Analysis of Microwave Assisted Magnetization Switching in Magnetic Material

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Abstract

The minimum switching field threshold and switching speed are key parameters for the magnetic recording in writing. This paper presents the dynamic precession of the moments of the grains based on LL equation. Under microwave-assisted reversal conditions, the influence of loading speed of reversal magnetic field in two interacting particles is investigated.

1. Introduction

With the rapid increase of recording density, more and more signal problems are bringing to write the signal magnetic recording. Facing of so many contradictions, scholars gradually adopt a variety of technical means to mitigate the contradictions, which are heat-assisted magnetic recording, perpendicular magnetic recording and study in this paper, namely microwave-assisted magnetic recording [1-2]. In the high-density magnetic recording media, because the signal recording unit is affected by high anisotropy energy to keep thermal stability, so the signal for the write head needs a magnetic field to make the magnetic moment of the signal upside down to be able to writing the signal. Microwave Assisted Magnetic Recording is to add a microwave field to assist magnetization switching [1-2].

For a single particle magnetic moment in the microwave field characteristics, the majority of the literature have shown that the microwave field can assist magnetic moment reversal [3-4]. This paper studies the effect of the microwave-assisted magnetization reversal in two-particle magnetic moment system. Based on the LL equation, this paper considers the exchange interaction and dipole interaction among the magnetic moment switching and analyses the effects of the loading speed of reversal magnetic field in two interacting particles.
2. A theoretical model

We mainly consider the magnetic moment in the case of interaction of the particles microwave assisted magnetization reversal dynamics.

Usually the magnetic field roles on the particles of magnetic moment are following: dipole field, exchange field, anisotropy field, the microwave field and the reversal field, the formula is as follows:

Dipole field:

\[
\vec{h}_{\text{dipole}} = \frac{\mu_0 M_s}{4\pi r^3} \sum_{j \neq i} m_j (\nabla \nabla \left( \frac{1}{r_{ij}} \right)) = \frac{\mu_0 M_s}{4\pi} \sum_{j \neq i} \left[ \frac{3r_{ij} (\vec{m} \cdot \vec{r}_{ij})}{r_{ij}^5} - \frac{\vec{m}_j}{r_{ij}^3} \right] \quad (1)
\]

The exchanging field:

\[
\vec{h}_{\text{exchange}} = J \sum_{j \neq i} \vec{m}_j \quad (2)
\]

The Anisotropy energy corresponding to the field can be written as:

\[
E_A = k \sin^2 \theta, \quad \vec{H}_A^k = \frac{2k(\vec{m} \cdot \vec{H}_k)}{M_s} \cdot \vec{H}_k \quad (3)
\]

In summary, all the particle magnetic moment of the field should be expressed as:

\[
\vec{h}_i = \vec{h}_{\text{dipole}} + \vec{h}_{\text{exchange}} + \vec{H}_{dc}, \quad \vec{h}_{\text{total}} = \vec{h}_i + \vec{H}_k + \vec{h}_{ac} \vec{H}_k \quad (4)
\]

so LL equation can be written as:

\[
\frac{\partial \vec{m}}{\partial t} = -\gamma \vec{m} \times \vec{h}_{\text{total}} - \frac{\alpha \gamma}{M_s} \vec{m} \times (\vec{m} \times \vec{h}_{\text{total}}) \quad (5)
\]

Where \( \gamma \) is the gyromagnetic ratio, \( \alpha \) is the damping coefficient.

For the two-particle magnetic moment system, compared with the single-particle magnetic moment, more than a dipole field and the role of exchange interaction, LL equation in the direction of the component X can be expressed as:
\[
\frac{\dot{m}_i}{\dot{t}} = -\omega m_i \left( H_d \cos \theta \pm 1 - \frac{m_i}{r_0} + Jm_i \right) \\
+ \omega m_i \left( H_d \sin \theta \sin \phi + h_a \sin(\phi(t)) + d\left(\frac{3(m_i r_o^+ + m_i r_o^-)}{r_0^+} - \frac{m_i}{r_0} + Jm_i \right) \right) \\
+ \omega \alpha \left( H_d \sin \theta \cos \phi + d\left(\frac{3(m_i r_o^+ + m_i r_o^-)}{r_0^+} - \frac{m_i}{r_0} + Jm_i \right) \right)
\]

Compared with the single-particle magnetic moment, two-particle magnetic moment system have dipole field and exchange field. We use fourth-order Runge-Kutta to numerical solution of the LL equation, the dynamics of two particles magnetic moments can be calculated.

3. Results and discussion

Joining the Reverse field plays the following role. First is to drive magnetic moment precession, and secondly, to adjust the effective magnetic field namely to adjust the resonant frequency. Then it can be sustained to ensure that the magnetic moment reversal pattern. The first role is clearly necessary, when the auxiliary microwave frequencies is away from the resonant frequency of the magnetic moment of the actual case, the main driving force of the precession of magnetic moment should come from the reversal field, the requirement of $H_{dc}$ should be greater than a certain value, it could not overcome the precession of magnetic moment induced by the effective field and microwave field.

It is obviously the main factors affecting the speed of the magnetic moment reversal to adjust the resonant frequency of the magnetic moment and the effective field. When the actual effective field of magnetic moment is weaker than the resonant frequency of the auxiliary microwave resonance frequency, the reverse of magnetic moment may receive the restrictions of microwave and no longer reverse back down, which makes $H_{dc}$ no longer continuous correspond to different $f_{ac}$ values, but certain values. Here we will discuss the relationship between the loading speed of reverse field and reverse time.

We definite the loading speed of reverse field: $v_{dc} = \frac{\text{duration time}}{\text{ascent time}}$

when directly loaded, the raising speed is $v_{dc} = \text{max}$.
When the loading rate of the reverse field is \( v_{dc} = 5 \), the microwave field frequency is \( f_{ac1} = 0.4f_r, f_{ac2} = 0.5f_r \), the reversed field should be \( 0.48H_k - 0.63H_k \) in order to further illustrate the effect of loading speed of reversal field on the reverse of the particle magnetic moment, we have chosen \( H_{dc} = 0.68H_k \). This reverse field should not be able to making magnetic moment reversal. Now we change the loading speed, making the magnetic field directly into through a relatively slow rising edge. The results shown in Figure 1. Both direct loading and loading with a larger speed can not reverse the magnetic moment, and when the speed slowed to 4.25, then it can be reversed. Although the reverse speed does not contact with the loading speed directly but the ability to reverse the magnetization reversal with the ability to continue to maintain the status they have some contact with the loading speed.

Adding the reversal field of \( H_{dc} = 0.32H_k \) shows that under the condition of auxiliary microwave frequency is \( f_{ac1} = 0.6f_r, f_{ac2} = 0.7f_r \), the magnetic moment of particles can not be reversed. But by adjusting the loading speed of reverse field, the results shown in Figure 2 when the reverse field reduced from 15 to 7.5, the magnetic moment have ability to reverse and ensure the reversal state, which again shows that reversal is not completely determined by the magnitude of reverse field. Loading rate equal to modulation actual resonant frequency of magnetic moment, when in a long time to keep close to the resonance frequency of magnetic moment, although not enough to overcome the anisotropy field and the
effective field interaction between the magnetic moment, but because of the changing the effective field of magnetic moment actual changing the resonance frequency, It can be achieved reverse and maintain the state by microwave-assisted reverse.

![Image](image_url)

Fig. 3 Z component of the effective field as a function of time with different loading velocity of the switching field, $f_{\text{mic}}=0.9f_r$, $f_{\text{mic}}=1.0f_r$, $H_{dc}=0.25H_k$

Figure 3 shows that, despite the reversal field is relatively small $H_{dc} = 0.25H_k$, but taking into account the interaction between the particle magnetic moment, so we join the microwave field frequency is less than the actual resonance frequency of 0.2 or more, since microwave time from zero no auxiliary magnetic moment precession, only makes the magnetic moment precession in small range near the equilibrium position. After slowing down the loading speed, a period of time to ensure that the magnetic moment of the actual resonance frequency match with the resonance frequency of the microwave field. so that the microwave assisted magnetic moment to be able to ensure a smooth anti-turn up.jump down for the effective field may be because the magnetic moment interaction, another moment particles with magnetic moment interactions reverse up, can be seen from the effective field size, effective field after jumping down about $0.7H_k$, rather than the initial case $1.37H_k$.

4. Conclusions

From the previous discussion, we have learned that the most important thing is the gap between the frequency of the microwave field and the actual resonant frequency and the reversed field of the effective field in the mediation of magnetic moment of particles to ensure writing quickly and effectively to the media signal.in a brief moment ,when a resonant frequency close to the frequency of the microwave field, and the reversing magnetic field should also ensure that the state does not change, which requires reversal field to wait for the particle magnetic moment effective field reversal jump, you must ensure the effective actual resonance frequency of particle magnetic moment should stay away from microwave-assisted magnetic field applied.so as to ensure that the magnetic moment subject to a small effect of microwave field, and to maintain the reversal status, In summary, the actual resonance frequency is the key for microwave-assisted reversal of magnetic moment.

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Reference


