The Application of Ultrasonic Nondestructive Testing Technology in Refrigeration Pipeline

Jian Chen[a, b]

College of Electrical and Information Engineering, Anhui University of Science and Technology, Huainan 232000, China

[a]13955430575@163.com, [b]1192471239@qq.com

Abstract

The working principle of refrigeration equipment is that the refrigerant changes state in the pipeline under the action of the compressor, so as to achieve the effect of refrigeration and cooling, so there can be no defects in the internal metal pipeline. Ultrasonic nondestructive testing technology is an efficient, accurate and non-invasive evaluation method, with the advantages of non-destructiveness, high precision, high efficiency, flexibility and low cost. It will not cause any damage to the refrigeration pipeline, ensuring the safety of the detection process and the integrity of the pipeline. At the same time, modern ultrasonic testing equipment has high resolution and sensitivity, which can accurately detect tiny defects and improve the reliability and accuracy of detection. In addition, the technology is suitable for refrigeration pipelines of various materials and shapes, including metal, non-metal and complex geometric shapes, and has a wide range of applicability. This paper attempts to summarize and analyze the nondestructive testing technology of ultrasonic waves in metal pipelines, explain the principles and methods of ultrasonic testing, and has important significance for promoting the development of nondestructive testing technology.

Keywords

Ultrasonic Nondestructive Testing; Pipelines; Defects.

1. Introduction

The frequency of ultrasonic wave in traditional ultrasonic testing technology is . Because of the low frequency, the detection resolution is not high, while the application of ultrasonic wave with short wavelength and high frequency will greatly improve the detection resolution. The working frequency of high frequency ultrasound is , and the detection resolution can reach . By using the physical property of ultrasonic wave penetrating metal pipe, we can make nondestructive testing to detect whether there are defects in metal pipe. The ultrasonic probe emits high frequency sound wave, and the ultrasonic wave will reflect and scatter at the defect of the inner wall of the metal pipe. The ultrasonic receiving device collects the reflected sound wave information, processes and analyzes the information, converts it into electric signal, and displays it on the oscilloscope in a certain waveform. The information processed by the display can reflect the shape, size and location of pipeline defects, so as to help us choose a more appropriate method to deal with defects. It can also make micro imaging of tiny defects within a certain depth for visual observation and operation, with the characteristics of high resolution, high sensitivity and intuition. Ultrasonic nondestructive testing technology has been widely used in mechanics, biology, materials science, optoelectronics and microelectronics.

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2. The Principle of Ultrasonic Nondestructive Testing

This paper mainly introduces the principle of air coupled ultrasonic testing [1]. Ultrasonic attenuation is the process of gradual weakening of acoustic energy or sound pressure due to air medium scattering, absorption and diffusion in the process of sound propagation. Air coupled ultrasonic nondestructive testing technology is mainly the attenuation caused by medium absorption[2]. Generally, there are three aspects that cause attenuation. Ultrasonic can cause the movement of rarefaction and densification of the medium in the process of propagation. In the process of medium movement, there will be obstacles to elastic movement, which will change the internal friction of the medium and consume ultrasonic energy. Ultrasonic will have vibration loss in the process of propagation, resulting in the absorption of acoustic energy stored in the medium and unable to spread out. Ultrasonic will have the phenomenon of heat conduction in the process of propagation. Because ultrasonic propagates in the air in the form of longitudinal wave, its sound wave is in the state of telescopic motion. The arrangement of particles is sparse and dense, and the temperature of sparse part is low, while the temperature of dense part is high. In this way, the medium will transmit heat from high temperature to low temperature, resulting in energy loss.

Therefore, in ultrasonic testing, we increase the frequency of the sound wave to improve the detection efficiency, but the attenuation of the sound wave is positively correlated with the increase of frequency, especially in air. The degree of attenuation is more obvious. The attenuation equation is:

$$p = p_0 e^{-\alpha s} \tag{1}$$

In the formula, is the sound pressure that the sound wave propagates to the distance s , p is the initial sound pressure, and α is the medium attenuation coefficient, which is related to the medium characteristics and temperature. Under standard atmospheric pressure.

the attenuation coefficient:

$$\alpha = 1.88 f^2 \times 10^{-11} \tag{2}$$

The above formula shows that the attenuation of ultrasonic waves is related to the distance and frequency, and is positively correlated with the square of the distance and ultrasonic frequency. We can use low-frequency ultrasound to enhance the quality of the echo signal and reduce the attenuation of sound waves.

The acoustic pressure round-trip transmission rate of ultrasonic waves at different material interfaces is generally:

$$T_{12} = \frac{4Z_1Z_2}{(Z_1 + Z_2)} \tag{3}$$

In the formula, Z_1 and Z_2 are the characteristic impedances of the material being measured.

From the above table, it can be seen that most of the refrigeration pipes are copper pipes. The acoustic impedance of brass is greater than that of other materials, and the attenuation rate in air reaches 89dB, so very little acoustic energy enters the tested material, and most of the energy is reflected by the interface, and the transmission coefficient is very small. We can use air coupled ultrasonic transducers to match the amplifier and ultra low noise preamplifier to improve the amplitude of the ultrasonic signal. When using transmission method to detect defects, the probe should be placed on both sides of the tested pipe. When there is a small defect in the pipe, some sound waves will be reflected; When the defect is large enough, the sound wave will be reflected in full at the defect, and the receiving probe cannot receive the signal.

Table 1. Comparison of transmission rate and attenuation of sound wave after passing through different media

medium 2	Acoustic impedance/MRay1	medium 2	transmittance T	attenuation rate/dB
brass	51	Water air	0.111020 0.000033	19 89
manganese steel	47	Water air	0.119885 0.000036	18 89
aluminum	17	Water air	0.298028 0.000099	11 80
organic glass	3.2	Water air	0.87 0.000053	1.2 66

3. Influencing Factors of Ultrasonic Nondestructive Testing

This paper discusses the air coupled ultrasonic nondestructive testing technology, which will be affected by many factors in the application, generally including the temperature, state and thickness of the coupling layer of the gas, as well as the properties of the material to be tested, generally including the roughness of the surface and the depth and area of defects. Because the acoustic impedance of different materials is different, the size of ultrasonic energy incident into the material is different. When the roughness of the material surface is rougher, the attenuation of sound wave is more obvious, so the detection effect is poor. The pressure and flow rate of the coupled gas will affect the coupling state[3], and the energy of ultrasonic wave in the tested material will change, which will affect the amplitude of surface acoustic wave vibration. Therefore, we need to study the influence of air flow rate, flow direction and air pressure on ultrasonic wave.

3.1 The Relationship between Ultrasonic Nondestructive Testing and Air Pressure

When ultrasonic wave propagates in air, the attenuation coefficient has a certain relationship with air temperature, air humidity and air pressure. The influence of air properties can reduce the results of air coupling detection. We can detect the environmental parameters through the control system, compensate the results of air coupling detection process, improve the sensitivity and accuracy of pipeline detection. When we use ultrasonic testing instrument to carry out nondestructive testing of materials in the air, we can improve the ability to detect defects by changing the gas pressure to increase the density of air coupling. The specific implementation steps are as follows. Understand and master the relevant parameters of the material to be tested, ensure that the ultrasonic can penetrate the material to be tested and achieve accurate detection under certain voltage and gain[4]. Determine the ultrasonic transmitter and receiver detector, and use an appropriate air-coupled ultrasonic transducer . Place the ultrasonic transmitter and receiver probe on both sides of the object to be tested, and select the appropriate pressure under the pressurization system of the high-pressure chamber. Scan the material to be tested through the detector and display the scanning image. For key parts or complex defects, an independent closed pressurization system is adopted to make the detection more flexible, improve the detection sensitivity and detection efficiency.

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3.2 The Relationship between Ultrasonic Nondestructive Testing and Air Flow

The influence of air flow on the detection of air coupled surface waves is used to illustrate the relationship between air coupled ultrasonic testing and air flow[5] . A drum wind system is used to make the air flow. Before the experiment, the wind speed is measured by an anemometer. Experiments are carried out at wind speeds of $2m/s$ and $5m/s$ respectively. Adjust the position of the defect in the pipeline, so that the probe of the ultrasonic detector can detect in the area without defects in the pipeline. Detect under different air flow rates and air flow directions, as well as static conditions, and then use the probe to receive the maximum amplitude of the signal and record it.

Table 2. Maximum amplitude of received signal under different air flow conditions

air flow rate	static	$2m/s$	$5m/s$
When the wind is along the direction of the connecting line between the two probes (reverse)	490	504	409
When the wind is perpendicular to the line connecting the two probes	490	558	427

When the air flow velocity is low, the maximum amplitude of the received signal is larger than that under static conditions, which is more favorable for defect detection. With the increase of air flow velocity, the maximum amplitude of the received signal attenuates, which is smaller than that under static conditions. This indicates that the air flow velocity within a certain range is beneficial to the propagation of ultrasound , but when the air flow velocity is too fast[6], it will hinder the propagation of air coupled ultrasound[7].

4. Application Suggestions of Ultrasonic Nondestructive Testing Technology in Refrigeration Pipeline

(1) Before testing, ensure that the pipe surface is clean and free of impurities to avoid oil stains, rust, etc. affecting the propagation and reflection of ultrasound. At the same time, check the coupling of the ultrasonic probe to ensure good contact.

(2) Adjust the parameters of the ultrasonic testing equipment, such as frequency and gain, according to the pipe material, wall thickness, and possible types of defects, to optimize the testing effect.

(3) Use appropriate scanning methods, such as straight line scanning, spiral scanning, or oblique angle scanning, to ensure that defects on the inner and outer walls of the pipe can be effectively detected. Key parts such as welds and elbows should be inspected carefully.

(4) For complex structures or suspected defect areas, multi-angle detection can be used to improve the reliability and accuracy of the detection.

(5) After the inspection is completed, carefully analyze the collected data to identify and confirm the location, type, and size of the defect. If necessary, other non-destructive testing methods can be used for verification.

(6) Carefully record the inspection process, results, and any abnormalities, and prepare a complete inspection report to provide a basis for subsequent maintenance or improvement.

(7) Regularly calibrate and maintain ultrasonic testing equipment to ensure that it is in good working condition, thus ensuring the accuracy of test results. Through the above measures, the smooth progress of ultrasonic non-destructive testing of pipelines can be ensured, and the efficiency and quality of testing can be improved.

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5. Conclusion

Ultrasonic nondestructive testing technology has important applications in pipeline detection. In refrigeration pipelines, ultrasonic nondestructive testing technology can efficiently and accurately detect defects such as corrosion and wall thickness thinning , which can lead to pipeline leaks, economic losses, and environmental pollution. By detecting regularly, potential problems can be discovered and repaired in a timely manner to ensure the safe operation of the pipeline. Ultrasonic nondestructive testing has the advantages of long detection distance, fast speed, and low cost, making it particularly suitable for the detection of long-distance refrigeration pipelines. It can not only improve detection efficiency but also reduce detection costs, providing strong support for the safe operation of refrigeration pipelines.

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