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A Study on Sound Energy Resonance Using the Special Acoustic Lens

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Abstract:

A modified fire fighting environment requires a new fire fighting technology that is different from the existing extinguish method, which relies exclusively on fire extinguish agents. The Sound Fire Extinguisher, first released by US Defense Advanced Research Projects Agency (DARPA) and George Mason University students, has a disadvantage that the sound energy is scattered all over the place, so it is not very effective for practical use in the fire fighting field. Sori Sound Engineering Research Institute (SSERI) has improved the disadvantages of existing Sound Fire Extinguisher by applying the special acoustic lens focusing sound energy. In this study, we tried to confirm the sound energy resonance effect of the special acoustic lens through experiment. Experimental results show that, when a special acoustic lens is applied to a sound energy of 60 Hz, the sound is output as much as 4 dB as compared with a case where a special acoustic lens is not applied. From these experimental results, it was confirmed that the special acoustic lens concentrates sound to the front and resonates greatly.

Keyword: Fire Fighting Environment, Sound Fire Extinguisher, Special Acoustic Lens, Sound Energy, Resonance

1. INTRODUCTION

Fire is an indispensable part of the development of human civilization. Biologically very fragile humans could become the lord of creation by using fire to develop civilization. In particular, the steam engine that transforms the heat energy of fire into kinetic energy has led the industrial revolution and created a momentum for the rapid development of human civilization. The development of human civilization is becoming more and more accelerated, and this can also be a part of the role of fire [1-2].

Fire gives humanity the pain as a disaster called conflagration as much as the benefit to mankind. Because human beings must use fire, the damage caused by conflagration is like fate. The development of civilization has made the buildings skyscraper and enlarging, and the conflagration of skyscraper and bigger building causes enormous damage. A new fire extinguish method is needed for the fire fighting environment due to the development of civilization. Existing fire extinguish methods depend mainly on the chemical reaction of fire extinguish agents, so they can be used only when conflagration occurs and there is a problem that fire extinguishing objects are destroyed. The existing fire extinguish method is a limit to apply to a changed fire fighting environment that develops into large conflagration in an instant and causes enormous damage. Therefore, a novel fire extinguish method is needed to suppress the diffusion of conflagration to the entire building and to prevent the occurrence of conflagration [1-2].

Sound Fire Extinguisher can be an alternative in a changed fire fighting environment because it uses the principle of sound unlike the existing fire extinguish method which relies exclusively on fire extinguish agents. Sound Fire Extinguisher was first announced in 2012 and 2015 by US Defense Advanced Research Projects Agency (DARPA) and George Mason University students. However, Sound Fire Extinguisher, released by DARPA and George Mason University students, has the disadvantage that the sound spreads in all directions and not enough sound energy is delivered to the flame. It also has the problem of producing very loud noise to deliver sound of the proper size for flame control [3-4].

The Sori Sound Engineering Research Institute (SSERI) of Soongsil University developed a special acoustic lens to focus sound components on the flame and apply it to Sound Fire Extinguisher. The special acoustic lens plays an important role in achieving a compact and lightweight Sound Fire Extinguisher as well as greatly enhancing fire extinguishing performance by resonating the sound through the horn effect to smoothly deliver sound energy to the flame [5-8].

In this study, we explain the principle applied to the special acoustic lens applied to the Sound Fire Extinguisher, and confirm how well the sound energy of the Sound Fire Extinguisher is resonated through the application of the special acoustic lens.

2. BASIC THEORY OF SOUND RESONANCE

2.1 A sound mixing effect

The sound does not change the direction and characteristics of transmission for each signal by the principle of superposition. However, at the point where the signals meet each other, interference occurs for each signal, and a composite wave is produced. At this time, when a sound having the same phase is compose, a constructive interference occurs in which the strength of the signal becomes stronger. Equation (1) represents constructive interference [9].

$$Y(t) = A\sin(\omega t - k) + A\sin(\omega t - k) = 2A\sin(\omega t - k) \quad (1)$$

On the other hand, if the sound of the same sound but opposite phase is compose, a destructive interference occurs in which the strength of the signal is weakened. Equation (2) represents destructive interference [9].

$$Y(t) = A\sin(\omega t - k) + A\sin(\omega t + \pi - k) = A\sin(\omega t - k) - A\sin(\omega t - k) = 0 \quad (2)$$

Constructive interference is used to amplify the signal strength, while destructive interference is used to reduce noise by reducing the strength of the signal.

2.2 A horn effect for speaker

To reinforce the output of the speaker, use several speakers. In this case, however, the sound quality is distorted due to the interference between each speaker sound. Another way to reinforce the speaker's output is to attach the horn to the speaker. Generally, it is known that when horn is attached, output can be increased by 10 ~ 50% [10].

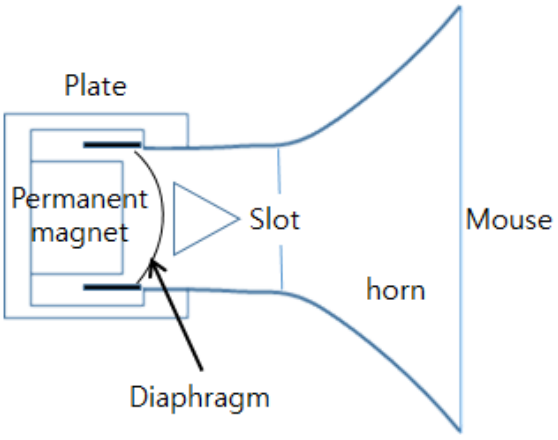

Fig 1. Structure of the Horn Speaker [10]

The horn speaker has a sound wave propagating inside the horn and a reflected sound wave simultaneously. If the horn is an exponential type, the sound pressure inside the horn can be expressed as equation (3) [11].

$$P = Ae^{-j(\beta - j\alpha)x} + Be^{-j(-\beta - j\alpha)x} \quad (3)$$

In other words, the horn is amplified as a composite wave of traveling wave and reflected wave. This amplification scheme is advantageous for the amplification of low-frequency sound with a smaller phase difference than the propagation distance difference between the traveling wave and the reflected wave[10].

2.3 A acoustic lens effect

Acoustic lens is used to focus the sound using the refractive index difference between mediums. Acoustic lens is mainly applied to sonar which is used for telecommunication and target detection by using the principle of collecting and concentrating propagated sound widely spread in water where electromagnetic wave is not transmitted well. In the design of a general acoustic lens, the difference in acoustic impedance between the medium and the acoustic lens must be large so that the energy loss due to the reflection is generated, so that the acoustic impedance difference should not be large. The structure of the acoustic lens is shown in Figure 2, and the focus(F) at which the sound is gathered due to the acoustic lens can be obtained by the equation (4) [12-13].

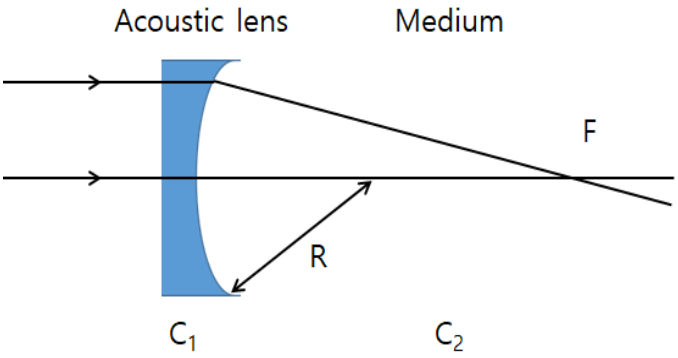

Fig 2. Structure of Acoustic Lens [12-13]

$$F = \frac{R}{1-(\frac{C_2}{C_1})} \quad (4)$$

F : Distance to focus
R : Radius of curvature of the lens
C_1, C_2 : Sound velocity of acoustic lens and medium

3. THE SPECIAL ACOUSTIC LENS EFFECT FOR A SOUND FIRE EXTINGUISHER

The acoustic lens eventually changes the direction of the sound to converge at one point to enhance the sound, and it mostly uses the refractive index difference between mediums. However, the Sound Fire Extinguisher uses the special acoustic lens to concentrate and resonate the sound in the horn, which changes the direction of sound through reflection, since the air is a medium.

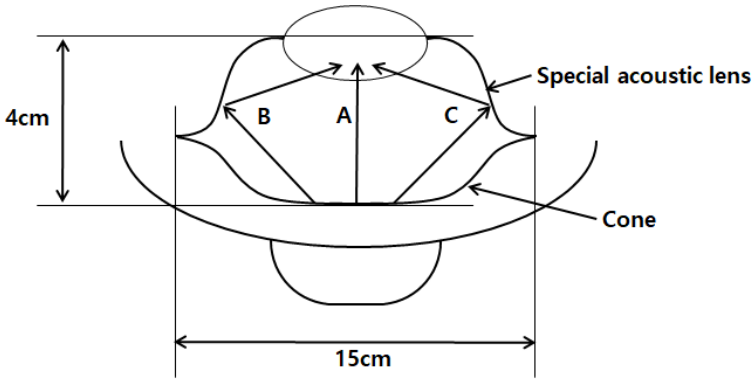

Fig 3. Structure of the Special Acoustic Lens

Figure 3 shows the structure of the special acoustic lens applied to the Sound Fire Extinguisher. The sound from the cone is combined with a traveling wave like A and a reflected wave such as B and C. The three sounds are waves with the same frequency and different magnitude and phase. The generated composite wave can be expressed as equation (5) [9].

$$Y(t) = A\sin(\omega t - k_A) + B\sin(\omega t - k_B) + C\sin(\omega t - k_C) \quad (5)$$

owever, when the Sound Fire Extinguisher uses a 60Hz low frequency, the wavelength is 600cm, while the difference in distance between the waves is relatively small, and the phase difference between the waves is insignificant. For a typical cone speaker, the directivity is very low at frequencies below 500Hz. However, it is known that the sound volume is reduced by about 3 dB on the 60 ° side, and by about 6 dB on the 90 ° side, compared with the front side. Considering the directivity of the loudspeaker, if the path is changed in a special acoustic lens with a narrow sound path, the composite wave can be predicted as shown in Figure 4.

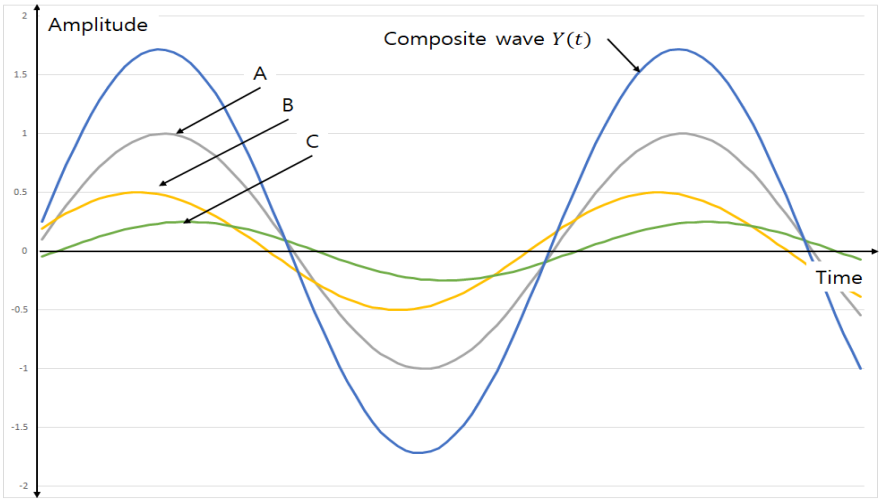

Fig 4. Composite Wave Reflected and Synthesized

4. EXPERIMENTS AND RESULTS

In chapter 4, we tried to confirm sound energy resonance effect of the special acoustic lens of Sound Fire Extinguisher. In the experiment, we measured the sound volume when the special acoustic lens was applied and when it was removed. The applied sound component was applied to the Sound Fire Extinguisher 's own 60Hz pure tone, and the output was the same. The experiment was carried out as shown in Figure 5.

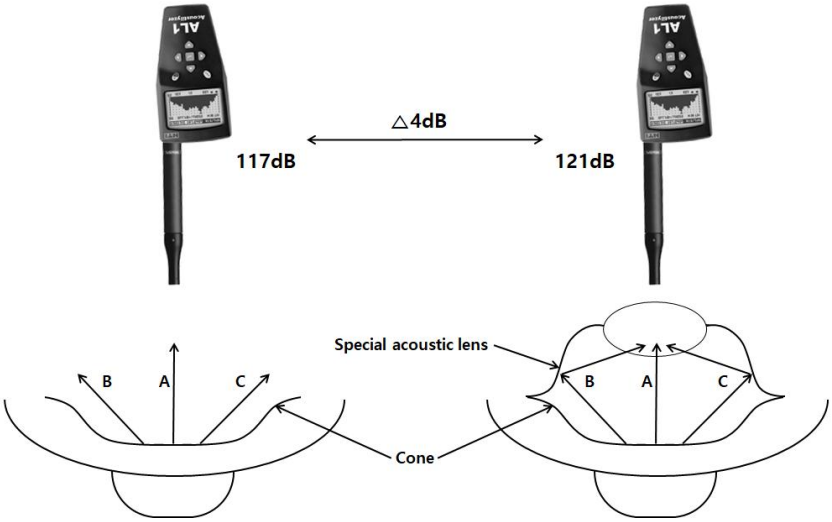

Fig 5. Experiment of Sound Energy Resonance Effect Using the Special Acoustic Lens

As shown in Figure 5, the sound output to the front of the Sound Fire Extinguisher was measured at 117 dB when the special acoustic lens was not applied. On the other hand, when the special acoustic lens is applied, the sound output to the front of the Sound Fire Extinguisher is 121dB, which is increased by 4dB. This result shows that the sound energy is concentrated to one point through the special acoustic lens and resonance is about 2.5 times larger. Table 1 shows the result of measuring the resonance effect obtained by applying the special acoustic lens to three different loudspeakers.

Table 1. The Result of Calculating Speaker Identification Rate

Speaker Type	Drive system	Speaker power	Resonance power
A (5.5 inch)	Quasi-sine wave	117 dB	121 dB
B (6 inch)	Quasi-sine wave	119 dB	122 dB
C (6.5 inch)	Sine wave	118 dB	123 dB

The results of this experiment show that the sound component of the Sound Fire Extinguisher affects the surroundings of the matches and matches, which can increase the ignition point by as much as 20℃, although the ignition point of the match may vary depending on the composition of the ignition agent or its state. As a result, the Sound Fire Extinguisher sound component can help prevent conflagration by suppressing heat accumulation and suppression of ignition.

5. CONCLUSION

The rapid development of human civilization has changed the fire fighting environment rapidly. Due to the rapidly changing fire fighting environment, it is necessary to develop a new fire extinguish method which is different from the existing fire extinguish method which relies exclusively on fire extinguish agents. Sound Fire Extinguisher, announced by DARPA and George Mason University students, is expected to play a role as a new fire extinguish method because it uses sound principles. However, Sound Fire Extinguisher, announced by DARPA and George Mason University students, is not well suited for fire fighting field because the sound spreads in all directions and the sound energy can not be supplied to the flame smoothly. To overcome these drawbacks, SSERI developed the special acoustic lens using horn effect to concentrate sound energy and applied it to Sound Fire Extinguisher.

In this study, we tried to confirm the sound energy resonance effect of the special acoustic lens through experiments. As a result, when Sound Fire Extinguisher output low frequency sound of 60Hz, it produced 117dB output when the special acoustic lens was not applied. On the other hand, when the special acoustic lens is applied, the output is 121dB, and it is

confirmed that the sound energy is resonated as much as 4dB than when it is not applied. When applying the special acoustic lens to various types of speakers, the sound energy was resonated by 3 ~ 5dB more than without the special acoustic lens. This shows that the special acoustic lens concentrates the sound energy of the speaker and resonates it more than twice the size. Concentration of sound energy is very important for the improvement of Sound Fire Extinguisher's digestion ability as well as Sound Fire Extinguisher's small size and light weight, so we expect to advance the practical use of Sound Fire Extinguisher through the special acoustic lens structure study.

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