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Design and Experimental Study of Bellows Type Standard Infrasound Generator

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Abstract: *Infrasound is widely used in nature and human activities, such as earthquakes, volcanic eruptions, mudslides, nuclear explosions, supersonic flight, weapons targeting, etc. Infrasound has strong penetrating ability, long propagation distance, low attenuation, and is widely used in environmental monitoring, military fields, industrial production and other fields. The monitoring of infrasound sound pressure signal mainly depends on the infrasound sensor, and the accurate measurement of infrasound sound pressure mainly depends on the calibration of the infrasound sensor, and the accurate measurement of the infrasound sensor is the premise and guarantee of the application of the infrasound sensor. In this paper, we propose a bellows type standard infrasound generator solution for the piston leakage problem of the most widely used gas cavity pressure method in the calibration of infrasound sensors, obtain the expression of sound field distribution in the bellows by theoretical derivation, and design a calibration device containing an infrasound sound pressure generator, feedback control and infrasound excitation system, data acquisition conditioning system and laser measurement calculation system. The above device was physically built and experiments were conducted on the bellows type standard infrasound generator, and the infrasound time-domain waveform maps from 0.01Hz to 20Hz were obtained. The experimental results show that the bellows type standard infrasound generator designed in this paper can generate standard infrasound sound pressure signals.*

Keywords: *Infrasound, Generator, Calibration, Bellows*

1. Introduction

Infrasound widely exists in nature and human activities, such as earthquakes, volcanic eruptions, mudslides, nuclear explosions, supersonic flight, weapons targeting. Infrasound has a strong penetrating ability, propagation distance, attenuation and other characteristics, and is widely used in environmental monitoring, military fields, industrial production and other fields. Since the appearance of infrasound is often accompanied by large explosions or high power events, it is difficult to be eliminated, the propagation distance is extremely long, so it has become the main means of monitoring the location and yield of nuclear explosions in the field of national defense, aircraft monitoring, a variety of large weapons targeting monitoring. Infrasound has a low frequency, long wavelength, long propagation distance, propagation attenuation is small, so the monitoring of infrasound is not restricted by the conditions of visibility, concealment, not affected by electromagnetic waves, monitoring a long range. At present, infrasound research has been widely used in the field of national defense and national economy, the development of infrasound equipment has reached a large scale, giving rise to infrasound industry in full swing expansion, and thus the need to improve the accuracy of infrasound sensors and calibration capabilities, improve the level of infrasound research, and enhance the ability to analyze infrasound signals. The monitoring of the infrasound sound pressure signal mainly relies on the infrasound sensor, and the accurate measurement of the infrasound sound pressure mainly depends on the calibration of the infrasound sensor, and the accurate measurement of the infrasound sensor is the premise and guarantee of the application of the infrasound sensor.

The calibration methods for infrasound sensors mainly include the coupled-cavity reciprocity method and the gas-cavity pressure method. The coupled-cavity reciprocity method is only applicable to the calibration of infrasound sound pressure above 2 Hz. For the calibration of infrasound transducers at low frequencies, the most widely used method is the gas-cavity pressure method, which means that the gas volume in the cavity is changed by electromagnetic actuators or other driving mechanisms, and then the dynamic pressure is obtained to achieve the calibration of the transducer.

At present, the calibration of infrasound sensors at home and abroad mainly uses laser piston generators. Take the infrasound generator developed by Zhejiang University and National Institute of Metrology in China as an example, the shaker adopts the displacement feedback method to drive the piston to do low displacement distortion sinusoidal motion in the closed infrasound generator cavity to generate the standard infrasound sound pressure signal; the laser vibrometer shoots a laser beam through the optical channel of the shaker to measure the displacement of the moving parts of the shaker and calculate the standard sound pressure value generated by the infrasound generator cavity; the calibrated infrasound sensor and the standard infrasound sensor are installed in the infrasound generation cavity, and the absolute calibration or relative calibration of the infrasound sensor can be achieved by detecting the output of the sensor being calibrated. As the frequency decreases, the air leakage becomes more serious and more difficult to correct, so it is not suitable for too low frequency, and the calibration frequency range is (0.1~20) Hz. In practical applications, many infrasound signal frequencies are lower than 0.1 Hz, and the existing calibration devices cannot meet the needs of practical use[1-2].

In short, the piston sounding way above the frequency 0.1Hz is relatively ideal, but because of the gap between the piston and the piston cavity, there is bound to be leakage. The piston and the piston cavity machining accuracy is only to increase the leakage time, but can not eliminate the leakage, when the frequency is very low, such as 0.01Hz, in up to 100s of cycles, its internal pressure is easy to leak, so that distortion of sound is generated. Therefore, it is necessary to adopt a sealed sound generation method to avoid the leakage from the principle. In this paper, we propose to use bellows for the design of a standard infrasound generator.

2. Principle

The ideal simplified theoretical model of the infrasound generator can be obtained by approximating the equation of state of the adiabatic process gas, whose expression is

$$p = \frac{\gamma P_0 \delta V}{V_0} \tag{1}$$

Where γ is the specific heat ratio, P_0 is the static pressure, V_0 is the initial volume, δV is the volume change.

However, at low frequencies, pressure leakage, heat conduction, and viscosity affect the infrasonic sound pressure inside the cavity; at large infrasonic sound pressure levels the above equation is also not applicable due to nonlinear compression. Therefore, it is necessary to obtain more accurate expressions for the distribution of the sound field considering pressure leakage, heat conduction, viscosity, and nonlinear compression.

The bellows is usually cylindrical, which is easier to process and at the same time can obtain the maximum surface area. Therefore, it is proposed to obtain the sound field distribution in the cylindrical cavity by theoretical calculations based on the acoustic equations considering pressure leakage, heat conduction, viscosity, nonlinear compression and other factors, and based on the boundary structure. After obtaining the sound field distribution, different structural parameters are changed through simulation to select and design the most suitable structure of the generator cavity.

According to the equation of acoustic wave fluctuations in column coordinates:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 p}{\partial \theta^2} + \frac{\partial^2 p}{\partial z^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{2}$$

Solving the equation, the expression for the distribution of the cylindrical sound field is obtained:

$$p = \sum_{m=0}^{\infty} J_0\left(\gamma_{0m}\frac{r}{a}\right)\left[A_m \cos\left(k_{z_0 m} z\right) + B_m \sin\left(k_{z_0 m} z\right)\right] e^{j\omega t} \tag{3}$$

Where r is the column coordinate radial coordinate, p is the infrasound sound pressure, c is the sound velocity, z is the column coordinate axial coordinate, θ is the column coordinate angular coordinate, t is the time, $J_0\left(\gamma_{0m}\frac{r}{a}\right)$ is the zero-order Bessel function $k_{z_0 m} = k\sqrt{1-\left(\frac{\gamma_{0m}}{ka}\right)^2}$, $k = \frac{\omega}{c}$, a is the diameter of the bellows, γ_{0m} is the root of the zero-order Bessel function, ω is the angular

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frequency. According to different boundary conditions, the specific expressions of the coefficients A_m, B_m and the infrasound pressure at different locations in the cylindrical sound field can be determined.

3. System Components

The overall design scheme is shown in Figure1. It mainly consists of 4 parts, including: infrasound pressure generator; feedback control and infrasound excitation system; data acquisition and conditioning system; laser measurement and calculation system.

The working process is: the control system controls the vibration of the infrasound excitation source, which drives the bellows reciprocating motion, and the bellows is like a spring that stretches and compresses periodically to produce the corresponding infrasound pressure by compressing the air in the closed cavity, and the harmonics of the generated infrasound pressure are suppressed by the reasonably designed cavity of the infrasound pressure generator. The feedback sensor measures the distortion of the generated waveform to the control system, and adjusts the vibration of the infrasound excitation source through the feedback of the control system to ensure that the cavity produces the infrasound waveform with small distortion[3].

The vibration velocity of the air mass in the cavity is precisely measured by a laser interferometer. The output signal of the laser interferometer is quantified by the data acquisition system and then enters the computer for subsequent processing. After obtaining the vibration velocity of the air mass, the standard value of the infrasound pressure can be calculated by considering the "mass vibration velocity-infrasound pressure" model correction formula of heat conduction, leakage and other factors.

The output of the microphone under test is amplified by the adjustment and data acquisition into the computer, and the output voltage of the calibrated microphone under the infrasound sound pressure input conditions in the sound field is calculated. The microphone sensitivity is obtained from the output voltage of the microphone and the standard value of infrasonic sound pressure. By changing the frequency of the infrasound excitation source and the vibration speed of the mass, the standard infrasound sound pressure of 0.01Hz~20Hz is obtained.

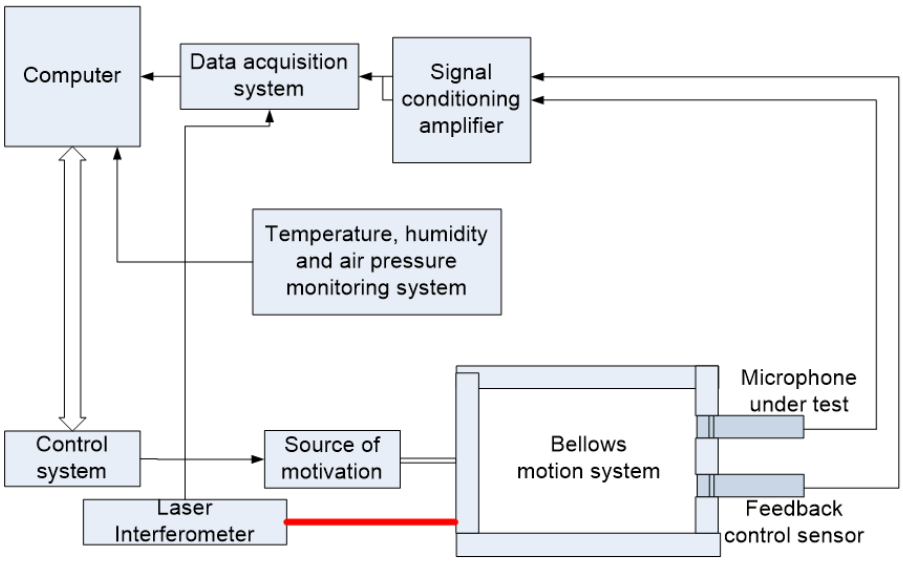

Figure 1: Block diagram of the overall design scheme.

4. Experiments

The physical bellows type infrasound generator built in this paper is shown in Figure 2. Experiments were conducted on the bellows type standard infrasound generator, and the experiments included obtaining the infrasound time domain curves from 0.01Hz to 20Hz. The specific method was the direct measurement method. The signal source provided the infrasound generator with different frequencies of sinusoidal signals, driving the low infrasound generator in the bellows cavity to generate infrasound. The

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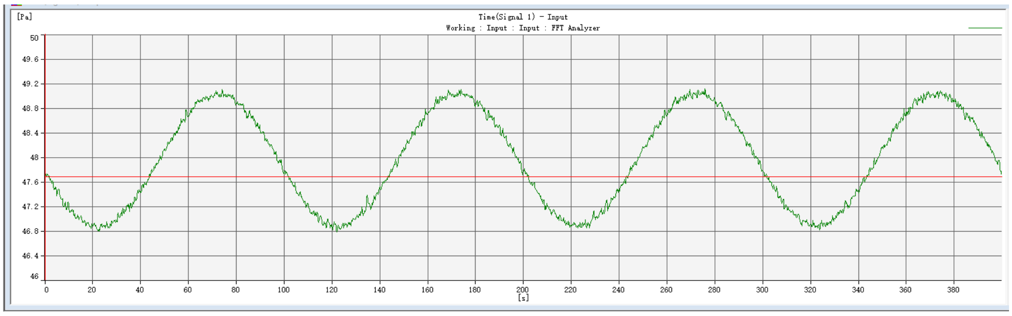
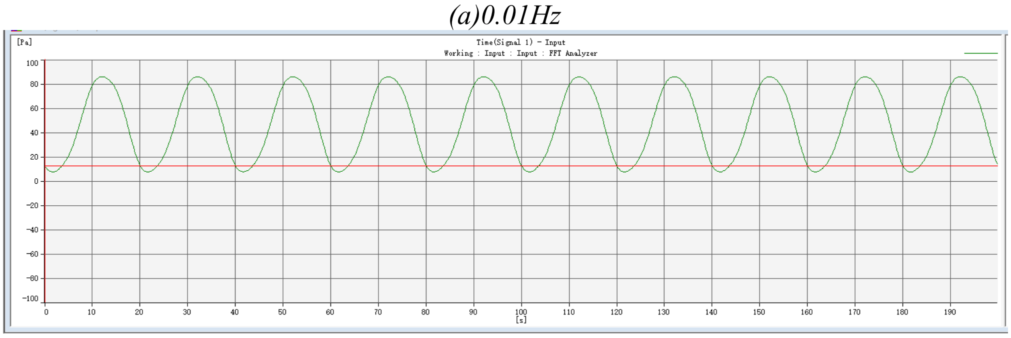
B&K 4964 infrasound microphone measured the sound pressure, and the dynamic signal analyzer measured the output of the infrasound microphone[4-5].

The experimentally obtained waveforms at each frequency are shown in Figure 3. From Figure 3, it can be seen that the bellows type standard infrasound generator is capable of generating standard infrasound sound pressure signals in the frequency range of 0.01 Hz to 20 Hz.

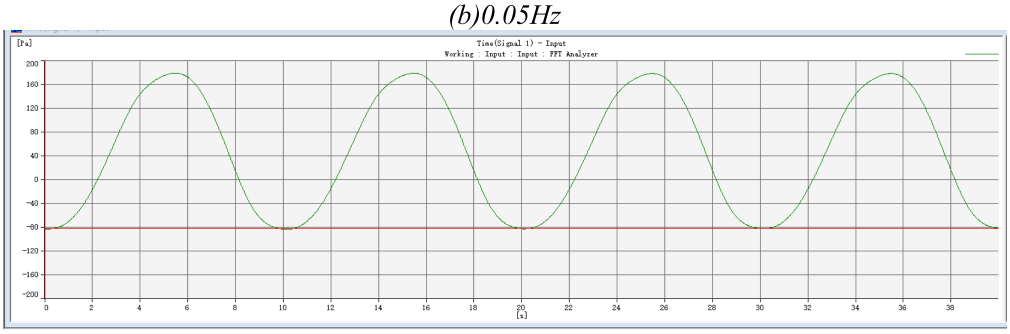
Figure 2: Physical diagram of bellows type standard infrasound generator.



(a)0.01Hz



(b)0.05Hz



(c)0.1Hz

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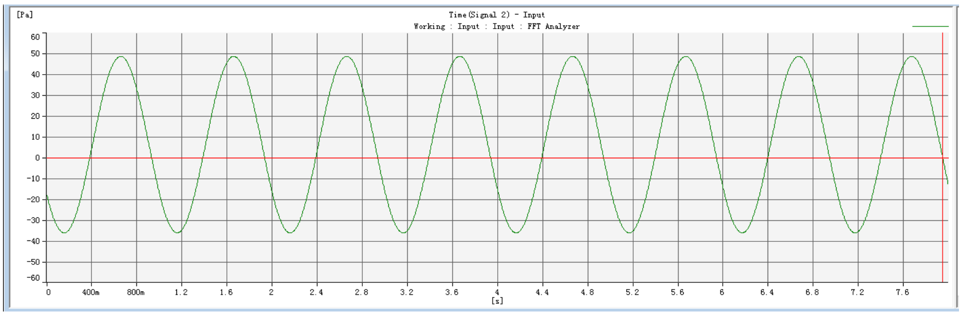
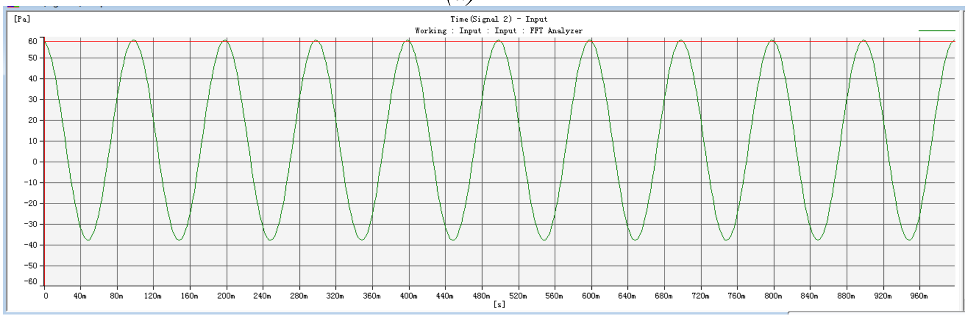
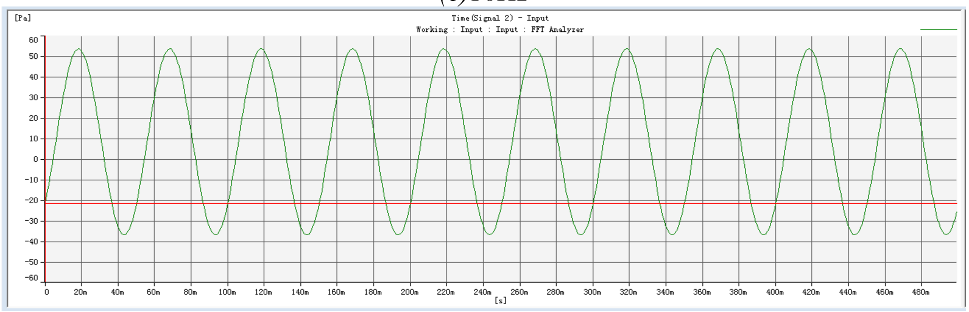


(d)1Hz



(e)10Hz



(f)20Hz

Figure 3: Waveforms of infrasound signal generated by bellows type standard infrasound generator.

5. Conclusions

In this paper, a bellows type standard infrasound generator is designed to solve the leakage problem of the conventional piston sounding method in the most common gas chamber pressure method for infrasound sensor calibration. The bellows type standard infrasound generator with sealed sound generation method avoids the leakage from the principle, and the system of laser test, data acquisition and feedback control is designed. The above device is physically built and experiments are conducted on the bellows type standard infrasound generator. Experiments are conducted to obtain the infrasound time domain waveforms from 0.01Hz to 20Hz. The experimental results show that the bellows type standard infrasound generator designed in this paper can generate standard infrasound sound pressure signals.

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