A Measurement System for Two-Dimensional DC-Biased Magnetic Property

Masato Enokizono*, Syuichi Takahashi* and Atsushi Ikariga*

Abstract - Up to now, DC-biased magnetic properties have been measured in one dimension (scalar). However, scalar magnetic properties are insufficient to clarify DC-biased magnetic properties because scalar magnetic properties can only impossibly consider the phase difference between the magnetic flux density B vector and the magnetic field strength H vector. Thus the magnetic field strength H and magnetic flux density B in magnetic materials must be directly measured as a vector quantity (two-dimensional). This paper presents measurement system to clarify the two-dimensional DC-biased magnetic properties.

Keywords: DC-biased magnetic property, two-dimensional magnetic property, single-sheet tester, grain-oriented silicon steel sheet

1. Introduction

Magnetic materials were used under the symmetrical AC exciting condition in many case. In recent years, however, the exciting condition was diversified with progress in power electronics. The permanent magnet motor, the electromagnetic acoustic transducer, and the electrical machine used with semiconductor devices are examples of diversification of the exciting condition. In these machines, DC-biased magnetization is possible in iron cores. The DC-biased magnetization will increase iron loss, maximum current, and noise. [1][2]

The DC-biased scalar magnetic properties cannot clarify serious problems; such problems are clear from the two-dimensional magnetic properties. [3] Thus, the magnetic field strength and magnetic flux density in magnetic materials must be directly measured as a vector quantity (two-dimensional). [4][5]

2. Measurement System

2.1 Definition of measurement quantity

The parameters used in measurements are defined in Fig. 1. We define the longer direction of a rectangular specimen as x-direction, and the other as y-direction. B_{xdc} and B_{ydc} are the DC magnetic flux densities, H_{xdc} and H_{ydc} are the DC magnetic fields strength, and B_{xac} and B_{yac} are the AC components of the magnetic flux densities.

Fig. 1 shows the hysteresis loop under the DC-biased condition. B_{xmax}, B_{xmin}, B_{ymax}, and B_{ymin} are the maximum magnetic flux densities and the minimum magnetic flux densities in each direction. B_{xm} and B_{ym} show the amplitude of B_{xac} and B_{yac}. ΔB_x and ΔB_y are the real shifted values under the DC-biased condition, which are not equal to B_{xdc} and B_{ydc}.

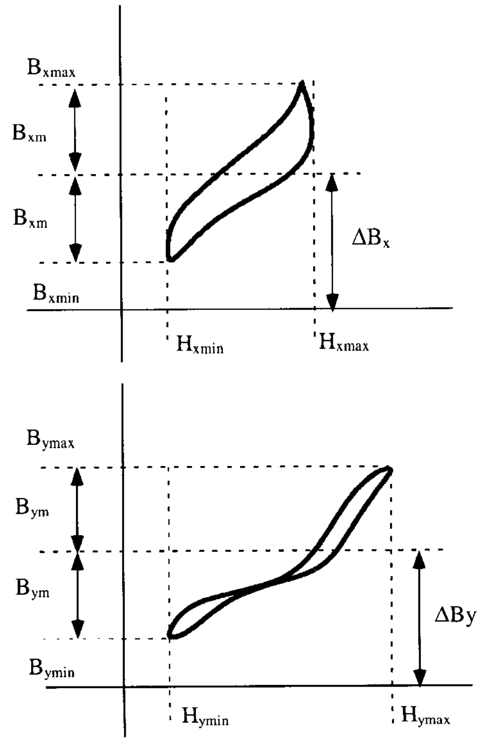

Fig. 1 Definition of measurement quantity

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2.2 Measurement system

Fig. 2 shows the measurement system. The waveform generator is for AC excitation. We can make any DC-biased condition using this equipment. The part surrounded by the dotted line shows the single-sheet tester. The output voltages from the H coils and B coils were very small, and were amplified using the DC Amplifiers. AC values were taken in the Digital Scope from each coil. DC values were measured with the four flux meters. The signals used as input to Digital Scope were sent to the computer through GP-IB.

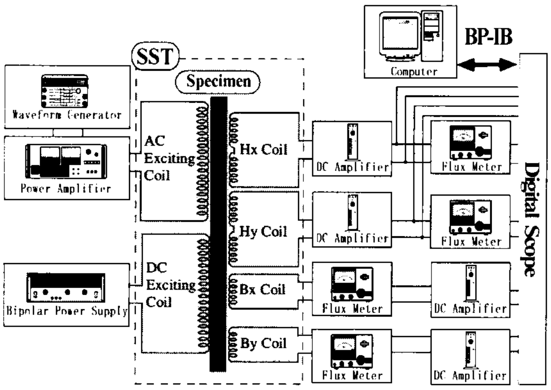


Fig. 2 Measurement system type-1

Fig. 3 shows the outline of the single-sheet tester type-1. As shown in Fig. 3, H coils were set on upper and lower sides of the specimen and wound in the x- and y-directions on the 50mm×50mm×2mm acrylic sheet. The H coils were set as close to the specimen, as possible. The B coils were wound on the frame that was laid surrounding the H coils. The B coils were wound 45 degrees and -45 degrees from the x-direction. Because the cross-sectional area of the B coils was larger than that of specimen, compensation coils were used. The 220-turns DC exciting coil was wound on the frame that was laid surrounding the B coils. The AC exciting coils were wound on the yokes to be 544×2 turns. The number of turns of the H coils and B coils were 3000×2 and 490, respectively.

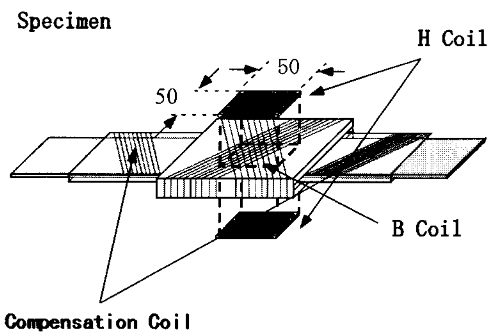


Fig. 3 Structure of B and H coil

As shown in Fig. 4, the components measured with B coils were separated in each direction. B_x and B_y were calculated with the separated values.

As shown in Fig. 5, the specimen was a grain-oriented silicon steel sheet and the magnetic easy axis was 22.5 degrees from the x-direction. The thickness is 0.23mm. The size of the rectangular steel sheet is 50mm×400mm. As shown in Fig. 6, the measurement conditions assumed were exciting frequency of 50Hz and AC exciting voltage of 2.0V. The DC exciting voltage was changed from 0 to 0.7V per 0.1V step.

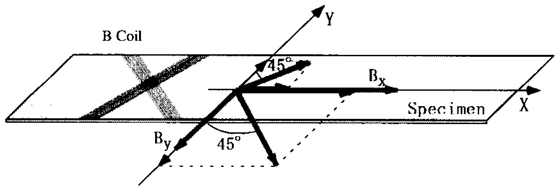


Fig. 4 Vector figure

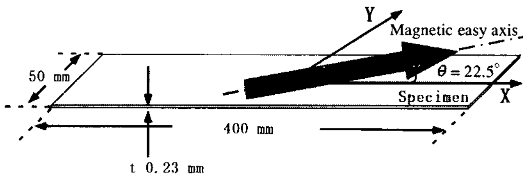
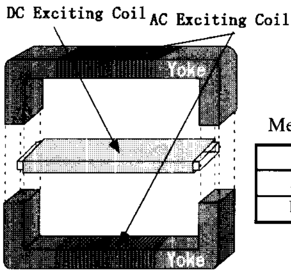


Fig. 5 Specimen and measurement condition



Measurement Conditions

Frequency : [Hz]	50
AC Exciting Voltage : [V]	2
DC Exciting Voltage : [V]	0~0.7

Fig. 6 Single sheet tester type-1

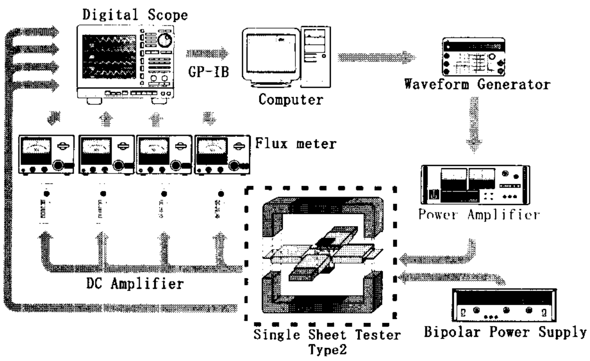


Fig. 7 Measurement system type-2

Fig. 7 shows the outline of the single-sheet tester type-2. As shown in Fig. 8, H coils were set on the upper and lower sides of the specimen and wound in the x- and y-directions on the 30mmx30mmx2.0mm acrylic sheet. The H coils were set as close to the specimen, as possible. The number of turns of the H coils and B coils were 3000x2 and 15, respectively. The B coils were wound through the 0.5mm-diameter holes in the center of the specimen. The distance between the holes was 40mm, 0.006mm-diameters copper wire was used for the B coils.

The specimen was identical to that used in type-1.

As shown in Fig. 9, assumed measurement conditions were exciting frequency of 50Hz and AC exciting voltage of 2.0V. The DC exciting voltage was changed from 0 to 1.4V per 0.2V step.

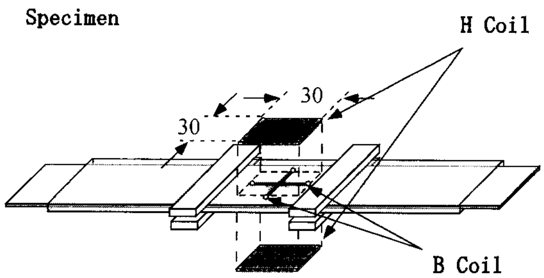
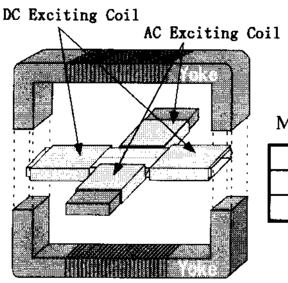


Fig. 8 Structure of B and H coil



Measurement Conditions

Frequency : [Hz]	50
AC Exciting Voltage : [V]	2
DC Exciting Voltage : [V]	0~1.4

Fig. 9 Single sheet tester type-2

2.3 Measurement procedure

Fig. 10 shows the measurement procedure, which is the same in type-1 and type-2. First, sample and yoke were demagnetized. When we demagnetized the specimen only, residual magnetic flux density was left in the circle regions. Therefore, we demagnetized the yokes without the specimen. Next, we measured offset voltage to remove offset voltage of the equipment. We measured B_{DC} and H_{DC} under DC excitation only to compare with ΔB and ΔH. Then, we added AC excitation to generate a DC-biased field and measured the magnetic flux density, the magnetic field, and ΔB and ΔH.

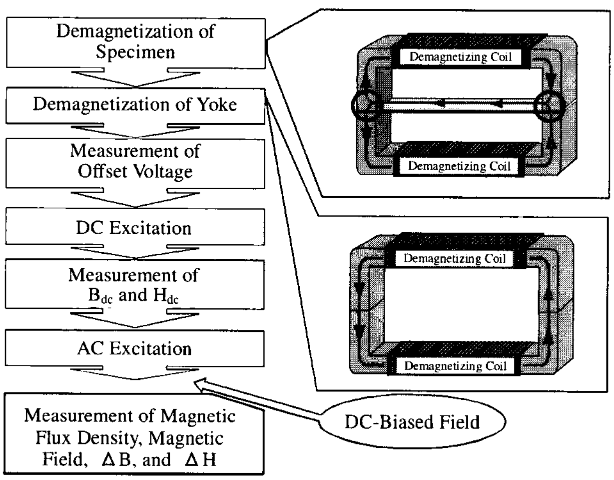
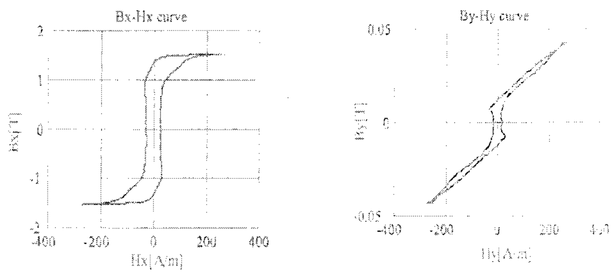


Fig. 10 Measurement procedure

3. Measurement Results and Discussions

3.1 Discussion of Type-1

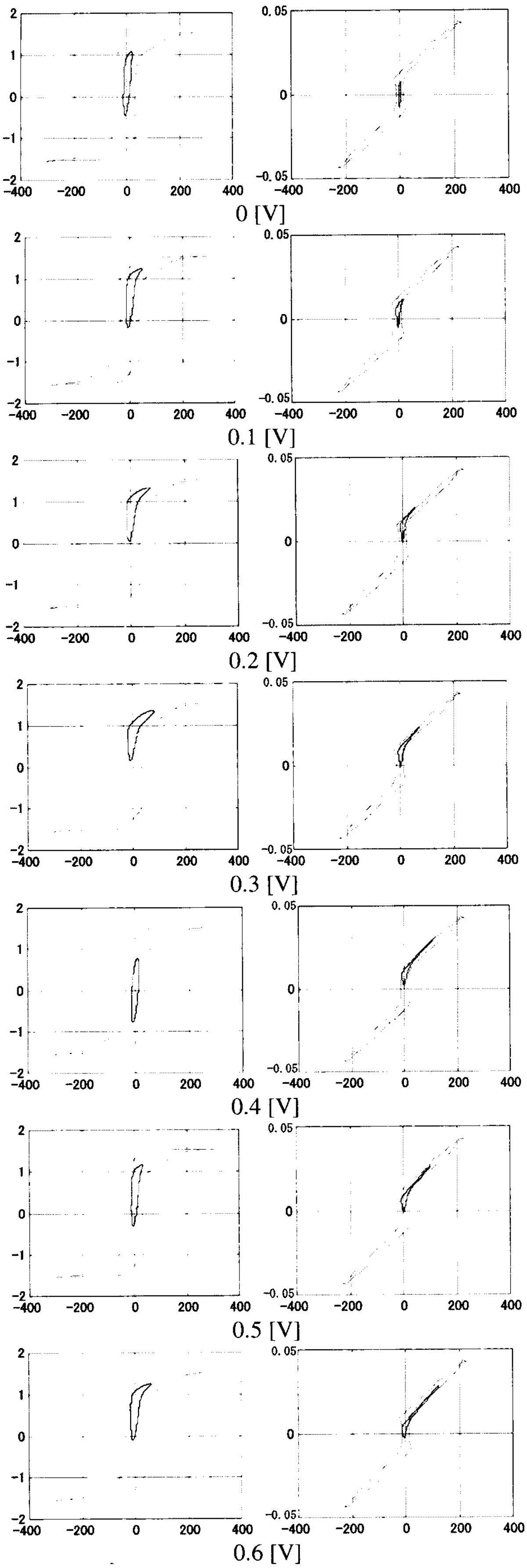
Fig. 11 shows the hysteresis loops in the x- and y-directions were saturated with the magnetic flux density. These hysteresis loops are shown for reference.



x-direction y-direction

Fig. 11 Hysteresis loop

The DC exciting voltage was changed from 0V to 0.7V per 0.1V. Fig. 12 shows the comparison of the DC-biased magnetic loci and the saturated hysteresis loop of the x- and y-directions. The DC-biased magnetic loci of the x- and y-directions are inside the saturated DC hysteresis loop. Therefore, it is possible to measure two-dimensional DC-biased magnetic properties. Fig. 13 depicts changes of B_{dc} and ΔB depending on DC exciting voltage, and aids in understanding that the value of ΔB differs from B_{dc}. Fig. 14 shows B_m depending on DC exciting voltage. This figure shows that the amplitude of the x-direction is small according to increased DC exciting voltage. Therefore, DC-biased magnetization becomes the cause of increased maximum current. Fig. 15 shows the iron loss depending on DC exciting voltage. Loss-x and Loss-y show the iron loss in each direction. The iron loss increases according to increased DC exciting voltage. Therefore, the iron loss of DC-biased magnetic conditions is larger than that of the symmetrical AC exciting condition.



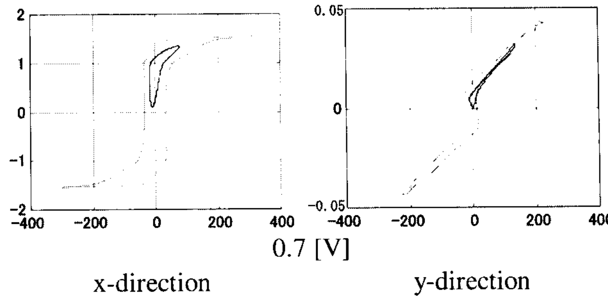


Fig. 12 Hysteresis loop under DC-biased field (horizontal: magnetic field strength [A/m], vertical: magnetic flux density [T])

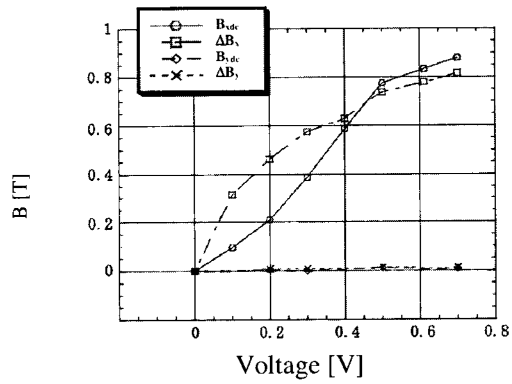


Fig. 13 B_{dc} and ΔB dependence on DC exciting voltage

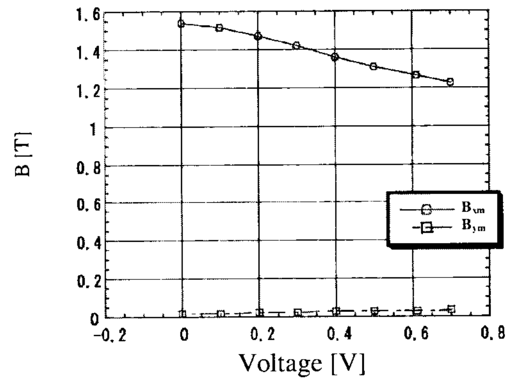


Fig. 14 B_m dependence on DC exciting voltage

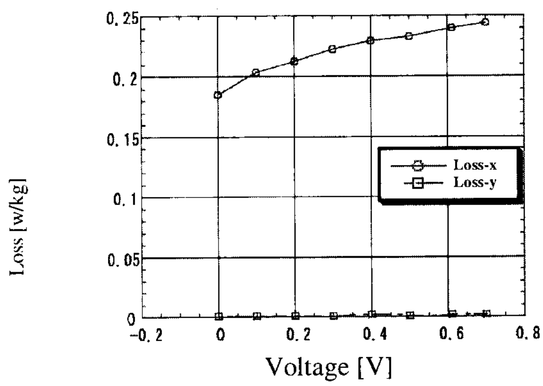
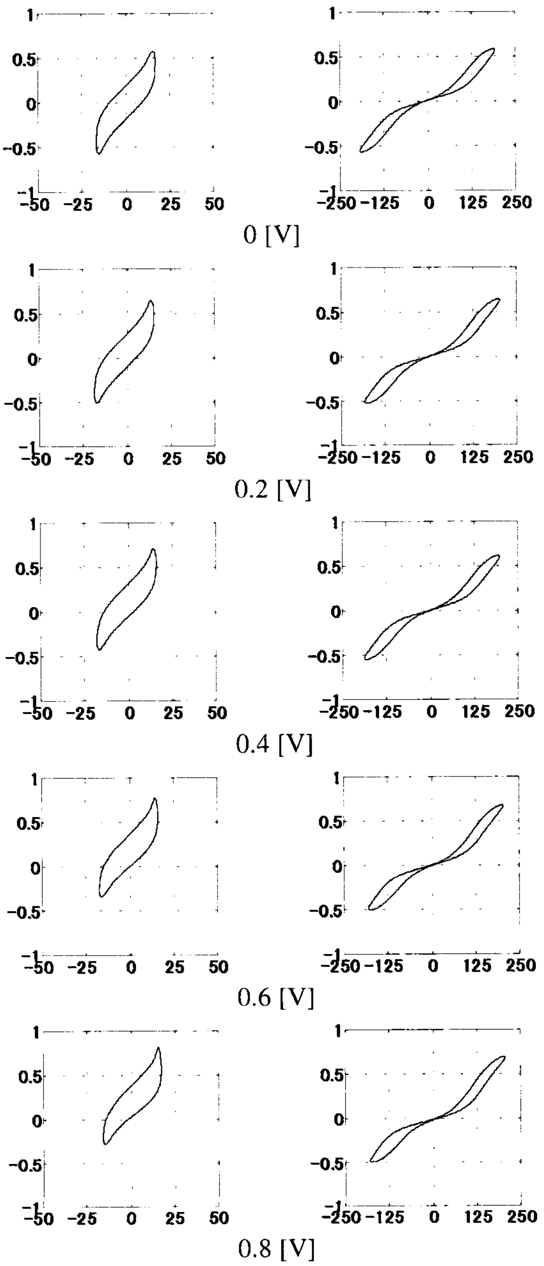


Fig. 15 Iron loss dependence on DC exciting voltage

3.2 Discussion of Type-2

As for the measurement system of type-1, the signal of the y-direction is much smaller than x-direction. Therefore, we devised the measurement system of type-2. Thus, we could obtain a larger y-direction signal than type-1. Figs. 16 shows the comparison of DC-biased magnetic loci in the x- and y-directions. Fig. 17 depicts changes of B_{dc} and ΔB depending on DC exciting voltage, and shows now the value of ΔB differs from B_{dc}. Fig. 18 shows the dependence of B_m on DC exciting voltage. Fig. 19 shows the iron loss depending on DC exciting voltage. Therefore, the iron loss of the DC-biased magnetic condition was larger than that of the symmetrical AC exciting condition.



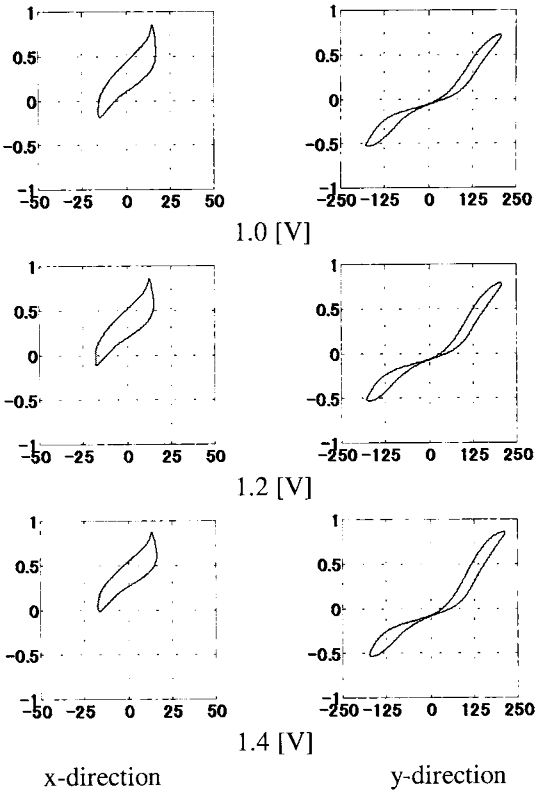


Fig. 16 Hysteresis loop under DC-biased field (horizontal: magnetic field strength [A/m], vertical: magnetic flux density [T])

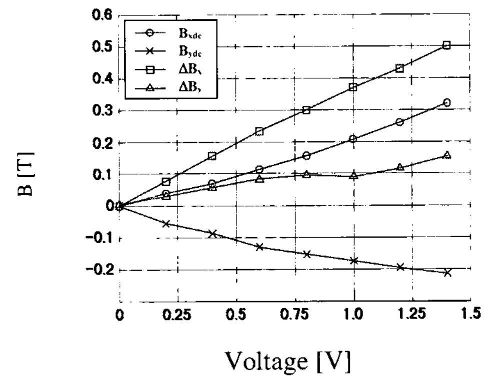


Fig. 17 B_{dc} and ΔB dependence on DC exciting voltage

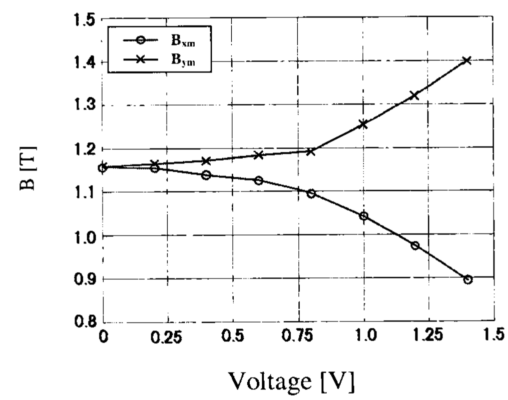


Fig. 18 B_m dependence on DC exciting voltage

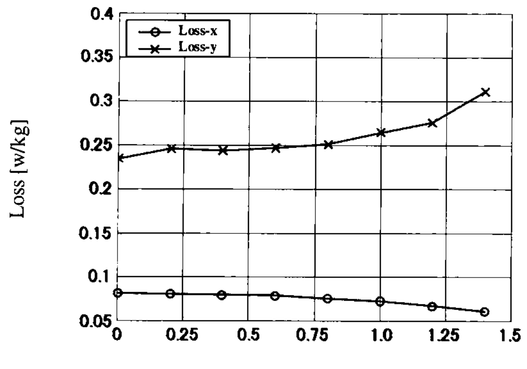


Fig. 19 Iron loss dependence on DC exciting voltage

4. Conclusion

To measure the two-dimensional DC-biased magnetic properties, we have proposed a single-sheet tester in the measurement system. The results show that the system presented here is very useful for measuring the two-dimensional DC-biased magnetic property and for facilitating the observation of very complicated tendencies.

We confirmed that the loss in the y-direction became larger under DC-biased conditions.

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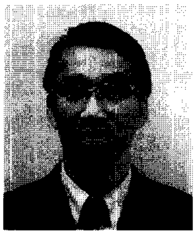

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