NEW GRAIN-DETECTING METHOD FOR GRAIN-ORIENTED Si-Fe SHEETS WITH COATING

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Abstract

A new grain-detecting method for grain-oriented silicon steel sheets with coating is presented by measuring surface normal magnetic flux using a Hall element. This method can solve all the problems involved in traditional grain-detecting method such as, (i) long time for removing the coating, (ii) danger for operators in treating powerful drugs such as HF, HNO_3 to remove the coating, and (iii) difficulty for treating drains.

I. INTRODUCTION

In this paper, a new grain-detecting method for grain-oriented silicon steels with coating is presented by measuring surface-normal flux using a Hall element [1]. In this method, silicon-iron sheets with coating in two series connected solenoid colis are magnetized with DC or AC field, and a Hall element is touched on the sheet in order to detect only the surface normal flux and is swept by a micromotor and gear devices. Positions of grain boundaries are easily detected in the accuracy over 90% by picking up sharp peaks of recorded curves of surface-normal flux ϕ, versus surface position x, of the sheet ($\phi - x$ curves). The average grain size is roughly predicted by only counting the number of zero crossing points of $\phi - x$ curve. The grain pattern near ends of sheets is also detected by contacting the end of another sheet with equal material and dimension to the end.

This new grain-detecting method has the following advantageous points in comparing with traditional ones:

(i) grain detectiong time can be largely reduced because of needlessness of coating removing,
(ii) operators are protected from danger of treating powerful drugs such as HF, HNO_3 and so on,
(iii) drain pollusion can be prevented,
(iv) grain-detecing procedure can be automatized by motor driving a Hall elemet and by constructing electronic circuits for peak-flux detecting.

This method also experimentally verifies a domain model used in computer analysis for dynamic domain size variation and iron losses in grain-oriented Si-Fe cores [2], [3].

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II. EXPERIMENTAL PROCEDURES

Fig.1 shows the schematic arrangement of grain-detecting system : a grain-oriented silicon steel sheet with coating is layed through series-connected two solenoid coils to which DC or AC magnetizing current are applied, and a Hall element is closely placed in order to detect only surface-normal flux on the sheet surface and continuously swept with constant speed along the rolling direction by micromotor driving. The Hall probe is connected with a magnetometer and then with an oscilloscope or a X-Y plotter to record the curves of $\phi - x$ relation.

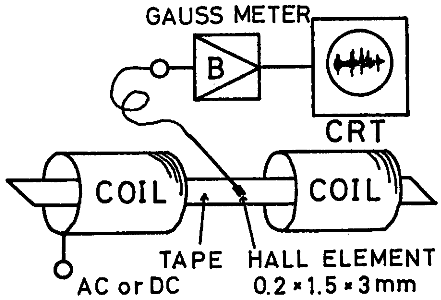

Fig. 1. Schematic arrangement of grain-detecting system.

III. GRAIN-DETECTING RESULTS

Fig.2 illustrates the measured curves of $\phi - x$ relation along the rolling direction on 3% Si-Fe grain-oriented sheets with coating (Hi-B, 0.3 mm thickness, 30 mm width, and 300 mm length) : (a) is the curve measured at each position with 2mm intervals on the sheet magnetized with DC field of 90 oe in the coils, while (b) is the result of continuously sweeping by micromotor driving, and (c) is the measured curve with 2mm intervals under DC field (real line) and AC field with 60 Hz (broken line). Black circles on the sheets are the predicted positions of grain boundaries corresponding to sharp peaks of each $\phi - x$ curves.

This correspondence is expressed by localized model of magnetic poles at grain boundaries as shown in Fig. 3. That is, magnetic pole with N or S pole is considered to be localized at grain boundaries because that many kinds of dislocations or non-magnetic inclusions are concentrated at ones. Therefore, surface-normal flux curve is obtained with sharp peaks corresponds to grain boundaries. The predicted positions (black circles) in Fig. 2 correspond, with accuracy of over 90 %, to real grain boundaries which are sketched after removing the coating using HF. In Fig. 2 (c), the dashed curve with 60 Hz AC field reveals same signed sharp peaks.

Since the number of zero-crossing points in (a),(b), and (c) is proportional to average grain size, which is smaller in (a) and (b), while is larger in (c), average grain size can be roughly predicted by this, although the position of grain boundaries cannot be detected.

It is difficult to detect grain boundaries near the end of the sheet because of the effect of demagnetizing field. Fig. 4 shows a method to overcome this problem by contacting two sheets at the ends each other with same material and dimension. Since two sheets are adsorbed each other as magnetized in the coils, a gap between two sheets becomes small.

Therefore, small variation of surface-normal flux can be detected close to the end in a few mm.

We next investigate some aspects of surface-normal flux variation. Fig. 5 illustrates the effect of superposition of two sheets (# 1 and # 2, Hi-B): $\phi - x$ curves by micromotor driving are shown in (a) and (b), respectively, and of # 1 sheet with # 2 sheet under it in (c). The pattern of curve in (c) is similar with one in (a), and the effect of large valued flux in (b) reveals partly in (c).

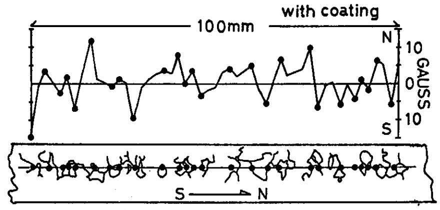

Fig. 2 (a)

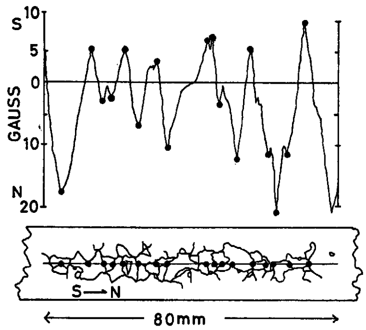

Fig. 2 (b)

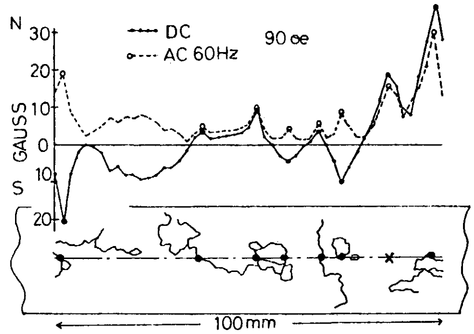

Fig. 2 (c)

Fig. 2. Measured curves of surface-normal flux on 3% Si-Fe sheets with coating:
(a) flux at each 2mm intervals,
(b) flux by continuously sweeping,
and (c) flux at each 2 mm intervals for DC and AC field.

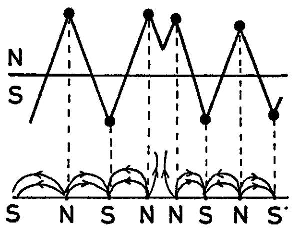

Fig. 3. Localized model of magnetic poles at grain boundaries.

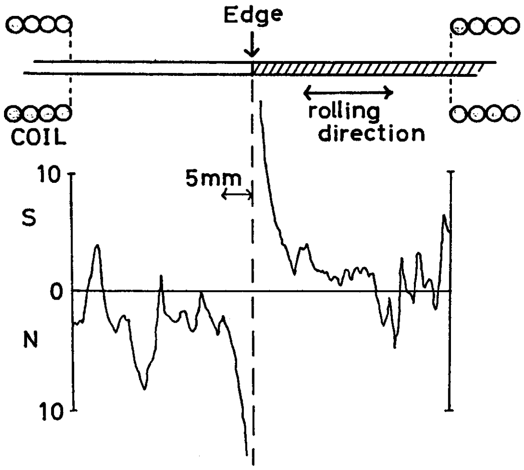

Fig. 4. A method for grain-detecting near the end of the sheet.

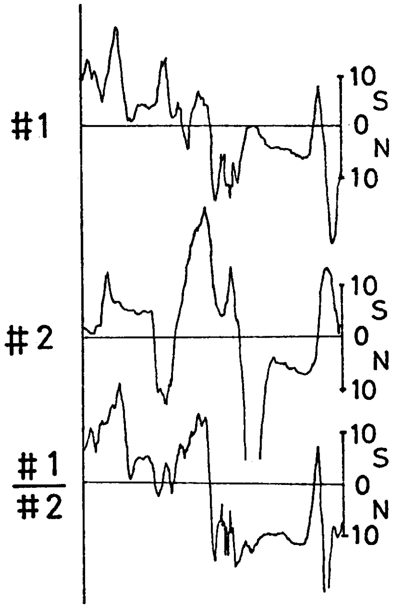

Fig. 5. Effect of superposition of two sheets on surface flux.

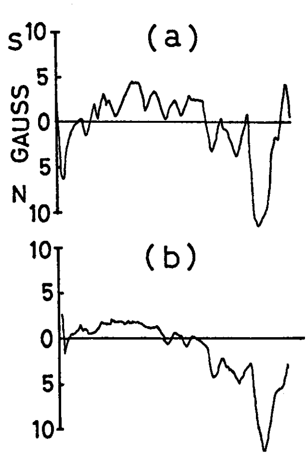

Fig. 6. Effect of magnetic annealing on surface flux.

Fig. 6 shows the relation of ϕ and the effect of magnetic annealing of a 3 % Si-Fe sheet : measured curve by motordriving in (a) is before, and in (b) is after magnetic annealing on the same line of the sheet along the rolling direction. The variation of $\phi-x$ curve in (b) was more smooth than (a). This result suggests the relation between smoothness of $\phi-x$ curves and reduction of iron losses in grain-oriented silicon steel. The magnetic annealing in our experiment is that the sheet is annealed in pure hydrogen gas from 1100°C to room temperature during about 4 hours magnetized with DC field of 20 oe.

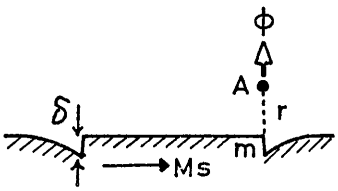

Fig. 7. A model for configulation of grain boundaries.

We now calculate the order of the depth of drain or step at grain boundaries due to a model as shown in Fig. 7. Surface-normal flux ϕ at the point A due to magnetic pole with magnitude m at a grain boundary is

$$H = \phi = m/\mu_0 r^2 \qquad \text{oe} \qquad (1)$$

where μ_o is permeability of vacuum and r is the distance of the position A from the grain boundary, and

$$m = M_s \ell \delta \qquad \text{gauss}\cdot\text{cm}^2 \qquad (2)$$

where M_s is saturation magnetization ($\fallingdotseq B_s/4\pi$), ℓ and δ are length of the Hall element and the depth of the drain or step.

The order of value of δ is obtained as

$$\delta = 10^{-2} - 10^{-1} \mu m \quad (3)$$

by substituting $H = 10^0 - 10^1$ oe, $\mu_0 = 1$, $r = 0.05$ cm, $\ell = 0.3$ cm, and $M_s = 2 \times 10^4 / 4\pi$ gauss.

The result verifies the domain model used in the analysis of dynamic domain size variation and iron losses [2] and [3].

Fig. 8 illustrates a schematic diagram for automatizing the grain detecting.

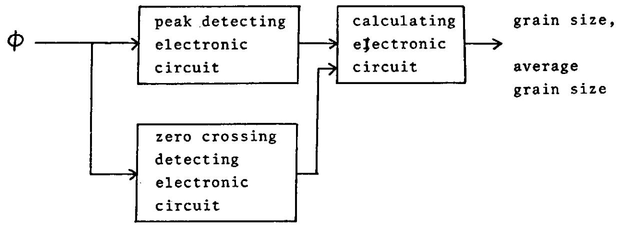

Fig. 8. A schematic diagram for automatization of grain detecting.

CONCLUSIONS

New results obtained in this paper are as follows;

(1) grain boundaries of grain-oriented silicon steel sheets with coating are accurately detected by picking up sharp peaks of measured curves of surface-normal flux versus surface position,

(2) important points for measuring surface-normal flux are to place a Hall element, which does not disturb original surface flux, on the sheet surface as close as possible in order to sense for only surface normal component, and to sweep dynamically by means of micromotor driving and so on or sample finely as possible,

(3) both DC and AC magnetizing fields are available,

(4) the number of zero crossing points roughly corresponds average grain size,

(5) surface-normal flux near the end of a sheet corresponding grain boundaries is detected by contacting the end of another sheet with same material and dimension to it,

(6) surface-normal flux becomes smooth after magnetic annealing.

This new grain-detecting method is anti-pollusion, anti-dangerous, and high speed one due to needlessness of coating removing.

ACKNOWLEDGMENT

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