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Symmetric hysteresis curves of rare earth-cobalt magnets measured by high magnetic fields

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SYMMETRIC HYSTERESIS CURVES OF RARE EARTH-COBALT MAGNETS MEASURED BY HIGH MAGNETIC FIELDS

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Abstract - $SmCo_5$ magnets show generally asymmetrical hysteresis curves in the region of ordinary magnetic field strength. However, if these magnets are magnetized by a field of over 14 T, hysteresis loop becomes symmetric, except for the experimental errors caused by the thermal fluctuation after effect. The influence of the after effect on the magnetization curve and the coercive force $_IH_c$ are discussed.

INTRODUCTION

It is a well known fact that the rare earth-cobalt permanent magnets such as $SmCo_5$ can be fully magnetized by magnetic field of only 1 or 2 T (Tesla) in the case of initial magnetization, but the coercive force $_IH_c$ attains almost 3200 kA/m (4 T). Therefore, the $SmCo_5$ magnets show generally asymmetrical hysteresis curves, which seems quite strange from the standpoint of common characteristics of magnetic materials. It is a matter of interest to study, if this situation will be changed under high magnetic fields.

We have measured at room temperature the magnetization curve of $SmCo_5$ magnets on the market using the high magnetic field installation and also studied the influence of thermal fluctuation after effect on the hysteresis loop and the coercive field.

SPECIMEN AND INSTALLATION

The measured specimen is CORMAX-1800 ($SmCo_5$-type) kindly provided by Sumitomo Special Metals Co., Ltd., Japan and has been shaped into a sphere which diameter is 5.04 mm. The measurement has been performed using high magnetic fields with resistive magnets of "Service National des Champs Intenses", which can produce easily 20 T. The details of the installation can be seen in ref. [1].

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RESULTS

Symmetrical Hysteresis Loop under High Magnetic Fields

The hysteresis curves measured by applying maximum field of 19 T are shown in Fig.1 against the effective magnetic field. It is easily seen from this figure that the hysteresis curves are exactly symmetric except for the experimental errors caused by magnetic after effect. The part of the magnetization curve approaching to the saturation and the decreasing part from the saturation magnetization are represented in detail in Fig.2. This figure shows that the hysteresis disappears above 14 T; namely it means that in order to obtain the symmetrical hysteresis loop for $SmCo_5$-type permanent magnet, it is necessary to apply a magnetic field of more than 14 T. The ordinary demagnetization curve I against effective field H in the case of applying 19 T is given in Fig.3.

Influence of Thermal Fluctuation After Effect on the Coercive Force

The demagnetization curve near the coercive force $_IH_c$ is difficult to be determined because of a thermal fluctuation after effect, which is very remarkable in the rare earth-cobalt magnets. It was already pointed out [2] that the magnetization curve and coercive force in permanent magnets can vary because of the thermal

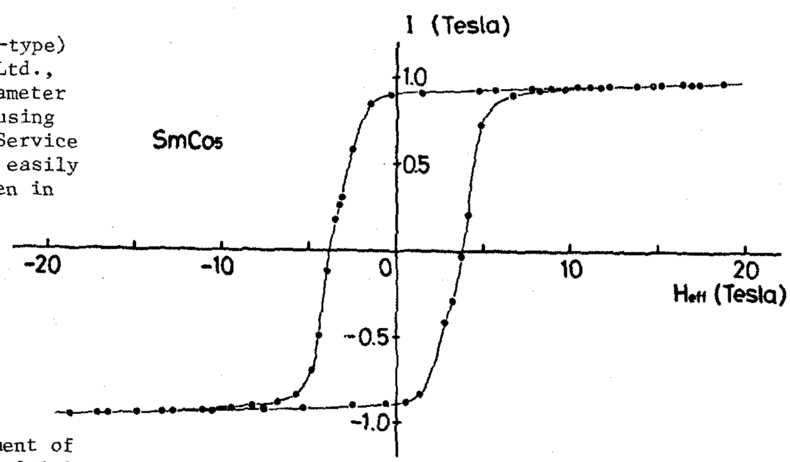

Fig. 1. Symmetric hysteresis loop of $SmCo_5$ magnet measured at room temperature by applying maximum field of 19 T.

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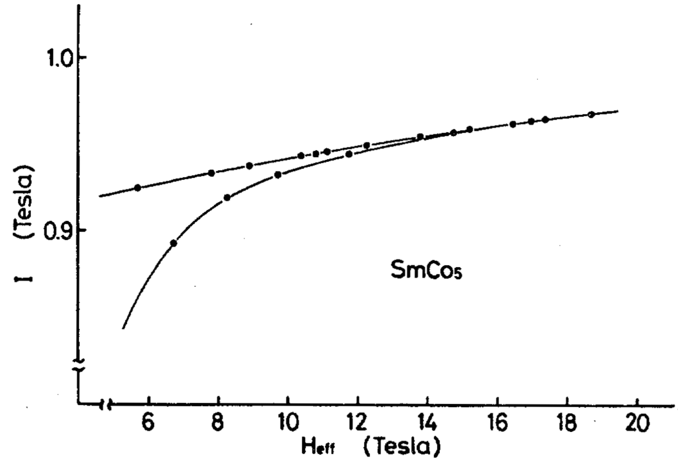

Fig. 2. The part of the magnetization curve approaching to the saturation and the decreasing part from the saturation magnetization of $SmCo_5$ magnet.

fluctuation after effect; if the magnetization is changed from A to B (zero magnetization) in Fig.4 by applying a field H for a long time, H may also be defined as a coercive force. Therefore there can be various values of coercive force according to various waiting times.

The magnetization change ΔI, for a time t, represented by AB of Fig.4 is given [3] by

$$\Delta I = \chi_{irr}\, S_v\, (Q + \ln t) \qquad (1)$$

where χ_{irr} is the irreversible susceptibility, S_v the after effect constant and Q a constant.

On the other hand, in Fig. 4 if the value of OC, coercive force to be measured at the moment where we apply the magnetic field, is designated by ${}_IH_c(0)$, and that of OB, coercive force measured at a time t after applying the magnetic field, by ${}_IH_c(t)$ and also the total differential susceptibility in the neighbourhood

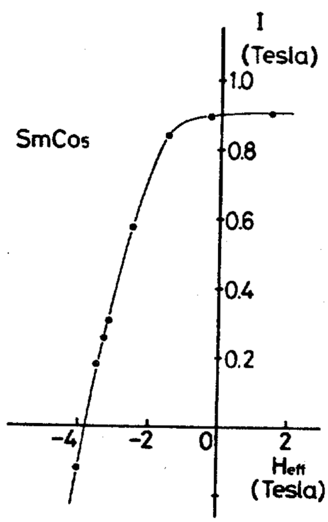

Fig. 3. Demagnetization curve I against effective field H in the case of applying 19 T for $SmCo_5$ magnet.

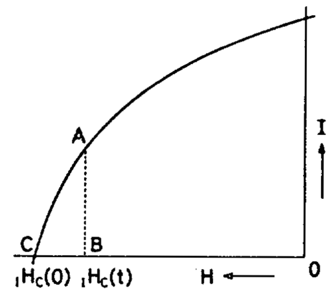

Fig. 4. Example of a magnetic field ${}_IH_c(t)$ which becomes a coercive force owing to the existence of after effect.

of point C is expressed by $a + \chi_{irr}$, where a is the reversible susceptibility, then we have

$$\Delta I = (a + \chi_{irr})\, [{}_IH_c(0) - {}_IH_c(t)] \qquad (2)$$

From (1) and (2) it is shown that the coercive force is expressed as a function of measuring time t after setting the applied field constant, namely

$${}_IH_c(0) - {}_IH_c(t) = \frac{\chi_{irr}\, S_v}{a + \chi_{irr}} (Q + \ln t), \qquad (3)$$

It is quite noteworthy that although the demagnetizing factor of specimen is different from zero, (3) is valuable independently of the demagnetizing factor of the specimen [4]. Our experiments show that the change of ${}_IH_c(t)$ between t = 1 and 10 second attains almost 8 kA/m (0.01T) and the value of S_v is 10 - 11 kA/m (0.013 - 0.014 T) at room temperature for $SmCo_5$-type magnets.

Peculiar Behaviour of the After Effect in $SmCo_5$ Magnets

The thermal fluctuation after effect in $SmCo_5$ magnets shows often a peculiar behaviour; if we repeat the same measurement by using the same field, we sometimes observe a smaller after effect for the second time, and still smaller for the third time, as shown in Fig.5 after effect measurements in remanent magnetization for a samarium-cobalt magnet [5]. The after ef-

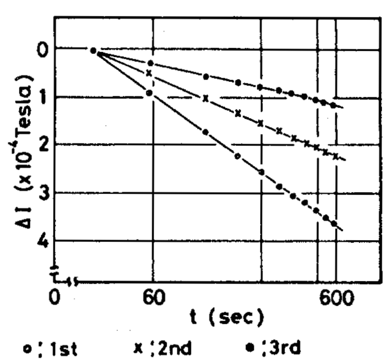

Fig. 5. After effect observed at the remanent state in cases of repeated measurements for a sample of a sort of samarium-cobalt magnet [5].

fect almost disappeared after the three times measurements, but after several days it recovered a little only in the first time measurement [5]. This peculiar behaviour of $SmCo_5$ magnets will also be a cause for experimental errors of the measurements.

CONCLUSIONS

$SmCo_5$ magnets show generally asymmetrical hysteresis curves in the region of ordinary magnetic field strength. However, if they are magnetized by fields of over 14 T, the hysteresis loops of $SmCo_5$ magnets become exactly symmetric except for the experimental errors caused by the thermal fluctuation after effect.

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