The Study The Preferred Magnetization Direction of Long Line Magnetostrictive Position Sensor

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Abstract

The long liner position sensor is a kind of position sensor that can measure the distance between the detected point and the receiving point by calculating the duration of the excitation and the receipt of ultrasonic waves. In our experiment, the unsymmetrical phenomenon of elastic waves was detected under different initial condition with the symmetrical sensor system, due to the anisotropy of magnetic domain, which may be anisotropy of crystal axis, stress and shape. This paper recorded and analyzed the data of experiment. The theory of unsymmetrical of long liner position sensor was discussed in ferromagnetic, electromagnetic and physics. The effecting factor of the physic unsymmetrical of magnetostrictive material was studied in this paper, and the mathematic model was constructed.

Keywords: magnetostrictive, anisotropy, ultrasonic waves, magnetic domain, tensional wave

1. Introduction

The long liner position sensor is a kind of absolute position sensor utilizing the magnetostrictive effect and inverse magnetostrictive effect of magnetostrictive material. It is mainly used in the field of distance measure and micrometric displacement control. The measure precise of the sensor is 2μm now, and it is widely applied in metallurgy, environment protection and chemical industry, especially in the flammable, volatile or caustic circumstance.

This kind of the sensor utilize the magnetostrictive effect and reverse magnetostrictive effect of material to get the displacement to be measured, while it is that natural physical character of the magnetostrictive material has a main effect on the performance and precision of the sensor. The experiment data showed that elastic waveforms detected by coil of sensor detection module was physically unsymmetrical in different initialization conditions of the symmetrical sensor system. To make the magnetic domain of the magnetostrictive line material ranged in one order, there is always an initialized direction which can get a more clear and effective signal than other initialized ones does. With the analysis of the principle and further experiment, it can be known that quality of the induced waves has a distinguishable difference under variously initialized methods. The physical unsymmetrical phenomenon

Foundation : National Natural Science Foundation of China（No.60744001）; Institution of higher learning doctor subject special foundation (20060112020)

of magnetostrictive line sensor was discussed from the perspectives of ferromagnetism, electromagnetism and physics theory. And the possible influence factor of the unsymmetrical phenomenon was studied. The mathematic model was established to provide theoretical basis, and the experimental data was provided for promoting the performance and precision of the sensor.

2. Main principle of magnetostrictive line sensor

The principle of the magnetostrictive line sensor is illustrated in Fig.1. With the impulse current I_p , the circle magnet field Φ_i will be generated around the magnetostrictive line; on the other hand, the permanent magnet field Φ_m will be generated along the line by permanent magnet near the material. Φ_i and Φ_m will merge into Φ, which is a instantaneous tensional magnet field. Due to the magnetostrictive effect, the elastic wave is induced at the point C in Fig.1, and it would transmit separately to point A and point B along the line. When the elastic wave arrives at the position of the coil, the magnetic domains under the coil would be changed and magnetic field intensity B would also be changed with the reverse magnetostrictive effect. Based on the faradism law, the faradism voltage e would be detected, which expressed as Eq.(1).

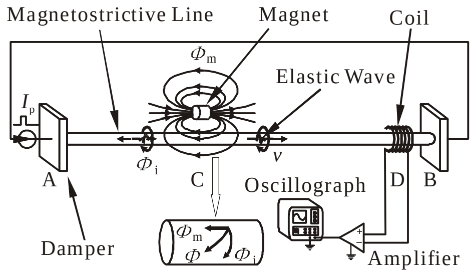


Fig.1 The principle of magnetostrictive line sensor

$$e = -NS(dB/dt)\ [V] \tag{1}$$

Where e is the faradism voltage; N is the rolls of coil; S is the cross section area of the coil; B is density of flux. If the time span of transmitting from permanent magnet to coil is t, and the transmit velocity of the elastic wave is v, the distant between permanent magnet and coil L can be calculated as Eq.(2).

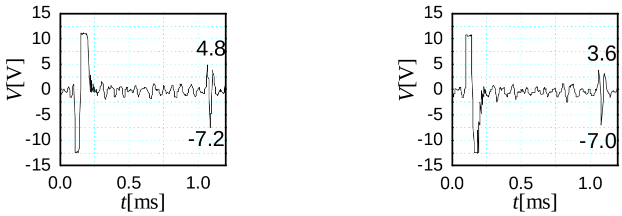
$$L = vt[m] \tag{2}$$

As known in Fig.1 and the principle of magnetostrictive line sensor, the long magnetostrictive line can be approximately considered as a geometrical symmetric one. When the permanent magnet is placed with the direction of N pole to S pole being horizontal to the magnetostrictive line, the permanent magnetic field Φ_m is dissymmetry whose symmetrical axis is the center of the permanent magnet, and when the permanent magnet is placed vertically, the Φ_m is symmetric relative to the permanent magnet center. The circle magnet field inferred by impulse current is also geometrically symmetric. The coil and the related detecting module have no effect on the elastic wave. The experimental system can be considered as a symmetric one.

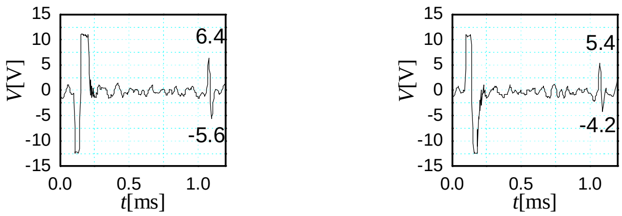
3. The relative experiment of preferred magnetization direction

By employing different initialized methods to magnetostrictive line, the elastic waveform and induced waveform were analyzed, which were generated by the sensor. The results showed that the signal intensity of the detected wave is different.

One initialized method is to move the permanent magnet from point B to point A in Fig.1 with the N pole of permanent magnet pointed to the magnetostrictive line, which would range all magnetic domains in the line in one order, and this initialized method is called N Method in this paper; the other kind of initialized method is to move the permanent magnet from point B to point A with the S pole of permanent magnet point to the line, which also would range all magnetic domains in one order different to N Method, and this initialized method is called S Method here. According to the N Method and S Method, there are still two ways to place the permanent magnet, which are horizontally and vertically. In the two ways above, the elastic wave and induced wave were detected separately and the experimental waveforms were showed in Fig.2.



(a) N Method, horizontally posed (b) S Method, horizontally posed



(c) N Method, vertically posed (d) S Method, vertically posed

Fig.2 Waveforms under different experiment conditions

In Fig.2, the peak values of elastic wave are measured. And the results showed that the peak-to-peak value of the elastic wave with N Method is bigger than the one with S Method, no matter the permanent magnet is placed horizontally or vertically. The waveform in Fig.2 is the induced and elastic wave amplified by 10000 times in the amplification module of detecting system. The range of induced wave signals are so big that the saturation and cut-off distortion occurred in the amplifier. The waveforms in Fig.2 are not exactly the original signal of induced wave, so the induced wave signals without amplifying under different condition were recorded and compared as showed in Fig.3.

The induced waves are generated by the magnetic domains moving and changing as the impulse current I_p occurring, which influenced the magnet flux in the detecting coil. As the showed Fig.3, the performance of induced wave under N Method is better than that of S Method in this experimental condition.

As the experiment illustrated, if only alternated the initialized methods without changing other conditions, the elastic and induced wave signal performance are different, and based on this experiment scheme, the magnetic domains have bigger displacement under N Method than that with S Method. The phenomena is defined as that the line material of long line magnetostrictive position sensor has preferred magnetization direction.

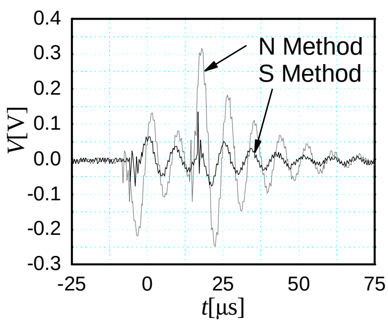


Fig.3 Induced waveform without amplifier

4. Analysis to preferred magnetization direction of the sensor

The experiments showed that the physical characteristics of elastic and induced wave of the long line magnetostrictive position sensor under the two initialized methods are unsymmetrical along the axis of line. The main factors effecting the magnetic domains in this system are the pose of permanent magnet, the circle magnet field generated by impulse current, the reverse magnetostrictive effect and so on. The unsymmetrical phenomena showed us that the magnetostrictive long line material is liable to be magnetization on one way than that in the other way along the line. It is that the line material of long line magnetostrictive position sensor has preferred magnetization direction, and this is the performance of anisotropic character of magnetostrictive long line material.

The long line material of magnetostrictive line, which has been prestressed, effected by anisotropism of magnetic crystal, anisotropism of stress and anisotropism of shape. (1) The long line material of sensor can be considered as a infinite long cylinder approximately, and the demagnetization factor of line is infinitesimal along the line and infinite along the radial under the theory of anisotropism of shape. But the anisotropism of shape should not be the main factor effecting preferred magnetization direction;(2) The magnetization of the prestressed magnetostrictive long line material should be enhanced along the axis, if the material is positive magnetostrictive material. On the other hand, the magnetization should be enhanced along the radial, if the material is negative magnetostrictive material. But the anisotropism of stress has the same the effect on the long line material sensor with two different initialized method, the anisotropism of stress should not be the main factor of the preferred magnetization direction; (3) The anisotropism of magnetic crystal would effect the moving and changing of magnetic domain with forced magnet field, so that it directly influences the generation and transfer of elastic and induce wave, and effects the structure of the magnetic crystal of material under the coil. So the anisotropism of magnetic crystal is the main factor effected to the preferred magnetization direction.

All magnetic moments in a magnetic domain are in one direction and in a state of saturation magnetization. Assumed that M_s is the saturation magnetization of magnetic moments in unit bulk, and V_i is the volume of a magnetic domain, the magnetic moment of the magnetic domain is M_sV_i. Without force magnetic field, the magnetic moment directions of every magnetic domain are disorganized. The value of magnetic moment of each magnetic domain in one direction is $M_sV_i\cos\theta_i$, as seen in Fig.4, θ_i is obliquity of magnetic moment of a magnetic domain. There are many magnetic domains in a unit bulk, and any direction has its own magnetic moment, so that the sum value of all magnetic moments of a unit bulk in any direction is equal to zero without force magnetic field.

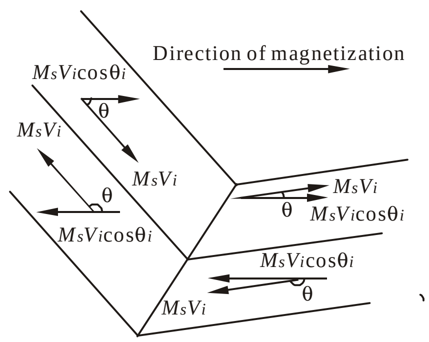


Fig.4 Value on a direction of magnetic moment of magnetic domain

$$\sum M_sV_i\cos\theta_i=0 \quad (3)$$

The magnetic moment value in the direction of magnetic field is not zero with force magnetic fields. The magnetic moment has a turning of $\triangle\theta_i$ and a volume changing $\triangle V_i$ due to the moving of magnetic domain wall. As M_s does not change during the process of magnetization, the value of magnetic moment of unit bulk in magnetic field direction can be expressed as Eq.(4).

$$\triangle M_H = M_s[\sum V_i\triangle(\cos\theta_i) + \sum \cos\theta_i \triangle V_i] \quad (4)$$

In Eq.(4), there are two parts contribute to the increase of magnetic moment in the direction of magnetic filed, one is △ $(\cos\theta_i)$, which means the rotation of the magnetic moment, the other is △ V_i, which means the movement of magnetic domain wall.

(1) The induced wave in long line magnetostrictive position sensor is generated directly by the changing of the magnetic flux of the line material through the coil, which is induced by the magnetization of the magnetic domain with the circle magnetic field impulsed by the current along the line. As in Eq.(4), the main factor of the change of magnetic flux can be divided into two sections: the rotation of magnetic domain and the movement of magnetic domain wall.

When the force magnetic field was being removed, the magnetism of magnetic material would descend along the hysteresis loop, and when it has been removed, some magnetism remained in the material body. The remanence of magnetic material is the macroscopical effect of mass magnetic domains. The preferred magnetization direction of magnetic domain in material could not be consistent with the direction of force magnetic field, so the remanence can be calculated by Eq.(5) as below.

$$M=\sum M_s V_i \cos\theta_i \quad (5)$$

(2) At the arrival of the elastic wave in magnetostrictive line sensor, the line material was twisted by the twisting wave. And it can be thought that the consistent turning of the magnetic moment changed △ θ_i with the change of the external magnetic field; on the other hand, V_i was changed with the movement of the magnetic domain wall under the reverse magnetostrictive effect. So at the arrival of elastic wave, the changing value of magnetic moment can be expressed as Eq.(6).

$$\triangle M = M_s[\sum V_i \triangle (\cos\theta_i) + \sum \cos\theta_i \triangle V_i] \quad (6)$$

Due to the theory of magnetization, the magnetic moment was changed in the magnetostrictive material with the change of force magnetic field. When the force magnetic field has been removed, the direction of magnetic domain in material is not consistent with the direction of force magnetic field, and there will be an angle θ_i between these two directions. The angle is the one between preferred magnetization direction of magnetic domain and the direction of force magnetic field. The magnetic domain and the preferred magnetization direction can not be symmetry along the line, so that the long line magnetostrictive position sensor can be liable to preferred magnetization in one direction than the other direction, that is the △ M_H in Eq.(4)and △ M in Eq.(6) are different under two different initialized method, which are $(\triangle M_H)_N \neq (\triangle M_H)_S$ and $(\triangle M)_N \neq (\triangle M)_S$.

5. Conclusion

The magnetostrictive material used in long line magnetostrictive position sensor has physical pheromone of anisotropism. The phenomena that the line material of long line magnetostrictive position sensor has preferred magnetization direction were specified with experiment in this essay. It is obviously that the performance of elastic waves signal and induced waves signal were affected by the preferred magnetization characteristic of the material. It is discussed that the unsymmetrical physical phenomenon of long line magnetostrictive position sensor with ferromagnetism, electromagnetism and physics theory, in order to promote the performance of the sensor and improve the precision of the sensor.

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