.

[7] João Candido Fernandes, "Effects of hearing protector devices on speech intelligibility", *Applied Acoustics*, vol. 64, Issue 6, pp. 581-590, 2003.