It is an important way to machinery fault diagnosis by analysing the sound and vibration signals. When the machinery fault occurs in the operation, the essential changes of the system are the dynamic and acoustic properties. We can find the cause and position of the mechanical anomaly more easily through the vibro-acoustic signals. In this paper, the same type of pressure vessels produce three kinds of abnormal noise under the normal operating conditions. We collected the sound signals of every kind of abnormal noise and the vibration signals of main position under different operating conditions. Through the analysis of vibro-acoustic signals, we accurately identified the frequency characteristics of each kind of abnormal noise and smoothly found out the causes and position of abnormal noise of the pressure vessels.

Keywords: vibro-acoustic analysis, machinery fault diagnosis, abnormal noise, machinery vibration

1. Introduction

Pressure vessels play an important role in modern industrial equipment, especially in the fields of petroleum and chemical engineering, and the proportion is about 80%. But at the same time, because of various factors, such as the corrosion of the medium in the vessel, the disqualification of the vessel material, or the inability to meet the standard of the welding process, the pressure vessel has the risk of failure. Failure of the pressure vessel will result in degraded productivity, environmental pollution or personal injury and so on[1-4].

In the process of pressure vessel's control, non-destructive testing technology plays an important role to control the quality of pressure vessel and safety use. At present, the mature and commonly used non-destructive testing technologies include radiographic testing, ultrasonic testing, penetration detection eddy current testing and magnetic particle testing, which are mainly aimed at the cracks on the surface of the vessels or the defects of the welds.

This article involves a kind of pressure vessel that uses centrifugal force to separate solid particles or liquid droplets in the air. Three different kinds of abnormal noise are emitted when the pressure vessel is running. It is necessary to analyze the causes and locations of the abnormal noise, while the above non-destructive testing technologies can't achieve this purpose. In addition, the pressure vessel has complex internal structure, so the maintenance personnel can't enter the inside of the vessel for inspection. We solved this problem by sound and vibration analysis. Through the analysis of vibro-acoustic signals, we accurately identified the frequency characteristics of each kind of abnormal noise and smoothly found out the causes and position of abnormal noise of the pressure vessels.
2. Field testing

2.1 Description

The purpose of field testing is to obtain the spectral characteristics of the abnormal noise when the pressure vessel is operating. We collected the time domain signals of abnormal noise by data acquisition instrument and microphone. They are shown in Fig.1 and the main parameters are shown in the following Table 1.

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Frequency range</th>
<th>Measuring range</th>
<th>Precision/Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data acquisition instrument</td>
<td>51.2kHz</td>
<td>120dB</td>
<td>24-bits</td>
</tr>
<tr>
<td>Microphone</td>
<td>20Hz~20kHz</td>
<td>134dB</td>
<td>50mV/Pa</td>
</tr>
</tbody>
</table>

At the scene, we found that the tone of abnormal noise had different characteristics with the change of flow. When the flow was less than 60%, there were two kinds of abnormal noise. One abnormal noise sounded like a train whistle, and the other abnormal noise was like the sound of a running chainsaw. But when the flow was higher than 60%, the above two kinds of abnormal noise would gradually disappear, and the third abnormal noise would appear. The third abnormal noise sounded like the clank when there was a collision between metals.

We collected the sound signals of whistling noise at 42% of the design flow, and the "chainsaw noise" at 56% of the design flow, and the clank noise at 83% of the design flow. The noise measurement point was 40cm distance from the shell of the pressure vessel.

2.2 Spectral characteristics of abnormal noise

We had performed spectral analysis of the acquired sound signals and the conclusion were shown in the following figures. Fig.2 shows the main frequency characteristics of the sound signal when the actual flow is 42% of the design flow. Through the frequency spectrum, we can see that there are two main frequencies of the signal, which are 610Hz and 772Hz. We filtered out the two frequencies of this sound signal, and then converted it to audio format. We played this audio with a loudspeaker and then we found that the whistling noise disappeared. As we filtered out any of the two frequencies, the whistling noise still existed. So the main frequencies of whistling noise are 610Hz and 772Hz. We found the spectrum characteristics of whistling noise through the sound signal analysis.
Fig. 3 shows the main frequency characteristics of the sound signal when the actual flow is 56% of the design flow. And Fig. 4 shows the three-dimensional spectrum of the sound signal. Through the frequency spectrum, we can see that there are many peaks at the frequency range of over 1000Hz, and we can see more directly the spectral features of the sound signal through the three-dimensional spectrum in Fig. 4. The yellow part represents a larger peak than the adjacent frequency. They have a lot of distribution above on 1000Hz and these peaks are intermittently distributed over time and they are periodic. The "chainsaw noise" we heard on the scene was also intermittently distributed. In the same case, only when all of these peak frequencies were filtered out, the "chainsaw noise" would disappear. So the main frequencies of "chainsaw noise" are above on 1000Hz.
As the flow increased, the whistling noise and "chainsaw noise" would gradually disappear, and the clank noise appeared. Fig. 5 is the three-dimensional spectrum of the clank noise when the actual flow is 83% of the design flow. We can see that the clank noise is intermittently distributed over time, but it has no periodicity. The frequency range of the clank noise is very wide. These characteristics are similar to the spectral properties of the impact.

![Three-dimensional spectrum of clank noise](image)

Figure 5: three-dimensional spectrum of clank noise

### 3. Identification of abnormal noise

What we can determine was that the abnormal noise was caused by the vibration of the internal structure. Therefore, we studied the internal structure design of the pressure vessel and determined that the weakest link is the separation components and the angle steel which was welded in the inlet. The angle steel was to protect the separation components. We obtained the natural frequency of the separation components and the angle steel by hammering method in the workshop. The spectrum characteristics are shown in Fig. 6 and Fig. 7

![Natural frequency of separation components](image)

Figure 6: Natural frequency of separation components
From Fig.6 and Fig.7, we can see that the natural frequency of the separation components is less related to the frequency of the abnormal noise, while the natural frequency of the angle steel is more consistent with the frequency of the abnormal noise.

The main frequencies of whistling noise are 610Hz and 772Hz, while angle steel has peak value at these two frequencies and nearby frequencies. Above 1000Hz, the peak frequencies of the angle steel is highly consistent with the peak frequencies of the chainsaw noise. Therefore, it can be concluded that the cause of the two kinds of abnormal noise is due to the resonance of the angle steel. They can disappear by strengthening the stiffness of the angle steel. Besides, the characteristics of clank noise are similar to the spectral properties of the impact, so it may be due to loosening of some internal components. Of course, it cannot be excluded that there are large particle impurities striking the internal components.

4. Conclusion

In this paper, we collected and analyzed the frequency characteristics of three kinds of abnormal noise of pressure vessels by using vibro-acoustic signals, and we smoothly found out the causes and locations of these abnormal noises. The third abnormal noise had been determined due to open welding of internal components. This is consistent with our analysis. Due to the time problem, the whistling noise and chainsaw noise have not received the actual feedback. Through the test and analysis of this paper, vibro-acoustic analysis as a kind of non-destructive testing technology can bring more convenience to mechanical fault diagnosis.

REFERENCES

2 Jiang, J. Y., Jiang, Y. A brief discussion on the problem of pressure vessels in the design, Soda industry, 1, 47-49, (2014)