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INFLUENCE OF INSULATION COATING OF ELECTRICAL STEEL SHEETS ON LOCAL TWO-DIMENSIONAL VECTOR MAGNETIC PROPERTIES

Shigeru Aihara* — Takashi Todaka — Masato Enokizono****

This paper presents a small-sized vector-hysteresis sensor (*V-H* sensor), which consists of piercing *B*-needles and double *H*-coil. The *B*-needle probe can break through the insulation coating of silicon steel sheets like a drill. The *H*-coil is made in very small size and the outside dimension is 4mm×4mm. The magnetic flux density vector ***B*** and the field intensity vector ***H*** are measured with the *B*-needle probe and the double *H*-coil, respectively. The influence of the insulation coating on distributions of vector magnetic properties in transformer model cores is investigated in measurements with the developed very small-sized *V-H* sensor.

Keywords: vector magnetic property, *V-H* sensor, needle probe method, *H*-coil, *B*-needle

1 INTRODUCTION

Recently measuring techniques of vector magnetic properties have been developed and their achievement has drawn much attention. The vector magnetic property enables us to know the rotational iron loss distributions and magnetic anisotropic properties in the relationship between the flux density vector ***B*** and the field intensity vector ***H*** [1], [2].

To understand distribution of local vector magnetic properties in practical transformer cores, the vector-hysteresis sensor (*V-H* sensor) was developed [3]. The *V-H* sensor consists of the *B*-needle proves and the double *H*-coils. The magnetic flux density vector ***B*** and the field intensity vector ***H*** are measured with the *B*-needle probe and the double *H*-coil, respectively. Thereby we can also evaluate local iron loss distributions in practical machines or model cores. The *V-H* sensor has so far been applied to measurements of local two-dimensional vector magnetic properties in transformer cores and three-phase induction motor model cores [4].

Disadvantages of the conventional *V-H* sensor are its size and requirement to remove insulation coatings of the electrical steel sheets. Since the sensor size depends on the dimension of *H*-coils, we have miniaturized *H*-coil size as small as possible. We have developed 4mm squared double *H*-coil by using the ultra fine magnet wire and precise ceramic frame. This enabled us more detailed magnetic property measurement and the resolution was improved. As to the electrical contact between two needle probes through the electrical steel sheets, we mounted very hard needles, which have ability to pierce the insulation coating by adding rotation mechanism like a drill. It made possible to measure local vector magnetic properties without removing the insulation coating. 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 was applied to measure distributions of vector magnetic properties in λ-joint and V-joint three-phase transformer model cores in order to demonstrate its performance. In this paper, we compare the vector magnetic properties of the λ-joint model cores with and without insulation coating and also the iron loss properties of the λ-joint and V-joint model cores. The results show that the new *V-H* sensor is a very useful tool.

2 MEASUREMENT METHOD

The new *V-H* sensor is based on the needle probe method to measure magnetic flux density ***B*** and the *H*-coil method to measure magnetic field intensity ***H***. The needle-probe method is a way to measure electric potential difference between the two needle tops. The voltage is the source to flow eddy current generated by the flux changes in an electric steel sheet and it is therefore proportional to the magnetic flux density. This method corresponds to the search coil method with a 1/2 turn coil [5], [6].

As mentioned in the above, we added a function to pierce the insulation coating of the electrical steel sheets. Because the *B*-needle probe can rotate like a drill in process when this sensor is pushed against the electrical steel sheets, the *B*-needle probe top pierces the insulation coating and reaches the conductive metallic surface of the electrical steel sheets. Consequently, it is needless to remove the insulation coating of the electrical steel sheets before measurements and to add a large load on the needle probe to pierce the insulation coating. It is therefore possible to perform measurements with this structure in the state near the original magnetic property, which has effects of tensile stress caused by the insulation coating of the oriented electrical steel sheets.

Figure 1 shows the photograph of the new *V-H* sensor and Table 1 shows the specification. As shown in Fig. 1, in order to make clear detailed distributions of the local vector magnetic properties of the electrical steel sheets, the 4mm×4mm double *H*-coil was manufactured and mounted at the sensor head. The *B*-needle probes were arranged around the double *H*-coil. The *V-H* sensor has two sets of *B*-needle probe and *H*-coil for measurements of x - and y - direction components.

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The each probe is supported by the spring pressure of 50 g and it can rotate up to 70 degrees like a drill when this needle probe is pushed against the electrical steel sheets. The distance between the *B*-needles for each direction is 7mm.

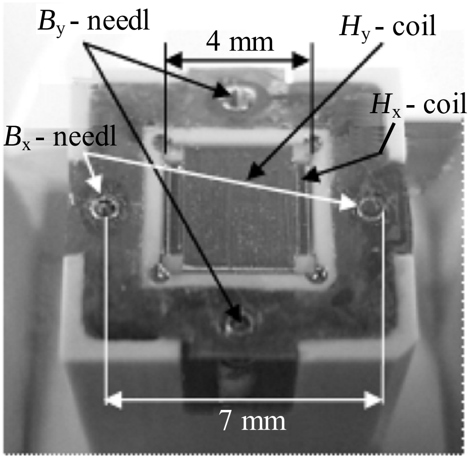


Fig.1. Photograph of the *V-H* sensor

Table 1. Specification of the V-H sensor.

H-coil	Size[mm]	4×4
	Number of turns	350
	Area turn (H_x) (cm^2turn)	5.25
	Area turn (H_y)(cm^2turn)	7.91
B-needle	Distance (mm)	7

In order to miniaturize the double *H*-coil in keeping sufficient sensitivity, the number of turns should be increased because the area turn is significantly reduced in accordance with the *H*-coil size. We used 0.012 mm in diameter ultra-fine enamel wire that has thin polyester insulation coatings. The *H*-coil frame was made by performing precise processing. As a frame material, alumina was used to reduce area turn variations due to temperature changes and to minimize angle error between *x* - and *y* - directions. In the measurement, the components of the magnetic flux density are given by

$$B_i = \frac{2}{S_{Bi}} \int_0^T e_{Bi} dt \quad (1)$$

where, e_{Bi} is the induced voltage, S_{Bi} is the effective area of the needles, and *T* is the period of the exciting waveform. The subscript "*i*" denotes the each component.

The components of the magnetic field intensity are given by

$$H_i = \frac{1}{S_{Hi} N_{Hi}} \int_0^T e_{Hi} dt , \quad (2)$$

where, e_{Hi} is the induced voltage of the *H*-coils and $S_{Hi}N_{Hi}$ is the effective area turn of the each coil.

The iron loss is given by

$$P = \frac{1}{\rho T} \int_0^T (Hx \frac{dBx}{dt} + Hy \frac{dBy}{dt}) dt \quad (3)$$

where, ρ is the material density.

3 MEASURMENT SYSTEM

Figure 2 shows the measurement system. The exact positioning of the *V-H* sensor with higher resolution is the most important in measurements. Also the measured results are influenced by the pushing force and inclination of the *V-H* sensor head. In the measurements, we used *xyz*-auto-positioning stage driven by stepping motors as shown in Fig. 2.

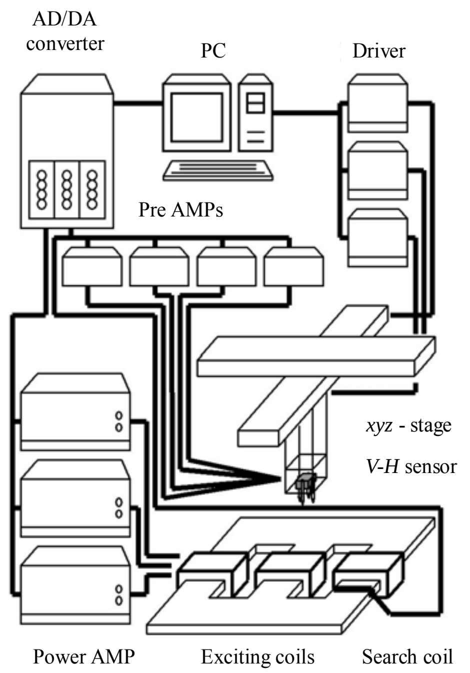
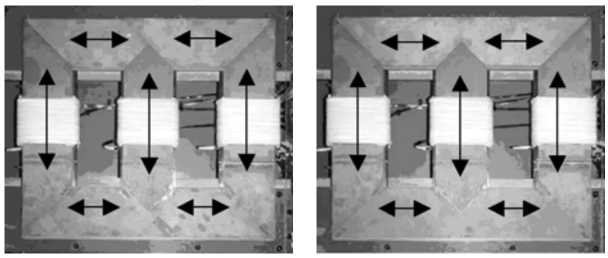


Fig. 2. Measurement system



(a) (b)

Fig. 3. Photograph of the λ-joint and V-joint three-phase transformer model cores: (a) λ-joint model core, (b) V-joint model core

In verification of the *V-H* sensor, two model cores were built whose T-joint parts were λ-joint, Fig. 3(a), and V-joint, Fig. 3(b), respectively. The each outline size was 400mm × 350mm and the window size was 80mm × 190mm. The specimen was the grain-oriented steel sheet (35Z159). The number of the stacked layers was 40 and the number of each windings was 110 turns. The arrows in Fig. 3 show the easy magnetization direction of the electric steel sheets. In the measurements, the three-phase transformer model core was excited with three-phase sinusoidal voltages. The exciting frequency was 50 Hz.

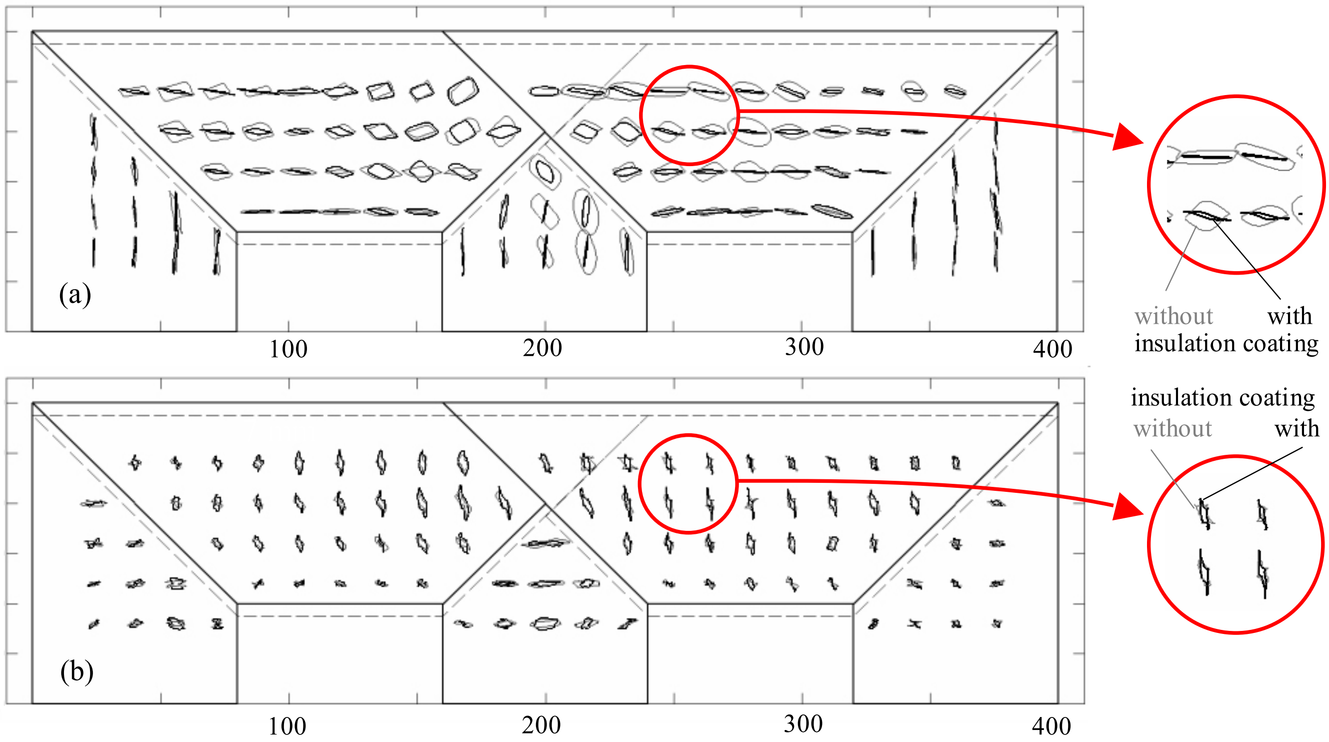


Fig. 4. Loci of :(a) − B_x-B_y , and (b) − H_x-H_y on the λ -joint three-phase transformer model core; without (grey lines) and with (black lines) insulation coatings

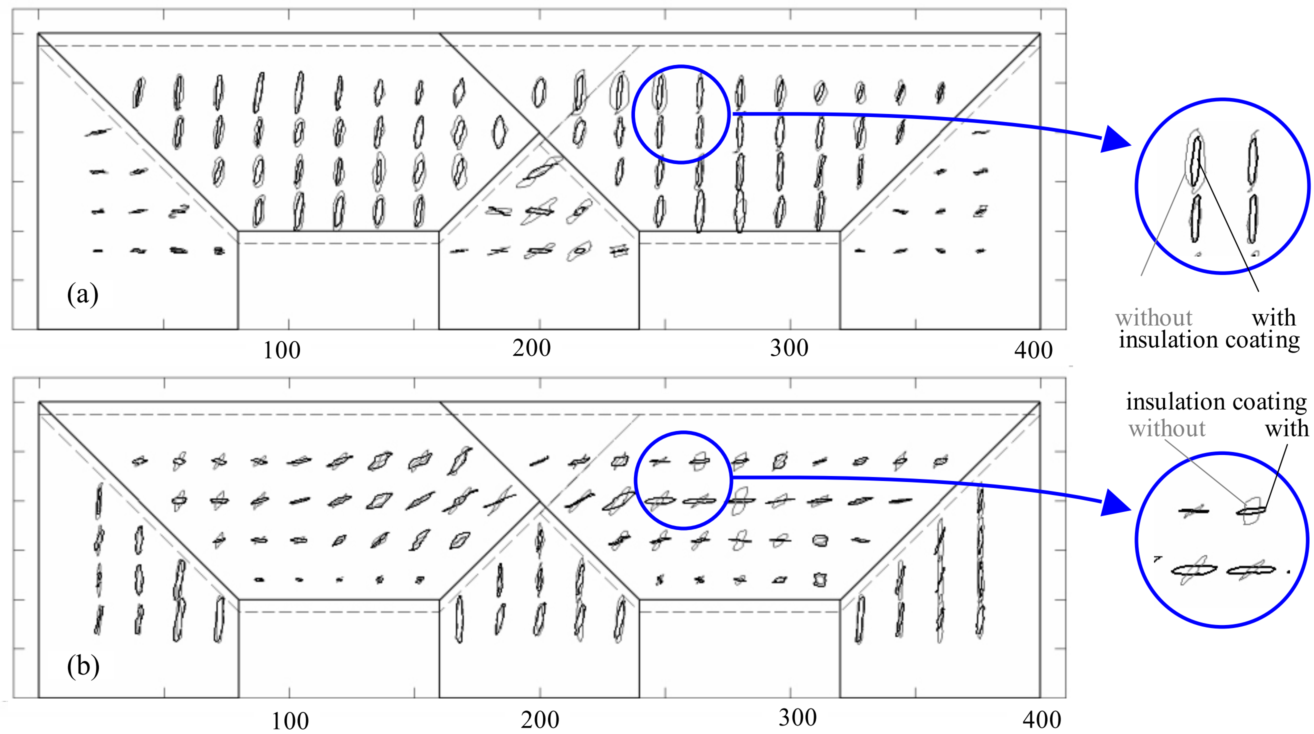


Fig. 5. Hysteresis loop of: (a) − H_x-B_x and, (b) − H_y-B_y on the λ -joint three-phase transformer model core; without (grey lines) and with (black lines) insulation coatings

The average flux density was measured with the search coil wound over the core. The magnetic flux condition used in the measurements was 1.0T. The measured points were distributed by keeping the same intervals of 16mm in x - and y - direction. The total numbers of the measured points of the λ-joint and V-joint cores were 91 and 92 points, respectively. The jointing parts of the electric steel sheets could not be measured because of the principle of the needle-probe method.

4 MEASURED RESULTS AND DUSCUSSION

Figure 4 shows the loci of B_x-B_y (a) and H_x-H_y (b) on the λ-joint three-phase transformer model core. The gray line indicates the measured results on the core without insulation coating and the black line indicates ones with coating. As shown in Fig. 4(b), the changes of the field intensity vector loci were not so large, because they mainly depended on the exciting current. The elongate axes of the H_x-H_y loci were mainly parallel to the transverse direction of the electrical steel sheet. This means that larger magnetic field intensity needs to direct the magnetic flux in the hard magnetizing direction corresponded to the transverse direction.

As to the magnetic flux density, large differences between the trajectory shapes in cores with and without the insulation coating were observed as shown in Fig. 4(a). The large rotational flux was generated in the core without coating and the iron loss increased in comparison with that with coating. The reason can be considered that the tensile stress in the rolling direction was weakened by removing the insulation coating and permeability was also little deteriorated in the rolling direction. At the same time, in the transverse direction, the permeability was increased relatively. It is evident that the magnetic permeability in the rolling direction is larger than that in the transverse direction in the core with the insulation coating.

Figure 5 shows the distribution of the hysteresis loops on the λ-joint model core: H_x-B_x (a) and H_y-B_y (b). Because the iron loss can be calculated as a sum of the hysteresis loops area in x - and y - direction, the total iron loss in the core without coating was larger than that with coating. The tensile stress due to the insulation coating is a result of difference of expansion factor in coating process. It is evident that the insulation coating is working to improve the magnetic permeability in the rolling direction. In consequence, we can point out that accurate vector magnetic property measurement should be performed in the electrical steel sheets with the insulation coating.

The local magnetic property distributions of the V-joint model core was similar to ones of the λ-joint model core. Because of the page limit, we neglect the local magnetic property distributions of the V-joint model core. In order to compare the total iron loss of the λ -joint and V-joint model cores, we calculated the average iron loss by using all the measured point data. Table 2 shows the comparison of the average iron loss. The iron loss of the V-joint model core was smaller than that of the λ -joint model core. Also the iron loss became larger in the cores without insulation coating.

Table 2. Average iron loss

Condition of insulation coating	Average iron loss (W/kg)	
	λ -joint	V-joint
With insulation coating	0.5023	0.3844
Without insulation coating	0.7711	0.7851

5 CONCLUSION

In this paper, *V-H* sensor consisted of the piercing *B*-needles to break through insulation coating and the 4 mm x 4 mm double *H*-coil was reported. By means of the *V-H* sensor, we measured local vector magnetic properties in the three-phase transformer model core with and without insulation coating. The results showed that large difference in the magnetic flux density loci existed and the coating could not be removed for an accurate measurement. The results also demonstrated that the developed *V-H* sensor was very useful for measurements of the local vector magnetic properties in practical constructed core with insulation coating. Increasing resolution of the *V-H* sensor and prolonging life-time of the *B*-needles remain as further problems to be solved.

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