Research on the untouchable ultrasonic leak evaluation method of the hermetical cabin for the Space Station

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The pressure change method was used to evaluate the leak rate of the hermetical cabin for the Space Station. But it can’t effectively locate the leaks and determine the leak rate of the single leak. The untouchable ultrasonic leak evaluation method can solve these problems, so it is very important for us to evaluate the leak rate of the hermetical cabin for the Space Station. Here based on a small environment simulator, a series of tests on the characteristic frequency spectrum occurred by the leak ultrasonic were done for the different size of leaks. According to the Fast Fourier Transform algorithm (FFT) of these leak ultrasonic signals, the characteristic quantity to evaluate the leaks was obtained. The result indicated that the characteristic frequency of the leak ultrasonic was about 40kHz, and the amplitude of this frequency can determine the size of the leak. Now this method can effectively evaluate the leak about 0.29mm. The conclusion here makes the foundation on building the relationship between the amplitude and the leak size.

1 Introduction

The Space Station meets the leak risk when it works on the orbit, so it is very important to judge whether the leak takes place. Now the pressure change method was used to evaluate the leak rate of the hermetical cabin for the Space Station. But it can’t effectively locate the leaks and determine the leak rate of the single leak. The untouchable ultrasonic leak evaluation method can solve these problems, so it is useful for us to evaluate the leak rate of the hermetical cabin for the Space Station. In January, 2004, the leak of the tube near the window of the Destiny cabin in the International Space Station occurred and the cosmonaut used this method to successfully locate the leak. At present there is no research about this method in China. In this paper, based on a small environment simulator, a series of tests on the
characteristic frequency spectrum occurred by the leak ultrasonic were done for the different size of leaks. According to the Fast Fourier Transform algorithm (FFT) of these leak ultrasonic signals, the characteristic quantity to evaluate the leaks was obtained. The result from these tests proved that the untouchable ultrasonic leak evaluation method was doable and made the foundation on quantificationally solving these problems.

2 Basic principle

According to aeroacoustic theory, the gas flows through the leaks which exit in the sealing structure from the high pressure to the low pressure under the pressure difference. When the gas passes through these leaks, the flow velocity is high and the flow is the turbulent flow. The turbulent flow consists of lots of vortexes and these vortexes always expand, break and produce the new vortex in the flow process in which the sound wave occurs\textsuperscript{[1-2]}. This wave propagates in the form of longitudinal wave in air. Fig.1 gives the leak flow situation when the gas passes through a little hole.

![Fig.1 the leak flow situation on a little hole leak case](image)

Lots of experiment results indicated that the leak frequency is between 10kHz and 100kHz, while the energy mainly distributes between 10kHz and 50kHz. The typical frequency spectrum of leak sound wave is showed in Fig.2\textsuperscript{[3]}. From Fig.2, we can see that when the frequency is bigger than 20kHz, the sound pressure level of the background noise decreases quickly, while the sound pressure level of leak sound wave changes slowly. In order to protect the leak sound wave from the background
noise, we should choose the frequency which is bigger than 20kHz. When the frequency is about 40kHz, the sound pressure level difference between the leak sound wave and background noise is bigger than that in other frequency. So this frequency range belonging to ultrasonic is the best range for this method on improve the detecting sensitivity.

![Fig.2 the frequency spectrum of the leak sound wave and background noise](image)

3 The test method

Based on the above analyse, we built a untouchable ultrasonic leak system including four ultrasonic sensor, a amplificatory circuit and a computer. The frequency band of ultrasonic sensor choosed in this system is inner 40kHz±3kHz. This system is showed in figure 3.

![Fig.3 picture of the untouchable ultrasonic leak system](image)
In order to simulate the pressure boundary of the Space Station, a small environment simulator whose diameter is 400mm was used. The outside of the environment simulator was the atmosphere condition and simulated the environment in the hermetical cabin of the Space Station. While the inside of the environment simulator was vacuum and simulated the vacuum environment outside the Space Station. The sketch map of the experiment equipment is showed in figure 4. Through this experiment system, the pressure boundary condition was simulated and the gas flowed from outside of the environment simulator to its inside through the leak 8. The experimenter can finish this tests in the atmosphere of the lab with the ultrasonic leak system.

![Sketch map of the test equipment](image)

1-ball valve; 2- needle valve; 3-vacuum gauge; 4-environment simulator; 5- needle valve; 6- gate valve; 7-vacuum pump; 8-a leak; 9-ultrasonic leak system

Fig. 4 The sketch map of the test equipment

The structure of the leaks used in this paper was showed in Fig.5 and their size list was showed in Tab.1. These leaks were the centre circular holes with a 2.5mm thickness and were made respectively by laser, electrical sparkle and machine technology on the same thickness flange of KF25.
Fig. 5 the picture of a leak in the experiment

Tab. 1 the list of leaks

<table>
<thead>
<tr>
<th>Length of leak (mm)</th>
<th>Diameter of the leak (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.29</td>
</tr>
</tbody>
</table>

The frequency spectrums of the different leaks listed in tab. 1 can be gained through the ultrasonic leak experiment and the difference between the leak case and no leak case can be easily obtained according to comparing with these characteristic frequency spectrum. In the same time, the effect of the detecting distance from the leak surface on the characteristic frequency spectrum were also studied. And the detecting distance were respectively 2mm, 10mm, 20mm, 40mm, 60mm, 100mm, 150mm vertically from leak surface. The test process was showed in Fig. 6 and the detecting distance was vertically changed along 1 direction.

Fig. 6 the test process about detecting distance

3 The test results
3.1 To gain characteristic quantity

With the above experiment equipments, the no leak case and the leak cases of different size of leaks were made and the results were showed in Fig.7 and Fig.8 respectively. These figures were finished according to the Fast Fourier Transform algorithm (FFT).

Fig. 7 the frequency spectrum on no leak case

(a) diameter $\phi 0.29$, detecting distance 20mm (b) diameter $\phi 0.3$, detecting distance 20mm
From the above figures, we can find that there were obvious difference between no leak case and leak cases in the frequency spectrum. In no leak case, the frequency spectrum was disorder and the amplitude was correspondingly small. While in the leak cases, there was a peak in the frequency spectrum and the peak was over bigger than the other amplitude. The peak tended to occur in the frequency about 40kHz. So the peak under 40KHz in the frequency spectrum can be seen as a characteristic quantity to judge whether the leak occurs. We can also find that leaks of different size correspond to different amplitude according to series of tests. This method can effectively evaluate the leak whose diameter is about 0.29mm.

3.2 The influence of the detecting distance on the result

In this section, we studied the relationship between the amplitude peak of the frequency spectrum and the detecting distance. The test results were showed in Fig. 9.
Fig. 9 the test results about detecting distance

From the above figure, we can see that the amplitude peaks basically decreased with the increase of the detecting distance and there were all maximum detecting distance for different leaks. The maximum detecting distance for different leaks were listed in tab. 2. We can also find that the amplitude peak do not increase with the increase of the size of leak at the same detecting distance. The amplitude peak had something to do with the size of the leak and surface condition of the leak. Because these factors have influence on the status in which the gas pass though the leak.

Tab. 2 maximum detecting distance for the different leaks

<table>
<thead>
<tr>
<th>Leak diameter mm</th>
<th>0.29</th>
<th>0.3</th>
<th>0.4</th>
<th>0.8</th>
<th>1.0</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum</td>
<td>150</td>
<td>60</td>
<td>&gt;150</td>
<td>150</td>
<td>&gt;150</td>
<td>&gt;150</td>
</tr>
<tr>
<td>detecting distance mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

4 Conclusion

1) The peak under 40KHz in the frequency spectrum can be seen as a characteristic quantity to judge whether the leak occurs.

2) The untouchable ultrasonic leak evaluation method can effectively evaluate the leak whose diameter is about 0.29mm.

3) The amplitude peak basically decreased with the increase of the detecting
distance for the same leak.

4) There were different maximum detecting distance for different leaks;

5) The bigger the peak amplitude was, the bigger the maximum detecting distance was.

6) The amplitude peak did not increase with the increase of the size of leak on the same detecting distance.

References

