Effects of Static Magnetic Properties on DC Biased Permeability of Various Metal Powder Cores

Katsu Yanagimoto*1, Kazuhiko Majima*2, Satoshi Sunada*2 and Yoshikazu Aikawa*1

*1Sanyo Special Steel Co., Ltd, 3007 Nakashima Shikama-Ku, Himeji 672-8677.
*2Faculty of Engineering, Toyama University, 3190 Gohuku, Toyama 930-8555.

SYNOPSIS
DC biased permeability (μAC) of the powder composite cores was examined for several soft magnetic materials with the viewpoint of partial DC permeability (μΔ) and coercivity (Hc). The materials with low coercivity had μAC in proportion to μΔ while the materials with higher Hc shows no relation between μAC and μΔ. It was confirmed that the low and constant Hc and high μΔ in the BH curves were necessary to improve DC biased permeability.

KEY WORDS
Powder cores, permeability, DC bias

1 Introduction
There exists an ongoing and increasing demand for the miniaturization of electronic devices such as notebook computers and cellular phones. As soft magnetic components for these devices such as chokes and transformers must be compacted in their size, both of higher permeability and lower core loss of the electromagnetic cores are required to obtain enough induction with limited core volume under high working frequency. On the other hand, good permeability under large DC bias current conditions is also demanded since large current should be applied for the compacted and complex circuit of today's electronic devices.

Sintered ferrite cores are the most popular choice for this application since they show good magnetic properties at high frequency of over several hundreds kiloHertz due to their high resistivity. On the other hand, because the saturation induction of the ferrite is lower than metallic materials, sintered ferrite cores are not used for DC bias current applications.

Powder compressed cores are components made of metallic powder which are electrically insulated from each other by an organic or inorganic insulation layer at the powder surface. Compared with ferrite cores, they have the advantage of higher saturation induction, making them suitable for large DC bias current applications. Although several materials such as pure iron, iron-silicon, amorphous metal and other soft magnetic alloys have been studied as powder cores in many applications, few reports have mentioned the difference between DC biased permeability and compositions of metallic powders for powder compressed cores.

In this study, DC biased permeability of four different soft magnetic materials were examined to find the basic mechanism of their DC biased permeability difference using the concept of basic DC magnetic properties.

2 Experimental Procedures
The experimental procedures are shown in Fig. 1, and the compositions studied are shown in Table 1. In this...
study four typical soft magnetic alloys were chosen; Fe-7Cr-2Si-0.6Al as soft magnetic stainless steel (SMSS), Fe-5Al as high B material (Fe-Al), Fe-9.6Si-5.9Al as high permeability material (Standard Sendust) and Fe-8.9Si-5.8Al as low core loss material (Modified Sendust\(^{10}\)). The powders of each alloy composition were produced by gas atomization. The alloy elements were charged and melted under an Ar atmosphere using a 2 kg capacity induction furnace. The molten alloy was superheated to the temperature of 150 K above the melting point of each composition, then atomized by Ar gas which was held at a constant pressure of 4.9 MPa. The atomized powders were then sieved to less than 45 μm and blended with silicon resin of 3 mass% relative to the atomized powders.

Toroidal powder cores for electromagnetic measurements were fabricated by forming the blended powder with a cylindrical ram of 14 mm outer/8 mm inner diameter at a pressure of 980 MPa. The cores were then heat treated at 973 K for 18 ks under a N\(_2\) atmosphere for stress relieving and resin hardening. The appearance of the atomized powder is shown in Fig. 2.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Magnetic Stainless Steel (SMSS)</td>
<td>Fe-7Cr-2Si-0.6Al</td>
</tr>
<tr>
<td>High Induction Alloy (Fe-Al)</td>
<td>Fe-5Al</td>
</tr>
<tr>
<td>High Permeability Alloy (Standard Sendust : S-Sendust)</td>
<td>Fe-9.6Si-5.9Al</td>
</tr>
<tr>
<td>Low Core Loss Alloy (Modified Sendust : M-Sendust)</td>
<td>Fe-8.9Si-5.8Al</td>
</tr>
</tbody>
</table>

The values of DC biased permeability of the toroidal cores, \(\mu_{AC}\), were measured with a LCR meter using a frequency of 100 kHz and AC current of 1 mA under the magnetic fields between 0 and 3200 A/m \(H_{DC}\) as DC bias. Their DC magnetic properties were measured with a BH loop tracer to obtain partial DC permeability, \(\mu_\Delta\), and coercivity, \(H_c\). As shown in Fig. 3, partial DC permeability was calculated by the equation \(\Delta B/\Delta H\) where \(\Delta B\) is a induction change of an initial induction curve between fixed magnetic field \(H_n\) and \(H_n-\Delta H\) \((\Delta H = 80 \text{ A/m})\), and \(H_c\) was measured from a BH loop magnetized with a maximum field \(H_m\) between 800 and 3200 A/m.

3 Results and Discussion
3.1 DC biased permeability \(\mu_{AC}\)

The DC biased permeability \(\mu_{AC}\) of the powder core for each composition between 0 and 3200 A/m is shown in Fig. 4. Two featured groups were observed. One is the group of the materials whose \(\mu_{AC}\) drastically decreased as...
the DC bias current increased (Group A), and the other is the group of the materials whose $\mu_{AC}$ values were almost constant irrespective of the DC bias current (Group B). Two Sendust alloys, S-Sendust and M-Sendust, belong to Group A while SMSS and Fe-Al belong to Group B.

3.2 Partial DC permeability ($\mu_A$)

Fig. 5 shows the values of partial DC permeability, $\mu_A$, at several different external fields of $H_n$ comparing with $\mu_{AC}$ for Group A, and Fig. 6 shows the ones for Group B. In Group A, the transitions of $\mu_A$ were very similar to $\mu_{AC}$ while no correlation was observed for Group B materials. Fig. 7 shows the correlation between $\mu_{AC}$ and $\mu_A$ of Group A materials. The linear relationship was observed for the values of $\mu_{AC}$ and $\mu_A$ of Group A materials.

3.3 Coercivity ($H_c$)

The coercivity changes of the powder cores under different maximum magnetic fields are shown in Fig. 8. Regarding the values of coercivity, two groups as labeled in Fig. 4 could also be observed. The coercivity of Group A materials was relatively low and constant for each external field, but the one of Group B increased as maximum magnetic field increased.

3.4 Correlation between $\mu_{AC}$ and DC magnetic properties

Group A materials whose $H_c$ was lower than Group B materials had $\mu_{AC}$ in proportion to $\mu_A$ while the values of Group B materials had no relation. To consider this difference, we used the schematic BH curves of Group A and B materials with superimposing the concept of $\mu_{AC}$. As seen in Fig. 9 (a), the gradient of the minor loop used
Katsu Yanagimoto, Kazuhiko Majima, Satoshi Sunada, Yoshikazu Aikawa

Fig. 9 Schematic figure of relationship between DC biased permeability and BH curve: (a) Lower Hc materials and (b) Higher Hc materials.

for measuring $\mu_{AC}$ matches with the one of the BH curve when the coercivity was low. In case of higher coercivity, however, the gradient of minor loop for $\mu_{AC}$ becomes lower than the one of the corresponding BH curve, as shown in Fig. 9 (b).

3.5 Results summary

The materials whose Hc was low had $\mu_{AC}$ in proportion to $\mu_{A}$, but no relation between $\mu_{AC}$ and $\mu_{A}$ was observed for the materials of higher Hc. This difference could be explained using the concept of the BH curves. For low Hc materials, the minor loop of $\mu_{AC}$ is consistent with the BH curve. This indicates that the higher $\mu_{AC}$ can be obtained for the materials which show low Hc and high DC permeability.

4 Conclusion

DC biased permeability, $\mu_{AC}$, of the toroidal powder composite cores using different magnetic materials was measured comparing with their DC magnetic properties such as partial DC permeability, $\mu_{A}$, and coercivity, Hc. Considering the relationship between basic BH curves and minor loops for measuring $\mu_{AC}$, the preferable magnetic properties to increase DC biased permeability are as follows:

(1) To maintain low Hc even when the external field increased.
(2) To show high DC permeability at the external field of corresponding DC bias current.

References