

Research of the Self-Restoration Speed of Low Remanence Toroid Cores

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Theory analysis and experiments have been done to find out the factors which decide on the self-restoration speed of low remanence toroid cores. The results show that in the right working circuit, the core with appropriate pulse permeability can be restored to its remanence after excitation within $1 \mu\text{s}$ without reset current. Therefore, the toroid core restoration in a MHz repeat frequency, multi-pulse induction cavity is likely to be solved by choosing the right material of cores and use proper working circuit.

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1. Introduction

Generally, the toroid cores are used to generate inductive pulses in a pulsed power system. In many systems, the inductive devices generate several high voltage pulses with the toroid cores working in MHz repeating rates, such as the acceleration cells of an Induction Synchrotron [1], and a multi-pulse Linear Inductive Accelerator (LIA) [2] and the cells of an Inductive-add Kicker Modulator [3]. Therefore these toroid cores require a very fast reset before each pulse [4], otherwise they will saturate during a voltage pulse [5].

When the drive pulse is off, the magnetic flux of the toroid core will restore to its remanence flux (B_r) automatically. That means, to a toroid core, the flux between the B_r and B_s (saturation flux) can be used repeatedly without any reset current. So that if the core's B_r is close to zero and time of the core's self-restoration from B_s to B_r is less than $1 \mu\text{s}$, the toroid core can generate

MHz frequency inductive pulses without additional reset system.

2. What determines the self-restoration speed of low B_r core?

Firstly, during the drive pulse on, the loop around the toroid cores play as a load of the pulsed power system, and part of the power will be stored in the cores when the current passes the loop. As the drive pulse is off, the power system cuts off from the loop, but the current will keep a while for the inductance of the loop. The power which is stored in the cores before will release, the loop plays as a power supply then. Therefore, when the drive pulse is off, increase in the resistance of the load of cores' loop can increase the restore voltage on the cores, and speed on the toroid cores' self-restoration.

TABLE I

Parameter's comparison of the low remanence toroid cores.

| No. | Material | 50 Hz | | 1 MHz | 2 MHz | 3 MHz | 4 MHz |
|--------|---------------------|---------------|---------|---------|-------|-------|-------|
| | | B_r/B_s [T] | μ_r | μ_i | | | |
| core A | nanocrystallization | 0.13/1.5 | 2200 | 1800 | 1080 | 750 | 580 |
| core B | amorphous | 0.15/1.2 | 40000 | 2300 | 1500 | 1130 | 930 |
| core C | amorphous | 0.11/1.5 | 1800 | 1200 | 800 | 570 | 440 |
| core D | amorphous | 0.10/1.3 | 1000 | 800 | 560 | 320 | 260 |

Secondly, the remanence flux B_r is the magnetic flux when the current passing the core's loop attenuates to zero. So, speed on the current attenuation after the drive pulse can short the restoration time of the core, and that requires the inductance of the toroid cores' loop as low

as enough. Therefore, the decrease in the cores' permeability μ in short pulse can speed on the toroid cores' self-restoration.

In order to examine the analysis above, four low remanence toroid cores were chosen to make experiments.

The properties of the cores are shown in Table I, μ_i is the initialization permeability, μ_r is the average permeability in 50 Hz AC.

3. Effect of working circuit to self-restoration speed

Three drive circuits were designed in this part. Sample “core A”, the nanocrystallization core, was taken into these circuits.

Figure 1a shows the circuit 1 which simulates an acceleration module in LIA. A 50 Ω cable with 60 ns length connects the pulsed power system and the loop around the toroid core. Parallel to the loop, there is a 50 Ω resistance to match the cable. In the beginning 120 ns after the drive pulse off, the loop played as a power supply, then the resistance of the core’s loop is 25 Ω (50 Ω cable parallel connects 50 Ω resistance); after that, the load should consider the 3 μF capacitance. Figure 1b,c shows the waveform and the B - T curve. Obviously, during the beginning 120 ns (380–500 ns in Fig. 1c), the magnetic flux B reduces soon, and then it slows down as the resistance changes.

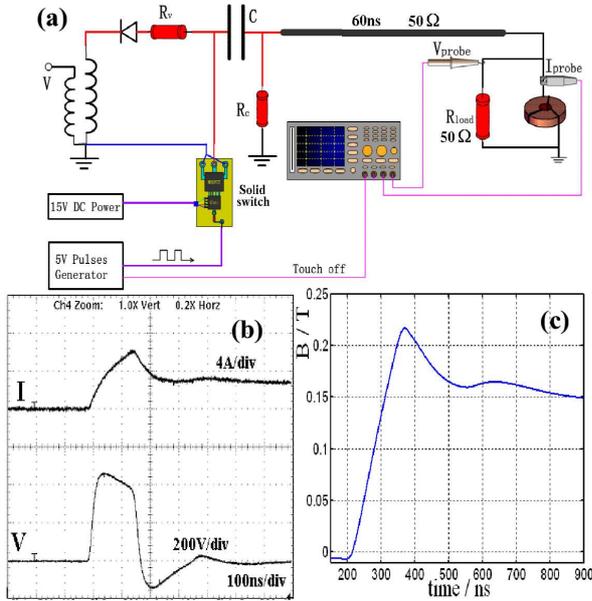


Fig. 1. (a) The experiment circuit 1, (b) the voltage and current waveform of the winding, (c) the B - T curve of core A.

The time of the core A self-restoration to B_r in this circuit is more than 1 μs .

In circuit 2, the length of the cable was extended to 1000 ns and took out the resistance which was parallel connected to the core’s loop. Then, the resistance of the loop would change to 50 Ω during 2 μs after drive pulse off. As Fig. 2c shows, core A can get back to B_r in 1 μs in this circuit.

In the third experiment, a capacitance of 20 μF displaced the 3 μF capacitance. In place of the loop of the

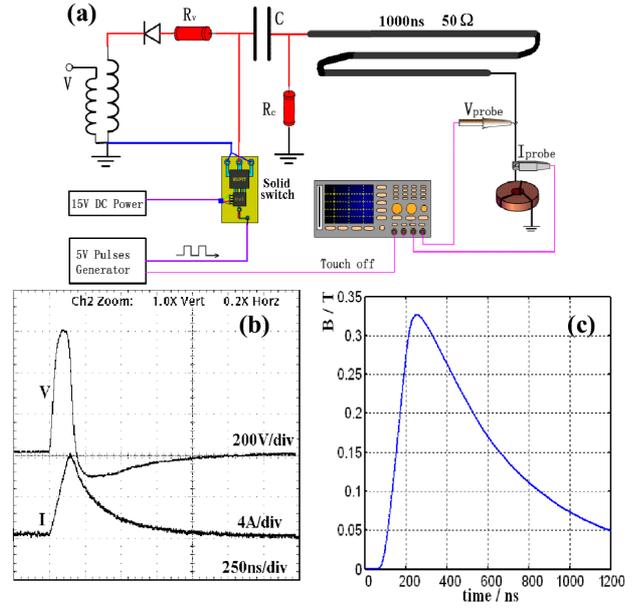


Fig. 2. (a) The experiment circuit 2, (b) the voltage and current waveform of the winding, (c) the B - T curve of core A.

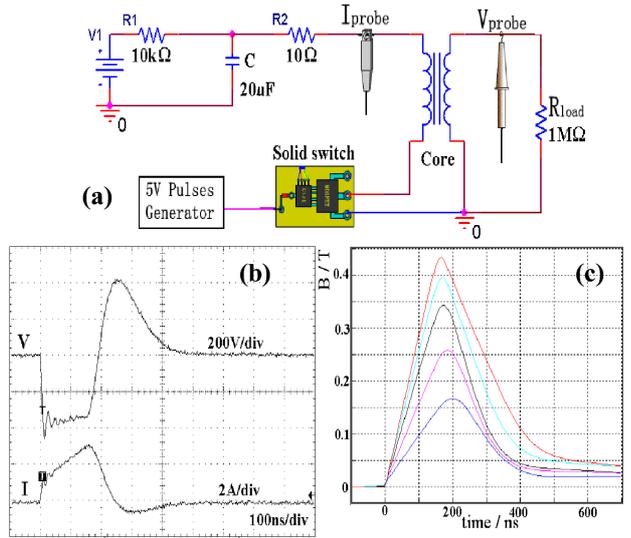


Fig. 3. (a) The experiment circuit 3, (b) the voltage and current waveform of the winding, (c) the B - T curve of core A.

core, the MOSFET switch and the capacitance was connected in series, as Fig. 3 shows. So when the drive pulse is off, because the switch opened, the resistance of the core’s loop is very big. Figure 3b shows the current reduced fastly. As Fig. 3c shows, core A can restore itself to B_r in 300 ns independent of the voltage of drive pulse.

To be a conclusion, the increase in the load resistance of the cores’ loop from the drive circuit can speed up the toroid cores’ self-restoration.

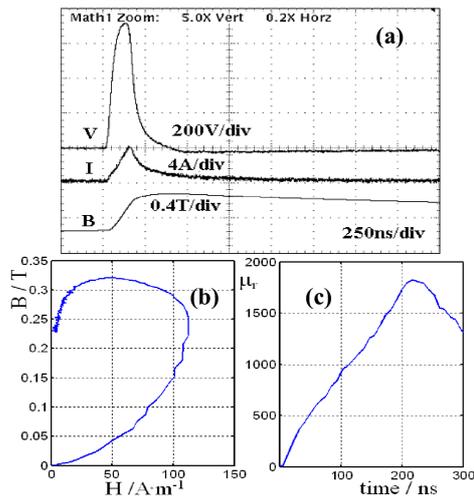


Fig. 4. The voltage, current, B - T (a), magnetization (b), permeability (c) curve of core B.

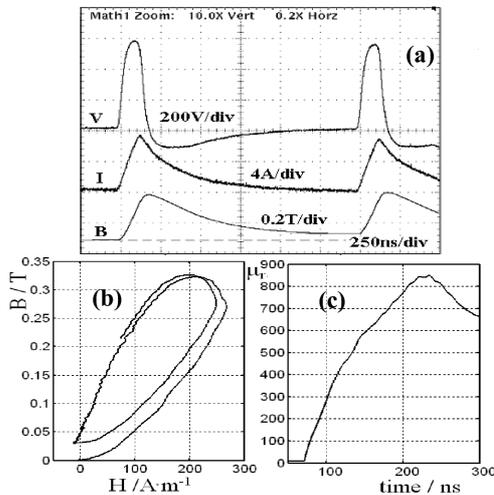


Fig. 5. The voltage, current, B - T (a), magnetization (b), permeability (c) curve of core C.

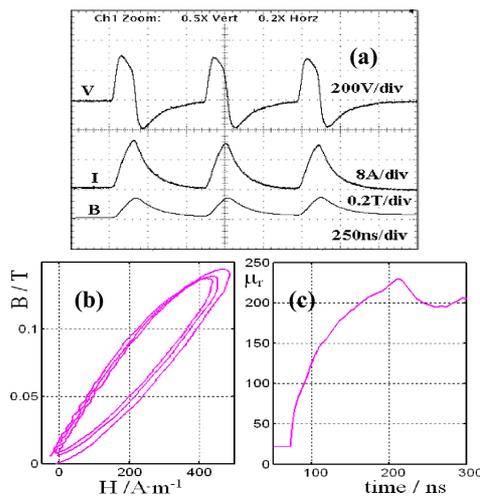


Fig. 6. The voltage, current, B - T (a), magnetization (b), permeability (c) curve of core D.

4. Effect of core's permeability to self-restoration speed

Let us take the second circuit to test the self-restoration speed of cores B, C, D. Figures 4–6 show the examining results of the toroid cores. Table II shows the pulse average μ_r and the self-restoration time of each core in this circuit.

TABLE II
The experiment results of the different cores in circuit B.

| No. | Maximal μ_r in pulse excitation | Average μ_r | Self-restoration time |
|--------|--|-----------------|--------------------------|
| core A | 900 | 450 | $< 1 \mu\text{s}$ |
| core B | 1800 | 900 | $> 2 \mu\text{s}$ |
| core C | 850 | 450 | $< 1 \mu\text{s}$ |
| core D | 230 | 150 | $< 0.5 \mu\text{s}$ |

The results appear that the decrease in the cores' permeability μ_r in short pulses can speed on the toroid cores' self-restoration. If the pulse average permeability [6] is about 400 (as core A and core C), the self-restoration time is less than $1 \mu\text{s}$ in circuit 2.

Decreasing the core's pulse permeability, such as core D, the core's self-restoration time can be shortened to $0.5 \mu\text{s}$. But considering the quality of the inductive pulses, the toroid core needs enough permeability, for example, to keep a 100 ns flat top of the inductive pulse, and the core's average relative permeability μ_r should be higher than 400. Therefore, to satisfy both the requirements of inductive pulse waveform and self-restoration speed, the toroid core's average pulse μ_r should be close to 400.

5. Conclusion

The paper analyses the factors which can determine the self-restoration speed of the toroid core. The experiments proved that choosing appropriate working circuit and appropriate low permeability core, the magnetic cores' restoration problem in MHz frequency pulse excitation can be solved by the core's self-restoration ability.

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