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Simulation Study on Directional Dispersion of Strong Noise

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Abstract. In dealing with emergencies, strong noise can effectively disperse the unruly crowd gathered illegally. Matlab was used to select different ultrasonic frequencies and individual transducer diameters, respectively, to carry out directional simulation of noise propagation, comparative analysis, to determine the selection of ideal ultrasonic frequency and transducer size. The directional image simulations of noise dispersal were carried out by selecting different array spacing of the transducer planar array. The noise dispersing sound pressure level was calculated to verify the noise dispersing efficiency. The determined optimal combination is ultrasonic wave with frequency f=40kHz, and the directional dispersing module selects a 4×4 array with diameter D=51mm and spacing $d1=d2$=1.2D=61.2mm.

Introduction

When dealing with mass emergencies such as large-scale illegal assembly and violent disturbance, targeted attack with strong noise can disperse effective targets without excessive harm to human body, and at the same time, it can produce ideal dispersing effect. However, the sound wave emitted by traditional loudspeaker is omnidirectional propagation, so it is difficult to produce audible noise with high directivity propagation and cannot achieve directional dispersing. Therefore, how to concentrate omnidirectional propagation noise in a specific direction domain and make it better directional propagation becomes the key link for the effective realization of directional dispersing of strong noise.

Principle of Noise Dissipation System [1]

Based on the principle of directional audio system, noise signal is transmitted by digital signal processor (DSP) loaded on ultrasonic signal. Because the acoustic attenuation coefficient is proportional to the second power of frequency, the ultrasonic waves and harmonics of higher frequency will be quickly absorbed by the air. The attack noise in the audible range is controlled to continue directional propagation in a certain area of space, and so the directional dissipation of noise can be achieved.

The directivity of strong noise propagation is mainly realized by transducer. The sound pressure level of a single transducer is relatively small, and the directional propagation ability of the modulated noise is limited, so it is difficult to achieve effective dispersal effect. So the transducer should be formed into a plane array to improve the sound pressure level and propagation directivity of dispersal noise. Therefore, the directional dispersion effect of strong noise on living targets, will be determined by the parameters of a single transducer and a planar array. How to determine the size and other parameters of the transducer, how to make the planar array of the transducers give full play to the dispersing efficiency, and to give consideration to the size and structure limitations of the equipment and its own economic requirements, These are the primary problems to be solved in the research and development of noise dispersing equipment.

Simulation Analysis of Noise Dissipation Directivity

The parameters of the transducer and its array and the frequency of the ultrasonic wave all directly affect the directivity of noise propagation. The influence of transducer size, array spacing and array number on ultrasonic wave propagation directivity can be analyzed through simulation comparison, it will provide reference for experimental verification.

For a single transducer, its directivity function is expressed as:

$$D(\theta)=\left|\frac{2J_1(ka\sin\theta)}{ka\sin\theta}\right|=\left|\frac{2J_1(\frac{\pi D}{\lambda}\sin\theta)}{\frac{\pi D}{\lambda}\sin\theta}\right| \tag{1}$$

Where: J_1 is the first-order Bessel function; a is the radius of the transducer; $D=2a$ is the diameter of the transducer; wave Numbers $k=2\pi/\lambda$.

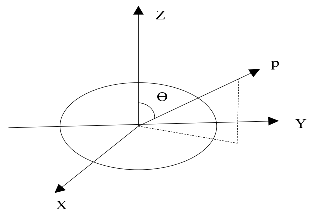

Figure 1. Directivity diagram of single transducer

Simulation on the Ultrasonic Propagation Directivity with a Single Transducer

According to equation (1), the quality of ultrasonic wave directivity is affected by the diameter of the transducer and ultrasonic wavelength directly. So it is necessary to study their effects on ultrasonic directivity respectively. The three-dimensional directivity map of the transducer ultrasonic directivity function can be made with MATLAB mapping function surf(x, y, z). The optimal parameter combination can be determined By comparing and analyzing the simulation results, with changing the diameter size of the transducer and ultrasonic wavelength.

The diameter of the transducer is set as D=51mm, and the frequencies are selected as 30kHz, 40kHz, 50kHz and 60kHz for simulation to study the characteristics of noise directivity propagation when the ultrasonic wavelength and frequency change. The simulations are shown in figure 2-5:

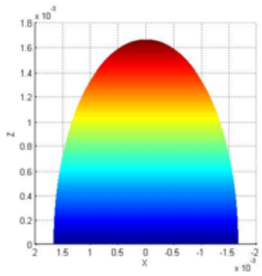

Figure 2. f=30kHz

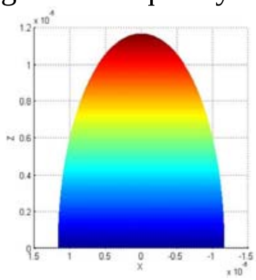

Figure 3. f=40kHz

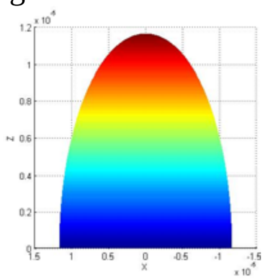

Figure 4. f=50kHz

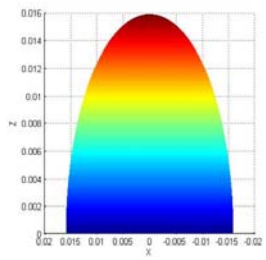

Figure 5. f=60kHz

According to the simulation results, for a single transducer with a certain diameter, the higher the ultrasonic frequency and the smaller the wavelength are, the better the directivity of the transducer will be. In practice, carrier frequency of 40kHz with corresponding wavelength λ=8.5mm is more appropriate, considering the characteristics, cost and noise signal processing algorithm of the transducer.

When the acoustic frequency f=40kHz, and the corresponding wavelength λ=8.5mm, The transducer diameter is chosen for simulation with 3λ, 5λ and 6λ respectively to study the directional characteristics of different transducer sizes. The simulation images are shown in figure 6-9 below:

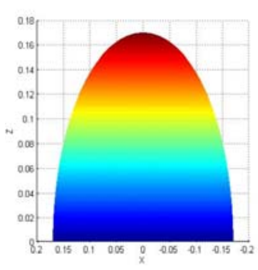

Figure 6. D=λ

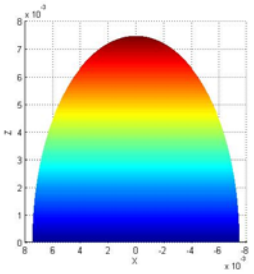

Figure 7. D=3λ

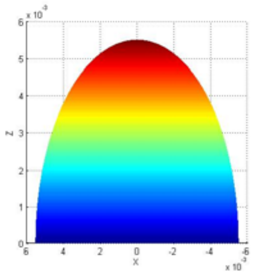

Figure 8. D=5λ

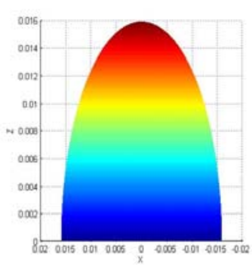

Figure 9. D=6λ

It can be seen from the simulation results that for a single transducer, when the ultrasonic wavelength is fixed, the diameter of the transducer increases and the directivity becomes better. However, in practical application, considering the size of the transducer, size of attack module, equipment structure and many other factors, the diameter of the transducer should not be too large, so the diameter of a single transducer is chosen D=6λ=51mm, the directional index of noise propagation can meet the demand.

Ultrasonic Propagation Directivity Simulation of Transducer Planar Array

The noise pressure level and directivity propagated by a single transducer are limited. In practical application, the sound pressure level and directivity of strong noise are improved by forming plane array.

The planar array of the transducer can concentrate the sound wave into a cylindrical space to achieve directional propagation. At the same time, it can effectively suppress side lobes in all directions in the three-dimensional space. The more array elements there are, the better the side lobes will be suppressed and the stronger the directivity will be. However, in practical applications, considering the limitations of the size of the transducer and the size of the equipment, the array composed of the transducer should not be too large. The selected array 4×4 is shown in figure 10.[2] the diameter of each transducer element of the array is greater than the ultrasonic wavelength lambda, so a single transducer cannot be treated as a point sound source. When deducing the array directivity function, the influence of the transducer diameter, array spacing and other factors on the ultrasonic propagation directivity should be taken into account.

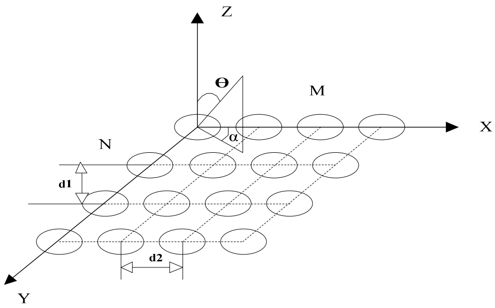

Figure 10. Schematic diagram of transducer plane array

According to formula (1), the directional function of the transducer array can be deduced according to the multiplication theorem [3,4].

When $\alpha = 0$, The directivity function of the transducer array in XOZ plane is:

$$D_r = \frac{\sin(\frac{\pi M D d_1}{\lambda}\sin\theta)}{M\sin(\frac{\pi D d_1}{\lambda}\sin\theta)} \cdot \left[\frac{2J_1(\frac{\pi D}{\lambda}\sin\theta)}{\frac{\pi D}{\lambda}\sin\theta} \right]^2 \quad (2)$$

When $\alpha = \pi/2$, The directivity function of the transducer array in YOZ plane is:

$$D_r = \frac{\sin(\frac{\pi N D d_1}{\lambda}\sin\theta)}{N\sin(\frac{2\pi D d_1}{\lambda}\sin\theta)} \cdot \left[\frac{2J_1(\frac{\pi D}{\lambda}\sin\theta)}{\frac{\pi D}{\lambda}\sin\theta}\right]^2 \tag{3}$$

The acoustic directivity simulation of transducer array is similar to the acoustic directivity simulation of point source surface array, but the influence of the diameter and array spacing of a single transducer must be considered, so Bessel function function in MATLAB should be called.

Select ultrasonic carrier frequency f=40kHz, wavelength λ=8.5mm, transducer diameter D=51mm, transducer array 4×4. On this basis, *d*1 and *d*2 are selected as D, 1.2D, 1.4D, 2D, 3D and 4D respectively for the distance between transducers for simulation, and the relationship between array spacing of transducers and noise propagation directivity is studied. The directivity simulations of ultrasonic propagation are shown in figure 11-16 below:

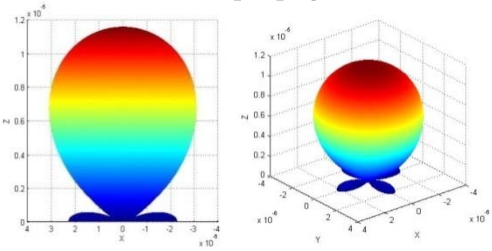

Figure 11. Directional simulation of *d*1=*d*2=D

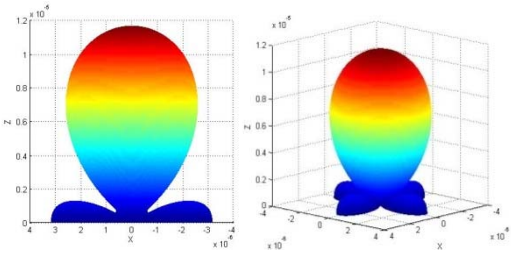

Figure 12. Directional simulation of *d*1=*d*2=1.2D

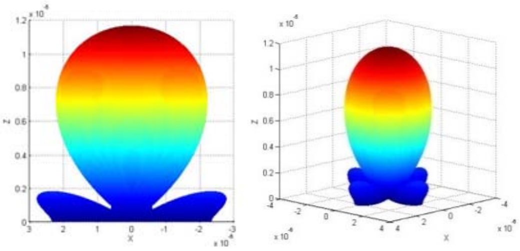

Figure 13. Directional simulation of *d*1=*d*2=1.4D

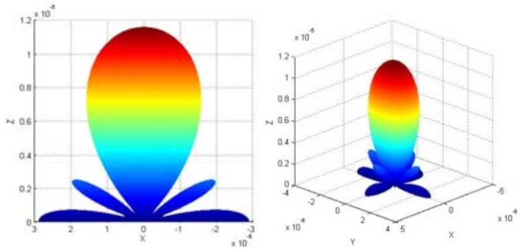

Figure 14. Directional simulation of *d*1=*d*2=2D

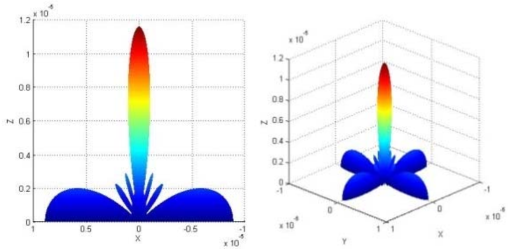

Figure 15. Directional simulation of *d*1=*d*2=3D

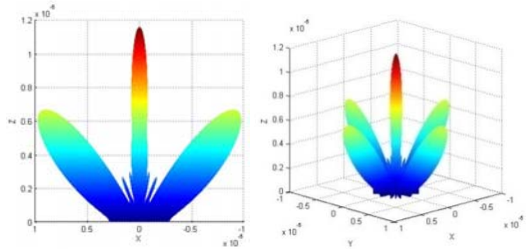

Figure 16. Directional simulation of *d*1=*d*2=4D

According to the simulation results, the directivity of ultrasonic wave propagation increases with the increasing of plane array area when the spacing of transducer array elements is within a certain range. When *d*1=*d*2=3D, the directivity effect is relatively good. Beyond this range, the number of side lobes increases and the directivity gradually deteriorates.

If only the characteristics of propagation directivity are taken into consideration, the ultrasonic directional transmission effect is best when the spacing of the transducer array is selected as *d*1=*d*2=3D. However, in the design and development of dispersing equipment, if *d*1=*d*2=3D is selected, the area of the transducer array is too large for the equipment. At the same time, for acoustic dispersing equipment, it is required to have a certain area of attack surface. Through comprehensive consideration of the size of the transducer, directional propagation effect and other aspects, the spacing of the transducer *d*1=*d*2=1.2D=61.2mm, the array is 4×4 surface array, and the ultrasonic frequency *f* =40kHz can meet the technical and tactical requirements.

Sound Pressure Level Calculation

When a strong noise directional attack ACTS on a living target, its energy must be within a certain range in order to disperse effectively. In order to evaluate the effect of noise attack, the sound pressure level of directional noise needs to be calculated, which is also the main basis for evaluating the performance of noise directional attack.

The surface element *ds* on the sound source of the transducer generates vibration, and the point P at the distance *r* from the transducer will finally generate the sound pressure acted by the surface element. The sound pressure can be expressed as:

$$dp_e = \frac{j\rho_0 c_0 k}{2\pi r} e^{-jkr} u_0 e^{-jk\varepsilon} ds$$

By calculation,

$$p_0 = 20\log\frac{p_{oe}}{p_b} = 20\log\frac{\rho_0 c_0 k u_0 a^2}{2rp_b} \tag{4}$$

Suppose the attack noise wavelength λ = 1.7mm, frequency f = 2000Hz, the plane array of the transducer is 4×4 surface array, the input power 5w, ρ_0=1.293kg /m^3,c_0= 331.6m/s, the point P is 5m away from the transducer array, calculate the sound pressure level at point P is P_0=100.12db.

If the transducer is composed into a plane array, the sound pressure generated at the far field point P is approximately equal to the sum of all the sound pressure generated by the array elements.

The sound pressure at point P also satisfies equation (4). Where the maximum sound pressure point θ= 0 °, the sound pressure sum of the surface elements can be derived as:

$$\begin{aligned} p_{0array} &= 20\log\frac{\rho_0 c_0 k u_0 S}{2\pi r} + 20\log n \\ &= p_0 + 20\log n \end{aligned} \tag{5}$$

Thus, the sound pressure level at point 5*m away* is P_{0array}=100.12+20log16=124.2db, and does not exceed 140db. Because ear noise of different frequency will produce different "loudness feeling", and 2KHz high frequency band is the most sensitive to the human ear voice, strong noise can make person produces far more than 124.2db illusion of the senses, leading to the target possible physiological reactions such as dizziness, nausea, and achieve the aim of tactical non-lethal disperse. [2]

Conclusion

Based on strong directivity noise propagation simulation analysis, considering of transducer size, the directivity effect and so on various factors, identify the ultrasonic frequency f =40KHz, directional disperse selection module array 4×4, diameter D=51mm, spacing d1=d2=1.2D = 61.2mm of planar array transducer, to achieve a reasonable non-lethal dispelling effect. An attack noise of 2kHz at 5m can generate a sense of loudness greater than 124db, which can achieve a reasonable non-lethal dissipation efficiency.

Acknowledgement

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