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CALIBRATION OF INFRASOUND SENSORS: AN EXTENSIVE STUDY ON ENHANCING DIFFERENTIAL NOISE SUPPRESSION

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Abstract: Infrasound, characterized by its low frequency, long wavelength, and extensive propagation range, is a pervasive phenomenon resulting from natural events and human activities. Its ability to penetrate over long distances with minimal attenuation renders it invaluable in applications ranging from environmental monitoring to military surveillance. Infrasound's role in detecting nuclear explosions, monitoring supersonic aircraft, and tracking large weapons targeting underscores its significance in national defense.

The propagation of infrasound remains unhindered by visibility or electromagnetic interference, making it an exceptional monitoring tool, ideal for long-range surveillance. The field of infrasound research has witnessed rapid expansion, leading to the growth of the infrasound industry. As a consequence, the accuracy of infrasound sensors and calibration capabilities has become a focal point for improvement. This endeavor seeks to advance infrasound research and enhance the analytical capabilities of infrasound signal data.

Key to the precise measurement of infrasound sound pressure is the calibration of infrasound sensors, which serves as the linchpin for accurate monitoring and analysis in a multitude of domains.

Keywords: Infrasound, Sensor Calibration, Environmental Monitoring, National Defense, Signal Analysis

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 of 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[1].

The infrasound generator used in the laser piston generator method is piston, and there is an inevitable gap between the piston and the piston cavity, which leads to the existence of leaks. The piston and piston cavity machining accuracy improvement only increases the leakage time, but cannot eliminate the leakage.

Since the infrasound sound wave length is very long, which is not easily reflected and absorbed, the infrasound sound motion in the ambient atmospheric pressure (such as mountain waves, door opening disturbance, wind noise, etc.) is difficult to filter out as environmental noise, and can interfere with the atmospheric pressure in the pressure chamber. In particular, the pressure cavity and the ambient atmospheric linkage will affect the waveform of the generated infrasound. For the 0.01Hz infrasound calibration, the infrasound period is 100s, and at least 3~5 complete waveforms need to be collected during the calibration process. Based on accumulated experimental data on atmospheric pressure, the local atmospheric pressure can vary by up to a dozen Pa in 500s. Therefore, this paper will optimize the design of the infrasound generator structure and sensor feedback control to reduce the impact of the infrasound waveform in the ambient atmospheric pressure [2].

2. System Design

2.1. Laser Absolute Method Infrasound Calibration Device

The composition of the laser absolute method infrasound calibration device is shown in Figure 1. The calibration device consists of laser vibrometer, low-frequency shaker, piston, main confinement chamber, reference confinement chamber, differential pressure sensor, isolation chamber, temperature and pressure monitoring system, data acquisition module, and computer. The working process is as follows: the shaker generates standard sinusoidal vibration under the control of the control system, which drives the piston to reciprocate. The piston is connected to the main confinement chamber, and the reciprocating motion of the piston compresses the air in the main confinement chamber to produce a standard infrasound signal. The laser vibrometer calculates the standard sound pressure value in the main confinement chamber by measuring the displacement of the moving parts of the shaker, and the calibrated infrasound sensor is

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installed in the main confinement chamber to collect the infrasound sound pressure signal[3].

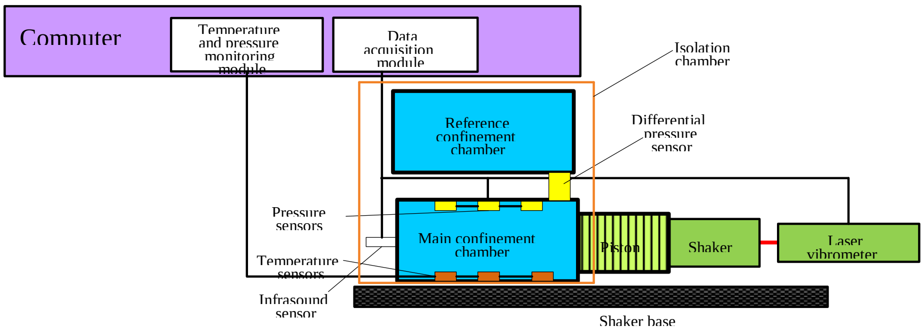

Figure 1: Scheme of laser absolute method infrasound calibration device.

The vibration velocity of the air mass in the cavity is precisely measured by a laser vibrometer. The output signal of the laser vibrometer 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 infrasonic sound pressure is calculated by modifying the "mass vibration velocity - infrasonic sound pressure" model taking into account thermal conduction, leakage and other factors. The output voltage of the microphone under the infrasound pressure input condition is calculated by the computer through the amplification and data acquisition system. The microphone sensitivity is obtained from the microphone output voltage and the standard value of infrasound sound pressure. The frequency of the infrasound excitation source and the vibration speed of the mass are changed to obtain the standard infrasound signal at different frequencies.

2.2. Differential Noise Reduction System

The differential noise reduction system consists of a main confinement chamber, a reference confinement chamber, a differential pressure sensor and an isolation chamber. The design scheme of the differential noise reduction system is shown in Figure 2. A second confinement chamber is set up as a reference confinement chamber at the location adjacent to the main confinement chamber with the same structure, shape and size as the main confinement chamber, and an additional isolation chamber is added outside the main confinement chamber and the reference confinement chamber to further reduce the impact of atmospheric pressure fluctuations on the infrasound signal. Because of the slow atmospheric fluctuations in the indoor environment, coupled with the above various shielding structure design, so that the fluctuation rate will be very low, and the infrasound dynamic coverage of space is very wide, so it can be considered that for a short period of time, the background interference noise in the main confinement chamber and the reference confinement chamber is the same. Thus, by installing a differential pressure transducer between the two confinement chambers, the output of which is the difference of the pressure in the two cavities, most of the background interference can be eliminated and the sound pressure generated by the infrasound generator in the main confinement chamber can be accurately measured[4]. Therefore, the infrasound generator can be controlled by feedback using the differential pressure transducer in the low frequency band.

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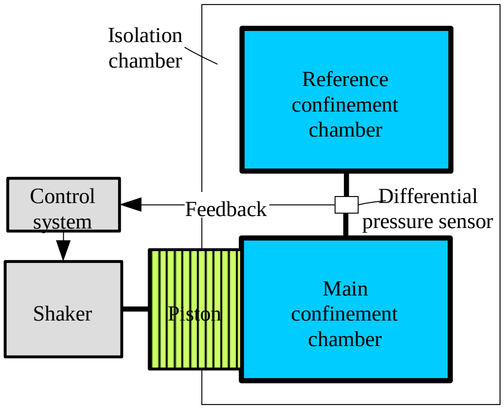

Figure 2: Block diagram of differential noise reduction system.

2.3. Calculation Method

The pressure at the end of the differential pressure sensor connected to the main confinement chamber is p_1, and the pressure at the end of the reference confinement chamber is p_2, then the output of the differential pressure sensor is:

$p = p_1 - p_2$ (1) Where p is the output of the differential pressure sensor, Pa.

p_1 is the sum of the pressure and background interference noise generated by the infrasound generator in the main confinement chamber, Pa.

p_2 is the background interference noise in the reference confinement chamber, Pa.

Under the shielding effect of the external isolation chamber, it is considered that the background interference noise in the main confinement chamber and the reference confinement chamber is the same for a short time, so the output of the differential pressure sensor is the pressure generated by the infrasound generator in the main confinement chamber.

3. Experiments

According to the design scheme of differential noise reduction system, the differential noise reduction system was built and the noise reduction effect of the differential noise reduction system was tested. The experiments include obtaining the time domain curves of atmospheric pressure in the main confined cavity and the reference confined cavity. The specific method is the direct measurement method, the signal source of the infrasound generator is turned off, and it can be assumed that the background interference noise in the main confinement chamber and the reference confinement chamber are the same for a short time, and the time domain curves of the atmospheric pressure in the main confinement chamber and the reference confinement chamber are measured using the differential pressure sensor, as

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shown in Figure 3.

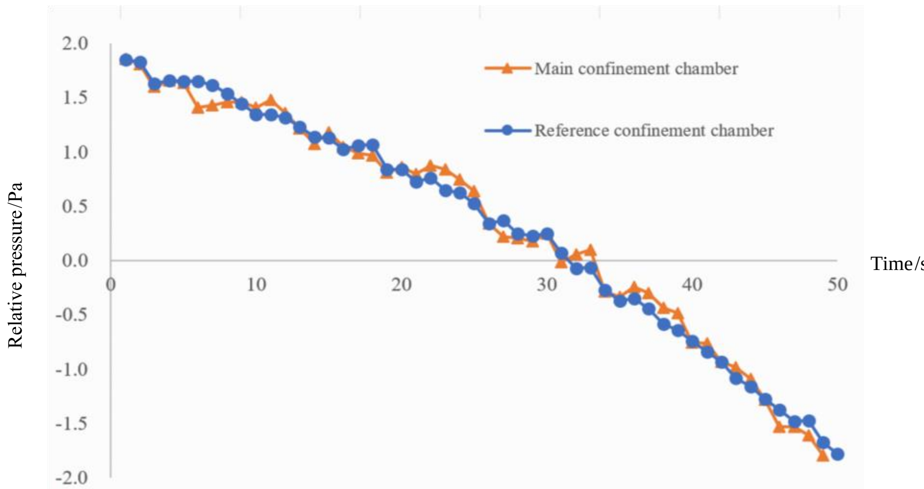

Figure 3: Relative pressure waveforms of main confinement chamber and reference confinement chamber.

As shown in Figure 3, the pressure changes in the main confinement chamber and the reference confinement chamber have the same trend, and the fluctuation of atmospheric pressure can be up to 4 Pa in 50 s. Moreover, the pressure fluctuation in the main confinement chamber is larger, and the pressure fluctuation in the reference confinement chamber is smaller. The reason for this phenomenon is that the main confinement chamber is connected to the piston and there is a gap between the piston and the piston cavity, which is more easily affected by the atmospheric fluctuation[5].

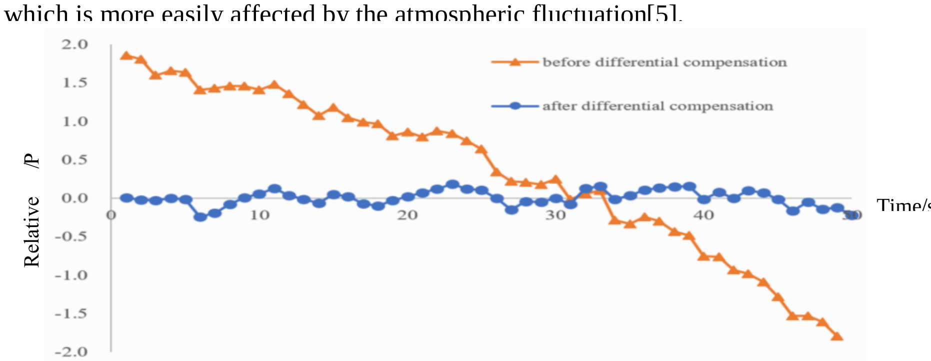

Figure 4: Main confinement chamber pressure waveform before and after differential compensation.

The difference between the main confinement chamber pressure value p_1 and the reference confinement chamber pressure value p_2 is made to obtain the differential system output p, and the relative values of the main confinement chamber pressure and the differential noise reduction system output pressure values are plotted in the same graph, as shown in Figure 4. As can be seen from Figure 4, the pressure fluctuation of the infrasound generator without differential noise reduction is ±2 Pa, and after the compensation of the differential noise reduction system, the pressure fluctuation is ±0.2 Pa, which significantly reduces the interference generated by the fluctuation of atmospheric pressure in the environment.

4. Conclusions

When using the laser piston generator method for infrasound sensor calibration, due to the gap between the piston and the piston cavity, external environmental noise and atmospheric pressure fluctuations will interfere with the pressure in the infrasound generator cavity, which in turn affects the waveform generated by the infrasound generator. This paper focuses on the differential noise reduction technique of the infrasound generator, through structural design, sensor feedback control and the addition of an isolation chamber, the interference in the atmospheric pressure is reduced. It is verified that the atmospheric pressure fluctuation within 50s can be reduced from ±2Pa to ±0.2Pa, which significantly reduces the interference generated by the atmospheric pressure fluctuation in the environment.

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