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ANALYSING OF THE MAGNETOSTRICTIVE EFFECT BY MICHELSON INTERFEROMETER

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Abstract
In this paper, a linear change in the magnetic field of some ferromagnetic substances was measured using a Michelson interferometer. The measurement accuracy of the Michelson interferometer is shown to be 10-7m. A graph of the linear variation of iron and nickel as a function of the magnetic field value is plotted.

Introduction

Magnetostriction is the change in size or shape of objects during magnetization. In ferromagnets, magnetostriction reaches large values (relative elongation $l/l_0 = 10^{-6}$-10^{-2}). In antiferromagnets, paramagnets and diamagnets, this value is very small [1].
In modern theory of magnetism, magnetostriction is considered to be the result of two main types of interactions in ferromagnetic bodies: electrical exchange and magnetic interaction. Accordingly, the magnetostriction in a crystal lattice can be of two types depending on the nature of the deformation [2]. Due to changes in magnetic forces and changes in alternating forces (dipole-dipole, spin-orbital).
In the magnetization of ferromagnets, the magnetic forces in the range from 0 to H are affected by the magnetic saturation of the sample. The magnetization of the field in this range is related to the shift of the boundary between the domains and the rotation of the magnetic moments of the domains. Both of these processes change the energy state of the crystal lattice, causing a change in the equilibrium distances between the nodes. Magnetostriction in this form is anisotropic in nature, and the linear dimensions of a crystal change without changing its size [3].
As mentioned above, the magnetostrictive effect is a change in the linear dimensions of a substance in its magnetization. But since such a change is so small, it cannot be detected in any experiment. In this article, we will look at ways to determine the above effect on a Michelson interferometer [4].
The article is formatted as follows. Section 1 presents the basic formulas describing light interference. In Section 2, we consider the method of determining the linear changes of ferromagnets on the Michelson interferometer due to the magnetostrictive effect. Section 3 provides a summary and references [5].

Basic equations of interference

Suppose that two coherent waves described by the following equations converge at some point M in space

$$x_1 = A_1 \cos\omega\left(t - \frac{s_1}{\upsilon_1}\right) \qquad x_2 = A_2 \cos\omega\left(t - \frac{s_2}{\upsilon_2}\right) \tag{1}$$

Where ω is the cyclic frequency of the light wave, S_1 and S_2 are the distance from the light source to the point where the wave joins, and υ_1 and υ_2 are the velocities of the waves [6].

Since electromagnetic waves consist of alternating electric and magnetic field strength vectors, their amplitude values are added by the cosine theorem, so the resulting amplitude of the waves is

$$A^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\delta \tag{2}$$

Since the wave intensity is proportional to the square of its amplitude ($I \sim A^2$), the following equation can be determined

$$I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\delta \tag{3}$$

The third term on the right side of the equation is called the interference limit, where δ is the phase difference of the waves joining at point *M* [7]

$$\delta = \omega\left(\frac{s_2}{\upsilon_2} - \frac{s_1}{\upsilon_1}\right) = \omega\left(\frac{s_2}{c/n_2} - \frac{s_1}{c/n_1}\right) = \frac{\omega}{c}(s_2n_2 - s_1n_1) = \frac{2\pi\nu}{c}(L_2 - L_1) = \frac{2\pi}{\lambda_0}\Delta \tag{4}$$

The following known equations are used here

$$\upsilon = c/n, \qquad \omega = 2\pi\nu, \qquad c/\nu = \lambda_0 \tag{5}$$

The product of the geometric path length of a light wave in an environment to the refractive index of that medium is called the optical path length

$$L = s\cdot n \tag{6}$$

The following is the difference in path lengths traveled by the optical wave

$$\Delta = L_2 - L_1 = s_2n_2 - s_1n_1 \tag{7}$$

this is called the optical path difference.

If the difference in optical path Δ is an integer multiple of the wavelength in a vacuum

$$\Delta = \pm m\lambda_0 = \pm 2m\frac{\lambda_0}{2} \qquad m = (0,1,2,\dots) \tag{8}$$

In this case, the waves joining at point *M* generate oscillations in the same phase, and the condition of maxima is satisfied. Here the phase difference is as follows

$$\delta = \pm 2m\pi \tag{9}$$

and the amplitude of the resulting wave increases at this point

If the difference in the optical path of the waves is an odd number of times the half-wavelength

$$\Delta = \pm(2m+1)\frac{\lambda_0}{2} \qquad m = (0,1,2,\dots) \tag{10}$$

In this case, the waves joining at point *M* generate oscillations in the opposite phase, and the minimum condition is satisfied [8]. Here the phase difference is as follows

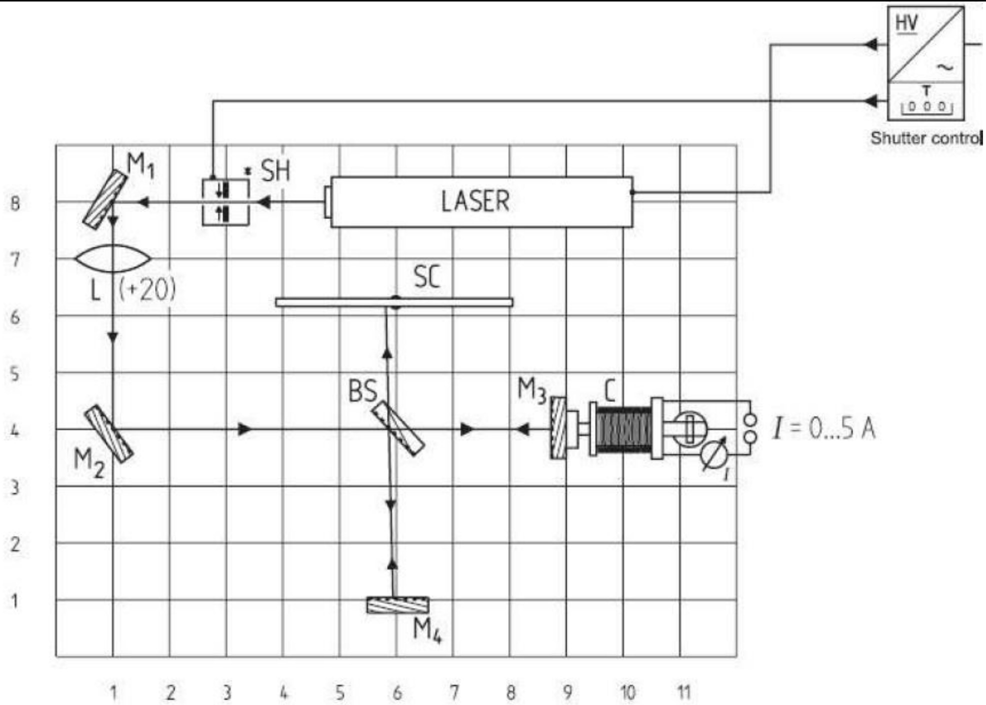

Fig 1.

$$\delta = \pm(2m+1)\pi \qquad (11)$$

and the amplitude of the resulting wave decreases. We will use the above formulas in the following sections.

Measurement of mangnotostrictive effect on a Michelson interferometer

With the aid of two mirrors in a Michelson arrangement, light is brought to interference. Due to the magnetostrictive effect, one of the mirrors is shifted by variation in the magnetic field applied to a sample, and the change in the interference pattern is observed. Testing various ferromagnetic materials (iron and nickel) as well as a non-ferromagnetic material (copper) with regard to their magnetostrictive properties [9].

Ferromagnetic substances undergo so-called magnetic distortions, i.e. they exhibit a lengthening or shortening parallel to the direction of magnetisation. Such changes are termed positive or negative magnetostriction. The distortions are on the order of to in size. As is the case in crystal anisotropy, the magnetostriction is also ascribable to the spin-orbit mutual potential energy, as this is a function of the direction of magnetisation and the interatomic distances. Due to magnetostriction, which corresponds to a spontaneous distortion of the lattice, a ferromagnet can reduce its total – anisotropic and elastic – energy [10].

Figure 1 shows a schematic of the Michelson interferometer. When the wire C is energized, the core in its magnetic field changes its length to Δl due to magnetostriction. As a result, it is possible to observe the interference landscape shift on the SC screen. This can be explained by the following equations. Assuming that the known intervals l_1 and l_2 correspond to the maximum interference

$$l_1 = \pm m_1\lambda_0, \qquad l_2 = \pm m_2\lambda_0 \tag{12}$$

Changes in optical path differences is

$$\Delta l = \pm \Delta m \lambda_0 \tag{13}$$

Here Δl is the change in the linear dimensions of an object in a magnetic field. This change can be compared to the change in the path difference of light on the Michelson interferometer. From the above equation, it can be said that as the body changes at each wavelength, one interference pattern shifts into one order. This means that linear changes in an object can be detected graphically by shifting the interference pattern. The following is the linear transformation of a metal depending on the magnetic field applied to it.

Figures 2 and 3 shown the experimental results of linear changes of iron and nickel under the influence of a magnetic field

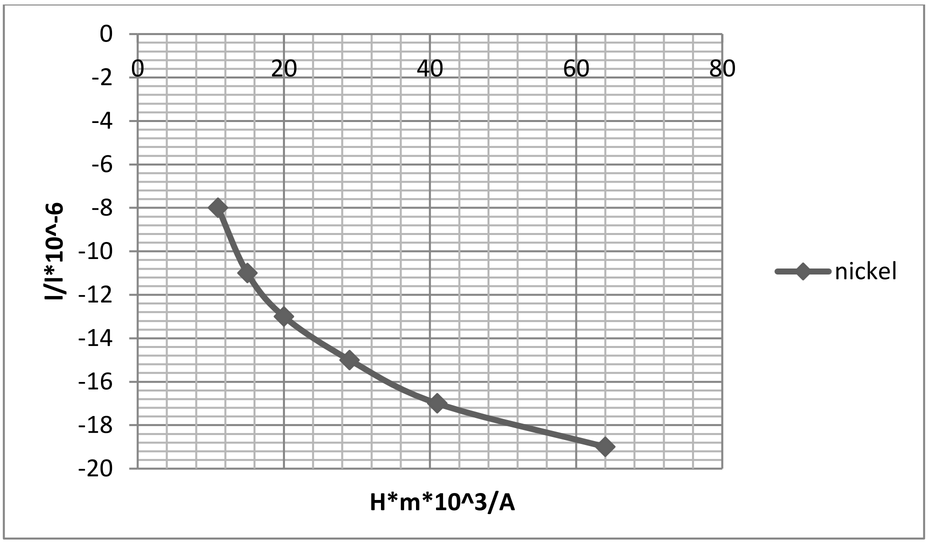

Fig 2. Linear change of nickel under the influence of a magnetic field

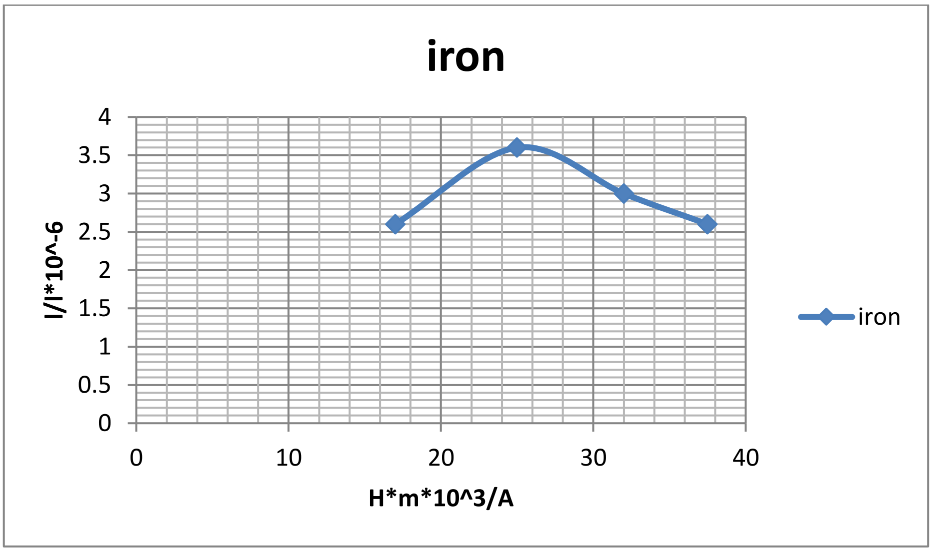

Fig 3. Linear change of iron under the influence of a magnetic field

Conclusion

In this paper, a linear change in the magnetic field of some ferromagnetic substances was measured using a Michelson interferometer. The measurement accuracy of the Michelson interferometer is shown to be 10^{-7}m. A graph of the linear variation of iron and nickel as a function of the magnetic field value is plotted. From the results of the experiment, it can be concluded that the Michelson interferometer can be used to measure the linear changes of not only ferromagnets but also paramagnets and diamagnets under the influence of a magnetic field.

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