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Characteristics of Magnetic Core in Magnetic Pulse Compression System

D.D. Zhang[a], P. Yan[a], Y.H. Sun[a,*], J. Wang[a], Y. Zhou[a,b] and R.Z. Pan[a,b]

[a]Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing, China

[b]Graduate University of Chinese Academy of Sciences, Beijing, China

In order to obtain the characteristics of magnetic core under ≈ 0.5–5 μs saturation time, a one-stage magnetic pulse compression circuit without external demagnetization circuits which are commonly used in magnetic compressors is designed. The current through the core is calculated by voltage across the resistive load, and the loop voltage is picked up with a single wire loop and integrated by software. B–H curves are derived from the measured voltage and current wave forms. B–H curves show that the core loss is in inverse proportion to the time to saturation, whereas the percentile core loss decreases as the charging energy increases. While the eddy current loss and dissipated energy are in direct proportion to dB/dt. The low inductance of magnetic switch indicates that the core is saturated and behaves as an air core. By applying custom characteristics to each stage in Pspice simulation, more practical energy transfer in magnetic pulse compression and the effects of leakage current are presented.

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1. Introduction

Magnetic switch (MS) [1] used in pulsed-power applications is superior in its high stability, high repetition rate, and long lifetime to electrical discharge switches which have unstable switching and short lifetimes due to electrode deterioration [2]. Recent pulse generators based on the new magnetic pulse compression (MPC) algorithm [2–4] have allowed high repetitive operation of MSs with very low losses, and made it possible to use repetitive pulsed power generated by magnetic pulse compressors in practical industrial applications such as water treatment, laser exciters, removal of volatile toxic compounds and decomposition of hazardous gases [2]. As the use of magnetic cores has become popular in pulsed power applications, there have been several studies on the pulse magnetic characteristics that are critical for a MPC system [1–4]. As the pulse width of excitation pulse stages in an MPC becomes shorter, the switching performance of the magnetic switch which is one of the dominant measures for overall performance becomes poor. However, there are still some necessities for researchers of magnetic cores to measure the pulse characteristics for more efficient MPC design.

In this paper, a one-stage MPC circuit based on the new MPC algorithm is fabricated to obtain ≈ 0.5–5 μm saturation time span. Also, the characteristics of the magnetic core for pulsed-power applications are described using the B–H curves derived from the measured voltage and current wave forms. Finally, the Pspice simulation is carried out with custom B–H curves for PT1.

* corresponding author; e-mail: yhsun@mail.iee.ac.cn

2. Experiment setup

A one-stage MPC circuit (see Fig. 1a) is set up to measure dynamic properties of the magnetic core. Demag-

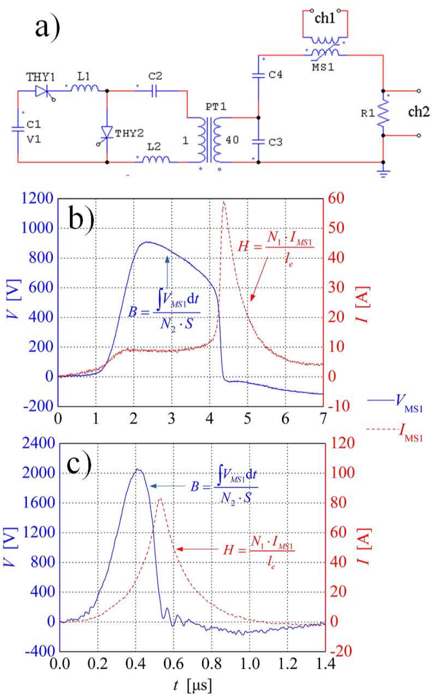

Fig. 1. (a) Schematic diagram of one-stage MPC circuit for measuring dynamic properties of the magnetic core. (b) Derivation method for B–H curves from the measured voltage and current wave forms ($\Delta t = 4.5$ μs, $N_1 : N_2 = 27 : 1$). (c) Derivation method for B–H curves from the measured voltage and current wave forms ($\Delta t = 0.5$ μs, $N_1 : N_2 = 10 : 1$).

netization circuit is not required because core reset is achieved due to the opposite directions of the currents during charging and discharging, therefore a maximum flux swing can be obtained. The magnetic core used in this study is a FINEMET core (1 K101, Liyuan Metal Corp., China), with a 60 mm inner diameter, 140 mm outer diameter and 24 mm height. In Fig. 1a, capacitor C2 is charged by capacitor C1 through inductor L1 when thyristor (THY1) is closed. At closure of the thyristor (THY2), the saturable pulse transformer (PT1) comes into saturation. Once PT1 is saturated, a voltage is applied across the magnetic switch MS1. The voltage across MS1, marked as V_{MS1}, which is picked up with a single wire loop, is measured by a oscillator high voltage differential probe (ADP300, Lecroy Co., American), and the discharge current I_{MS1} is calculated by voltage across the resistive load V_{R1}, and V_{R1} is measured by an oscillator high voltage probe (P6015 A, Tektronix Inc., American). An oscilloscope (240Xi, 2 GHz, Lecroy) is used to record single shot signals from the measurement devices. B–H curves are derived from measured voltage and current wave forms (see Fig. 1b, Fig. 1c).

The flux density, B, is obtained from [4]:

$$B = \frac{\int V_{\mathrm{MS1}}\mathrm{d}t}{N_2 S} = \frac{1}{S}\int V_{\mathrm{MS1}}\mathrm{d}t, \qquad (1)$$

where N_2 stands for the number of winding turns, $N_2 = 1$, and S stands for the effective cross-section area which is the actual area of the magnetic material in the core excluding the area of the inter-laminar insulation.

The magnetic field, H, is given by [4]:

$$H = \frac{N_1 I_{\mathrm{MS1}}}{l_{\mathrm{e}}} = \frac{N_1 V_{\mathrm{R1}}}{l_{\mathrm{e}} R_1}, \qquad (2)$$

where l_{e} stands for average magnetic path length, $l_{\mathrm{e}} = \frac{2\pi(r_{\mathrm{o}}-r_{\mathrm{i}})}{\ln r_{\mathrm{o}}/r_{\mathrm{i}}}$, r_{o} for outer diameter, and r_{i} for inner diameter.

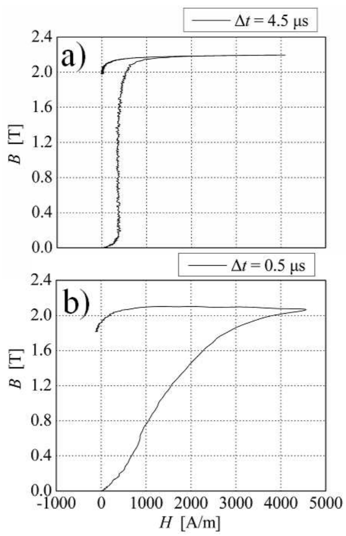

Fig. 2. Derived B–H curves at applied pulsed width across MS1 with amplitude Δt, (a) $\Delta t = 4.5\ \mu$s. (b) $\Delta t = 0.5\ \mu$s.

The B–H curves are derived from the measured voltage and current wave forms (see Fig. 2) using Eqs. (1) and (2). From the hysteresis loops, it can be seen that (a) the ratio of remnant flux density to saturation magnetic flux density ($B_{\mathrm{r}}/B_{\mathrm{s}}$) is close to 1, and the maximum flux swing over 2.2 T is obtained, which means that this core can withstand larger pulse energy compared to those ferrite cores [4], (b) low core loss under μs level pulse excitation is expected from the narrow area of the hysteresis loop, so it is quite suitable for using in preceding stage saturable transformer, and (c) the eddy current loss, the dissipated energy as well as the leakage current are in direct proportion to dB/dt, therefore the switching performance of this core is poor when it is used in final stage magnetic switch.

3. Pspice simulation with custom B–H curves

In this study, Pspice [5] has been used to carry out the simulation study on a one-stage MPC system (see Fig. 3a) with customary B–H curves (see Fig. 3b). The one-stage MPC includes main storage capacitor C2, saturable pulse transformer PT1, magnetic switch MS1, inductor L1 and L2, together with resistive load. During the relatively fast discharge of C3 and C4, L2, having a high impedance, switches most of the current through

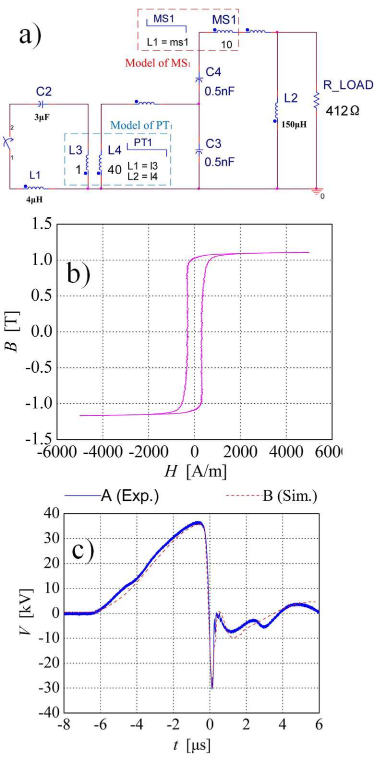

Fig. 3. (a) Schematic diagram of the simulation circuit for a one-stage MPC. (b) B–H curve for the magnetic core of PT1. (c) Comparison of the voltage wave form for C3 between experiment and simulation.

the load. The capacitances of C2, C3 and C4 are 3 μF, 0.5 nF and 0.5 nF, respectively. The charge voltage on C2 is 1 kV. PT1 is a saturable step-up transformer with the voltage gain of 40. A 412 Ω resistor is used as the load.

On switch closure in the pulse generation stage, the pulse across PT1 is about 6 μs with amplitude of about 1 kV. Besides, PT1 has the effect of reducing the switching loss [4]. Thus, an MPC system which consists of a saturable pulse transformer and a solid state switch can be operated with higher repetition rate, longer lifetime and higher reliability than conventional ones. Pspice simulation results (see Fig. 3c) show that the voltage across C3 is basically in coincidence with that of practical output. With customary B–H curves for PT1, it is inclined to simulate the MPC system more accurately.

4. Conclusions

It was concluded that the following critical characteristics for the repetitive pulsed-power operation of MPC system have been observed from the derived B–H curves for a magnetic core: a maximum flux swing of about 2.2 T, a high ratio of remanent flux density to saturation magnetic flux density ($B_{\mathrm{r}}/B_{\mathrm{s}}$) and low core loss. Comparison studies between experiment and simulation have been carried out using Pspice simulation. With customary B–H curves for PT1, it is inclined to simulate the MPC system more accurately. Besides, the simulation result shows that the voltage across C3 is basically in coincidence with that of practical output. Based on the present study, it is believed that it is possible to design an MPC with a higher accuracy by using the customary characteristics for the magnetic core of pulse transformer and magnetic switch.

Acknowledgments

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