

Research on Vibration Characteristics of Piezoelectric Ceramic Atomizer Based on ANSYS

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Abstract. In the design and application of ultrasonic atomizer, the resonant frequency and vibration mode of piezoelectric transducer have an effect on the working state and atomization effect of the atomizer. In order to deeply study the piezoelectric ceramic ultrasonic atomizer Vibration characteristics, piezoelectric coupling simulation analysis was performed by ANSYS software, multi-order vibration mode of piezoelectric ceramic atomization sheet obtained by modal analysis method, combined with harmonic response analysis to obtain resonant frequency of piezoelectric ceramic ultrasonic atomization sheet, and analysis the influence of the main size of the atomized sheet on the vibration mode. According to theoretical analysis and experimental tests, the effectiveness of the finite element analysis can be verified, and then provide a theoretical basis for the study of ultrasonic atomizers.

1 Introduction

Ultrasonic atomization technology is widely used in agricultural aerosol cultivation, medical inhalation therapy, air humidification and many other fields because of its good atomization effect, uniform fog and small particle size. The ultrasonic atomizer generates high-frequency pressure waves by using the piezoelectric effect. The liquid medium is subjected to high-frequency vibration by the influence of ultrasonic waves, and alternately stretches and contracts on the surface of the liquid to form a surface tension wave. When the vibration reaches a certain intensity, the liquid is in the air. In the process of dispersion, numerous tiny droplets are formed to achieve atomization [1].

The core of the ultrasonic atomizer is a piezoelectric transducer, which is bonded by a piezoelectric vibrator ring and a metal cover [2]. With the inverse piezoelectric effect, the piezoelectric transducer generates high-frequency oscillation deformation when a high-frequency electric field is applied. When the resonant frequency of the piezoelectric crystal is equal to the frequency of the applied electric field, the resonance reaches a mechanical resonance state, which in turn produces high frequency vibration [3]. At this time, the electromechanical energy conversion efficiency is the highest, and the atomizer has the highest working efficiency. Therefore, studying the resonant frequency of the ultrasonic atomizer is important for the atomization effect. The finite element analysis method is a numerical analysis method widely used in engineering practice [4]. This paper will use ANSYS software to simulate and analyse the piezoelectric ceramic ultrasonic atomization sheet, by comparing with the Theoretical value, the effectiveness and accuracy of

ultrasonic nebulizers can be studied by using the finite element analysis.

2 Vibration Simulation Analysis of Piezoelectric Ceramic Atomized Sheet

The finite element analysis method is also called numerical analysis method. The basic principle is based on the variational principle and the split interpolation. The continuous structure is decomposed into a finite number of tiny elements, the node interpolation function is constructed, the equations are established, and the solution is solved by computer. Finally, observation graphs or tables are used to analyse the results in Post-processing links [5].

2.1. ANSYS Modeling and Meshing

The piezoelectric ceramic ultrasonic atomizing sheet is formed by bonding a ring-shaped piezoelectric ceramic sheet and a circular metal plate. The schematic structure of the piezoelectric ceramic ultrasonic atomizing sheet is shown in Figure 1. The piezoelectric ceramic ultrasonic wave with a theoretical resonant frequency of 160 kHz is obtained. The atomization sheet structure and material parameters are shown in Table 1.

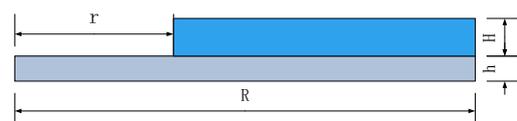


Fig. 1. The structure of piezoelectric ceramic ultrasonic atomizing sheet.

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Table 1. Piezoelectric transducer sheet parameter.

Parameter	SUS304	PZT4
Elastic Modulus (Gpa)	206	-
Poisson's ratio	0.3	-
Density (kg^m ³)	7930	7500
Outer diameter/R (mm)	5	5
Inner diameter/r (mm)	-	2.5
Thickness/H (mm)	0.12	0.6

The ultrasonic atomized sheet was modeled in the pre-treatment section. The piezoelectric ceramic material (PZT4) was selected from SOLID5 structural unit, and the metal wafer material was selected as SOLID45 structural unit [6]. The density, Poisson's ratio and dielectric properties of the two materials were respectively set. Parameters such as electrical constant, piezoelectric coefficient and elastic modulus.

Due to the good symmetry of the model, one-quarter modeling can be used to reduce the number of grids and save computing time. The mesh sweep is performed by the VSWEEP method. The finite element model summary is viewed through the List. The number of nodes divided by the model is 1600, and the number of meshes is 1044. Applying boundary conditions to the model structure, since the degrees of freedom of each unit of the model are mutually coupled, it is necessary to couple the upper and lower surface nodes and apply full boundary displacement constraints [7]. The effect of applying boundary constraints and degrees of freedom coupling is shown in Figure 2.

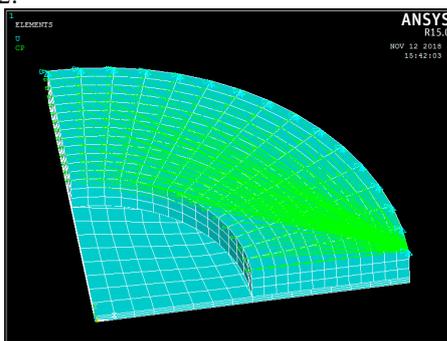


Fig. 2. The figure of applying boundary constraints and degrees of freedom coupling effect.

2.2 Modal analysis

Modal analysis is used to analyse the vibration characteristics of the structure in order to determine the natural frequency and mode shape of the structure. It can visually represent the vibration of the structure under the constraints. As one of the foundations of the dynamic

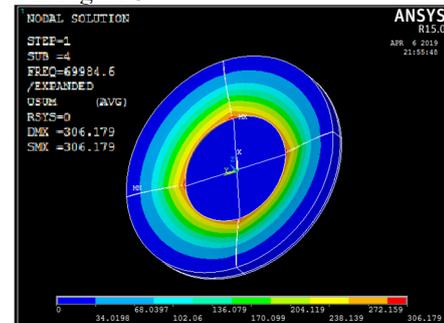
analysis, it determines Whether the system structure can achieve the optimization of power conversion [8].

In the analysis and solving module, the analysis type is defined as modal analysis, which is solved by Block Lanczos method, and is set in the frequency range of 20 kHz to 260 kHz to extract the vibration mode of the 16th order. The natural frequency table of the 16th order is shown in Table 2.

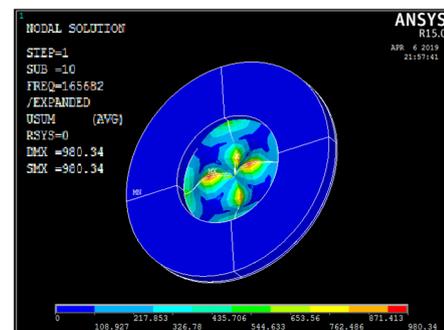
Table 2. 16 order natural frequency table.

Modal order	1	2	3	4
Natural frequency (kHz)	30.069	38.934	69.347	69.984
Modal order	5	6	7	8
Natural frequency (kHz)	83.544	95.700	101.364	120.043
Modal order	9	10	11	12
Natural frequency (kHz)	151.609	165.682	178.699	181.202
Modal order	13	14	15	16
Natural frequency (kHz)	186.395	234.910	255.656	257.246

Then use the general post-processor to view the vibration deformation of the atomized sheet, and select a representative 4th and 10th order vibration mode diagram as shown in Figure 3.



(a) 4th order (69.984kHz)



(b) 10th order (165.682kHz)

Fig. 3. Vibration deformation diagram of atomized sheet

It can be seen from Fig. 3 that there is a peak in the central region of the 10th-order atomizer, and the vibration is severe. If there is sufficient amplitude and vibration speed, the atomizer can be atomized under the vibration mode, and the fourth-order vibration mode is unavailable. Vibration mode, due to the actual operation of the atomizing sheet, the metal substrate boundary needs external force clamping. If the piezoelectric ceramic ring has severe vibration, the outer boundary vibration of the metal substrate will be more severe, it is difficult to find reasonable fixing measures, and Seriously affect the service life of the atomized sheet. Therefore, the principle of selecting a suitable mode shape is that the vibration at the center of the atomizing sheet is severe, and the vibration amplitude of the piezoelectric ceramic ring is weak to ensure the service life of the atomizing sheet.

2.3 Harmonic response analysis

The harmonic response analysis is to analyse the forced vibration of the linear structure and the steady-state dynamic behavior with time, and give the response curve of the displacement of the structure with the frequency, so as to obtain the response peak and the structural stress under the peak structure [9]. Through the harmonic response analysis, using the FULL method and selecting the sparse matrix solver, the relationship between the response peak and the frequency can be obtained. For the atomizers of different sizes, the response peak value can be obtained under the harmonic response condition, and the atomizer can be optimized.

The voltage peak across the piezoelectric ceramic is set to 20V, 20kHz~260kHz, and the harmonic response analysis is performed at 100Hz. After the ANSYS operation is completed, select 0.2mm from the center point to check the harmonic response. The vibration amplitude at the center point varies with frequency as shown in Figure 4.

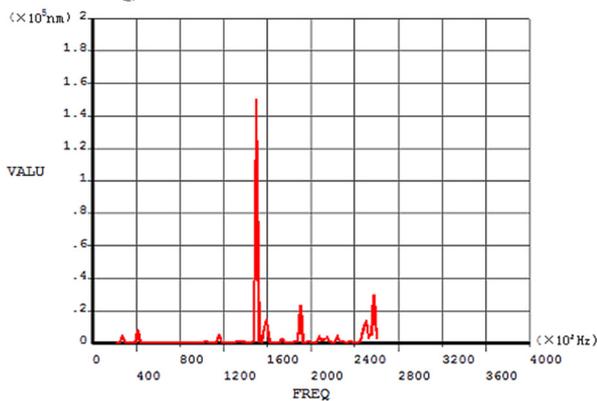


Fig. 4. Vibration amplitude at the center point as a function of frequency

As can be seen from the curve in the figure, at the frequency of 158.927 kHz, the maximum displacement of the atomizing sheet at the center position is 151.9 μm , and the atomizing sheet has the largest vibration amplitude. The theoretical atomization effect is the best. The general-purpose post-processor is used to view the vibration deformation of the atomization piece at 158.927 kHz into

a usable vibration mode, so 158.927 kHz can be used as the resonance frequency.

3 Effectiveness of finite element analysis of ultrasonic atomizer

The piezoelectric ceramic ultrasonic atomizing sheets with resonant frequency design values of 108 kHz, 113 kHz and 160 kHz were modeled and analysed to verify the effectiveness of ANSYS in the vibration analysis of piezoelectric ceramic ultrasonic atomizing sheets. Finally, the resonant frequency simulation values were obtained. The simulation value and design value pair are shown in Table 3.

Table 3. Comparison of simulated values and design values of different atomizers.

Kind	1	2	3
Inner diameter (mm)	2.5	3.9	4.0
Outer diameter (mm)	5	8	7.9
Ceramic thickness (mm)	0.6	0.6	0.6
Metal wafer thickness (mm)	0.12	0.17	0.16
Design value (mm)	160	113	108
Simulation value (mm)	158.927	115.118	109.775
Amplitude ($10^2\mu\text{m}$)	1.519	1.825	1.693

It can be seen from Table 3 that the simulation values of the resonant frequency of different atomizers and the design value are within 2 kHz, which is sufficient to prove the effectiveness of finite element analysis in determining the resonant frequency of piezoelectric ceramic ultrasonic atomizer.

In order to verify the atomization effect of different atomized sheets, the piezoelectric ceramic ultrasonic atomized sheets of 108 kHz, 113 kHz and 160 kHz were subjected to atomization experiments under the same liquid composition, with black as the background, and connected by high speed camera at the same angle and distance. In the shooting mode, the atomizer starts to work and the mist does not settle, and the atomization effect of the atomizer can be accurately determined. The atomization effect diagram of different atomized sheets is shown in Figure 5. Among them, the 113 kHz atomization sheet has the best atomization effect, the nutrient solution particle group is the largest, and after ANSYS finite element simulation analysis, the 113 kHz atomization sheet has a center point amplitude of 182.5 μm at the resonance frequency, and the 108 kHz and 160 kHz atomization sheets The amplitudes are 151.9 μm and 169.3 μm , respectively, indicating that the greater the

vibration displacement at the center point, the higher the amount of fog, and the better the atomization effect.



(a) 108kHz



(b) 113kHz

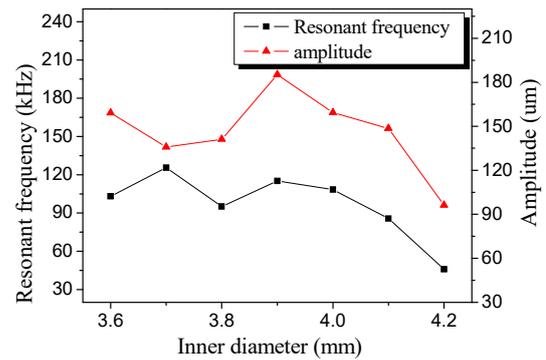


(c) 160kHz

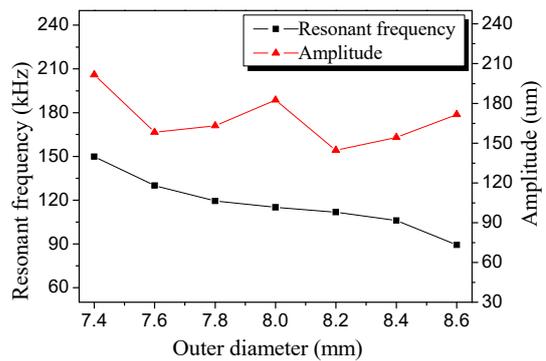
Fig. 5. Atomization effect diagram of different atomized sheets

4 Influence of different parameter sizes on the vibration of the atomized sheet

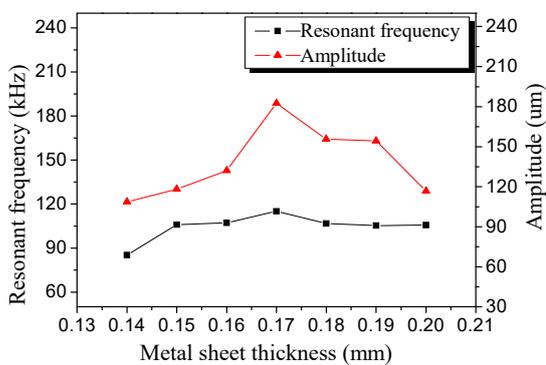
In order to investigate the influence of various main parameters of piezoelectric ceramic atomizing sheet on the resonant frequency and the amplitude of the center point, this paper changes the geometric parameters by modifying the APDL code in ANSYS software, respectively, and the inner diameter and outer diameter of the ultrasonic atomizing sheet with a design value of 113 kHz. The diameter, the thickness of the metal sheet and the thickness of the piezoelectric ceramic ring are modified by different amplitudes for simulation analysis, and the relationship between the different structural parameters and the resonant frequency of the atomizing sheet and the amplitude of the center point can be obtained as shown in Figure 6.



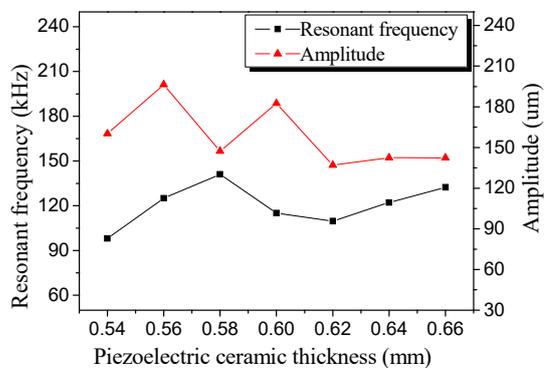
(a) Relationship between inner diameter and resonant frequency and amplitude



(b) Relationship between outer diameter and resonant frequency and amplitude



(c) The relationship between the thickness of the metal sheet and the resonant frequency and amplitude



(d) The relationship between the Piezoelectric Ceramic Thickness and Resonant Frequency and Amplitude

Fig. 6. Relationship between atomization sheet with different parameters and resonance frequency and center point displacement

It can be seen from Fig. 6 that the size and thickness of the inner and outer diameters of the piezoelectric ceramic ring have a significant influence on the resonance frequency, and within a certain range, the outer diameter is inversely proportional to the resonance frequency. Similarly, in different structural parameters, although peaks appear at some frequencies, by looking at the vibration cloud map corresponding to the frequency, the frequency is not available, indicating that the frequency cannot be used as a design reference [10], as shown in Figure 6-b. When the outer diameter is changed to 7.4mm, the resonance frequency is 149.87kHz, and the maximum amplitude is 201.6um. However, by looking at the vibration cloud image as an unusable vibration mode, the frequency cannot be used as a design reference value. Therefore, in the design of the piezoelectric ceramic ultrasonic atomization sheet, a reasonable setting of various parameters is required to ensure the maximum amplitude at the resonance frequency, thereby achieving an optimal atomization effect.

5 Conclusion

The multi-order vibration mode of piezoelectric ceramic ultrasonic atomizing sheet can be obtained by modal analysis of ANSYS software, and a reasonable vibration mode can be selected, and the frequency-displacement response curve can be obtained by combining harmonic response analysis to determine atomization. The resonant frequency of the slice.

The relationship between response peak and frequency can be obtained by harmonic response analysis. The larger the vibration displacement at the center point, the higher the amount of fog and the better the atomization effect. According to the different size of the atomizer, the response peak condition can be reached under the harmonic response condition, and the main size of the atomizer can be optimized.

The inner and outer diameters and thickness of the piezoelectric ceramic ring have a significant influence on the resonant frequency, and within a certain range, the outer diameter is inversely proportional to the resonant frequency. In the design process of the atomized sheet, it is necessary to undergo multiple simulation analysis to find out the reasonable structural parameters and ensure the service life and atomization effect of the atomized sheet.

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