Matteucci Effect of Rapidly Quenched Co-Fe Alloy Ribbon and Its Application

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Ribbon-shaped 70%Co-Fe and/or 12-14%Al-2%Co-Fe alloys were formed by a rapid quenching method with a single roller. Matteucci effect was measured on the ribbon after annealing in a dry hydrogen atmosphere. The ribbons were very flexible: could be wound around a rod with 1mm diameter and could put up with repeated winding. The sharp pulse voltage was induced between both ends of the ribbon against ac field due to Matteucci effect. The voltage was sufficiently high and increased with an increase in frequency and/or field strength. The temperature dependence of pulse voltage was measured at the temperature ranges from 50 to 200°C. Furthermore, experimental results were shown for an ac current sensor as an application of these ribbons.

1. Introduction

It has been long known that iron-cobalt alloys have excellent magnetic characteristics: a high magnetic flux density as well as a high Curie temperature and a large magnetostriction. In spite of such good magnetic characteristics, there has been no practical application of these alloys due to extreme hardness and poor mechanical workability.

The authors found, however, that the application of a splat cooling technique made them easy to fabricate pliable ribbons. Their superior magnetic characteristics draw attention to their possible uses as magnetoelectric transformation elements in high temperature ranges. The basic investigations of magnetostriction characteristics at room temperature as a preliminary step were presented1).

Sensitive and reliable pulse-out type magnetic sensors have been constructed using twisted and/or helically wound amorphous magnetostrictive ribbons2). The sharp voltage pulses are induced between both ends of the ribbon, in which sensitive Matteucci effect occurs in the ribbon. In this paper, the characteristics of pulse voltage versus ac exciting field are presented for twisted and/or helically wound 70%Co-Fe and 12-14%Al-2%Co-Fe ribbons. Experimental results are also shown for a current sensor, as an application of these ribbons.

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2. Matteucci Effect

2.1 Sample preparation

70%Co-Fe and 12-14%Al-2%Co-Fe ribbons were prepared by a rapid quenching method with a single roller which was made with stainless steel.

An iron-cobalt alloy has the transformation point at 980°C and Fe-Co order-disorder transformation temperature around 730°C. The alloy, therefore, must be annealed under 980 °C and needs to be cooled at an adequate cooling rate under 750°C. So, the as-prepared ribbons were annealed at 850°C for 1 hr in a dry hydrogen atmosphere, and then cooled at the rate of 14°C/hr under 750°C. Annealed samples were twisted or helically wound around a rod.

2.2 Pulse voltage characteristics for twisted ribbon.

Fig. 1 shows characteristics of pulse voltage versus number of twists under various ac exciting fields and of duty factor (D.F.) versus number of twists where D.F. is given by tp/T/2 (tp: half value width for pulse, T: period). The pulse voltage sharply increases with half-twisting, and then gradually increases with an increase in the number of twists. These results can be understood from the experimental results in which maximum flux density increases with an increase in the number of twists. Duty Factor is nearly constant under various numbers of twists. This result may be explained from nearly constant of squareness ratio of major hysteresis curve under various exciting conditions. Fig. 2 shows the field dependence of pulse voltage and duty factor for the ribbon with the parameter of number of twists. The pulse voltage linearly increases with an increase in ac magnetic field under twice
twisting and constant exciting frequency. Duty Factor decreases and reaches constant value $13 \times 10^{-3}$ with increasing the magnetic field. These characteristics suggest an applicability of ribbon for a current sensor.

Cobalt is very expensive, so the magnetic characteristics of Al-Co-Fe ribbons with same order magnetostriction as that of 70%Co-Fe were investigated. Fig. 3 shows the twist dependence of pulse voltage for three kinds of ribbons. The pulse voltage for 70%Co-Fe ribbon is larger than that for 12-14%Al-2%Co-Fe ribbon. Further investigation related to this difference between two kinds of ribbons will be carried out in the future.

The temperature dependence of pulse voltage characteristics for twisted ribbons is important for their application to sensors, and so were investigated. Fig. 4 shows the characteristics for 70%Co-Fe ribbon. The pulse voltage is nearly constant at the temperature up to 150°C and increases little at higher temperature than 150°C. It may be considered due to an increase in the domain wall mobility at higher temperature. The temperature dependence of pulse voltage for 12-14%Al-2%Co-Fe ribbons is similar to that for 70%Co-Fe ribbon.

2.3 Pulse voltage characteristics for helically wound ribbon

The characteristics of pulse versus angle between the ribbon axis and the direction of an exciting field for helically wound ribbons are shown in Fig. 5. The pulse voltage increases with increase in the angle, reaches the maximum value at 10°, and then decreases at the angle more than 10°. The maximum value at 10° and 5 kHz is 15 times of that at 0° and the same exciting frequency.

3. Current sensor

The magnetic characteristics above described suggest that 70%Co-Fe and 12-14%Al-2%
Fig. 5 Characteristics of pulse voltage versus angle between the ribbon axis and the direction of ac exciting field for 70%Co-Fe helix ribbon.

Co-Fe ribbons could be a prospective material for a current sensor in high temperature range. An electrically insulated current sensors are important for feedback controls of electric power devices.

A simple ac-current sensor is constructed by setting a helix ribbon neatly around an insulated electric wire as shown in Fig. 6. The ribbon is easily set around the wire by setting one edge and then rotating the ribbon. The ribbon is stretched or shrinked along with the wire and fixed for inducing more sharp pulses between the ends of the ribbon due to the effect of the torsional stresses. Fig. 6 shows the pulse voltage versus current characteristics at 50 Hz for 70%Co-Fe and 12-14%Al-2%Co-Fe helix ribbon with the diameter of 3.2 mm. The relationship between the pulse voltage and the current at current range of 5 to 15 A has a good linearity.

However, the linearity between the pulse voltage and current is not so good at lower current range than 5 A, and must be improved in the future.

4. Conclusion

The 70%Co-Fe and 12-14%Al-2%Co-Fe ribbons were prepared by a rapid quenching single roller method. The ribbon was annealed at 850°C for 1 hr in a dry hydrogen atmosphere and then cooled at the rate of 14°C/hr under 750°C. The characteristics of pulse voltage, which is mainly induced between both ends of the ribbon against ac field due to Matteucci effect, versus ac exciting field, number of twists and angle between the ribbon axis and the direction of ac magnetic field were investigated for twisted and / or helix
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ribbons. The results are summarized as follows:

1) The pulse voltage sharply increases with half-twisting and then gradually increases with an increase in the number of twists for twisted ribbons.

2) The pulse voltage linearly increases with an increase in ac magnetic field under twice twisting and constant exciting field. Duty Factor decreases and reaches constant value $13 \times 10^{-3}$ with increasing the magnetic field.

3) The temperature dependence of pulse voltage for ribbons is nearly flat at the temperature up to 150°C.

4) The maximum pulse voltage for helix ribbon is obtained for 10°.

5) The characteristics of pulse voltage versus ac-current are presented for an ac-current sensor using helix ribbon. The good linearity is obtained at certain current range.

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References
