Magnetostrictive Measurement Experiment Based on Optical Lever and Image Processing

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Abstract: Using optical lever, He Ne laser and several mirrors in the vertical plane, an experimental platform for measuring the magnetostrictive coefficient was set up. The relationship between the magnetostrictive coefficient and the length and diameter of metal rod was quantitatively studied when the magnetostrictive saturation of Fe Ni and Ni Zn alloys was not achieved. It was found that the magnetostrictive characteristic of metal rod was independent of the length but positively related to the diameter. By comparing the magnetostrictive characteristics in the steady magnetic field and the alternating magnetic field, that is, the dynamic method and the static method, it is proved that the measurement method is more accurate. By designing magnetostrictive measurement experiment suitable for teaching and scientific research, a new method for material selection in physical experiment teaching and scientific research experiment is provided.

1. Introduction

Magnetostrictive effect refers to the phenomenon that the internal magnetic field of the material is rearranged along the magnetic field after being influenced by the external magnetic field, resulting in the change of length. Magnetostriction coefficient is one of the parameters to measure its characteristics, which refers to the relative change of the volume or length of the metal rod. The size is within the range of 10^{-6}-10^{-3} , and the general measuring tools are not easy to measure accurately. The optical lever device used in this paper uses the optical conversion amplification method. The He-Ne laser is used as the light source, and the elongation of magnetic materials is amplified by seven times reflection of multiple plane mirrors, and finally it is printed on a vertical fixed ruler. Considering the small range of reading change, the fixed stand of the camera device is installed in front of the optical path slant, and the specific size of the expansion is determined by tracking pixel points through image processing. [1-2]

At present, in addition to the optical lever method, the main methods to measure the magnetostrictive coefficient are unbalanced bridge method, Michelson interference method, strain gauge method, differential capacitance method, linear frequency modulation laser heterodyne technology method, etc. [3-7]. The experimental devices are more complex, and the principle is more complicated, and the demonstration effect is poor. However, the existing optical lever device [8] uses telescope to read, which has complex collimation and focusing, and large reading error caused by parallax. The purpose of this paper is to build a simple and visual experimental device to measure the above relationship, and to study the magnetostrictive characteristics of different metal rods by using the basic optical amplification principle.

2. Principle of measuring

The physical diagram and schematic diagram of the experimental platform are shown in Fig. 1 and Fig. 2 respectively. The experiment is designed by using the optical lever method. The power supply excitation coil generates a magnetic field, which makes the magnetic material placed in it produce magnetostrictive effect. The optical lever conversion amplification and image processing are used to get the size of the elongation, and the magnetostrictive phenomenon is quantitatively analyzed.

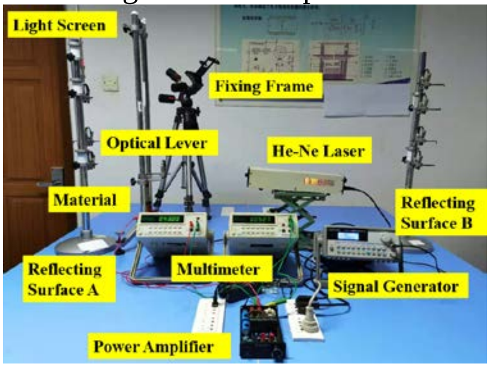


Fig. 1 Physical diagram of experimental platform

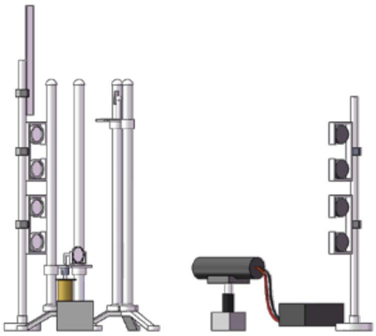


Fig. 2 Schematic diagram of experimental platform

1.1 Magnetic field excited by an electrified solenoid

The magnetic field can be generated by connecting the two ends of the excitation coil with a DC power supply. Considering the current in the coil winding, the magnetic field intensity on the axis generated by the excitation coil [9] is:

$$H = \frac{NI}{2(R_2-R_1)} \cdot ln(\frac{R_2+\sqrt{R_2^2+\frac{l^2}{4}}}{R_1+\sqrt{R_1^2+\frac{l^2}{4}}}) \tag{1}$$

In the above formula, N is the number of coil turns, I is the DC current in the coil, R_2 and R_1 are the outer diameter and inner diameter of the coil respectively, and l is the coil length. Then the magnetic induction intensity on the axis of the DC coil is B:

$$B = \frac{\mu_0}{2} \cdot \frac{1}{(R_2-R_1)} \cdot NI \cdot ln\frac{R_2+(R_2^2+l^2/4)^{1/2}}{R_1+(R_1^2+l^2/4)^{1/2}} \tag{2}$$

1.2 Optical lever amplification

Generally, the size of the deformation variable is measured by the magnetostrictive coefficient γ:

$$\gamma = \frac{\Delta L}{L_0} = \frac{L_B-L_0}{L_0} \tag{3}$$

Where, ΔL is the length change caused by magnetostriction, L_0 is the original length of the metal bar. L_B is the length of the metal rod after elongation (or shortening) under the action of external magnetic field. The rotation of the lever will cause the position of the light spot on the scale to move, as shown in Fig. 3.

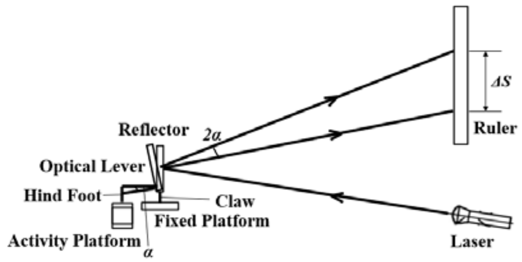


Fig. 3 Structure of Optical Lever

Then the magnetostriction coefficient:

$$\gamma = \frac{d_2 \Delta S}{2 d_1 L_0} \tag{4}$$

Where d_1 and d_2 is the distance between the front two feet of the optical lever and the reading ruler and the horizontal distance between the rear foot of the optical lever and the front two feet (optical lever coefficient).

1.3 Image processing aided reading

In order to improve the accuracy of the reading, the image is binarized, that is, the gray level of the image point is manually set to 0 or 255 for denoising, and the interference background image other than the light spot is excluded. Then the image is fitted by circle to find the center of the laser spot. In the demonstration experiment and students' experimental teaching, mobile phones can be used as camera equipment, and the above image processing can be realized by built-in software.

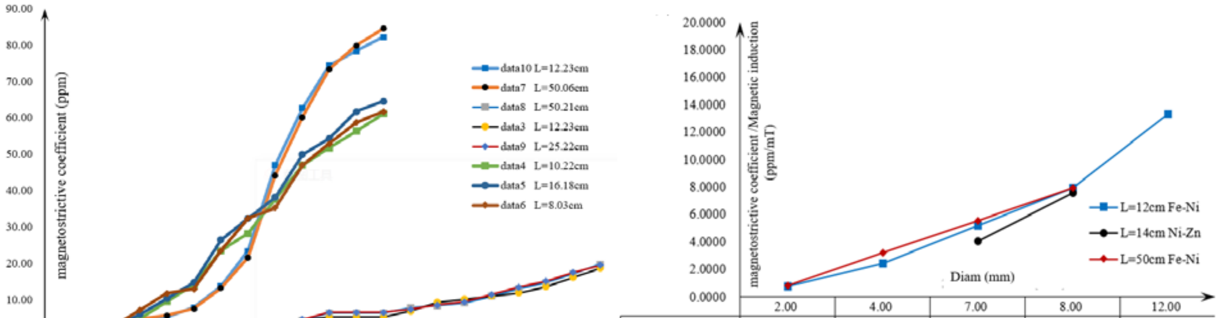
1.4 Extracting the amplitude of fundamental frequency signal by Fourier transform

In order to extract the unique frequency signal which is consistent with the frequency of alternating magnetic field, the displacement waveform is transformed into Fourier transform, and the time domain signal is converted into frequency domain signal to determine the most likely frequency signal (fundamental frequency) of the displacement waveform. If it is consistent with the current variation signal, the maximum elongation of the metal bar under the alternating magnetic field can be determined by the amplitude of the fundamental frequency. The magnetostriction characteristic is independent of the direction of the current, so the frequency of the metal bar magnetostriction is twice of the excitation current signal frequency.

3. Static measurement of magnetostrictive coefficient

By measuring the magnetostriction coefficient of different materials under different excitation current excitation magnetic fields, the data are processed according to the different groups of material length, diameter and type, and the influence of different factors on the magnetostrictive characteristics of metal rods is analyzed.

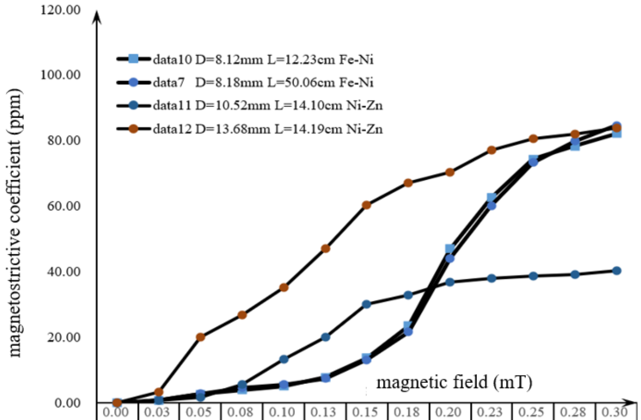
Three groups of metal rods with the same diameter and different length are selected to study their magnetostrictive properties by static method. Fig. 4 shows that the clustering characteristics of magnetostrictive properties of the same material with the same diameter are obvious. It is speculated that the speed of the change of magnetostriction coefficient of metal rod with the change of external magnetic field is independent of the length of metal rod, and is positively related to the diameter.



	2.00	4.00	7.00	8.00	12.00
L=12cm Fe-Ni	0.7691	2.4113	5.1724	7.9334	13.3360
L=14cm Ni-Zn			4.0605	7.5822	
L=50cm Fe-Ni	0.8182	3.1868	5.5553	7.9239	

Fig. 4 Relationship between magnetostriction and material length & diameter

The magnetostrictive properties of alloy bars with similar or same diameter and different materials are compared and analyzed. According to the recorded data, fig. 5 is obtained.



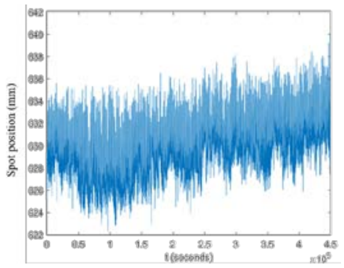
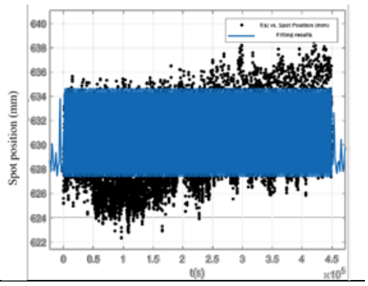
	0.00	0.03	0.05	0.08	0.10	0.13	0.15	0.18	0.20	0.23	0.25	0.28	0.30
data10 D=8.12mm L=12.23cm Fe-Ni	0.00	0.78	2.74	3.92	5.09	7.83	13.71	23.50	47.01	62.67	74.43	78.34	82.26
data7 D=8.18mm L=50.06cm Fe-Ni	0.00	0.94	2.82	4.70	5.64	7.52	13.16	21.62	44.19	60.17	73.33	79.91	84.61
data11 D=10.52mm L=14.10cm Ni-Zn	0.00	0.67	1.68	5.71	13.43	20.15	30.22	32.90	36.93	37.94	38.61	39.28	40.29
data12 D=13.68mm L=14.19cm Ni-Zn	0.00	3.36	20.15	26.86	35.25	47.01	60.44	67.15	70.51	77.22	80.58	81.92	83.94

Fig. 5 Relationship between magnetostrictive properties and materials

It is found from the above figure that the magnetostrictive properties of metal rods of different materials are different under the external magnetic field. In the magnetic field with magnetic induction less than 0.2-0.3mT, the magnetostrictive phenomenon of Ni-Zn soft ferrite is more obvious. When the external magnetic induction is greater than 0.2-0.3mT, the magnetostrictive coefficient of Ni-Zn alloy tends to be saturated, while that of permalloy (Fe-Ni soft ferrite) tends to be saturated The shrinkage factor continues to increase.

4. Dynamic measurement of magnetostrictive coefficient

The alternating current is applied to both ends of the coil to obtain the alternating magnetic field, and the variation of the length of the metal rod with time (the magnetic induction intensity of the magnetic field) is obtained. Taking a metal bar as an example, the displacement waveform and Fourier transform results are shown in Fig. 6.

<table>
<tr><td colspan="4">Stick 5: D=6.14mm L=161.8mm Fe-Ni
Current frequency: 3Hz; Current RMS: 0.9A</td></tr>
<tr><td colspan="2">Displacement waveform</td><td colspan="2">Fourier function fitting results</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
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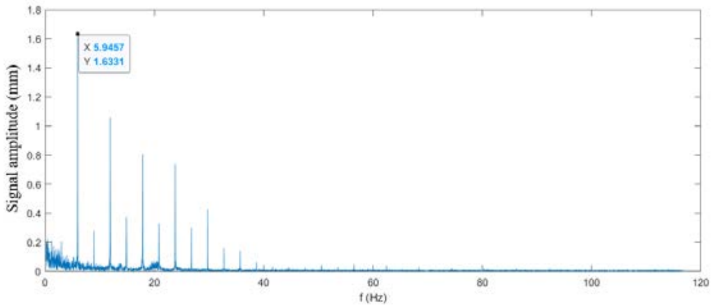
<tr><td colspan="4">Fourier transform results

</td></tr>
<tr><td>R^2</td><td>0.5292</td><td>magnetostrictive coefficient (ppm)</td><td>63.1</td></tr>
</table>

Fig.6 Dynamic measurement of magnetostrictive coefficient

The unique waveform is fitted by Fourier function, and the fundamental frequency signal is resolved at the same time. The Fourier transform results of each experiment are obtained by using mathematical software. The results show that the fundamental frequency of the displacement waveform signal is twice that of the current signal, which proves that the magnetostrictive characteristics of the metal rod has nothing to do with the direction of the magnetic field.

5. Evaluation

5.1 Comparison of results

The magnetostrictive coefficient measured by dynamic and static method is compared as shown in Fig. 7.

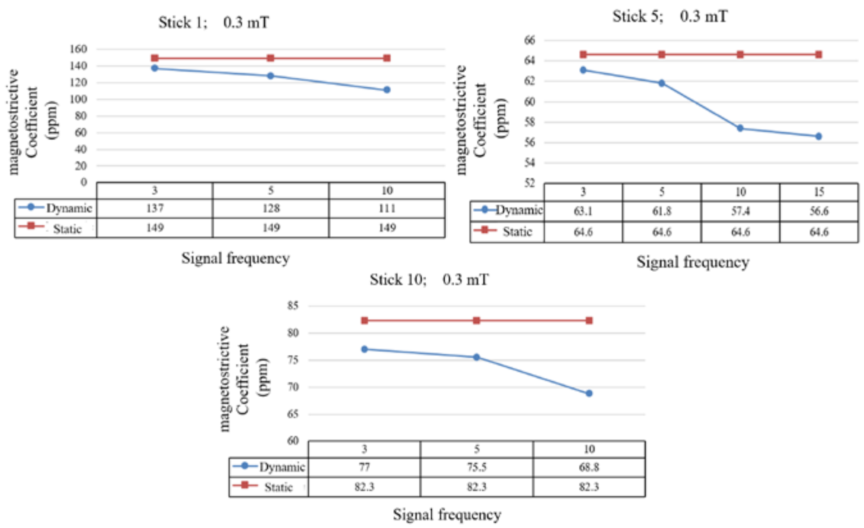


Fig. 7 Comparison of magnetostriction with dynamic and static measurement

With the increase of the frequency of AC signal, the magnetostrictive coefficient measured by alternating magnetic field gradually decreases, and gradually deviates from the data measured under the steady magnetic field. But on the whole, when the frequency of AC signal increases to 10Hz, the deviation between the measured value and the measured value under the steady magnetic field is within 15ppm.

5.2 Device sensitivity

Considering the minimum graduation value of the image processing reading after the device uses the mobile phone camera to take photos, the minimum magnetostrictive coefficient value that can be measured by the device is :

$$\gamma_{min} = \frac{d_2 \Delta S_{min}}{2 d_1 L_0} = \frac{0.08125}{L_0} \tag{5}$$

Where, ΔS_{min} is the minimum graduation value of the reading, L_0 is the length of the material to be tested (m), γ_{min} is the minimum magnetostrictive coefficient that can be measured by the device (ppm). The minimum magnetostrictive coefficient of metal rods with different lengths is 0.08-0.50. It is considered that the sensitivity of the device is better than original methonds.

5.3 Device accuracy

The angle approximation $tan\alpha \sim \alpha$ result in systematic error:

$$\delta = 1 - \frac{2\alpha}{tan2\alpha} = 0.07\% \tag{6}$$

The magnification of the device can be more than 100 times, so the system error is small. However, when measuring giant magnetostrictive materials and other materials with large magnetostrictive coefficient, the systematic error can not be ignored and can be calculated by the following formula:

$$\delta = 1 - \frac{2\alpha}{tan2\alpha} = 1 - \frac{2arctan\frac{\gamma}{d_2}}{\frac{2\gamma}{d_2}} \cdot [1 - \left(\frac{2\gamma}{d_2}\right)^2] \tag{7}$$

In the above formula, d_2 is the optical lever coefficient, γ is the magnetostrictive coefficient, and δ is the system error.

6. Conclusion

The device used in this experiment is simple, high-precision and easy to observe. It can quantitatively study the relationship between magnetostriction coefficient and the magnetic field environment. It has broad application prospects for the selection of materials, calibration of instruments and popularization of Science in school.

In recent years, magnetostrictive phenomenon has been more and more widely used. Some scholars have developed intelligent magnetostrictive material driven electro-hydraulic actuator based on the basic principle of power telex [10], and used giant magnetostrictive acoustic transducer to produce high-intensity ultrasound [11]. In terms of detection technology, magnetostriction is used to detect oil-water interface [12] and conduct guided wave detection and analysis of atmospheric furnace tube corrosion [13]. In addition, magnetostrictive displacement sensor based on magnetostriction phenomenon has been widely used in metallurgy, chemical industry, environmental protection, pharmaceutical and other civil fields [14]. This device can be used for basic test of material selection of these new physical elements, providing convenience for its research and development.

In addition, as a classical optical amplification method for micro displacement in the history of physical experiment research, the optical lever method has the advantages of high precision, high sensitivity and convenient adjustment, which are still difficult to replace. Nowadays, new instruments and devices for measuring micro displacement emerge in endlessly, such as the application of various high-sensitivity sensors in experiments [15]. The experimental principles, research methods and means involved in the classical basic experimental research still play an irreplaceable role in the development of physical experiments.

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