Two-Peak Output Waveforms in Uniform Rotation Switching of Thin Films*

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A theoretical model for high-drive switching of a thin-film, finite length, ferrite, cylindrical shell or toroid is developed from Gilbert's equation. The equation of uniform magnetization reversal includes terms which result from an arbitrary applied field and terms due to the axial demagnetizing field. Machine solution of the equation shows the existence of two peaks in the output waveform which are directly traced to the axial demagnetizing field. The dependence of these peaks on the applied field is also shown. Comparison with published data on a thin-walled toroid is made. A physical description of the reversal mechanism which leads to the two peaks as they result from the axial demagnetizing field is included. Principal conclusions based on the various solutions are as follows: (1) The two-peak effect is a direct result of the axial demagnetizing field. (2) The damping constant, over the range studied, results in slower switching time as α increases; however, minimum switching as a function of α exists in this model. The higher values of α tend to damp out the two-peak effect. (3) Increased intensity of the applied field decreases the appearance of the two peaks. (4) Greater values of the saturation magnetization cause the two-peak effect to be accented, but the switching constant is essentially independent of M.

INTRODUCTION

THE purpose of this study is to investigate the uniform rotation switching of a thin-film, ferrite, cylindrical shell of finite axial length. Provision for a general applied field is made, but the computer solutions include only step functions and linear rise pulses. It is seen that the analysis applies to a finite-width, infinitely long, thin-film strip. Some previous models are in Refs. 1–4. Each assumes the film to have infinite area so that only the demagnetizing field normal to the plane of the film need be included.

STATEMENT OF PROBLEM AND ASSUMPTIONS

An equation of motion of the circumferential component of M is to be obtained for switching from saturation in one peripheral direction to the other. Some other assumptions are: material is isotropic, M rotates almost entirely in the plane of the film, M is constant and equal to M_s, sample is developed into an infinitely long rod, no load exists, and axial demagnetizing factor β is constant. The last assumption is based on calculations by O'Dell[5] showing that β for typical memory core dimensions (a and b in Fig. 1) may be taken as a constant of the order of 1.5×10^{-4} for a thickness of 1000 Å so that $H_z=-\beta M_z$.

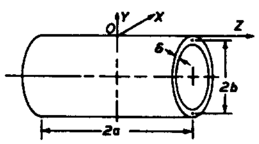

FIG. 1. Thin-film cylindrical shell.

SOLUTION AND DISCUSSION

With $M=M_s$, Gilbert's modification of the Landau–Lifshitz equation is

$$d\mathbf{M}/dt=\gamma(\mathbf{M}\times\mathbf{H})-(\alpha/M)(\mathbf{M}\times d\mathbf{M}/dt), \quad (1)$$

where H is the total field acting on M, γ is the gyromagnetic ratio$=-2.2\times10^5$ (rad/sec)/(A/m), and α is the damping constant ($\alpha<0$).

An initial solution is made with the use of $M^2\approx M_x^2+M_z^2$. It cannot be assumed that M_y is negligible in

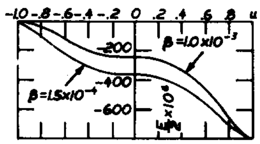

FIG. 2. "Spring" energy as function of β: $H_a=520$ A/m; $H_0=160$ A/m; $M=24\times10^4$ A/m; $\alpha=-1.0$.

H. Accordingly, define

$$\mathbf{H}=H_n\hat{x}-M_y\hat{y}-\beta M_z\hat{z}, \quad (2)$$

where $H_n=H_a-H_0$, H_a is the applied field in $+x$ direction, and H_0 is the uniform rotation threshold field. Unity radial demagnetizing factor is assumed. Substituting Eq. (2) and $\mathbf{M}\approx M_x\hat{x}+M_z\hat{z}$ in Eq. (1) and separating components yield a redundant system of equations in dM_x/dt and dM_z/dt. A necessary and sufficient condition for removal of the redundancy is

$$M_y=(M_z/\alpha M)(H_n+\beta M_x). \quad (3)$$

This problem formulation is easily solved, but it lacks the detail of the solution which follows.

In the final solution M is not initially restricted; so, $\mathbf{M}=M_x\hat{x}+M_y\hat{y}+M_z\hat{z}$. When this relation and Eq.

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(2) are substituted into Eq. (1) and the components are separated, the following results:

$$dM_x/dt-(\alpha M_z/M)dM_y/dt+(\alpha M_y/M)dM_z/dt = \gamma(M_yM_z-\beta M_yM_z),$$
$$(\alpha M_z/M)dM_x/dt+dM_y/dt-(\alpha M_x/M)dM_z/dt = \gamma(H_nM_z+\beta M_xM_z),$$
$$-(\alpha M_y/M)dM_x/dt+(\alpha M_x/M)dM_y/dt+dM_z/dt = -\gamma(H_nM_y+M_xM_y). \quad (4)$$

Equations (4) are solved for dM_x/dt, dM_y/dt, and dM_z/dt, which are identical to those of Kikuchi[2] if $\beta=0$, and the expression for dM_x/dt is differentiated. Substitutions for dM_y/dt and dM_z/dt are made. The resulting equation is reduced by eliminating M_y^2 with $M^2=M_x^2+M_y^2+M_z^2$; Eq. (3) is used to remove M_y; and M_z is removed by $M^2\approx M_x^2+M_z^2$.

Defining $\gamma_0=\gamma/(1+\alpha^2)$, $M_x=Mu$, and $H_n=Mh_n$, the final equation is

$$(1/M)d^2u/dt^2+\alpha\gamma_0[(2+\beta)u^2+2h_nu-\beta]du/dt$$
$$+\gamma_0^2M(1-\beta)\{2\beta(\alpha^2-\beta+1)u^4+2(\alpha^2-\beta+1)h_nu^3$$
$$-\beta(2\alpha^2-3\beta+2)u^2$$
$$-[(2\alpha^2-3\beta+2)h_n-\alpha/(\gamma_0M(1-\beta))dh_n/dt]u-\beta^2\}u$$
$$=\gamma_0^2M(1-\beta)h_n+\alpha\gamma_0dh_n/dt. \quad (5)$$

Equation (5) retains the property that no switching occurs if **M** and $\mathbf{H}_a$ are colinear. Examination of the damping force shows it to be a retarding one except near $u=0$. The absorbed "spring" energy E is examined for various values of β and h_n with $dh_n/dt=0$. The "spring" term is always aiding the switching process, and the shape of the curves (Fig. 2) shows that two peaks may appear in the output.

Reciprocals of switching time versus H_a are plotted from computer solutions with α ranging from -0.1 to -1.3 yielding straight lines in agreement with experiments. A plot of the corresponding switching constant versus α permits the selection of α. Effects of β, M, H_a, and dH_a/dt for linear rise pulses are studied. A

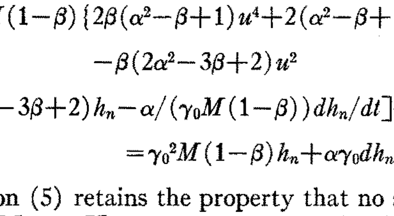

FIG. 3. Comparison of wave shapes.

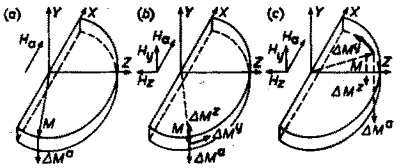

FIG. 4. Fields acting on M and resulting displacements of M: (a) initial, (b) before half-switched, (c) after half-switched.

typical output waveform compared with data by Gyorgy and Hagedorn[4] is shown in Fig. 3 where the major peaks have been made to coincide. A more appropriate, higher value of β would improve the comparison.

For a physical interpretation no losses are considered, but they are assumed to bring M to rest. In Fig. 4(a), ΔM^a occurs for a step function of H_a. In Fig. 4(b), ΔM^a has caused $-M_y$ which yields $+H_y$ and thus ΔM^y. Precession around H_y gives H_z and ΔM^z which opposes ΔM^a so that switching is retarded. After the half-switched position, Fig. 4(c), ΔM^z reappears with a change in sign. Thus, ΔM^z aids the growth of H_y and ΔM^y to accelerate switching.

LOSSLESS CASE

The constraint of Eq. (3) is limited to $\alpha\neq0$. Setting $\alpha=0$ in Eqs. (4) and assuming that M rotates almost entirely in the plane of the film yield

$$d^2u/dt^2+\gamma^2M(1-\beta)(\beta u^2+h_nu-\beta)u=\gamma^2M(1-\beta)h_n. \quad (6)$$

Study of the energy supplied by the driving field term and the energy lost due to the "spring" term shows that the switching time approaches infinity as α approaches zero with M mainly precessing about H_a if $\beta>h_n$ and precessing about H_y if $\beta<h_n$.

CONCLUSIONS

The two-peak effect occurs due to β in uniform rotation reversal. An increase in β, such as for a thicker film, causes a greater difference between amplitudes of the two peaks. Increase in H_a decreases the distinctiveness of the peaks. Increasing M causes an effect similar to that of increasing β. The switching constant is essentially independent of M. The risetime of H_a has little effect if it is completed before switching has progressed significantly. Over the range studied, slower switching results as α increases, and higher values of α tend to damp out the two-peak effect. Minimum switching as a function of α exists in this model.