Characterized Hysteresis Model and a Magnetic Pulse Compression Circuit

著者	Iwahara Masayoshi, Yamada Sotoshi
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CHARACTERIZED HYSTERESIS MODEL AND A MAGNETIC PULSE COMPRESSION CIRCUIT

Masayoshi Iwahara and Sotoshi Yamada*

Mathematical model of hysteresis is introduced, and it is characterized to analyze highly saturable magnetic equipment on the effect of specific parameters. Using this mathematical model, performance of magnetic pulse compression circuit is numerically analyzed.

Keyword: saturation, hysteresis, mathematical model, bisection approximation, magnetic pulse compression circuit.

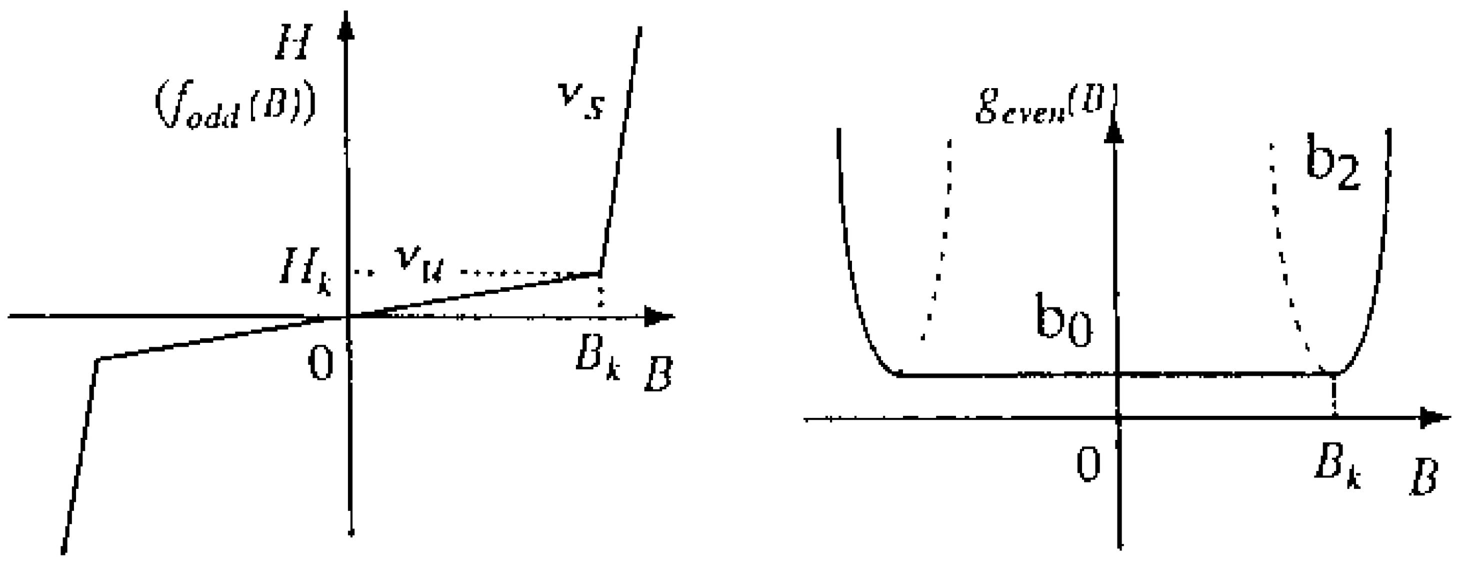
1 INTRODUCTION

In the view of industrial application, it is an important subject to be realized small size and transportability of the high power laser[1]. In order to reduce the size, the magnetic pulse compression (MPC) circuit[2], [3] composed of passive elements is watched for the power supply of laser equipment with keen interest in addition of a high reliability. However, the expected performance of this equipment is not yet obtained in spite of simple configuration of this circuit. To solve this problem, a mathematical model is introduced, and numerical analysis is performed on the MPC circuit.

2 MATHEMATICAL MODEL OF SPECIALIZED HYSTERESIS

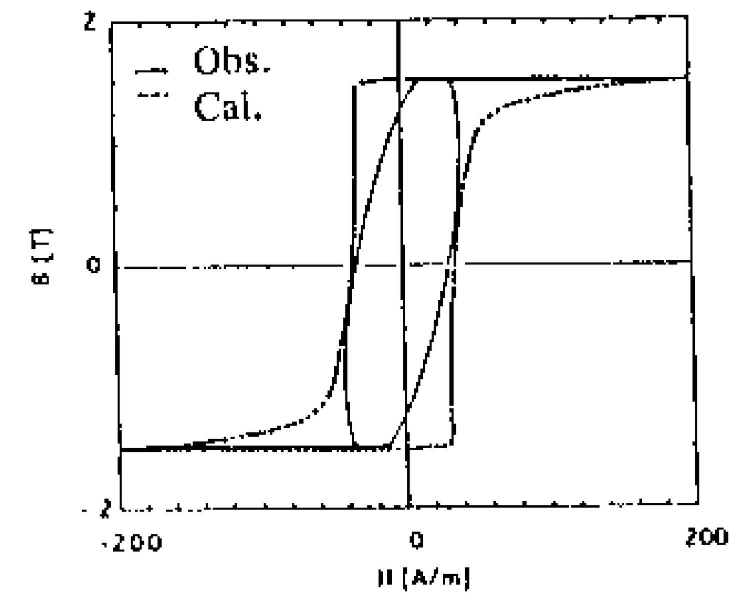
Generally magnetic materials has a magnetic nonlinearity and hysteresis varying with the magnetomotive force. To obtain the exact analytical results, it is required to have a mathematical model, which should be able to treat a device made by a magnetic materials under the condition of the lower to the higher exciting level continuously. For this purpose, we introduce a hysteresis model with a characterized parameters (μ_u, μ_s, H_c, H_{cd}: dynamic coercive force) for the exact analysis as follows,

$$H = f_{odd}(B) + g_{even}(B)\frac{dB}{d\theta}; \qquad \theta = \omega t \tag{1}$$

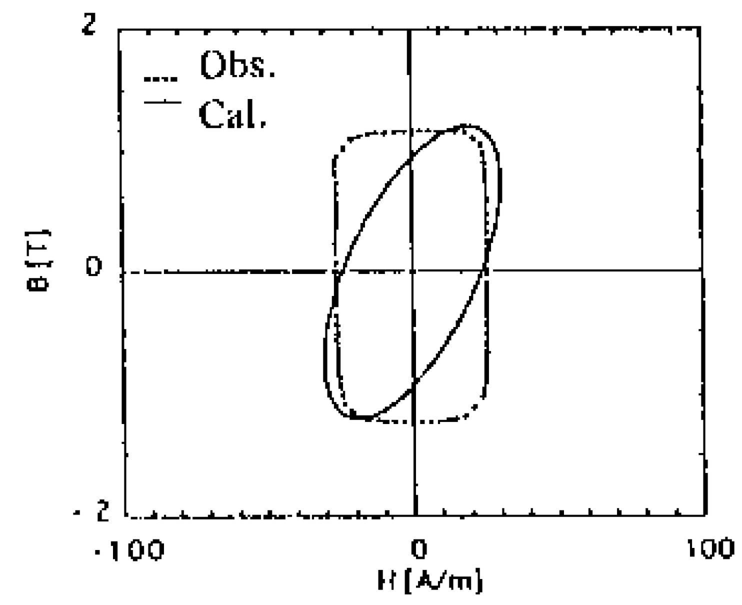


a) $f_{odd}(B)$ b) $g_{even}(B)$

Fig. 1 Elements of proposed hysteresis model



a) Bm = 1.57T

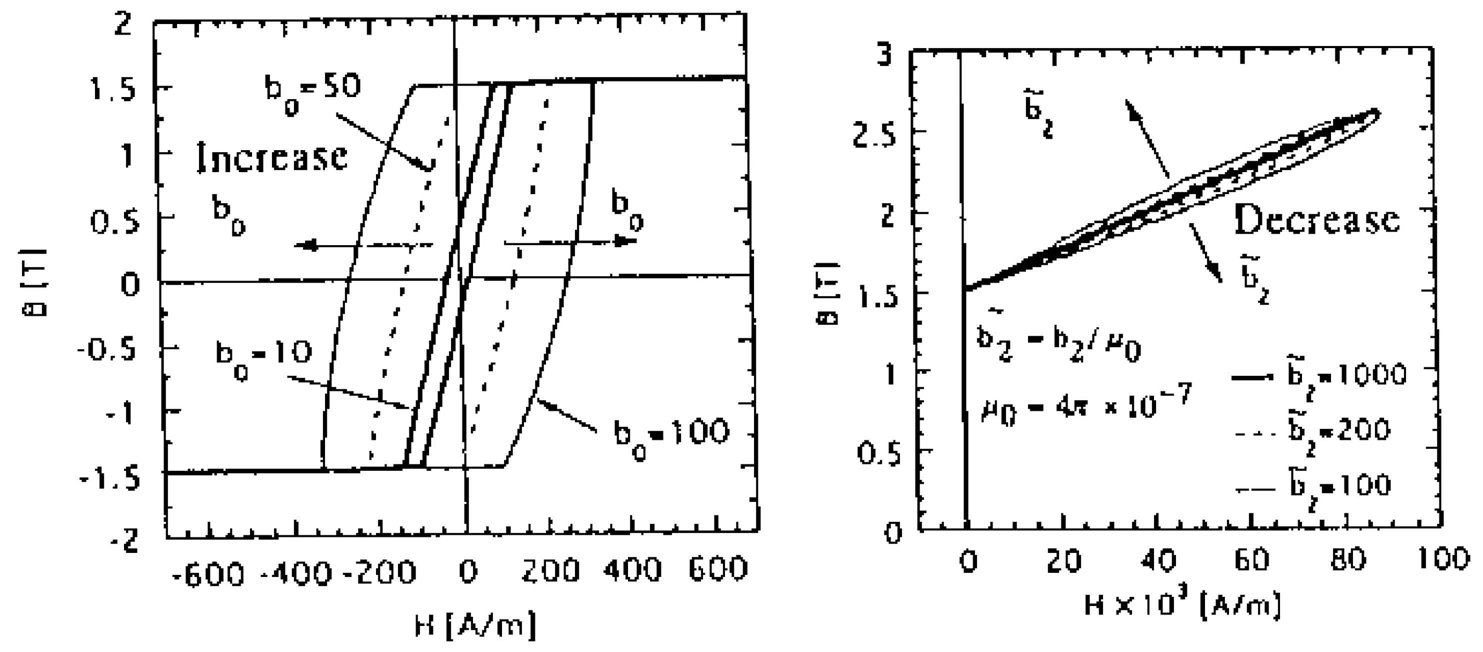


b) Bm = 1.1T

Fig. 2 Simulated and observed hysteresis (f = 50Hz)

$$f_{odd}(B) = \left.\begin{array}{ll} \nu_u B; & |B| \le B_k \\ = \nu_s(B - B_k) + H_k; & B \ge B_k \\ = \nu_s(B + B_k) - H_k; & B \le -B_k \end{array}\right\} \tag{2}$$

$$g_{even}(B) = \left.\begin{array}{ll} b_0; & |B| \le B_k \\ = b_2(B - B_k)^2 + b_0; & B \ge B_k \\ = b_2(B + B_k)^2 + b_0; & B \le -B_k \end{array}\right\} \tag{3}$$



a) dependency of b_0 b) Dependency of b_2

Fig. 3 Characteristics of proposed hyteresis model

* Department of Electrical and Computer Engineering, Faculty of Technology, Kanazawa University, Kodatsuno 2-40-20, Kanazawa 920 Japan. E-Mail: iwahara@magstar.ec.t.kanazawa-u.ac.jp

here, H: magnetic field strength (A/m), B: magnetic density (T), $\nu=1/\mu$; μ: permeability, b_0: a coefficient correspond to static coercive force H_c, b_2: a coefficient correspond to a dynamic coercive force, and $\omega=2\pi f$; f: frequency (Hz).

Both right hand terms of equation (1) are shown schematically in Fig. 1. And a comparison between estimated and observed hysteresis in a toroidal core made by 50% NiFe are shown under the different exciting levels. As it is easily shown, the second term of equation (1) is corresponded to nonlinear loss of core. Fig. 3 shows resultant hysteresis of magnetic materials depend on coefficients b_0, and b_2.

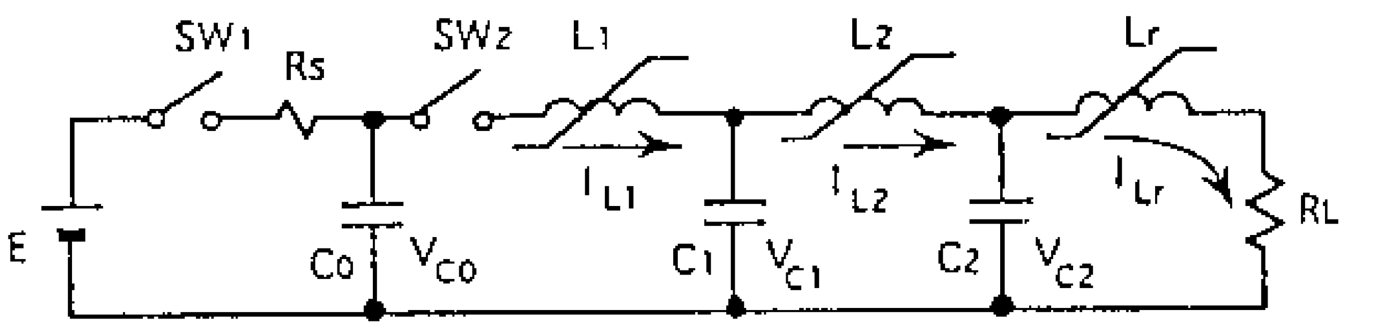


Fig. 4 MPC circuit using saturable magnetic cores

3 MAGNETIC PULSE COMPRESSION CIRCUIT USING SATURABLE CORES

Magnetic Pulse Compression Circuit composed of LC ladder circuit as is shown in Fig. 4 is used for the power supply of laser equipment. This circuit supplies instantaneously pulsated power to the load. In this circuit, precharged energy in the capacitor C_0 is transferred to C_1, C_2 and RL step by step using the resonance of LC circuit.

It was difficult to explain the transient behavior of the MPC circuit with the magnetic nonlinearity and eddy current effect of core. To be clear this behavior, numerical analysis has been performed in the criteria of best energy transfer condition, that is L1/L2=2, and a comparison of voltage and current waveform in the circuit is shown in Fig. 5. It is shown the coefficient b_2 is depend on the waveform in the region of core saturation.

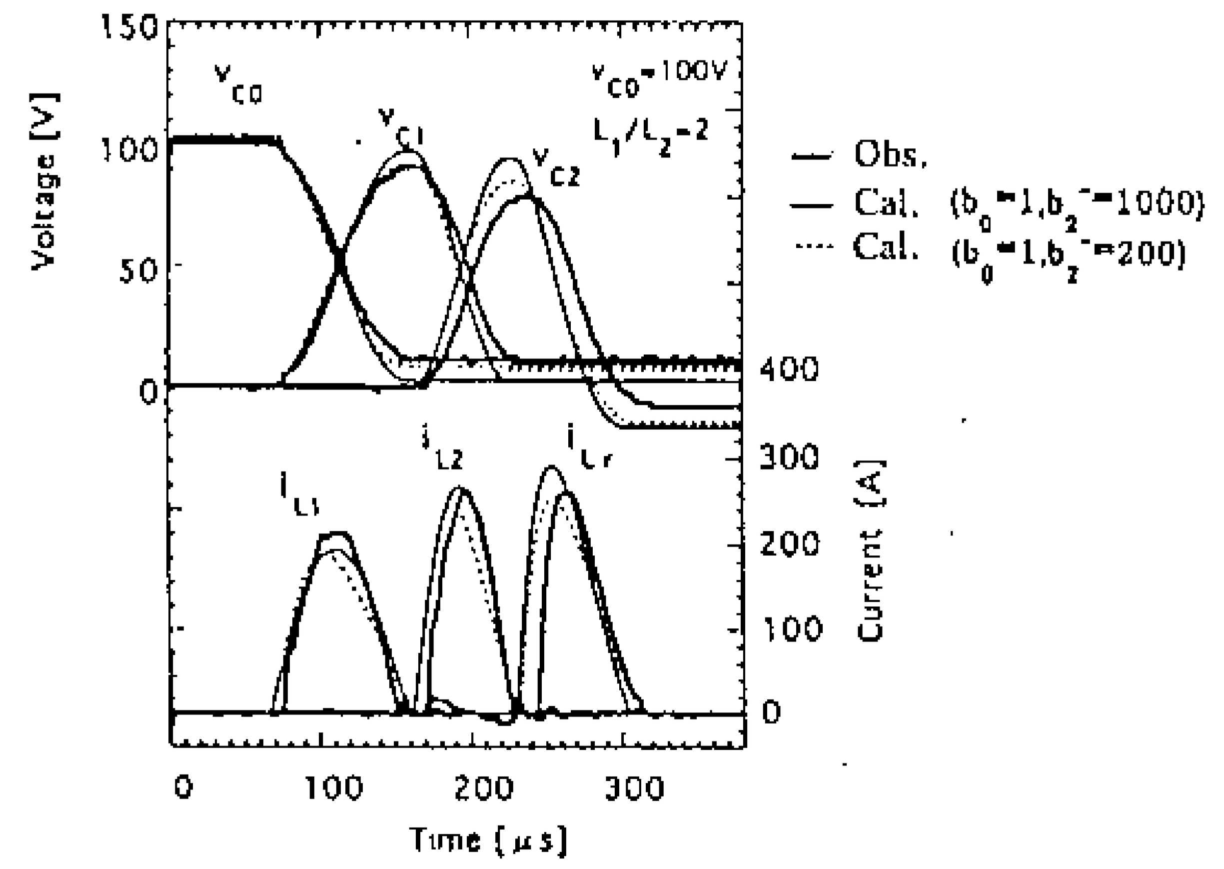
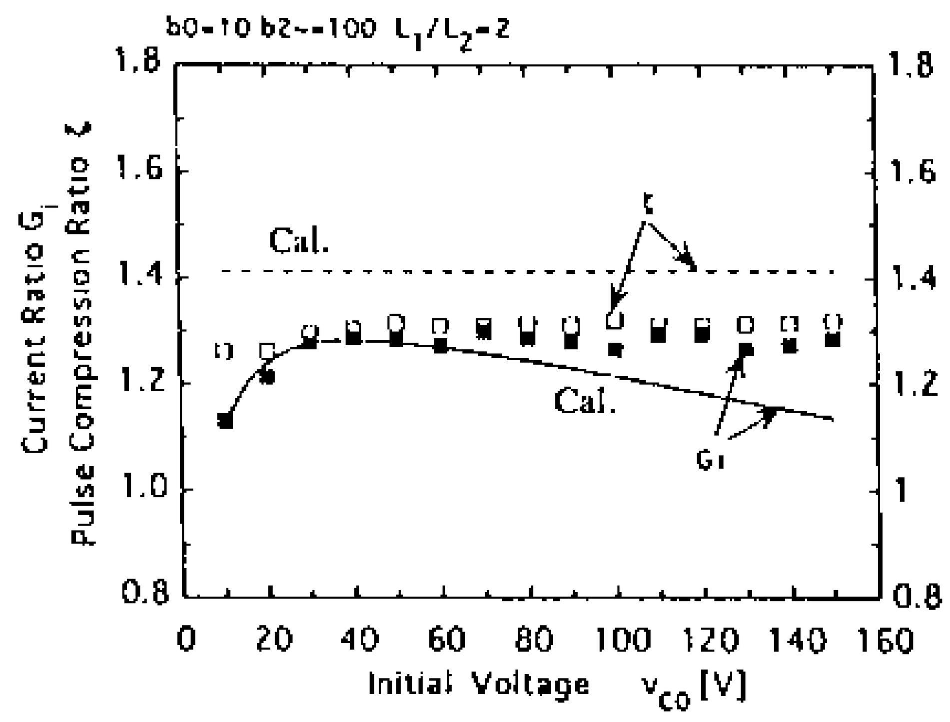
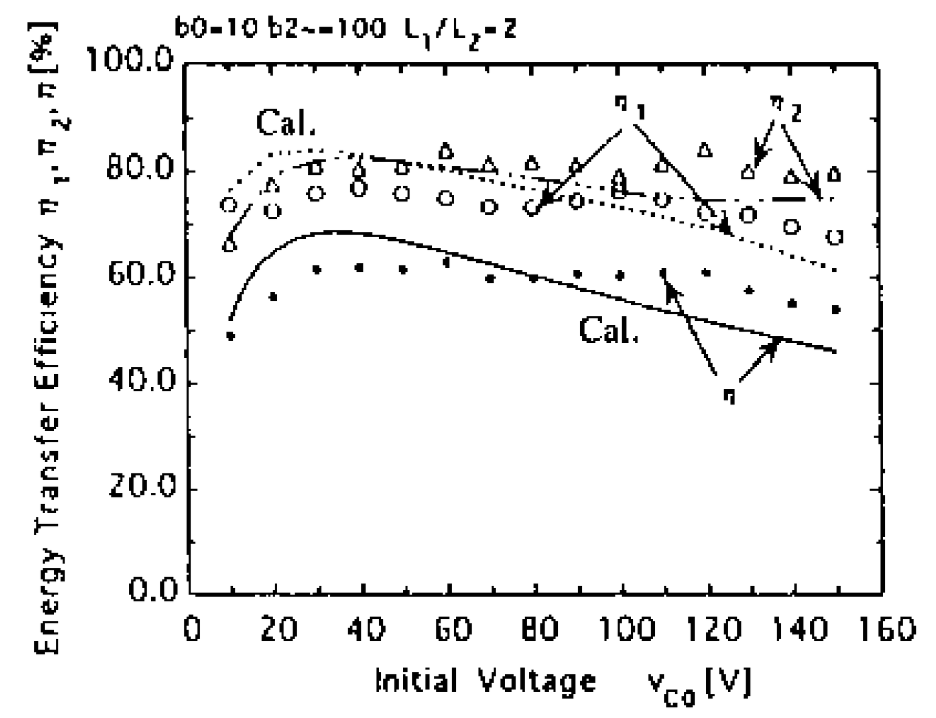


Fig. 5 Comparison of observed and estimated waveform



a) Current amplification and pulse compression ratio



b) Energy transfer ration

Fig. 6 Performance of the MPC circuit

4 MPC PERFORMANCE BY THE MODEL OF MAGNETIC HYSTERESIS

As the performance evaluation of this circuit is done by the index[4] of a) energy transfer ratio, b) pulse compression ration, c) current amplification ratio, value of these index is evaluated here using this model. Estimated circuit performance is given in Fig. 6. We can obtained a good agreement with the pulse compression ratio and energy transfer efficiency as is cleared in Fig. 6. But, it is a poor agreement in the amplification ratio.

5 CONCLUSION

Simple and generalized hysteresis model having a wide utilization has been introduced, and discussed on that feature and demonstrated on the result of utilizing for the magnetic pulse compression circuit. As the results, it is cleared that circuit behavior in the un-saturation region of core is dominated by the coefficient b_0, and in the saturated region of core the coefficient b_2 is important.

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