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Conical Helmholtz Resonator-Based Triboelectric Nanogenerator for Harvesting of Acoustic energy *

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***Abstract*-This paper present the conical Helmholtz resonator-based triboelectric nanogenerator (CH-TENG) designed for highly efficient harvesting of acoustic energy in various occasions. This CH-TENG consists of an acoustic collecting tube, a conical Helmholtz resonant cavity and an aluminum film with uniform distributed pinholes, and a dielectric soft film with one side ink-printed for electrode. Furthermore, the effects of resonant cavity structure, sound wave frequency, sound pressure level and sound collection tube on the performance of CH-TENG are systematically studied. Compared with previous research, the proposed CH-TENG can generates higher acoustic sensitivity per unit area and power density per unit sound pressure, because the acoustic collecting tube structure gathers more sound waves and sound wave amplification capability of the Conical Helmholtz Resonator stronger. Meanwhile, this new technique to some extent can serve as a sensor.**

I. INTRODUCTION

With the development of the times, modern society pays more and more attention to the development and utilization of new energy sources (such as solar energy, wind energy, mechanical movement, geothermal energy, etc.). As a kind of energy generated by vibration and propagated in the multiple medium, acoustic energy belong to new energy sources. acoustic energy is widely distributed in nature. For example: ship engine room, factory machinery premises, traffic roads and other places have a large amount of acoustic energy and are sustainable energy sources [1-3]. Although the acoustic energy is widely distributed and rich in energy, it is almost wasted due to the low energy density of sound waves and the lack of effective collection technology. Most of the current researches are based on electromagnetic induction or piezoelectric effect to convert acoustic energy, which is vibration energy [4-7], into electrical energy. These two conversion mechanisms are difficult to effectively convert acoustic energy into electrical energy, the main reason is that the energy density of acoustic energy becomes very low due to the diffusion of acoustic energy in the process of propagation in the medium, and acoustic energy is a high-frequency vibration energy, which causes the above two conversion mechanisms [8-10] to be unable to efficiently collect acoustic energy. Therefore, it is very important to propose an efficient acoustic energy collection device. In recent years, with the rise of the triboelectric nanogenerator (TENG) technology, new ideas have been provided for efficient collection of acoustic energy. Since the triboelectric nanogenerator can use flexible materials as electrodes, TENG will be very sensitive response for external disturbance, this feature is very suitable for collecting sound wave energy. There has been work to collect acoustic energy using TENG for a long time [11]. Yang et al [12] reported an acoustic energy collection device based on a Helmholtz resonance cavity and organic thin film TENG. The acoustic collection device they reported can generate a voltage of 60.5V and a short circuit current of 15.1μA at acoustic pressure level of 110dB. Fan et al [13] reported a result of making copper and paper into a micro-hole array to enhance the collection of acoustic energy, and designed a thin and flexible acoustic energy collection TENG. Under the action of 117dB acoustic pressure, the device can generate a maximum instantaneous power density of 121mW/m2. The TENG uses paper to capture acoustic energy. Although the structure is innovative, the electrical output is still limited. Zhao et al [14]. reported an acoustic energy collection device based on a double-tube Helmholtz resonant cavity. Due to the unique double-tube design, the Helmholtz resonant cavity's amplification effect on acoustic energy is improved, making it the most efficient currently reported. Acoustic energy TENG, the above report is enough to show that TENG is very suitable for acoustic energy collection [15-18].

In this work, we propose a triboelectric nanogenerator based on a conical Helmholtz cavity (CH-TENG). The CH-TENG consists of a conical Helmholtz resonance cavity and a power generation unit. The power generation unit is composed of an aluminum film with pinholes and an FEP film. The sound waves are first collected and amplified by the conical Helmholtz cavity, and then the FEP film and the aluminum film are excited to make alternate contact and separation. The two dielectric materials undergo electron transfer to convert acoustic energy into electrical energy output. This research systematically analyzes the output performance of CH-TENG in theory and experiment. Compared with the traditional Helmholtz resonant cavity TENG, the Through a large number of experiments and simulations, we found that CH-TENG has better output performance，because the conical Helmholtz resonant cavity has better sound wave amplification capabilities than other

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forms of resonant Helmholtz cavity. Then we verified the influencing factors of CH-TENG's output performance through experiments and simulations. The results of experiments and simulations showed that sound wave frequency, sound pressure level, and conical cavity structure all have a significant impact on the output performance of CH-TENG.

II. Results and Discussion

A. CH-TENG structure and working principle

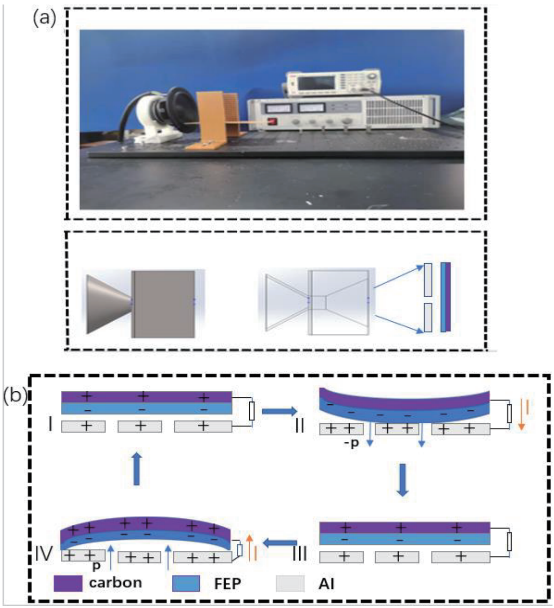

Figure1. (a) Acoustic test bench and Structure scheme of the CH-TENG. (b) Working mechanism of the CH-TENG.

As shown in Figure1.1b, the CH-TENG consists of an acoustic collecting tube， conical Helmholtz cavity, an aluminum film with uniform distributed pinholes, and a FEP film. Among them: acoustic collecting tube can gather sound waves to improve the output performance of CH-TENG. The conical Helmholtz resonant cavity is a kind of resonant cavity with powerful sound wave amplification function. The aluminum film and FEP film are important components of the power generation unit. The conical Helmholtz resonant cavity used in this paper is a special form of resonant cavity. Compared with the traditional Helmholtz resonant cavity, it has a better sound wave energy amplification performance, and in order to improve the collection of sound waves by the cavity. Ability to add a cone-shaped collection tube in front of the conical resonant cavity. In order to improve the output performance of TENG, we have performed surface micro-treatment on FEP film. Fig.1b shows the working principle of CH-TENG intuitively. First, there is a cone-shaped sound wave collecting tube at the front to collect the sound waves into the conical Helmholtz resonant cavity, the conical Helmholtz resonant cavity expands the amplitude of the sound wave, and finally the amplified sound wave acts on the FEP through the uniform small holes in the aluminum film. On the membrane, because the sound wave is a form of energy in the form of vibration, the pressure between the FEP film and the aluminum film changes periodically, and the periodic change in pressure causes the FEP film and the aluminum film to repeatedly contact and separate. When the two films are in contact, the electrons of the FEP film are negatively charged due to the different electronegativity of the two films (FEP is higher than that of aluminum), and the aluminum film loses electrons with a positive point (Fig1.bi). When the pressure in the cavity changes due to the effect of sound waves, The FEP film is far away from the aluminum film under the action of acoustic pressure, and free electrons flow from the conductive ink electrode to the aluminum electrode through an external circuit to balance the local electric field, thereby generating a positive charge on the conductive ink electrode (Fig1.1bii). Push to the aluminum film. At this stage, the voltage difference weakens, and the free electrons in the aluminum flow back through the external circuit to the conductive ink electrode (Fig1.iv). The two surfaces of the FEP film and the aluminum film contact again, and the charge distribution returns to its original state (Fig1.i). At this point, the entire power generation cycle is completed. Therefore, CH-TENG produces an AC pulse electrical output under the action of sound waves.

B. Influence of Helmholtz resonant cavity geometry

Currently reported devices that use electromagnetic induction, piezoelectric effect or TENG mechanism to convert acoustic energy into electrical energy, almost all of them use Helmholtz resonant cavity to collect and increase the amplitude of incident sound waves. The traditional Helmholtz resonant cavity is composed of the sealed cavity is composed of a short tube. The volume of the short tube is much smaller than the volume of the resonant cavity. However, there are many types of resonant cavity. After analyzing the performance of various forms of resonant cavity, we finally determined the conical Helmholtz cavity has the best acoustic amplification performance. The Fig2. shows the geometry of the double-tube Helmholtz resonant cavity and the Conical Helmholtz resonant cavity. We have built a systematic acoustic test bench to study the performance of CH-TENG's acoustic energy collection. As shown in the Fig1.(a), the sine sound wave of the test bench is provided by a speaker with a rated power of 100w, and a

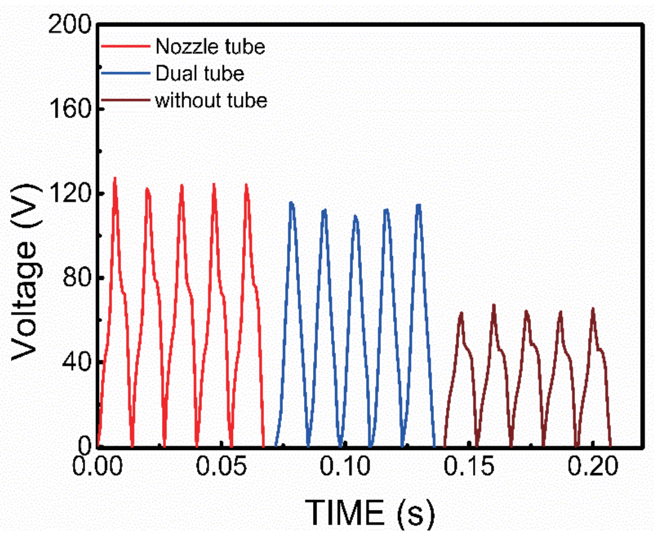

Figure2. Open-circuit voltage of the different tube of HR-TENGs under the same sound wave condition.

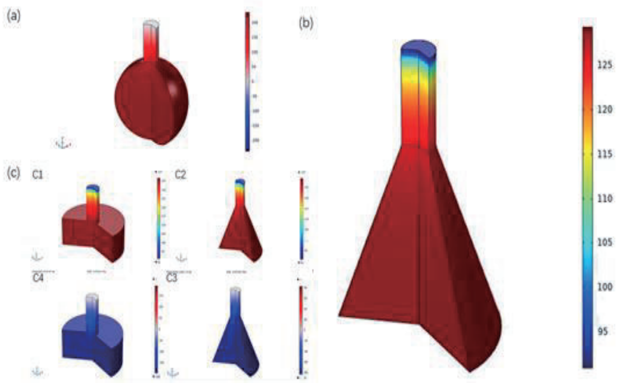

Figure3. The simulation results of different acoustic pressure level based on multiple shapes of resonant cavities.

function signal generator is used to provide a sine wave signal. Adjust the frequency of the acoustic source, the output signal of CH-TENG is collected by the data acquisition card and displayed on the computer programmed with LabVIEW software. In addition, a decibel meter with an accuracy of 1.5dB and 0.1 resolution is placed near the FEP membrane to measure the acoustic pressure level. In order to ensure the accuracy of the experiment, all the experiments in this article were done under the condition of changing different types of Helmholtz while keeping the TENG power generation unit unchanged, so the influence of different TENG performance on power generation performance was excluded. Fig2. shows the open-circuit voltage of the different tube of TENGs under the same sound wave condition. As expected, the nozzle tube can increase the power output of the TENG. The peak voltage of the Nozzle tube TENG is 130V, compared to that with a dual tube, the Helmholtz resonator with nozzle tubes can improve the output performance of the TENG by 18.1%. Fig3. shows that the simulation results of different acoustic pressure level based on multiple shapes of resonant cavities, this result indicates that compared to with the traditional Helmholtz resonator with can improve the sound waves amplification capability. Fig4.(a) displays the open-circuit voltage of the CH-TENG and traditional Helmholtz resonator-based triboelectric nanogenerator (TH-TENG) under the same sound wave condition, in order to compare the acoustic pressure amplification performance of the two resonators. The maximum open-circuit voltage of CH-TENG can reach 185 V, and the maximum open-circuit voltage of CH-TENG can reach 225V, this result indicates that, 21.6% higher than the maximum voltage of the CH-TENG with the conventional resonator. Fig4(b) shows their peak open-circuit voltages at different acoustic frequencies. With the application of the conical Helmholtz resonator, the electrical output of the TENG is improved. The maximum open-circuit voltage can reach 230 V at the optimal frequency of 130Hz. Therefore, it is proved that CH-TENG has better performance for harvesting of acoustic energy. We further studied the influence of the taper of the conical cavity on the output performance of TENG. The taper was changed by changing the size of the front-end circular hole D1, and other conditions remained unchanged.

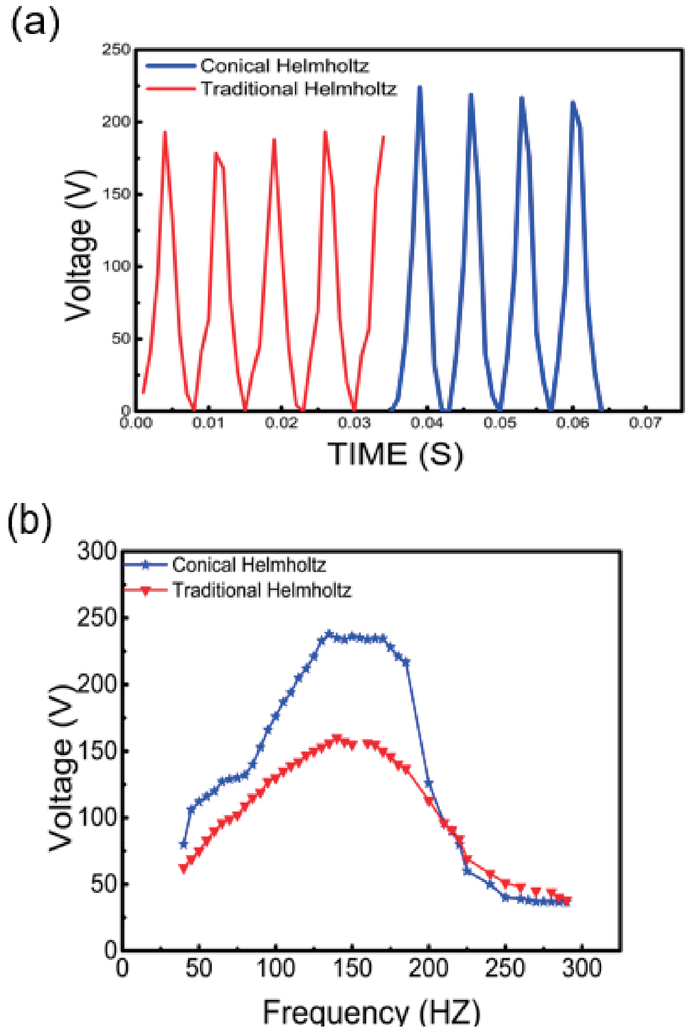

Figure4. (a)Open-circuit voltage of the CH-TENGs and TH-TENG under the same sound wave condition. (b)Open-circuit voltage of the Conical Helmholtz and Traditional Helmholtz at different acoustic frequencies.

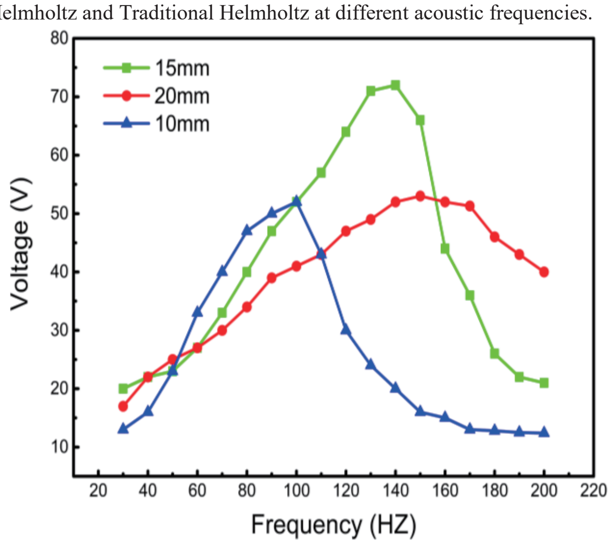

Figure5. The influence of the size of the front hole on CH-TENG

The Fig5. shows three different front-end circular holes D1 CH-TENG in Peak open circuit voltage at different acoustic frequencies. As the diameter of the hole changes, the output performance of CH-TENG has made a significant change. The TENG output performance has changed significantly. The acoustic source frequency range is 30-

200Hz and the acoustic pressure level range is 70.1-92.3dB. When the acoustic source frequency is 50-100Hz, the CH-TENG with a hole diameter of 10mm has the best output performance. The voltage continues to increase with the increase of the acoustic source frequency and reaches a peak voltage of 52.6V when it reaches 100Hz. However, when the frequency is higher than 80Hz, the output performance begins to decrease. When the frequency range is 100-160Hz, the output performance of the 15mm hole TENG is the best, reaching a peak voltage of 75.1V at a frequency of 140Hz.When the frequency is greater than 160Hz, the 20mm hole TENG has the best output performance. What is more interesting is that as the hole diameter increases, the optimal response frequency of CH-TENG gradually increases, and at the same time the frequency bandwidth gradually increases, but the output performance first increases and then decreases.

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III. CONCLUSION

In summary: the conical Helmholtz resonant cavity has better acoustic pressure amplification performance, and has a wider response bandwidth, so it is very suitable for making an acoustic energy collection device. This device has a wide range of application scenarios. It can be used as an acoustic energy sensor and placed in mechanical equipment. The acoustic information of mechanical operation is collected nearby, and the acoustic information collected by CH-TENG can be analyzed for failure detection of mechanical equipment. This is a new type of self-powered acoustic sensor. You can also integrate CH-TENG and place it on the side of the highway to make it into a highway noise barrier that can collect acoustic energy and reduce vehicle noise.

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