Research on Two-dimensional Fabry-Perot Ultrasonic Sensing Technology

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Abstract. According to the laser interference method, a two-dimensional Fabry-Perot fiber optic sensor is used as the core, and the difference between the propagation speed of the ultrasonic transverse wave and the longitudinal wave in the solid medium is used to measure the ultrasonic wave propagating in the solid to realize the ultrasonic positioning. An F-P interference cavity is formed with a coated quartz film, the end face of the fiber end, and air. At the same time, the cantilever beam design can be used to simultaneously extract longitudinal ultrasonic waves based on Fabry-Perot cavity interference and transverse ultrasonic signals based on cantilever fibers in a solid rod-shaped acoustic waveguide. In this paper, the position of the ultrasonic wave is determined by the difference of the longitudinal and transverse ultrasonic wave speeds in the detected ultrasonic signals.

1. Introduction

From the end of the 19th century to the beginning of the 20th century, after the piezoelectric effect and the anti-piezoelectric effect were discovered in physics, people have solved the method of using electronics to generate ultrasonic waves, and have since quickly opened the historical chapter of the development and promotion of ultrasonic technology. Ultrasound has the characteristics of strong penetrating power and high resolution. Therefore, by detecting the ultrasonic release or reflecting the acoustic wave signal inside the medium, especially the solid medium, the information such as the structure and physical properties of the medium can be directly obtained, which can be used as the basis for defect evaluation of equipment and materials. Due to the different propagation rates of the transverse and longitudinal waves of the ultrasonic wave in the medium, different sensors detect the time difference of the signal, and we perform positioning based on the time difference.

Fiber-optic ultrasonic sensors have gradually become one of the hot research fields of various detections due to their anti-electromagnetic interference and portability. At present, the optical fiber sensors that detect ultrasonic signals can be divided into intrinsic types (such as Mach-Zehnder type sensors, Sagnac type sensors) and extrinsic types (such as Fabry-Perot type sensors). Based on the original Fabry-Perot interference cavity, the reflective Fabry-Perot interference optical fiber sensor prepared in this paper can measure the P and S waves of the ultrasonic waves generated at the same time, and reach the P and S signals with different wave speeds. The time difference can accurately locate the ultrasonic generation point.
2. Theoretical analysis

2.1. Composition of experimental system
The block diagram of the experimental system composition scheme is shown in Figure 1. According to the direction of the signal, there are five major components: strain generating unit, sensor, voltage amplification unit, A / D board and computer. The strain source adds the measured signal to the F-P sensor. The output signal of the F-P sensor is converted into an electrical signal by the photodetector, and then amplified and A / D converted, and sent to the computer for processing.

2.2. Model and principle of cantilever Fabry-Perot interference optical fiber sensor
As shown in Figure 2. The monochromatic light emitted from the light source passes through the fiber optic circulator and enters the sensing probe along the fiber. The incident light undergoes the first Fresnel reflection at the fiber core-gas interface, and some of the light is reflected back to the fiber. After entering the cavity, it is reflected by the reflective film before entering the optical fiber. Interference occurs at the coupling, and the resulting light intensity is:

\[ I = 2I_0R[1 + \cos\left(\frac{4n_0\pi}{\lambda}l\right)] \]  
\[ \Delta \varphi = \frac{4n_0\pi}{\lambda}l \]  

The response frequency of the F-P interference method depends on the silicon film parameters of the F-P cavity. As shown in the following formula:

\[ f_n = \frac{A_0}{2\pi R^2} \times \frac{D_R}{ \sqrt{hw}} \]
In the formula, \( A \) is a constant related to the vibration mode; \( R \) is the diameter of the chamber; \( h \) is the thickness of the film; \( g \) is the constant of gravity; \( w \) is the mass of the diaphragm; \( D \) is the curvature of the rigidity and \( \alpha \) is a constant related to the material. It can be seen that the response frequency of the system is directly proportional to the thickness of the film and inversely proportional to the area of the film. The structural parameters of the cantilevered F-P interference cavity can be adjusted according to the ultrasonic waves with different frequency characteristics.

The response frequency \( f_n \) of the single-ended fiber cantilever beam can be estimated by the following formula:

\[
f_n = \frac{A_n}{2l^2} \sqrt{\frac{EI}{\rho}}
\]  

(4)

In the formula, \( E \) is the Young's modulus of elasticity; \( I \) is the area moment of inertia; \( r \) is the static load distributed uniformly; \( l \) is the length of the fiber cantilever beam; \( A_n \) is the mode coefficient.

3. Experimental test

The cylindrical stainless steel metal rod forms an acoustic waveguide for ultrasonic waves, and the ultrasonic wave travels a long distance, which is convenient for remote measurement. On the basis of the original Fibry-perot interference cavity, the added cantilevered bare fiber core can simultaneously measure the longitudinal and transverse waves of ultrasonic waves propagating in a cylindrical stainless steel metal rod. Occurs accurately.

By measuring different lengths of cylindrical stainless steel metal rods and different selections of the display time period of the oscilloscope, the laws of the ultrasonic re-medium propagation process can be obtained as shown in Figures 3 (a) and (b). Measure iron rods with lengths of 0.2 m, 0.3 m, 0.5 m, and 1 m, respectively. When the ultrasonic generator generates ultrasonic waves, the ultrasonic generator generates ultrasonic electromagnetic noise that propagates at the speed of light, and sets it as the zero point.

![Figure 3(a). 500 microsecond waveform.](image)

![Figure 3(b). 100 microsecond waveform.](image)

It can be known from Fig. 3 (a) and (b) that the ultrasonic wave receives longitudinal and transverse waves and the time difference during the propagation of irons of different lengths. When ultrasonic waves propagate in a medium, the P-wave velocity is greater than the S-wave velocity. The velocity of longitudinal and transverse waves in the same medium is constant. The peaks of the P-wave and S-wave are extracted and fitted respectively and subjected to Fourier transform to obtain the amplitude-frequency characteristic spectra (Figure 4 (a), Figure 4 (b)). The vibrating membrane of the sensor is bonded to the stainless steel rod by hot-melt adhesive. From Figure 4 (c), the longitudinal wave is a limited vibration with a life of about 0.1 milliseconds and only two to three cycles, which gradually decays. From Figure 4 (d), the sensor also attenuates after receiving the shear wave. It can be seen that the P-wave attenuation speed is greater than the S-wave attenuation speed.
Figure 4(a). P-wave amplitude-frequency characteristic spectrum.

Figure 4(b). S-wave amplitude-frequency characteristic spectrum.

Figure 4(c). P-wave attenuation waveform and fitting function.

Figure 4(d). S-wave attenuation waveform and fitting function.

From Figure 3, the occurrence times of P-wave and S-wave at distances of 0.2m, 0.3m, 0.5m, and 1.0m can be found, and then the wave velocity differences at each distance can be calculated and fitted to obtain a linear fitting curve. From Figure 5, it can be obtained by fitting the linear curves of the longitudinal and transverse wave velocities. The propagation time and distance of the longitudinal and transverse waves are linear, that is, the wave velocity is proportional to the distance when the time is constant.

Figure 5. Fitting linear curve of longitudinal and transverse wave velocity.
That is, the speed formula, as in equation (5), obtains the longitudinal wave velocity of the ultrasonic wave in the iron is about 4.6km/s and the transverse wave velocity is about 1.5km/s. It can be calculated that the difference between the wave velocity of the longitudinal wave and the transverse wave is about 3.1km/s.

$$v = \frac{x}{t}$$

Where \(v\) is speed, \(x\) is distance, and \(t\) is time.

4. Conclusion

In this paper, based on the principle of optical interference, the cavity is composed of a quartz film and the end face of the fiber core, and a two-dimensional Fabry-Perot cavity optical fiber sensor is prepared. The analysis of the waveform attenuation after the sensor receives the P-wave and P-wave is consistent with the theoretical results. The speed of the longitudinal and transverse waves in the same medium is fixed. A fiber-optic ultrasonic measurement system model was established to measure the positions of ultrasonic waves at different distances to determine the propagation speed of longitudinal and transverse waves in ferrous media. This article can use the wave speed difference and time difference to locate the ultrasonic generation location, which can be used for passive acoustic measurement, can be widely used in power, railway, municipal construction and other related fields of metal wire rod health detection.

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