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Demagnetization Performance According to Vertical and Horizontal Magnetic Bias Fields

Young-Hak Kim[1]*, Ki-Chan Kim[1], Kwang-Ho Shin[2], Kwan-Seob Yoon[3], and Chang-Seob Yang[4]

[1]*Department of Electrical Engineering, Pukyong University, Busan 608-736, Korea*
[2]*Department of Electronics and Information Communication Engeering, Kyungsung University, Busan 608-737, Korea*
[3]*Maritime R&D Lab., LIGnex1 Co., Ltd., Yongin 446-912, Korea*
[4]*Agency for Defense Development, Jinhae 645-016, Korea*

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Demagnetization for a tube sample which was made of a galvanized steel sheet was performed by applying a magnetic field with a decrement to remove the remanent magnetization of the material. An orthogonal fluxgate magnetic field sensor was used to measure a magnetic field created from a ferromagnetic material. To evaluate the remanent magnetization, the measured magnetic fields were separated into two magnetic field components by the remnant magnetization and the induced one. The horizontal and the vertical bias fields should be controlled separately during demagnetization to remove the horizontal and the vertical components of the remanent magnetization of the tube sample.

Keywords : remnant magnetization, demagnetization, bias magnetic field, earth magnetic field, anhysteretic curve

1. Introduction

Orthogonal magnetic field greatly influences on the magnetization of a ferromagnetic material and its effect is different depending on the shape of the material such as a toroidal core or magnetic shield can, and the way of applying magnetic field [1-3]. The orthogonal field can be used to demagnetize a ferromagnetic material [4]. When a ferromagnetic material is demagnetized by a magnetic field with a decrement during demagnetization process, the material's operating magnetization moves from the saturation magnetization to the origin of B-H hysteresis loop through the initial magnetization curve [5]. It is not generally easy for the magnetization to be back to the exact origin by demagnetization because there are many pinning sites of domain walls due to the inducing stress and defects, etc in the material. As a result, the remnant magnetization of the material has a deviation from the origin. Even though a ferromagnetic material doesn't have a remnant magnetization, it can be also magnetized by earth magnetic field. From the military point of view, the ratio of the magnetic field by the remnant magnetization to the magnetic field by the induced one due to earth magnetic field is important to evaluate the demagnetization performance. Accordingly, the magnetic fields which a ferromagnetic material produces after demagnetization need to be separated into two field components, which are by the remnant magnetization and by the induced magnetization due to earth magnetic field, respectively [6]. In addition, each field component should be decomposed into two directional components which are the same directions as the longitudinal and the vertical directions of earth magnetic field, respectively This study was made in the view of navy magnetic treatment technology for vessels and submarines as one of magnetic applications and deals with the effects of the longitudinal and the vertical bias fields on the magnitude and the direction of the remnant magnetization after demagnetization.

*Corresponding author: Tel: +82-51-629-6316
Fax: +82-51-629-6305, e-mail: kimyh@pknu.ac.kr

2. Experimental Procedure

Demagnetization was performed by applying a magnetic field with a decrement to remove the remanent magnetization of a ferromagnetic material. After demagnetization, a magnetic field was measured to estimate the remanent magnetization of the material. Fig. 1 shows an experimental setup for demagnetization and magnetic

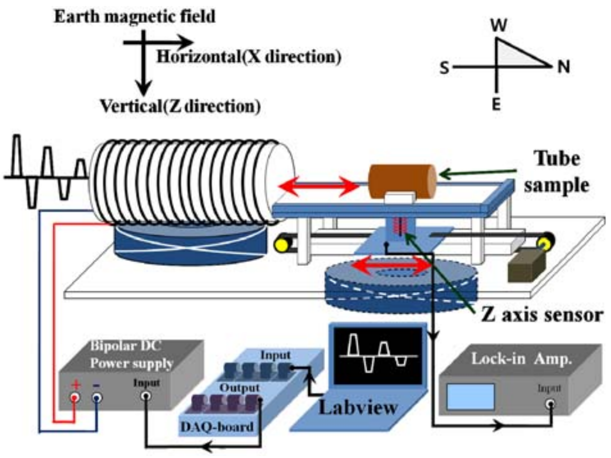

Fig. 1. (Color online) Experimental setup for demagnetization and magnetic field measurement.

field measurement. Since the magnitude and the direction for the magnetization of a ferromagnetic material by earth magnetic field could not be negligible and should be defined, it is very important that a solenoid coil for demagnetization and a sensor rail for the magnetic field measurement are necessary to be headed toward the horizontal direction of earth magnetic field (x-direction). An orthogonal fluxgate magnetic field sensor was used to measure the vertical component of a magnetic field, $H_z(x)$ created from a ferromagnetic material. The location of the sensor is 23 mm away below a sample. The magnetic field measurement was taken with the sensor moving along a sensor rail (x-direction). The sign of sensor's measurement values becomes plus when the direction of magnetic field is the same as the vertical direction of earth magnetic field (up to down in the northern hemisphere). The measurement values of the sensor by only earth magnetic field at all measurement positions were removed from all data presented here. Two circular coils with many turns are available to generate magnetic field against the vertical component of earth magnetic field. One was for the cancellation of the vertical component of earth magnetic field when the magnetic field was measured. The other was used to produce a vertical bias field when demagnetizing. The solenoid coil generates an alternating magnetic field with a longitudinal bias field. The magnitude of the field was controlled as a ramped step pulse sequence. The first pulse and the last one of the sequence had the magnitude of 1450 A/m and 16 A/m, respectively and the direction of the two pulses was against the original remanent magnetization direction of a ferromagnetic material. The rising time and the falling one of the ramped step pulse were 1 second which is sufficient time not to generate the eddy current over a sample thickness. The turn-on time and the delay time until next pulse were 1 second. The pulse sequence had a decrement of 30 A/m. The demagnetization was done again after pre-demagnetization with the first pulse of 15 kA/m. The tube-shaped sample used in this experiment was made of a galvanized steel sheet with the thickness of 0.16 mm. The length and the diameter of the tube sample were 100 mm and 60 mm, respectively.

3. Separation of Magnetic Fields by the Induced Magnetization Due to Earth Magnetic Field and the Remnant One of a Ferromagnetic Material

In evaluating the remnant magnetization of the sample, the measured magnetic fields should be separated into H_{ILM} and H_{PLM}, $H_{IVM,}$ $H_{PVM,}$ where H_{ILM} is a magnetic field by magnetization due to the horizontal component of earth magnetic field and H_{PLM} is the one by the horizontal component of remnant magnetization, H_{IVM} is the one by magnetization due to the vertical component of earth magnetic field and H_{PVM} is the one by the vertical component of the remnant magnetization, respectively. Therefore, H_{LM} becomes the sum of H_{ILM} and H_{PLM} and also H_{VM} is the sum of H_{IVM} and H_{PVM}. The separation can be illustrated by Fig. 2. Fig. 2(a) and (b) show $H_{z,s\text{-}n}(x)$ and $H_{z,n\text{-}s}(x)$ measured at every moving position of the sensor rail (x-direction) when the remnant magnetization direction of the sample is headed toward south-north and reversely north-south, respectively. The amplitude in the direction of south-north is larger than the one in the north-south because the remnant magnetization and the induced one by earth magnetic field have an effect on the magnetic field from the sample in the same direction. H_{LM}

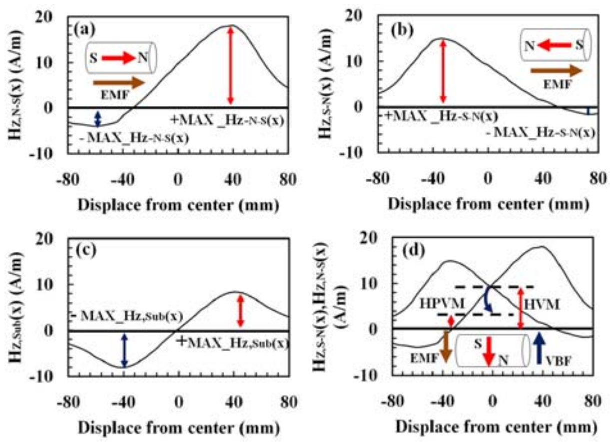

Fig. 2. (Color online) Illustration for the separation of magnetic fields by the remenant magnetization and the induced one due to earth magnetic field.

can be defined as {+ maximum $H_{z,s\text{-}n}(x)$ − (− maximum $H_{z,s\text{-}n}(x)$)}/2. H_{PLM} can be also defined as {+ maximum $H_{z,sub}(x)$ − (− maximum $H_{z,sub}(x)$}/2 from $H_{z,sub}(x)$ which is the difference between $H_{z,s\text{-}n}(x)$ and $H_{z,n\text{-}s}(x)$ as shown in Fig. 2(c). Fig. 2(d) represents the way of separating H_{PVM} from H_{VM}. If there is no vertical component of the magnetization on the sample, the magnetic field in the cross point of $H_{z,s\text{-}n}(x)$ and $H_{z,n\text{-}s}(x)$ which are at the centre of sample length must be zero. However if there is the vertical component, H_{VM} becomes the magnetic field at the cross point and is in proportion to the vertical magnetization. When the circular coil below sample generates a magnetic field against the vertical direction of earth magnetic field, the magnetic field of the cross point of $H_{z,s\text{-}n}(x)$ and $H_{z,n\text{-}s}(x)$ varies from the original point by canceling the vertical component of earth magnetic field. The varied value just is defined as $H_{PVM.}$

4. Results and Discussion

Fig. 3 shows the dependence of two directional components of magnetic field by the magnetization of the tube sample on the horizontal bias field. In Fig. 3(a), H_{PLM} varied −7 A/m to +5 A/m with the horizontal bias field increasing. The variation of H_{PLM} indicates that the horizontal component of the remnant magnetization was moved from +B region to –B region with the origin of B-H loop as the center. However there is no great variation in the magnetic fields (H_{PVM}) due to the vertical component of the magnetization as shown in Fig. 3(b). It can be confirmed from Fig. 4 that the negative sign of H_{PLM} results from the waveform reverse of $H_{z,sub}(x)$ at the bias fields of above 30 A/m. As illustrated in the Fig. 5, as the vertical bias field increases, H_{PVM} varied from positive value to negative value. H_{PLM} was almost constant. Given that the change in magnetization during demagnetization occurs by the domain wall motion, it can be seen that the variations of H_{PLM} and H_{PVM} was due to the magnetization-biased effect that the magnetization of the sample inclines toward the direction of each bias field. It can be also seen that H_{PVM} greatly depends on the magnetic moments on the right and left sides of the tube sample which are more susceptible to the vertical magnetic field than those on the bottom. Fig. 6 shows two directional components of the magnetic field by the magnetization of the tube sample when the horizontal bias field varied 0 A/m to 40 A/m at the vertical bias fields of 16 A/m. H_{PLM} and H_{PVM} varied negative value to positive value and vice versa, respectively along with the increase of the horizontal bias. The bias fields which H_{PLM} and H_{PVM} equal to zero, respectively are different each other as shown Fig. 6(a) and Fig. 6(b). Since the demagnetization of the sample

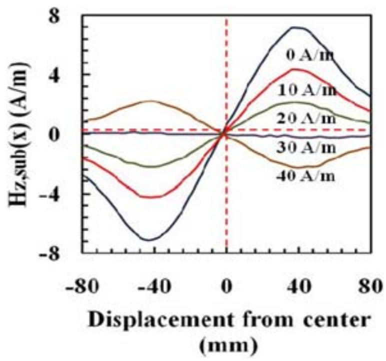

Fig. 4. (Color online) Separation of the magnetic fields by the longitudinal component of the remanent magnetization from magnetic fields by the longitudinal components of the remanent magnetization and the induced one.

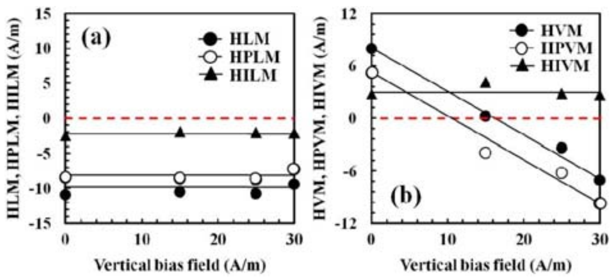

Fig. 5. (Color online) Dependence of magnetic fields on the vertical bias field.

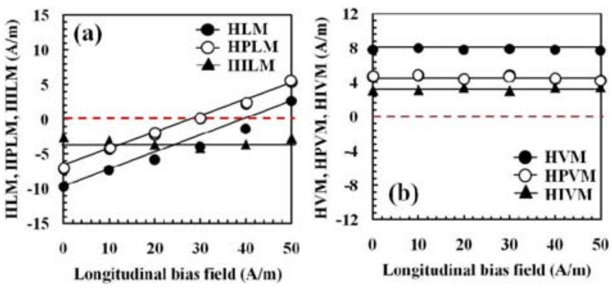

Fig. 3. (Color online) Dependence of magnetic fields on the horizontal bias field.

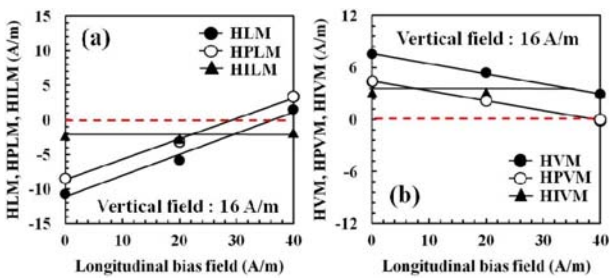

Fig. 6. (Color online) Dependence of magnetic fields on the horizontal bias field at the vertical bias field of 16 A/m.

was performed under the orthogonal magnetic field which is composed of the vertical bias field and the alternating magnetic field with the horizontal bias field applying toward the longitudinal direction of the sample, the sample has two effects. One is, as above mentioned, a magnetization-biased effect. Another is anhysteretic-like effect that hysteresis loop area become small and permeability is high by an orthogonal magnetic field. Accordingly, the result of Fig. 6 indicates that those two bias fields make a magnetization-biased effect more prominent by anhysteretic-like effect.

5. Conclusion

When the horizontal and the vertical bias fields were independently applied to tube sample, those bias fields had an influence on the horizontal and the vertical component of the remnant magnetization, independently. Also each bias field had each component of the remnant magnetization incline toward each bias direction. However, when the bias fields were applied simultaneously, two components of the remnant magnetization were varied together along with the bias fields and were not zero simultaneously. Accordingly, during demagnetization, those bias fields should be controlled separately in order to make each component of the remnant magnetization of the tube sample zero.

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