Magnet Behavior in High Frequency Field Using Micromagnetic Simulator

F. Akagi[1], and Y. Honkura[2],
[1]Kogakuin University, Shinjyuku 163-8677, Japan
[2]Aichi Steel Corporation, Tokai 476-8666, Japan

1. Introduction

Bonded Magnet is one of the most important and useful permanent magnets industrially. It enables to achieve complex shapes and is superior in strength to other kinds of magnets. Above all, NdFeB anisotropic bonded magnet is used for motors of automobiles and magnetic hard disk drives and sensors utilized in a wide variety of products[1)]. It will be expected for motors of hybrid vehicles (HV) and electric vehicles (EV) to realize smaller size and higher rotational speed. However, we have to pay attention to 'magnetic fatigue' of the magnet itself. Motors will be applied high frequency field with a maximum frequency of 10 kHz and average amplitude of 40 kA/m (0.5 kOe) at high temperature in near future. It will also be applied a static field of approximately 240 kA/m (3 kOe). As a result, high frequency field and thermal stress might demagnetize NdFeB anisotropic bonded magnetization. It is called 'magnetic fatigue'.

In this study, magnet behavior in high frequency field and high temperature was simulated using micromagnetics simulator. A simple grain model and basic magnetic characteristics were assumed, and behaviour of magnetic fatigue was simulated.

2. Micromagnetics simulator

It is important to make sure magnet behaviour in high frequency field in order to calculate a dynamic magnetic reversal process. The simulator is based on Landau-Lifshitz-Gilbert equation as follows;

$$\frac{d\boldsymbol{M}}{dt} = -\gamma(\boldsymbol{M} \times \boldsymbol{H}_{eff}) + \frac{\alpha}{M_s}\left(\boldsymbol{M} \times \frac{d\boldsymbol{M}}{dt}\right). \quad (1)$$

$\boldsymbol{M}$ is the magnetization and $\boldsymbol{H}_{eff}$ is the effective field which is the sum of external fields, static field, anisotropy field and exchange field. A stochastic thermal field was, however, not considered since grains could be regarded as thermally stable because of large volumes and high anisotropy. γ is the gyromagnetic ratio, and α is the damping factor.

Magnetic characteristics at room temperature are shown in Table 1. Intergrain exchange energy was assumed as 0, because non-magnetic grain boundary isolates grains perfectly. The saturation magnetization (M_s) was assumed to decrease according to the Brillouin function, and the anisotropy constant (K_u) was k×M_s (k: coefficient depends on temperature) to fit an experimental data.

Fig. 1 shows a grain model. Each grain is a hexagonal prism with a grain size of 200 nm, and it is not divided into small cells since the grain diameter is smaller than the critical diameter in between single domain and multidomain, and then grains were assumed to reverse according to the Stoner-Wohlfath model.

3. Results and discussions

In studying magnetization behaviour in the high frequency, damping factor α is one of the indispensable parameters. When the frequency is high, precession of the magnetization depends on α and effects on magnetization reversal. Therefore, we looked through the damping constant α dependence of magnetization behavior,

M-H loops with different temperatures are shown in Fig. 2 (a). While the temperature increases the magnetization decreases, but the shapes of the M-H loops were not changed. M-H loops with different damping factor α at 400 K are shown in Fig. 2 (b). M-H loops are almost equivalent between both damping factors. Fig. 3 shows the cycle of the frequency dependence of magnetization behaviour applying a high frequency field. Damping factor α was changed from 0.01 to 1.　X-axis is the cycle of the frequency, namely elapsed time. An external field (H_{ext}) was -0.33×H_k, where H_k is an anisotropy field. The frequency was 10 kHz with the amplitude of 40 kA/m and the standard deviation of C-axis orientation distribution ($\sigma_{C\text{-axis}}$) was 5 degree. The temperature was 400 K. From this graph, though the high frequency field keeps oscillating the magnet, magnetization seems to be stable at first sight, but magnetization oscillates slightly as shown in Fig. 3 (b) and (c). The cycle of oscillation is equal to that of the high frequency field. It was also found that magnetization decreased with decreasing α. Therefore, If α is small, the external field causes to demagnetize the magnet.

Table 1 Magnetic characteristics at 293 K

M_s (T)	K_u (MJ/m^3)	$\sigma K_u/\langle K_u \rangle$ (%)	$\langle H_k \rangle$ (kA/m)	Intergrain Exchange (J/m^2)
1.61	4.9	0	6077	0.0

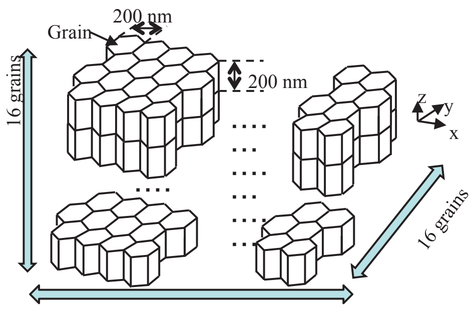

Fig. 1 Grains are hexagonal prism with grain size of 200 nm

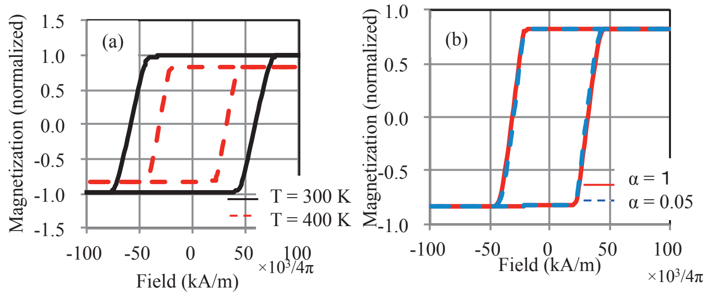

Fig. 2 (a) Temperature dependence of M-H loop at α of 1 and (b) α dependence of M-H loop at T of 400 K.

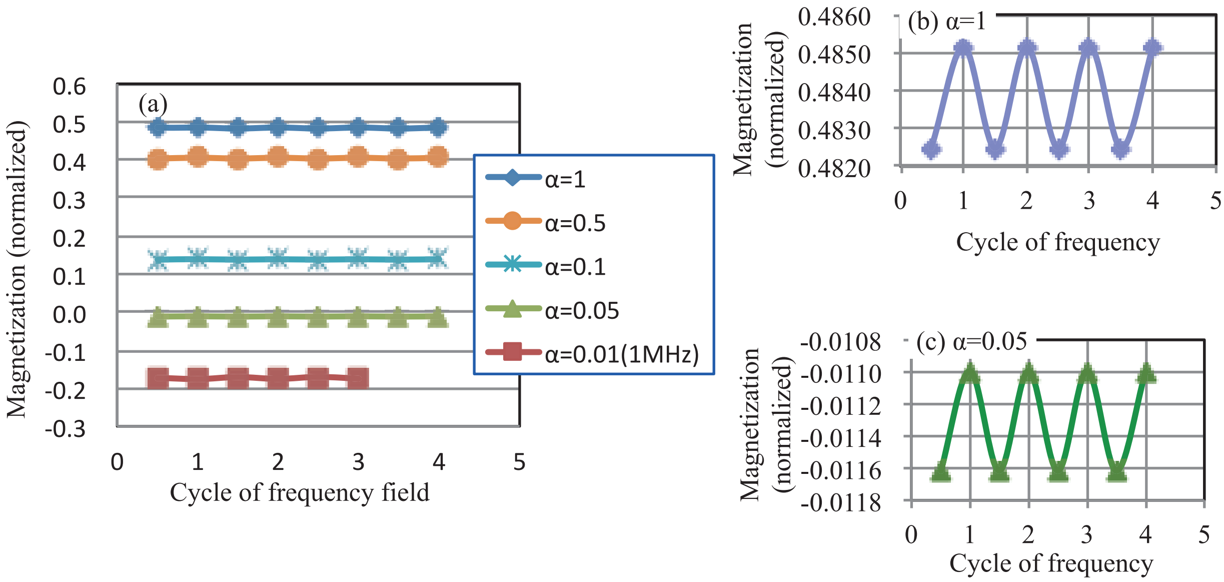

Fig. 3 Damping factor α dependence of magnetization behavior at high frequency field
(a) α = 0.01 – 1 , (b) enlarged graph at α of 1 , and (c) enlarged graph at α of 0.05

References

1) Y. Honkura, Proceeding of 19th International Workshop on Rare Earth Permanent Magnets and Their Application, Beijing, CHINA 2006, p.231.