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Harmonics Analysis of Magnetostriction in 3% SiFe

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The higher order harmonic components of magnetostriction during ac magnetization in 3% SiFe are measured as a function of the magnetizing angle respect to [001] axis using a constructed laser interferometry. The magnetostriction with magnetizing angle from [001] axis agrees with the calculation based on domain reorientation. The relative amplitudes of odd and even harmonics respectively for magnetic induction and magnetostriction decrease with the order of harmonics, accompanying the contraction of the amplitudes. The contraction of harmonics order of magnetostriction harmonics is shown to be the even number times of that of magnetic induction.

1. Introduction

A lots of work for magnetostriction in 3% SiFe have been continued during last 30 years for the understanding of relationship with domain dynamics during magnetization [1]. For the practical problems in application such as iron loss and acoustic noise, the related experiment is still performed on the reduction of magnetostriction by controlling the domain configuration [2].

The magnetostriction associated with the domain reorientation exhibits hysteresis during cyclic magnetization as a function of applied field [3], and the acoustic noise produced by power transformer at high flux density is associated with the magnetostrictive vibration of the core material of 3% SiFe. The harmonics of hysteric magnetization are attributed to the nonlinear characteristics of ferromagnetic materials [4], and their components are related to the material and magnetic parameters, such as anisotropy, grain size and external stress [5].

However, no literature exists for the harmonic analysis of magnetostriction, being responsible for the acoustic noise spectra of electrical equipment. Present work is concerned with the harmonics of magnetostriction during the magnetization in 3% SiFe as a function of φ, the angle between the field direction and [001] axis using a laser interferometry.

2. Experimental

A high purity sample of 3% SiFe alloys of (110)[001] texture is cut at the angle from [001] axis with the size of 0.36 mm$\times$15 mm$\times$120 mm, and annealed to remove the induced stress during cutting. The magnetic field is applied by a primary coil wound on the sample where the magnetic flux path is enclosed by a yoke. The magnetic induction is measured from the induced voltage of a secondary coil which is inside of the primary coil.

The magnetostriction is measured by a Michelson interferometry using He-Ne laser. A mirror attached to piezoelectric transducer (PZT) consists of a reference beam path. The interferometer signal due to the change of the sample length is fed to PZT adjusting the position of reference mirror to keep the path difference constant, where the performance of feedback system is shown in Fig. 1. The feedback voltage is calibrated to the distance variation by the interferometer fringe shift. The magnetostriction is measured at magnetizing frequency of 0.1 *Hz*, where the frequency limit was the order of ~*Hz* due to the distortion of mechanical motion. A sinusoidal form of field is used to focus the harmonics analysis. The harmonics of magnetostriction and magnetic induction were analyzed by a digital oscilloscope (Lecroy 9300A).

3. Results and discussion

3.1 B-H loop

The wasp-waisted *B-H* loops observed for $\varphi>30^\circ$ are associated with the involvement of closure domains signified by the appearance of zig-zag domains on the surface [6]. Fig. 2 represents the harmonics profile of the magnetic induction for $\varphi=0^\circ$, 40° and 90°, where the odd order harmonics are attributed to the asymmetric nature of the magnetization for the applied field. The amplitude of harmonics decreases with the order, and the amplitude contraction appears as φ increases, i.e., 21^{st} for $\varphi=40^\circ$ and 15^{th}, 39^{th} order for $\varphi=90^\circ$.

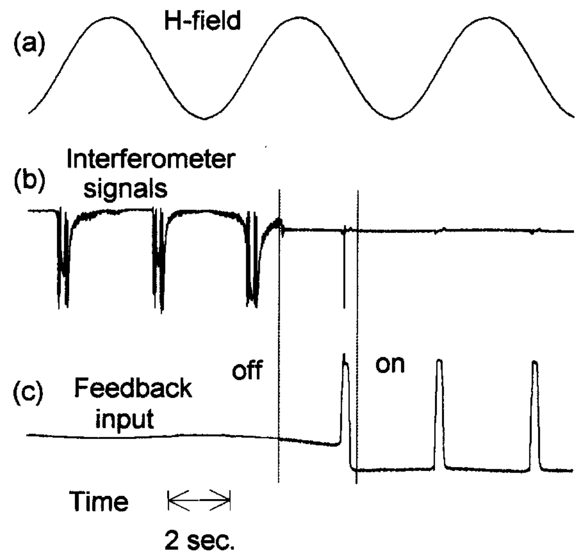

Fig. 1. Performance of feedback system to keep the interferometer signal constant (a) applied magnetic field, (b) interferometer signal and (c) feedback input.

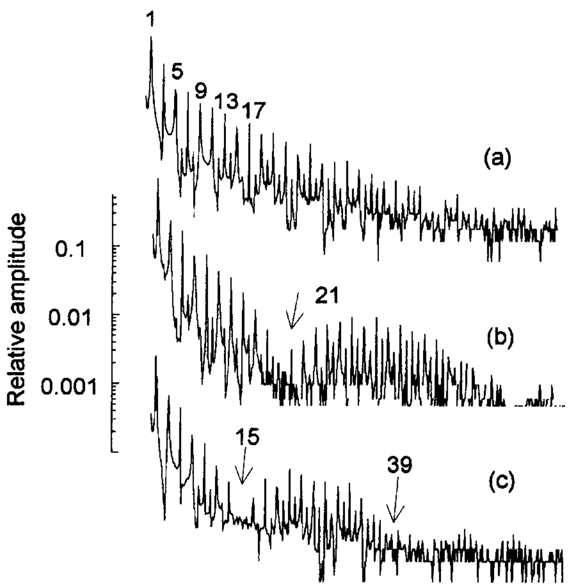

Fig. 2. Relative amplitude of the harmonics of magnetic induction for (a) φ=0°, (b) 40° and (c) 90°.

3.2 Magnetostriction with φ

Magnetostriction profiles during a cycle of magnetization are shown in Fig. 3(a)-(c) for φ=0°, 40° and 90°, respectively. The profiles vary with φ, that is, magnetostriction becomes negative for φ<55° as field increases from zero, while positive for $\varphi \geq$ 55°. The φ dependence of magnetostriction, obtained from Fig. 3, is shown in Fig. 4.

Magnetostriction is caused by the reorientation of domains, and is given as a function of φ as following: [6, 7]

$$\lambda(\varphi) = \frac{\sqrt{2}\sin\varphi}{\cos\varphi + \sqrt{2}\sin\varphi}(sin^2\varphi/2 - \cos^2\varphi) \quad (1)$$

where λ_{100} is magnetostriction coefficient in <100> direc-

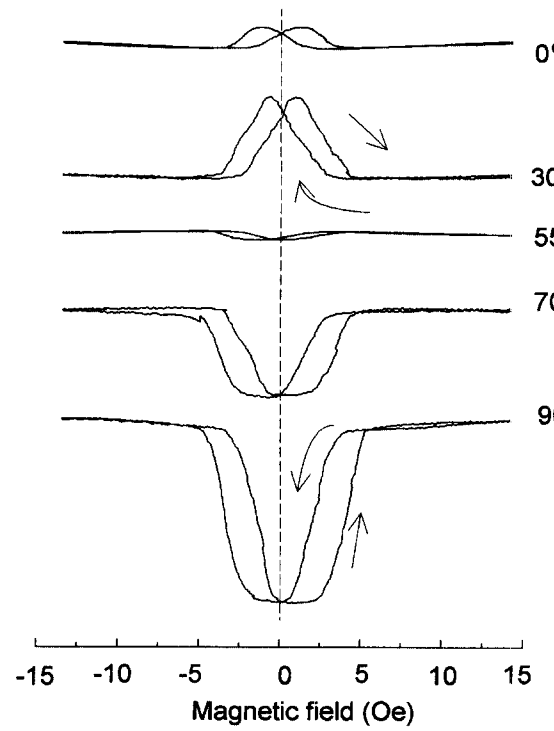

Fig. 3. Profiles of magnetostriction along the field direction.

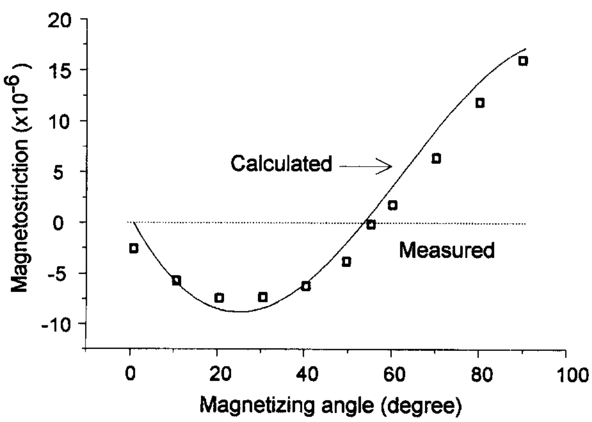

Fig. 4. φ dependence of magnetostriction.

tion and equal to 23.7×10^{-6} for 3% SiFe. The full curve of theoretical calculation from Eq. (1) gives a fairly good agreement with the measured ones.

3.3 Harmonics with φ

The even harmonics are observed in the magnetostriction, due to the symmetrical nature of magnetostriction with respect to the applied field. The relative amplitude of harmonics decreases with the harmonic order as shown in Fig. 5(a)-(c) for φ=0°, 40° and 90°, respectively. The order number of the amplitude contraction was 60th for φ=0°, 40th for φ=40°, and 28th and 56th order for φ=90°.

The first contraction harmonics order of magnetostriction and magnetic induction decreases with φ as shown in Fig. 6, suggesting the first contraction harmonics decreases with anisotropy depending on the magnetization angle respect to [001] axis. The contraction order of magnetostriction

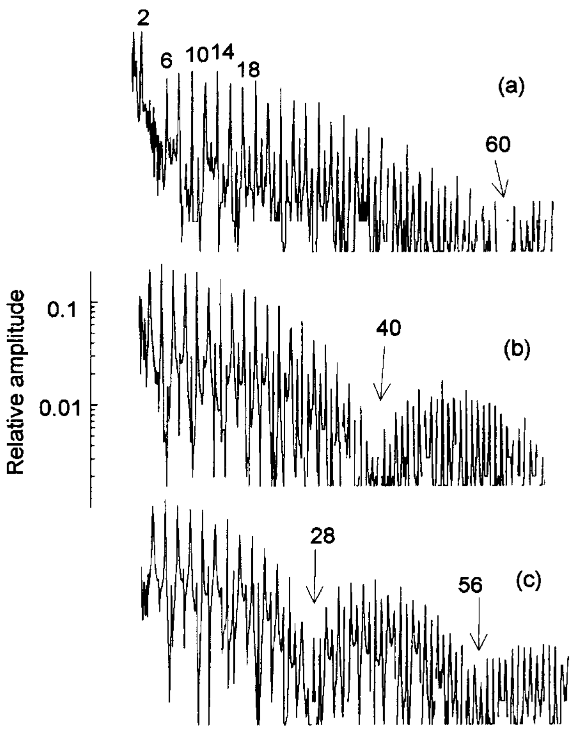

Fig. 5. Relative amplitude of the harmonics of magnetostriction for (a) φ=0°, (b) 40° and (c) 90°.

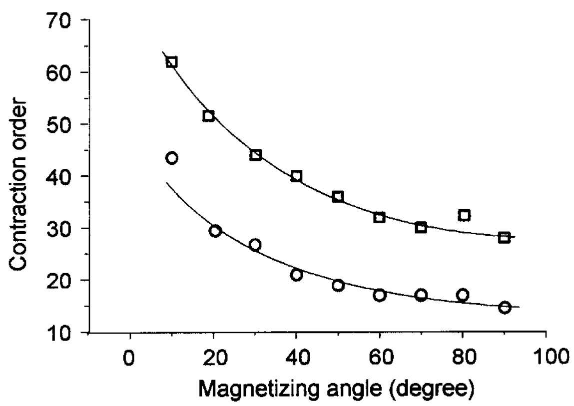

Fig. 6. Dependence of the contraction order with φ for magnetostriction (□) and magnetic induction (○).

harmonics, N_{MS} is shown to be the even number multiplied by that of magnetic induction, N_{MI} and their relationship for $\varphi > 40°$ is expressed as

$$N_{MS} = (N_{MI} - 1) * 2n \quad (2)$$

where n is the integer. It is difficult to measure the harmonics of magnetostriction in high magnetizing frequency due to the distortion of mechanical motion. However, this relationship provides the harmonics characteristics of magnetostriction by measuring the harmonics of magnetic induction which is relatively easy up to high frequency range.

4. Conclusion

The harmonics of magnetostriction during ac magnetization in 3% SiFe are measured as a function of the magnetizing angle respect to [001] axis using a constructed laser interferometry. The magnetostriction with magnetizing angle from [001] axis agrees with the calculation based on domain reorientation. The relative amplitudes of even harmonics of magnetostriction and odd harmonics of magnetic induction decrease with the order number in 3% SiFe, accompanying the amplitude contraction. The contraction order of both in magnetic induction and magnetostriction decreases with magnetizing angle from [001] axis, where the contraction order of magnetostriction harmonics is shown to be the even number times of that of magnetic induction. The simple relationship between the contraction harmonics order of magnetic induction and magnetostriction provides easy assess of harmonics characteristics of magnetostriction up to high frequency range from those of magnetic induction.

Acknowledgment

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