Shigeru AIHARA[1,2] Takashi TODAKA[2], Masato ENOKIZONO[2]

Nishi Nippon Electric Wire & Cable (1), Oita University (2)

Characteristic Evaluation of 4mm-square-sized double H-coil

Abstract. *Two-dimensional vector measurement has become popular as an accurate evaluating method, which can measure the relationship between the magnetic flux density vector B and the magnetic field strength vector H. In order to improve the resolution of the two-dimensional vector magnetic measurement, 4mm-square-sized double H-coil was manufactured and evaluated with a developed evaluation system, which consists of a standard solenoid coil and a high-precision turntable. The V-H sensor combined the H-coil with double needles, was applied to measure distributions of local magnetic characteristics in a model core.*

Streszczenie. *Cewka tangencjalna H-coil jest powszechnie używana do pomiaru pola magnetycznego w badanej próbce. W pracy opisano podwójną cewkę H-coil o rozmiarze 4 mm przeznacz\oną do badania pola magnetycznego z dużą rozdzielczością geometryczną. Cewkę taką sprzężono też z dwoma czujnikami igłowymi do równoczesnego pomiaru indukcji. (**Podwójna cewka tangencjalna o rozmarze 4 mm**)*

Keyword: Two-dimensional vector magnetic measurement, V-H sensor, Needle prove method, Double-H-coil.
Słowa kluczowe: cewka tangencjalna , czujnik igłowy.

Introduction

Rotational magnetic flux distributions in transformer and motor model cores have so far been measured with cross-type search coil method [1, 2]. However the search coil method needs making holes and it affects the magnetic properties of the electrical steel sheets and the local flux distributions. Furthermore this method is unsuitable for measuring flux distributions in a wide region of core materials because of troublesome task. To overcome this difficulty, the double needle method [3, 4] has been employed to measure local flux distributions in the electrical steel sheets without the insulation coating. This method has wide application, however it is not possible to make clear effects of the insulation coating, which is used for producing tensile stress in some kinds of grain-oriented silicon steel sheets.

On the other hand, the relationship between the magnetic flux density vector and the field strength vector is known as vector magnetic property and given us particular information to reduce iron losses [5]. We have developed a two-dimensional magnetic sensor (V-H sensor) combined the double needles method with the H-coil method [6]. This V-H sensor allows us to measure the plural-local-magnetic-variable distributions at the same instance. The magnetic flux density components are measured with two pairs of needle probe without making holes and the field strength components are measured with the double H-coil, which is placed among the needles. Therefore the resolution of the V-H sensor is strongly depending on the H-coil size.

In the past, the outer diameter of the H-coil was 12 mm and the outer diameter of the H-coil winding was about 0.02 mm. In order to improve the resolution of the V-H sensor by down-sizing the H-coil, we have newly developed 4 mm-square-sized H-coil whose extra-fine-enameled wire diameter is 0.014 mm. We also used very hard needles, which have ability to pierce the insulation coating by adding rotation mechanism like a drill. Therefore measurements of local vector magnetic properties without removing the insulation coating are possible by using the developed V-H sensor.

This paper reports evaluated results of the V-H sensor and its performance. The V-H sensor is applied to measure distributions of local magnetic characteristics in a model core. The detailed magnetic characteristic distributions of the maximum flux density, the maximum field strength, and iron loss distribution are presented.

H-coil

Fig. 1 shows the photograph of the new H-coil. The Hy-coil was wound over a former and the Hx-coil was wound over the Hy-coil. The size of the double H-coil was 4 mm × 4 mm. The thickness was about 0.6mm. The number of turns of each H-coil was 350 turns. The material of the H-coil former was a non-magnetic ceramic. We used 0.014 mm in diameter extra-fine-enamled wire in order to down-size the H-coil. This enables us more accurate local magnetic field measurements in keeping the area turn value as large as possible.

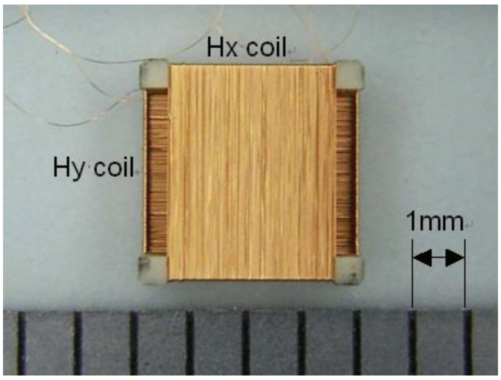


Fig.1. Photograph of the double-H-coil

Evaluation of the double-H-coil

As the characteristics of the H-coil, the area turn, the frequency response and the angular error of each H-coil winding were evaluated. Fig. 2 shows the compensation system. The area turns of the Hx- and Hy-coil were measured in comparison with one of the standard H-coil that the area turn was known. In this measurement, we used a standard solenoid coil, which has a high-precision turntable. The length and diameter of the standard solenoid coil were 2100 mm and 110 mm, respectively. The exciting frequency of the solenoid coil was 50 Hz. In the solenoid coil, the standard H-coil and the evaluating H-coil were placed coaxially on the turntable. We rotated the turntable and the output voltages from the H-coil were measured. The angle between the maximum output signals should be 90 degrees, thus we can evaluate the orthogonality between the Hx- and Hy-coil. The mechanical angle was measured by combining the area turn measurement system with the optical prism and the laser beam. Also the frequency responses of the H-coil's area turns were measured by changing the exciting frequency up to 1000 Hz. In addition, the dimension of the frame was measured before winding by using a microscope. Fig. 3 shows the measurement parts of the H-coil frame.

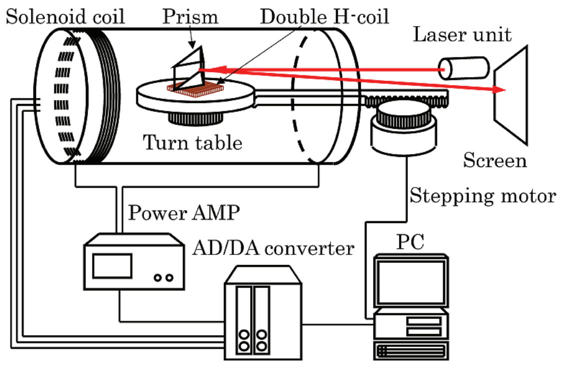


Fig.2. Compensation system with the solenoid coil

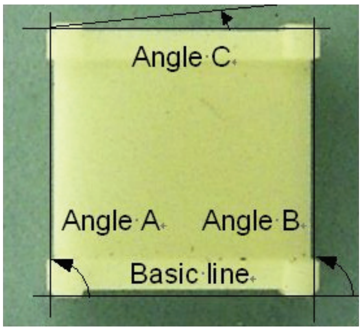


Fig.3. Measurement parts of the H-coil frame

Measured results on the double-H-coil

Table 1 shows the area turns and the frequency dependencies. Because the Hx-coil was wound over the Hy-coil, the area turn of the Hx-coil was larger than that of the Hy-coil. Moreover, the frequency response was flat even 1000 Hz. Table 2 shows the orthogonality between the Hx- and Hy-coil. The angular error was 0.64 degrees. As shown in Table 3 the processing accuracy of the double-H-coil's frame was within ± 0.08 degrees, and the mechanical error was small in comparison with the angle error measured by using the compensation system. It can be considered that the main cause is winding irregular.

Table 1. Area turns and frequency responses of the H-coil

Frequency [Hz]	Area turn of Hx-coil [mm^2]	Area turn of Hy -coil [mm^2]
50	1766.317	1274.044
100	1766.712	1274.392
500	1766.544	1273.740
1000	1767.122	1274.572

Table 2. Angular error of the H-coil

	Orthogonality between the Hx- and Hy-coil [deg]
Angular error	0.640

Table 3. Angle error of the H-coil frame

Measurement part	angle [deg]
A	90.078
B	89.993
C	0.079

V-H sensor

The V-H sensor combined the 4mm-square-sized double H-coil with the double needle-probes was made as a prototype. Fig. 4 shows the photograph of the V-H sensor. The local two-dimensional vector magnetic properties in practical or model cores can be measured by using the needle-probes and the H-coil without opening holes. The output voltage of the needle-probe method is equivalent to that of a 1/2 turn search coil. We can also measure the local two-dimensional vector magnetic properties without removing the insulation coating on the electric steel sheets. As for the electrical contact between two needle probes and the electrical steel sheets, we mounted very hard needles of the cemented carbide, which have ability to pierce the insulation coating by adding rotation mechanism like a drill. Because the insulation coating of the oriented electrical steel sheets is working to improve magnetic property in rolling direction by adding tensile stress, the developed V-H sensor is very useful to make clear the effect of the insulation coating on the local vector magnetic properties. The manufactured new V-H sensor is applied to measure distributions of vector magnetic properties of a three-leg model core with insulation coating as shown in Fig. 5.

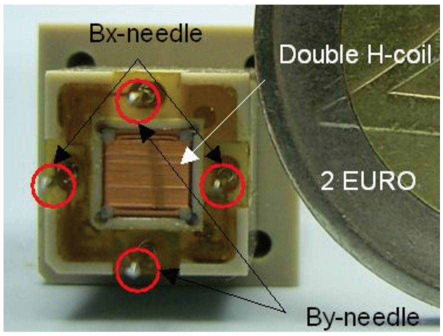


Fig.4. Photograph of the V-H sensor

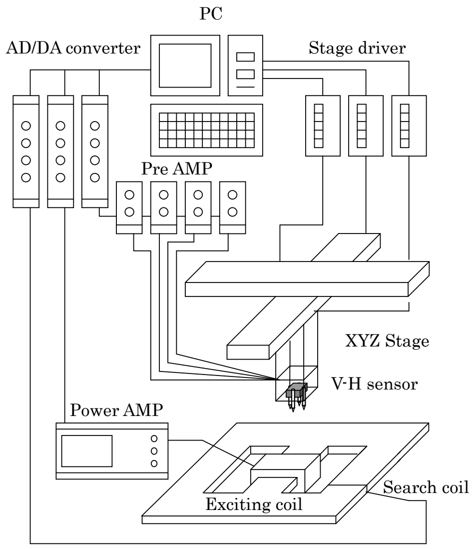


Fig.5. Measurement system.

Measurement system

Fig. 5 shows the measurement system. Because exact positioning of the V-H sensor with higher resolution is the most important in the measurements, we used the XYZ-auto-positioning stage driven by stepping motors as shown in Fig. 5. Also because the measured results are influenced by the pushing force and inclination of the V-H sensor head [4], we controlled the pushing force with a load cell and a fixing jig.

Model core

Fig. 6 shows the model core for the measurement. Usually, the magnetic property in the rolling direction of the grain-oriented steel sheets differs greatly from that in the transverse direction. Therefore, the magnetic circuit is constructed along the rolling direction of the grain-oriented steel sheets by using lamination of the segmented cores. In this measurement, we used a special sheet in order to check the durability and accuracy of the V-H sensor. The three-leg cores were manufactured by cutting out from the grain-oriented steel sheets (20ZDK90) without segmentation. The outline size was 400 mm × 350 mm and the window size was 80 mm × 190 mm and the thickness was 0.23mm. The number of the stacked layer was 27.

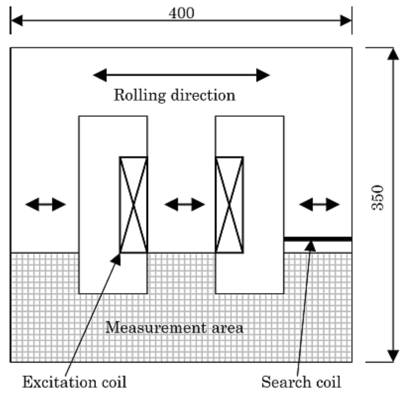
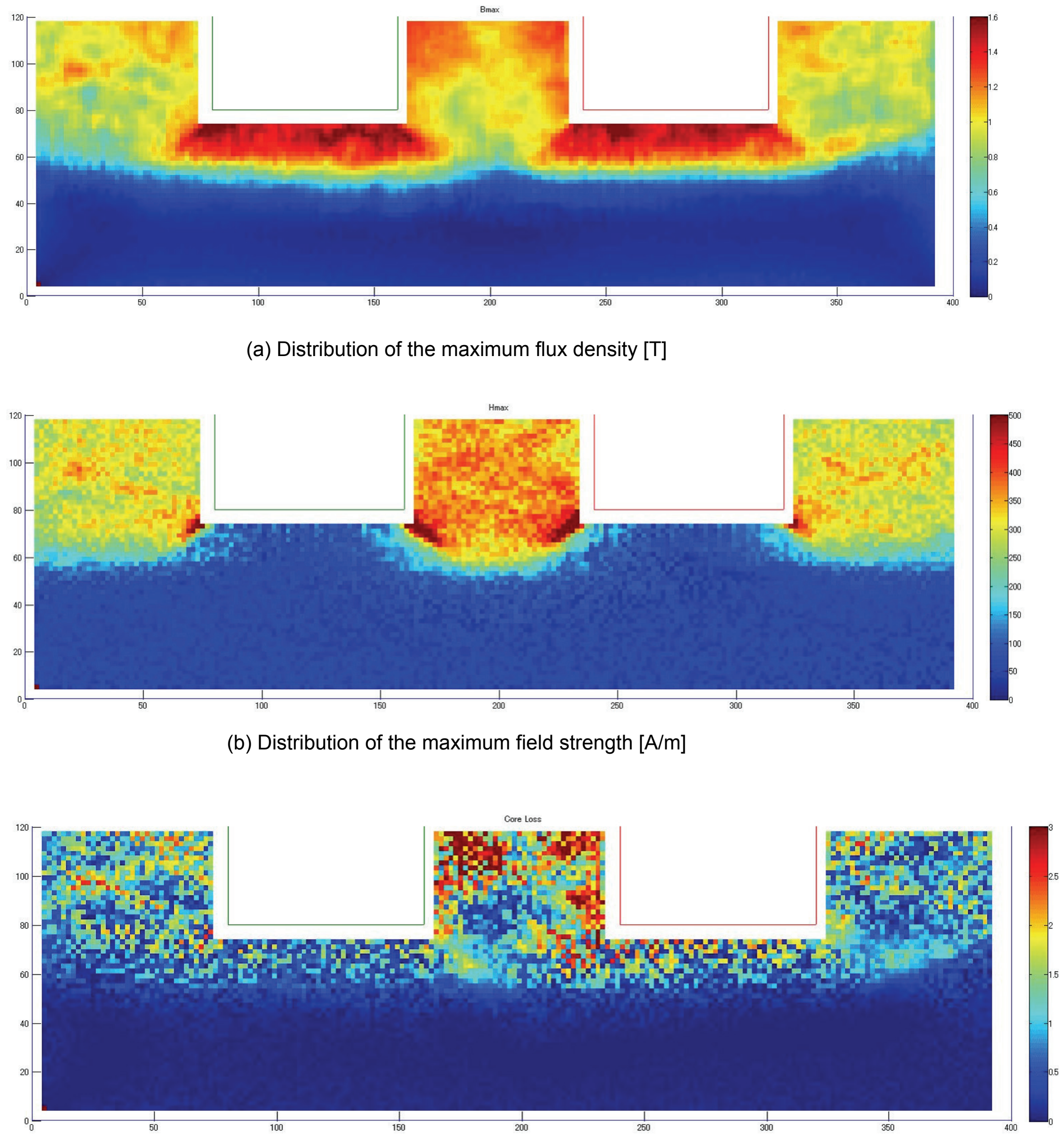


Fig. 6. Model core



(a) Distribution of the maximum flux density [T]

(b) Distribution of the maximum field strength [A/m]

(c) Distribution of the core loss [W/kg]

Fig. 7. Distributions of the maximum flux density, the maximum field strength, and the core loss in the model core.

Measurement conditions

The model core was excited with sinusoidal voltages. The exciting frequency was kept to be 50 Hz. The average flux density was measured with the search coil wound over the core as shown in Fig. 6 and used as a reference. The magnetic flux density condition used in the measurements was 0.5 T. The measured points were distributed keeping the same intervals of 2 mm in the both X- and Y-direction. The total numbers of the measured points were 9000 points.

Measured results with the V-H sensor

Fig. 7 shows the distributions of the maximum flux density (a) and the maximum field strength (b) and the core loss (c). These figures demonstrate that the detailed magnetic property measurements on the electric steel sheet, which has the insulation coating, are possible. As shown in the Fig. 7 (a), large magnetic flux densities occurred in the rolling direction (easy magnetization direction). Since the magnetic path length tends to become the shortest, the large magnetic flux densities could be observed mainly near the window side. In the hard magnetization direction (transverse direction), since the magnetic reluctance becomes larger, the magnetic flux gets around the leg parts.

In contrary to the magnetic flux density distribution, as shown in the Fig. 7 (b), the magnetic field strength became larger at the leg parts where the magnetic flux went through the transverse direction. This is because the magnetic permeability of the rolling direction of the grain-oriented steel sheet is about 1000 times larger than that of the transverse direction.

Fig. 7 (c) shows the iron loss distribution. The iron loss became large not only at the parts where the magnetic flux densities were large but also at the parts where the field strengths were large.

Conclusion

In this paper, the characteristic evaluations of the 4mm-square-sized double H-coil and the V-H sensor consisted of the piercing B-needles to break through insulation coating and the double H-coil were reported. By means of the V-H sensor, we have measured the local vector magnetic properties in the model core, which has the insulation coating. The results also demonstrated that the developed V-H sensor was very useful for measurements of the local vector magnetic properties in high resolution. The measurement of a practical constructed core remains as a further problem.

REFERENCES

[1] M. Enokizono, T. Suzuki, J. Sievert and J. Xu, Rotational power loss of silicon steel sheet, *IEEE Transactions on Magnetics,* (1990), Vol. 26, No. 5, 2562-2564

[2] V. Gorican, A. Hamler, M. Jesenik, B. Stumberger, M. trlep, Measurement of alternating magnetic properties of grain-oriented materials using a round rotational single sheet tester, *Physica B*, (2006) Vol. 372, pp. 194-197.

[3] W. Brix, K.A. Hempel and F.J. Schulte, Improved method for the investigation of the rotational magnetization process in electrical steel sheets, *IEEE Transactions on Magnetics*, (2006), Vol. MAG-20, No. 5, pp. 1708-1710

[4] K. Senda, M. Ishida, K. Sato, M. Komatsubara, T. Yamaguchi, Experimental evaluation of the accuracy of local magnetic measurement by stylus probe method, *Tech. Report of IEE Japan*, (1994), MAG-94-71, Vol. 115(1), pp.50-57

[5] M. Enokizono, K. Kawamura and J. D. Sievert, New magnetic search coil system for two-dimensional magnetic measurement, *Simulation and Design of Applied Electromagnetic Systems*, (1994) pp.21-24

[6] M. Enokizono, M. Morikawa, K. Kawamura, and J. Sievert: Distribution of two-dimensional magnetic properties in three-phase induction motor model core, *IEEE Transactions on Magnetics*, (1996), Vol. 32, No. 5, pp. 4989-4991

***Authors**: manager S. Aihara NISHI NIPPON ELECTRIC WIRE & CABLE Co.,LTD. R&D department, Kasugaura, Oita 870-0011, Japan, E-mail: aiharas@nnd.co.jp; Prof. T. Todaka, Oita University, Faculty of Engineering, Oita 870-1192, Japan, E-mail: todaka@oita-u.ac.jp, Prof. M. Enokizono, Oita University, Faculty of Engineering, Oita 870-1192, Japan, E-mail: enoki@oita-u.ac.jp*