Evaluation method for high frequency magnetic properties and core loss of large ferromagnetic cores

T.Hikosaka, M.Miyamoto, M.Yamada, and T.Morita
Power Apparatus Development Dept., Fuji Electric Corporate Research and Development, Ltd.
7 Yawata-Kaigandori, Ichihara, Chiba, 290, Japan

Abstract

It is very important to obtain high frequency magnetic properties of ferromagnetic cores for designing a magnetic pulse compressor. But, it is difficult by using a conventional AC excitation method at high frequency(~MHz) to measure full B-H curve of large toroidal cores of which diameter is some hundreds of mm. Therefore we have developed a novel pulse excitation method to get high frequency magnetic properties.

The sample cores are excited by a sinusoidal voltage pulse of which waveform is expressed as a function of a time t like $f(t)=V_0(1-\cos(2\pi ft))$ until magnetic saturation occurs at the peak voltage V_0. The excitation frequency f is decided by the constants of the elements of the charge transfer circuit composed by two capacitors and an inductor. The change of magnetic flux density ΔB and magnetic field H are calculated respectively by induced voltage of a search coil and magnetizing current through the sample.

ΔB-H characteristics from reverse saturation of four different kinds of large cores were measured in frequency range from 50 kHz to 1 MHz. The shape of the curve of Ni-Zn ferrite is different from the others of Fe based amorphous, Co based amorphous, and Finemet.

1.INTRODUCTION

Saturable inductors and pulse transformers are main component parts of a magnetic pulse compressor (MPC) to drive excimer lasers and particle accelerators, etc.[1] These parts consist of windings and large ferromagnetic toroidal cores of which diameter exceed 100 mm, are magnetized by high frequency(kHz~MHz) voltage pulse. Designing the MPC,we need magnetic properties of cores from reverse saturation to obverse saturation in the wide frequency range mentioned above.[2] This is especially important for designing a high repetition rate type MPC in which the temperature of the core may rise by the core loss.

A conventional AC excitation method to measure high frequency magnetic properties of cores adopts the method to get magnetic field H from magnetizing current through primary winding and to get magnetic flux density B from induced voltage at secondary winding. But a power source more than some MW is required to measure a full B-H curve of some hundreds of mm diameter core at 1 MHz excitation. So we have developed a pulse excitation method to get high frequency magnetic properties of large cores.

In this paper we propose the principle of the pulse excitation method and report the experimental data of high frequency magnetic properties of four large cores.

2.MEASUREMENT CIRCUIT

Figure 1 shows the measurement circuit of the pulse excitation method. The sample core is magnetized by a charge transfer circuit composed of a capacitor C1, an inductor L, and a capacitor C2. If $L_{unsat} \gg L_0 \gg L_{sat}$, where L_0 is an inductance of the inductor L, L_{sat} is a saturated inductance of the sample core, and L_{unsat} is an unsaturated inductance of the sample, turning on the switch after C1 was charged by the voltage V_0 causes the charge transfer from C1 to C2. Consequently the voltage across the sample V(t) until magnetic saturation is expressed as $V(t)=V_0(1-\cos(2\pi ft))$, where f is the excitation frequency determined by C1, L, C2. V(t) increases with the time and reaches maximum value at $t=1/(4\times f)$.

In this circuit, as the capacitances of C1 and C2 are same value, the change in the inductance of inductor L makes it possible to vary the excitation frequency.

The initial magnetic state on B-H curve of the sample is controlled by a reverse bias current through one turn reset winding.

It is requested to make a magnetic field by the reverse bias current at least as large as a coercive force Hc of the direct B-H curve in order to get magnetic properties from reverse saturation to obverse saturation.

The change of magnetic flux density ΔB is calculated by equation (1), where V is induced voltage of a search coil, n is excitation winding turns of the sample, S is a cross section of the sample.

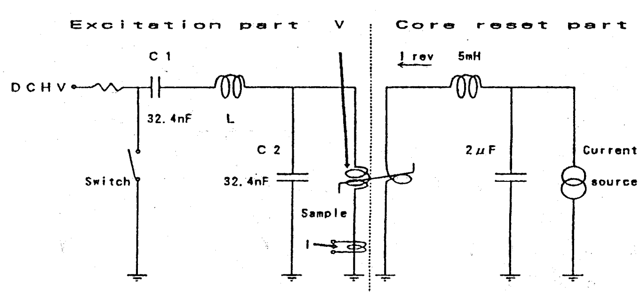


Figure 1. Pulse excitation circuit

$$\Delta B = \int V dt / (n \times S) \qquad (1)$$

Magnetic field H is calculated by equation (2), where I is magnetizing current through the sample, l_s is an average magnetic path length of the sample, and I_{rev} is a reverse bias current.

$$H = (n \times I - I_{rev}) / l_s \qquad (2)$$

So we can get ΔB-H characteristics by measuring the induced voltage V and the magnetizing current I.

3.MEASUREMENT METHOD

A measurement process of high frequency magnetic properties from reverse saturation to obverse saturation of the sample core is as follows.

A. Determination of excitation frequency

This means a decision of the inductance L_0 in the charge transfer circuit, and then the turns of winding of the sample core is determined to verify the following relationship $L_{unsat} \gg L_0 \gg L_{sat}$.

B. Determination of measurement condition

If the charging current of C1 is so large that the initial magnetic state on B-H curve of the sample is set to reverse saturation, the reset part of the measurement circuit may be negligible. But if we want to get magnetic properties of cores of large diameters or relatively high Hc, the reverse bias current I_{rev} of more than some amperes should be needed.

The charging voltage V_0 is determined to satisfy the requirement that a magnetic saturation occurs when the induced voltage at the search coil reaches maximum value.

C. Calculation of ΔB-H characteristics

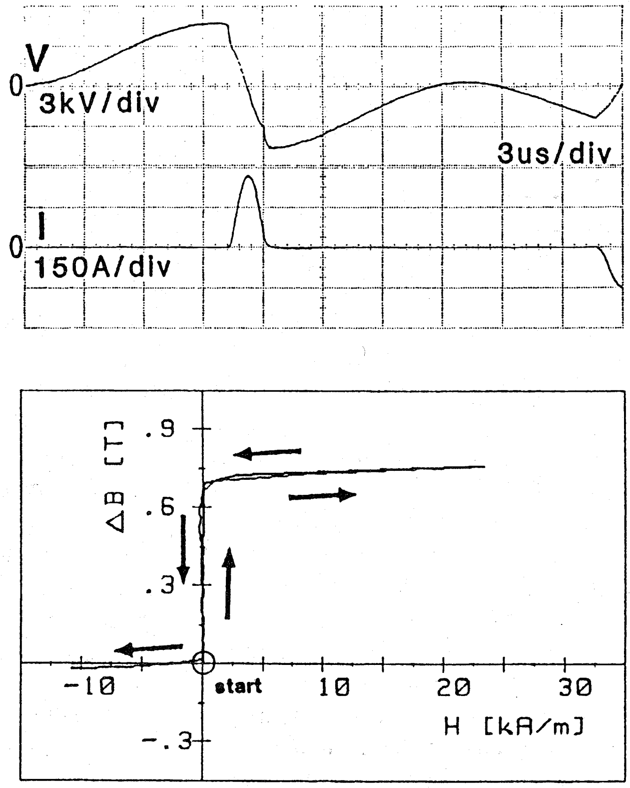
V and I waveforms are measured by a digitizing storage oscilloscope, and the data are transferred to a personal computer which calculates ΔB and H according to equations (1) and (2). Figure 2(a) shows measured V and I waveforms and calculated ΔB-H characteristics.

This V and I data acquisition pattern to the digitizer makes it possible to get full B-H curve. But magnetic properties until saturation are not clear because of the short of the vertical resolution(8bit) of the digitizer. So a vertical sensitivity and a time base of the digitizer are expanded to get enough accuracy until saturation. Figure 2(b) shows these results.

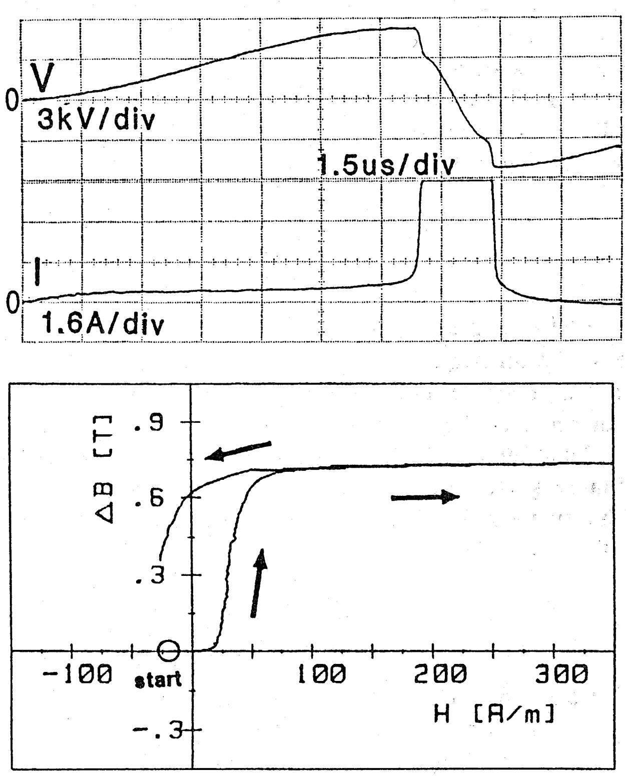
4.EXPERIMENTAL DATA

Table 1 shows the size and direct magnetic properties of four different kinds of sample cores where Bm is a saturation flux density and Br is a residual flux density.

Figure 3 shows the effect of an excitation frequency



(a) Measured waveforms and full B-H curve



(b) Measured waveforms and expanded curve

Figure 2. Measured waveforms and ΔB-H characteristics

Table 1. Size and direct magnetic properties of sample cores

	Size(mm)			Direct properties	
	outer diameter	inner diameter	width	Bm+Br (T)	Hc (A/m)
Fe based amorphous	200	150	25	1.60	4.5
Co based amorphous	150	70	24	0.76	0.5
Finemet	155	58.5	26	1.92	0.8
Ni-Zn ferrite	226	178	10	0.65	35.8

upon ΔB-H characteristics of each core. Maximum value of ΔB in Fig.3 is identical with Bm+Br in Table 1. The shapes of the characteristic curve of Fe based amorphous, Co based amorphous, and Finemet which are composed by rolled ferromagnetic thin films with dielectric thin films resemble one another. However the shape of the curve of Ni-Zn ferrite composed by a baked block is different.

Figure 4 shows the effect of an excitation frequency upon maximum relative permeability μ_{rmax} calculated from the tangent of the curve of each core. In case of Fe based amorphous, Co based amorphous, and Finemet, each μ_{rmax} is proportional to the minus 0.9th powers of the excitation frequency, though μ_{rmax} of Ni-Zn ferrite is proportional to the minus 0.4th powers of the excitation frequency.

Figure 5 shows the effect of an excitation frequency upon the core loss calculated from the area of the ΔB-H characteristics of Fig.3. The core loss of Ni-Zn ferrite is proportional to the 0.2th powers of the frequency though those of the others are proportional to about 0.4th~0.5th powers of the frequency.

From this result, if the excitation frequency is more than 1 MHz, Ni-Zn ferrite has the advantage of low core loss in applying to the MPC.

5.SUMMARY

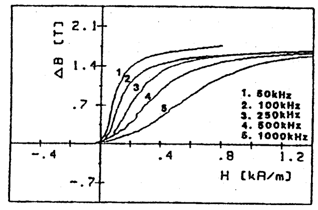
We have developed a novel pulse excitation method to measure high frequency magnetic properties of large cores and ΔB-H characteristics of four different kinds of cores in frequency range from 50 kHz to 1 MHz were measured.

The features of this method are the controllability of the initial magnetic state at will, less heating of the sample core with a single pulse operation and same excitation way as in a MPC.

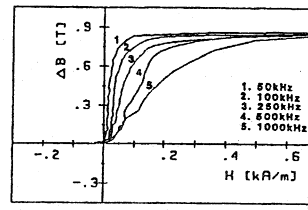
6.REFERENCES

[1] Carl H.Smith, "Applications of amorphous magnetic materials at very-high magnetization rates", J. Appl. Phys. 67 (9), pp5556-pp5561 (1990)

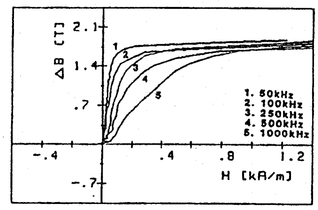
[2] M.Greenwood and J.Gowar, "An optimization strategy for efficient pulse compression", IEEE 19th Power Modulator Symposium, pp187-pp191 (1990)



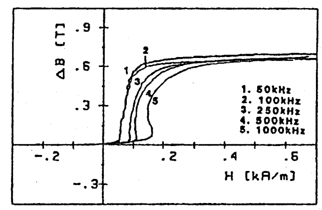
(a) Fe based amorphous



(b) Co based amorphous



(c) Finemet



(d) Ni-Zn ferrite

Figure 3. Effect of the excitation frequency on ΔB-H characteristics from reverse saturation to obverse saturation

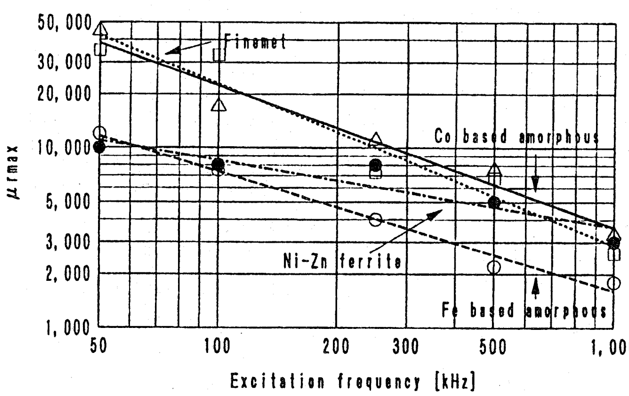


Figure 4. Maximum relative permeability versus excitation frequency

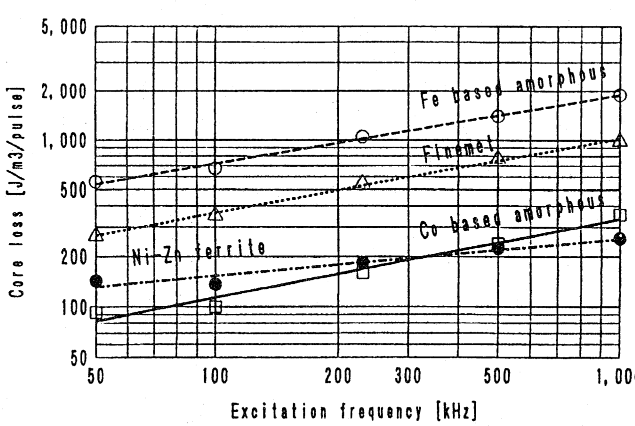


Figure 5. Core loss versus excitation frequency