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dc-type voltage reset characteristics for soft magnetic cores at high frequencies

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dc-type voltage reset characteristics for amorphous ribbon, permalloy ribbon, sendust ribbon, and amorphous fiber were examined and compared with constant current reset characteristics (CMC) up to 500 kHz. A new instrument with square-wave driving is developed. We defined the control force by using the average value of control current when the control current flows forwardly with control voltage. An amorphous core with ribbon thickness of 5 μm exhibited highest gain among the cores. This clarified that the average value of reset magnetizing force for an amorphous core corresponds to the average speed of flux reset and that dc-type voltage reset characteristics for an amorphous ribbon are almost identical to CMC at high frequencies. These results are applicable for a detailed steady-state analysis of magnetic amplifiers.

I. INTRODUCTION

Flux resetting characteristics for saturable cores[1–4] are now practically applied for high-frequency control devices such as magnetic amplifiers[5] driven with low control circuit impedance. However, detailed operation of the devices is not clarified completely because voltage reset characteristics[1,2,4] of the cores have not been examined.

We developed a new instrument for measuring dc-type voltage reset characteristics[2] up to 500 kHz and examined the operation for the cores composed of amorphous ribbon, amorphous fiber,[6] permalloy ribbon, and sendust ribbon.[7]

Relation between voltage reset and current reset is also examined by using control magnetization curve (CMC).[1–4] It is found that voltage reset characteristics for amorphous cores are identical to CMC. This is useful for analysis of control operation of high-frequency magnetic amplifier.

II. SAMPLE CORES AND EXPERIMENTAL PROCEDURE

Table I shows the specification of the test samples. Amorphous cores AR1-AR9 are identical in width and number of wraps of ribbon, inner diameter, and composition of material. Samples AR1-AR3 are made of chemically etched thin ribbon.

Figure 1 shows circuit configuration for dc-type voltage reset,[1,2,4] control magnetization curve (CMC),[1–4] and practical magnetic amplifier. These operations are switched by S1 and S2 in control circuit as explained in the figure. Each circuit applies flux reset to the core. Switching-type field-effect transistor (FET) Q1 drives load circuit with square waveform.

In case of dc-type voltage reset, control circuit impedance becomes very low and therefore flux is reset by constant voltage. Control circuit and load circuit operates alternately according to the switching of Q1 and Q2.

CMC is measured under constant current reset due to high control circuit impedance. Resistance R_c represents control circuit resistance in practical magnetic amplifier.

Voltage reset characteristics and CMC represent relations between reset flux density ΔB_r and control force H. Reset flux density is given by time integral of induced voltage e_v. Control force is obtained from the average control cur-

TABLE I. Dimensions and weight of the test samples; d: ribbon thickness; b: ribbon width; n_t: number of wraps; D_i: inner diameter; D_0: outer diameter; S: cross-sectional area; W_g: weight. (1) Co-base amorphous ribbon. (2) Diameter of single fiber.

No.	d (μm)	b (mm)	n_t	D_i (mm)	D_0 (mm)	S (mm^2)	W_g (mg)
AR 1$^{(1)}$	5	3.0	20	4.0	4.50	0.32	33
AR 2$^{(1)}$	7	3.0	20	4.0	4.55	0.42	43
AR 3$^{(1)}$	10	3.0	20	4.0	4.60	0.61	63
AR 4$^{(1)}$	12	3.0	20	4.0	4.60	0.74	77
AR 5$^{(1)}$	13	3.0	20	4.0	4.70	0.80	84
AR 6$^{(1)}$	15	3.0	20	4.0	4.75	0.89	94
AR 7$^{(1)}$	18	3.0	20	4.0	4.95	1.04	113
AR 8$^{(1)}$	21	3.0	20	4.0	4.95	1.29	139
AR 9$^{(1)}$	24	3.0	20	4.0	5.00	1.44	157
Amorphous fiber (Ref. 6)	20$^{(2)}$	···	12 500	3.5	5.2	3.93	122
Permalloy ribbon	3.1	···	~46	3.1	4.9	0.20	22
Sendust ribbon (Ref. 7)	19	6.0	15	11.8	12.2	1.74	445

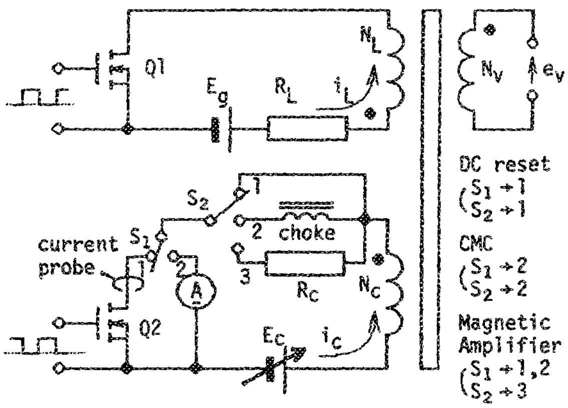

FIG. 1. Measuring circuit for flux resetting characteristics. Reverse control current in voltage reset passes through N_c winding, E_c, terminal 1 of S_1, terminal 1 of S_2, and then back to N_c winding.

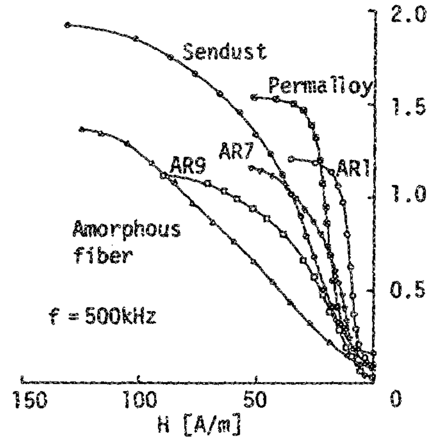

FIG. 3. dc-type voltage reset characteristics for soft magnetic cores.

rent. Instrumentation was supported by a microcomputer and digital equipments.

III. REVERSE FLOW OF CONTROL CURRENT

Figure 2 explains control current waveform under dc-type voltage reset. When control circuit turns on at $t = 0$(①), control current flows reversely with control voltage E_c because of square-wave gate drive. The reverse flow continues until flux reaches residual value②. Therefore, we calculated control force from average current between $t = t_a$ and $t = T/2$ where control current flows forwardly with control voltage:

$$H = S_r N_c / [(T/2 - t_a)\pi D], \quad (1)$$

where S_r is the time integral of control current as shadowed in Fig. 2(b). D is the mean diameter of the core. If the load circuit is driven with sinusoidal wave, Eq. (1) is almost identical to conventional definition.[1]

IV. EXPERIMENTAL RESULTS ON VOLTAGE RESET CHARACTERISTICS

Figure 3 shows typical dc-type voltage reset characteristics for soft magnetic cores at 500 kHz. The slope of the curve reflects the core gain.[2,8] The product of ΔB_r and H is proportional to iron loss during flux reset.[2] Therefore, amorphous core AR1 with ribbon thickness of 5 μm is the most preferable core. Sendust ribbon has as good a performance as an amorphous ribbon having same thickness.

Figure 4 compares the dc-type voltage reset characteristics with CMC. These characteristics are identical for amorphous ribbons. We think that dynamic domain pattern and number of domains in the ribbons are unaffected by reset condition under high-speed flux reset[4] in the same manner as grain oriented 50% Ni-Fe.[9]

V. INFLUENCE OF CONTROL CIRCUIT RESISTANCE ON PERFORMANCE OF HIGH-FREQUENCY MAGNETIC AMPLIFIERS

In practical high-frequency magnetic amplifiers,[5] the control circuit condition lies between voltage reset and current reset depending on the value R_c of control circuit resistance. Connecting switch S2 to terminal 3 in Fig. 1, we can estimate the influence of the resistance on flux reset.

When switch S1 is connected to terminal 1, the control circuit and load circuit operate alternately. In this case, the operation for the sample AR1 is obtained as shown in Fig. 5. Control force H is calculated by Eq. (1). It is seen that the

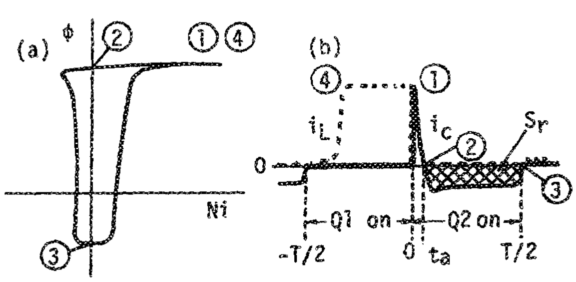

FIG. 2. Definition of control magnetizing force; (a) dynamic hysteresis loop, (b) resultant waveform of applied magnetization force.

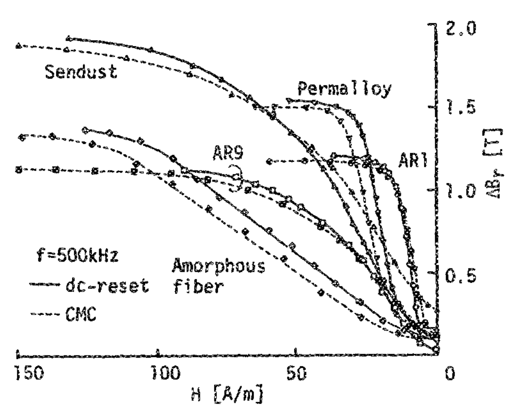

FIG. 4. Comparison of voltage reset characteristics with current reset characteristics (CMC).

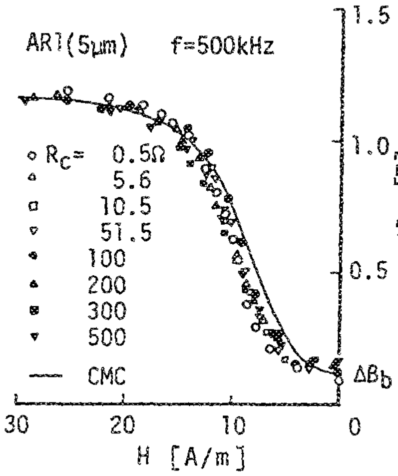

FIG. 5. Flux resetting characteristics when control circuit and load circuit operates alternately.

flux resetting characteristics are almost independent of the resistance, although instantaneous reset voltage became nonuniform with the increase of the resistance.

When switch S1 is connected to terminal 2, control circuit is conducted throughout a cycle. In this case, excess control circuit current flows during gate half-cycle owing to the induced voltage across N_c winding. Accordingly, reset force increases with the decrease of the resistance R_c as shown in Fig. 6(a). If control force is calculated by Eq. (1), the characteristics become almost independent of the resistance as represented by Fig. 6(b).

Figures 5 and 6 clarify that the average reset force for amorphous cores corresponds to the average speed of flux reset. It is unaffected by instantaneous speed of flux reset.

Based on this consideration we can calculate control characteristics of magnetic amplifiers. As an example, when switch S1 is connected to terminal 1 and S2 to terminal 3 in Fig. 1, the control characteristics is given as follows:

$$E_c = \pi R_c DH / N_c + 2fN_c S(\Delta B_r - \Delta B_b), \qquad (2)$$

$$I_L = (E_g - 2fN_L S\Delta B_r)/2R_L, \qquad (3)$$

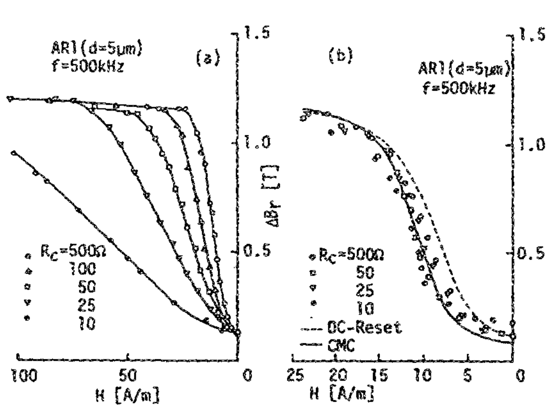

FIG. 6. Induced voltage of the core affected by control circuit resistance AR1 ($d = 5\ \mu$m), $f = 500$ kHz, $H = 15$ A/m (3 V/div, 500 ns/div).

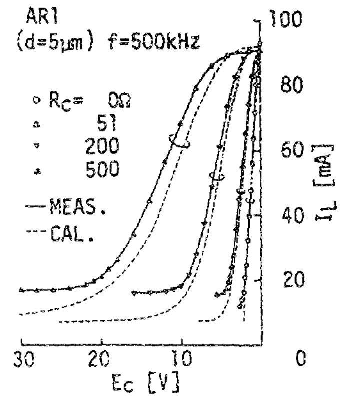

FIG. 7. Flux resetting characteristics when control circuit steadily conducts; (a) control force is calculated from average control current, (b) control force is calculated by Eq. (1).

where ΔB_b is the residual flux density indicated in Fig. 5. R_c and R_L include resistance of winding and on-resistance of FET. Relation between control force H and reset flux density ΔB_r is given by CMC in Fig. 5. Calculated characteristics agree well with measured ones as shown in Fig. 7.

VI. CONCLUSION

dc-type voltage reset characteristics for soft magnetic cores were examined under square-wave gate drive up to 500 kHz. Square-wave gate drive causes reverse flow of control current against control voltage when reset circuit turns on. We accordingly modified the definition of control force.

An amorphous core with ribbon thickness of 5 μm exhibited the highest gain. dc-type voltage reset characteristics for an amorphous ribbon are almost identical to CMC. Furthermore, the average reset force for an amorphous core corresponds to average speed of flux reset at high frequencies. These results are applicable for a detailed steady-state analysis of magnetic amplifier.

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