Influence of crystal orientation on magnetostriction waveform in grain orientated electrical steel

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A B S T R A C T

Aiming to gain insight into the mechanisms of grain-oriented electrical steel sheet magnetostriction waveforms, we investigated the influence of crystal orientations. An increase in the β angle results in an increase in the amplitude of magnetostriction waveform, but does not affect the waveform itself. By slanting the excitation direction to simulate the change of the α angle, change in the magnetostriction waveform and a constriction–extension transition point in the steel plate was observed. The amplitude, however, was not significantly affected. We explained the nature of constriction–extension transition point in the magnetostriction waveform by considering the magnetization rotation. We speculated that the change of waveform resulting from the increase in the coating tensile stress can be attributed to the phenomenon of the magnetization rotation becoming hard to be generated due to the increase of magnetic anisotropy toward [001] axis.

1. Introduction

It has been known for some time now that for the amplitude of a magnetostriction waveform λp–p, the smaller the material is, the smaller the transformer noise is in regard to magnetostriction. However, recently it has been discovered that not only the waveform amplitude, but also the magnetostriction waveform itself and its harmonic component can be shown to strongly influence the noise.

When we measure the magnetostriction waveform of a grain oriented electric steel plate in the condition of product steel plate, at first the steel plate shrinks with an increase in the magnetic flux density, B. However as the steel plate extension shifts near to B at ~1.5 T, a transition point can be observed (Fig. 1).

Such change suggests that harmonic component is superimposed more than the fundamental wave in the magnetostriction waveform and may be one of the reasons for the increase in the noise. However, there are only a few instances focusing on the developmental mechanism itself in harmonic components of magnetostriction waveform studies so far. As such the mechanism that influences the magnetostriction waveform with improvement of crystal orientation, known as a remedial measure, for transformer noise has not been clarified.

The measurement of the magnetostriction waveform has been conducted with a single crystal specimen in this study to evaluate the angle α (the ND rotation angle for [001] axis) and the angle β (the elevation angle to ND axis for [001] axis), separately (Fig. 2).

2. Experimental procedures

3% Si steel single crystal was prepared from 0.27 mm-thick grain oriented electrical steel covered with forsterite coating. These grains, which were oriented to an approximate Goss orientation, were specially grown to more than 100 mm in diameter. It was cut into a 55 mm square size single crystal after applying phosphate coating (the amount of application: 10 g/m2), and was then, to remove shear strain, annealed for 3 h at 973 K in Ar atmosphere. The crystallographic orientation was determined by an X-ray diffraction and the specimens were then cut so that α angle was about 0° (approximately parallel toward [001] axis). That is, specimens with forsterite and phosphate coatings had the different misorientation angle β under the same misorientation angle α.

We then conducted an influence assessment for this specimen. First, to evaluate only the influence of the β angle, we measured the magnetostriction waveform as the excitation direction for the specimen of β=1.5°, 2.5°, and 3.8° which was parallel to the [0 0 1] axis. Later, to evaluate the influence of the α angle simultaneously, we measured the magnetostriction waveform of the specimen of

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$\beta=2.5^\circ$ with the external magnetic field inclined to the [0 0 1] axis, and the angle θ, between external magnetic field and [0 0 1] axis, was set to $\theta=0^\circ$, 2°, and 4° (Fig. 3). The measurement was conducted using a strain gauge [1] (gauge length: 5 mm, gauge factor: Ks=2.1) and the excitation requirement was set to 1.7 T/50 Hz.

3. Experimental results

3.1. Influence of β angle

The measurement results of the magnetostriction waveform set to $\theta=0^\circ$ for the specimen $\beta=1.5^\circ$, 2.5°, and 3.8° are shown in Fig. 4. Any obvious differences were not observed for magnetostriction waveform at any β angle. This shows that the steel plate was shrinking as the excitation magnetic flux density increased, but we

Fig. 1. Typical magnetostriction waveform.

Fig. 2. Definition of α/β angle in Goss orientation ((1 1 0) and [0 0 1]) crystal.

could not observe the shrinking to extending transition point during the excitation.

Therefore, we found that β angle did not influence the shape of waveform, but largely influenced the λp–p. Since magnetostatic energy becomes large due to a magnetic pole formed on the surface as β angle increases, the formation of lancet magnetic domain was also increased.

3.2. Influence of excitation direction

For the specimen of $\beta=2.5^\circ$, the results are shown in Fig. 5 at the time when we measured the magnetostriction waveform at $\theta=0^\circ$, 2°, and 4° for simulating an influence of α angle. As it was inclined towards the excitation direction from parallel to external magnetic field and [0 0 1] axis, it was confirmed that a transition point was observed in the product steel plate. This indicates that the steel plate shifts from shrinking to extending in the excitation direction. On the other hand, when we examined λp–p, any large value changes influenced by θ were not noticed.

4. Discussion

4.1. Introduction

It was assumed that magnetostriction waveform of grain oriented electric steel plate was caused by the generation/disappearance of the lancet magnetic domain. This means that a steel plate shrinks when the magnetic flux density and the lancet magnetic domain increases, or conversely, a steel plate is extended when magnetic flux density decreases and lancet magnetic domain disappears. However, as shown in Fig. 5, it is difficult to explain a shrinking–extension transition point caused by inclining excitation direction through the disappearance of lancet magnetic domain. When examining the waveform at $\theta=0^\circ$ in Fig. 5, it is assumed that the disappearance of lancet magnetic domain does not take place since any shrinking–extension transition point does not appear in the waveform. In the case of a large θ, it could be thought that a steel plate will shrink when a generation of lancet magnetic domain, with magnetization component toward TD direction is facilitated, but actually it becomes extended. This fact suggests that a factor other than the generation/disappearance of the lancet magnetic domain would have influence on the magnetostriction waveform. Since we are presently conducting excitation by inclining an external magnetic field from the [0 0 1] axis, magnetic rotation could be considered as the influencing factor.

Therefore, based on the experimental results, we attempted to comprehend magnetostriction waveforms in this discussion with the consideration of magnetic rotation other than generation/disappearance of lancet magnetic domain.
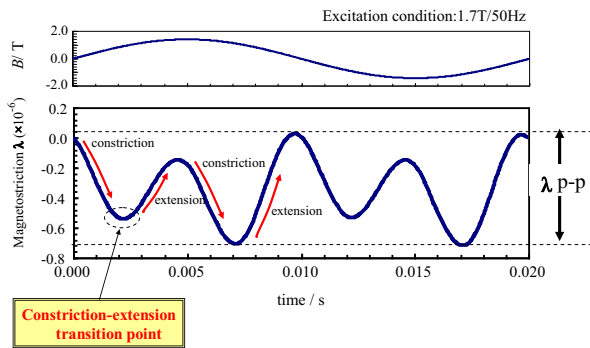

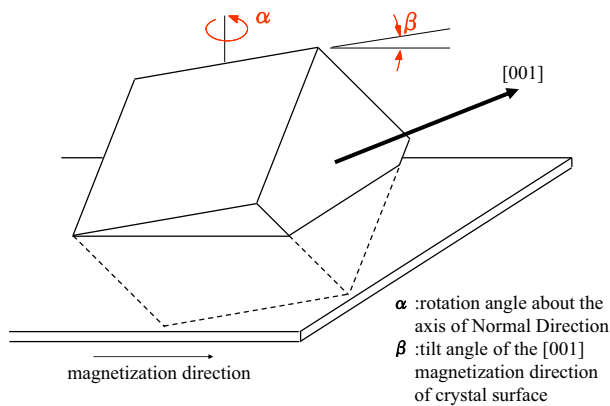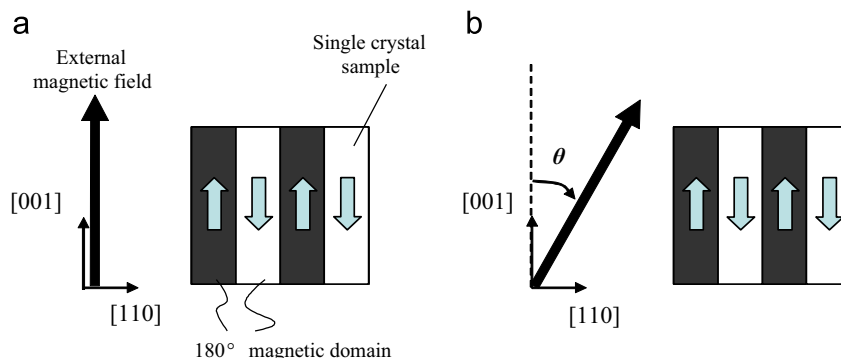**Fig. 3.** Sample arrangement for external magnetic field on this experiment. (a) External magnetic field is parallel to [0 0 1] axis ($\theta=0^\circ$) and (b) $\theta=2^\circ$, 4°.