Research of a High Thermal-noise Test System Based on Progressive Wave Sound Field

Zhiqiang Shen, Guiqian Fang, Yao Wu, Xinming Li and Jungang Zhang
Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China

277099061@qq.com

Abstract. Basing on the existing situation of the thermal source, this paper designed a thermal noise load simulation test system which can make the 1200 mm × 1200 mm large panel structure meet the requirement of 165 dB (GJB150.17 A - 2009) and 1200 °C. This paper introduced the overall design and the design method of the key components. In this paper, the acoustic field uniformity of progressive wave and the acoustic field distribution at the surface of the specimen under high temperature are analyzed by means of numerical simulation. Finally, the developed system was verified by using 1200 mm × 1200 mm wallboard structure which led to a stable and good effect.

1. Introduction
Re-entry space vehicle is one of the important development directions in the international aerospace field.[1-2] The flight environment of the re-entry space vehicle is extremely demanding. The high sound intensity noise in the local area exceeds 180 dB, and the thermal load exceeds 1200 kw/m²[3-4]. The high-temperature environment will have a serious impact on structural material properties, structural dynamics, and automatic control[5-6].

During high speed reentry, the local temperature of the re-entry space vehicle can reach to 2000 °C. Extremely high surface temperatures, high temperature gradients, high noise pulsating pressures and long cruises are the distinguishing features of re-entry space flying environments. Therefore, the effects of the thermal-noise composite load environment must be considered during the structure design of the new-typed re-entry space vehicle. The integrity and durability of the structure in a thermal noise environment must be assessed too[7].

In this paper, the research of a high thermal noise load simulation test system based on progressive wave sound field is carried out. The system consists of a heat source and a progressive wave tube. The existing heat source is composed of a quartz lamp array, which can provide a heat flux density of 1.2 Mw/m², a filament temperature of 2000 °C and the wavelength of 3 to 4 nm. Basing on the existing situation of the thermal source, this paper designed a thermal noise load simulation test system which can make the 1200 mm × 1200 mm large panel structure meet the requirement of 165 dB (GJB150.17 A - 2009 [8]) and 1200 °C.

2. Design of the high thermal noise test system based on progressive wave sound field

2.1. Overall design
The high thermal noise load simulation test system based on progressive wave sound field includes: air supply, sound source, horn, progressive wave tube body, silencer, acoustic measurement and control subsystem, as shown in Figure 1. After the modulator is carried out by the air supply, the noise generated by the modulator is amplified by the horn and transmitted to the test section, where a noise test environment is formed. The heat source heats the test product through a quartz glass window, as shown in Figure 2.

Figure 1. Progressive wave test system.

Figure 2. Type of heating.

2.2. Test section design of the progressive wave tube

The design of the progressive wave tube is the key point to the design of the high thermal noise test system. The total sound pressure level of the progressive wave tube is closely related to the cross-sectional area of the progressive wave tube and the sound power of the sound generator. First, the smaller the cross-sectional area of the progressive wave tube is, the easier it is to meet the requirement of high sound intensity. Secondly, in order to avoid acoustic reflection, the bending of the progressive tube and the mutation of the cross-sectional area should be minimized. The goal of the system is to carry out a thermal noise test of a large plate structure of 1200 mm × 1200 mm. Considering the above two factors comprehensively and combining with the matching method of the progressive wave tube and the horn, the cross section of the progressive wave tube adopts a rectangular cross section, and the sectional size is designed to be 1500 mm × 300 mm.

The modal frequency is calculated according to the characteristic equation of the rectangular progressive wave tube.

\[
f_{n_x, n_y} = \frac{c_0}{2} \left[ \left( \frac{n_x}{l_x} \right)^2 + \left( \frac{n_y}{l_y} \right)^2 \right]^{1/2}
\]

The cut-off frequency of the progressive wave tube is 113 Hz. The design of the progressive wave tube length is based on the criterion that the inside of the tube can accommodate a wavelength, and the length of the progressive wave tube is designed to be 6 meters. The progressive wave tube is divided into three sections for processing, which are respectively the test section, the front section and the rear section, each section having a length of 2 meters.

When the test section of the progressive wave tube is the most important structural part of the progressive wave tube, the test product is installed on the side wall of the test section, and the heat source heats the test product through the quartz glass. The design of the progressive wave tube test section is shown in Figure 3. It includes: product mounting surface, quartz glass heating window, test section body, water circulation cooling subsystem.

The test section is welded by a high temperature alloy steel (GH3536) with the thickness of 20 mm. The long-term use temperature of GH3536 high temperature alloy steel reaches 900 °C (the temperature that does not decrease the mechanical properties for more than 24 hours), and the temperature exceeds 1100 °C within 4 hours. It is one of the highest temperature-resistant alloy steel materials in China. In order to ensure that the system can withstand high temperatures of 1200 °C, a
coating material that can be insulated from 100 °C to 150 °C on the surface of the alloy steel is used in this paper. A cooling water pipe is installed on the quartz glass mounting surface and the back side of the product mounting surface for cooling. The quartz heating window is made of a monolithic glass whose size is 1400 mm×1300 mm. After installation, the heating window size is 1300 mm×1200 mm. The near-ultraviolet and near-infrared transmittance of the quartz heating window are more than 90%.

![Figure 3. Test section of the progressive wave tube.](image)

2.3. The sound source design of the progressive wave tube

The relationship between the total sound pressure level of the progressive wave tube and the sound power is as follows.

\[ L_p = 10 \log \left( \frac{W}{S} \right) + 114 \text{ (dB)} \] (2)

The system's total sound pressure level requires 165dB, and the required sound power is about 57,000 sound watts. The sound source of the system includes a high frequency modulator and a low frequency modulator. The high-frequency modulator period is the EPT200 type modulator produced by LING company, as shown in Figure 4. The low-frequency modulator is a high-power modulator LF60 type modulator produced by SEREME company. The two modulators can be used together with a sound power of up to 60,000 watts to meet system requirements.

![Figure 4. EPT200 modulator.](image)  ![Figure 5. LF60 modulator.](image)

2.4. The horn design of the progressive wave tube

In order to solve the problem of impedance matching between the sound source and the progressive wave tube, an ideal and practical method is to add a finite length horn with a certain shape between the sound generator and the progressive wave tube. The horn gradually expands into an impedance matching component according to an exponential function. The front end of the horn is connected to the sound source, the rear end is connected to the progressive wave tube, and the low frequency horn and the high frequency horn are arranged up and down.
The cross-sectional area $s$ of the exponential type horn is calculated according to the following formula.

$$s = s_0e^{mx} \quad (3)$$

The cutoff frequencies of the two horns (Fig. 6) of the system are 50 Hz and 200 Hz, respectively. The cutoff frequency is 50 Hz, the horn inlet diameter is 100 mm, the outlet section size is $1100\,\text{mm} \times 300\,\text{mm}$, and the length is 2000 mm. The horn of the cutoff frequency of 200 Hz has a diameter of 100 mm, the outlet section size is $400\,\text{mm} \times 300\,\text{mm}$, and the length is 410 mm.

Figure 6. Horns of the progressive wave tube.

3. Numerical simulation of the high thermal noise test system based on progressive wave sound field

3.1. Analysis method

According to the design scheme, the progressive wave tube acoustic simulation model is established, and the sound field intensity and distribution inside the progressive wave tube are simulated to verify whether the sound intensity can meet the index requirements and the sound field distribution uniformity is evaluated. The simulation calculation can provide the basis for the acoustic design of the progressive wave tube and the subsequent acoustic test. The noise simulation analysis in this paper is based on the acoustic boundary element method (BEM), which is analyzed by professional noise analysis software Virtual.Lab Acoustics[9].

3.2. Frequency response and uniformity analysis

In order to study the uniformity of the sound field in the progressive wave tube perpendicular to the test specimen, this paper analyzes three parallel field planes along the longitudinal direction of the progressive wave tube and parallel to the direction of the test specimen, taking the midpoint of each plane as the response output Point (Figure 7), the calculation results are shown in Figure 9. In addition, this paper has analyzed the uniformity of the two-dimensional plane sound field parallel to the test specimen, taking the field point plane parallel to the test specimen, and selecting the response output point at the corresponding position of the four corner points of the test specimen (Fig. 8), the calculation results are shown in Figure 10. The above analysis results indicate that the sound field uniformity in the progressive wave tube is good.

Figure 7. Vertical view of the progressive wave tube.  
Figure 8. Vertical view of the progressive wave tube.
3.3. Analysis of the influence of temperature on sound field

In this paper, the distribution of sound field in the progressive wave tube before and after the temperature field is analyzed. The results show that the sound field distribution at the surface of the test specimen changes after adding the temperature field, but the distribution is still very uniform. It
can be seen that the change of the temperature field does not affect the uniformity of the sound field distribution.

Figure 11. Sound pressure distribution without heating.  
Figure 12. Sound pressure distribution when heating.

4. Verification of the high thermal noise test system based on progressive wave sound field

When the system was installed, the engineers verified the overall technical specifications of the system. The test site is shown in Figure 13. The heat source heats the internal test specimen of the progressive wave tube (size: 1200 mm × 1200 mm) by means of quartz lamp radiation. When the surface temperature of the test specimen reaches 1200 °C, the engineer starts the air source, sound generator and other acoustic equipment to perform noise testing. The sound pressure level of the test system can reach 165 dB, the control spectrum is shown in Figure 14.

The test results show that the sound field of high thermal noise test system meets the sound spectrum requirements of GJB 150.17A-2009, and the control error is in the range of 1 dB when the total sound pressure level is 165 dB. When the system is applied with both thermal and acoustic loads, the performance of the progressive wave tube test section does not change.

Figure 13. Test site of the system.  
Figure 14. Acoustic test control spectrum.

5. Conclusion

Based on the existing heat source, this paper develops a large-scale high-heat noise test system based on the progressive wave sound field. During the development and test process, the following results are formed:

(1) This paper provides a progressive wave sound field design method, and designs a progressive wave sound field test system that meets the requirements of high intensity noise loading and high thermal loading according to the key component design theory.

(2) In this paper, the uniformity of the sound field of the system is analyzed by numerical simulation. The sound pressure frequency response of the field points on the same cross section is basically the same. The difference of the sound pressure frequency response around the test product field is small, and is allowed in the error range.

(3) The change of the temperature sound field has little effect on the sound field distribution of the test specimen in the progressive wave sound field, and does not affect the test effect.

(4) The system can realize a thermal noise load simulation test of 1200 mm × 1200 mm large plate structure with 165dB high sound intensity (GJB 150.17A-2009 sound spectrum) and 1200 °C high temperature.
6. References

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