Design of an active ripple compensator for the 50 T high-stability flat-top pulsed magnetic field

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I. Introduction

High-stability flat-top pulsed magnetic field (HFPMF) is a special kind of long pulse magnetic field which is integrated with the advantages of steady high magnetic field and pulsed high magnetic field [1]. The flat-top of HFPMF has the features of high field and low ripple, and has a long duration of flat-top, so the HFPMF is widely used in the scientific experiment to provide the environment for observing the characteristics of materials under magnetic field [2], [3].

II. Magnetic Field System Based on Active Ripple Compensator

The overall topology of the system is shown in Fig.1 and consists of two major parts: 50 T dual-coil magnet system and active ripple compensator.

At the WHMFC, a 50 T dual-coil magnet is energized by a 100 MVA generator-rectifier power supply [4]. The 50 T magnet has two coaxially coils and the mutual inductance is 4 mH. The inductance of outer coil and inner coil are 48.5 mH and 5.1 mH, respectively [4].

Active ripple compensator consisting of discharge circuit, control system, touch screen (type MT8050iH, made by Weintek) and compensation coil is shown in Fig. 2.

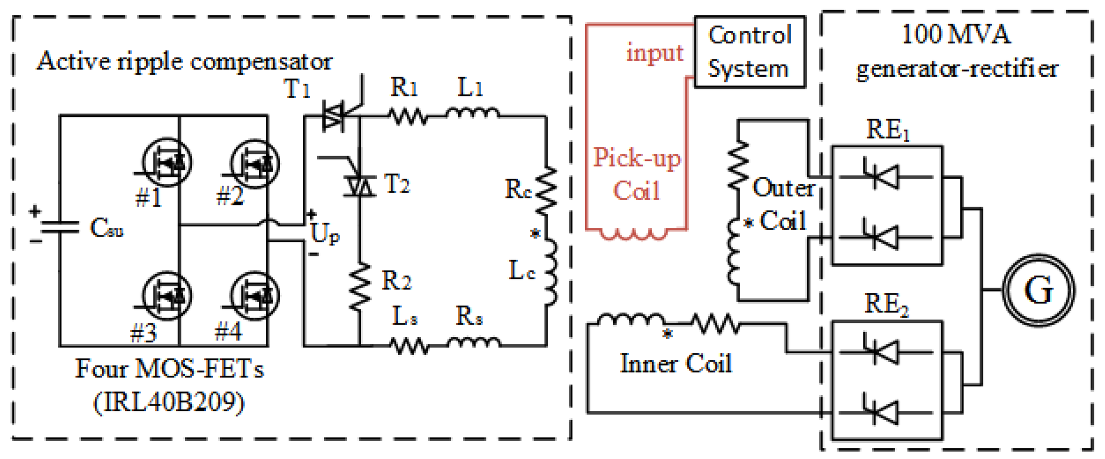

Fig. 1. Topology of the magnetic field system.

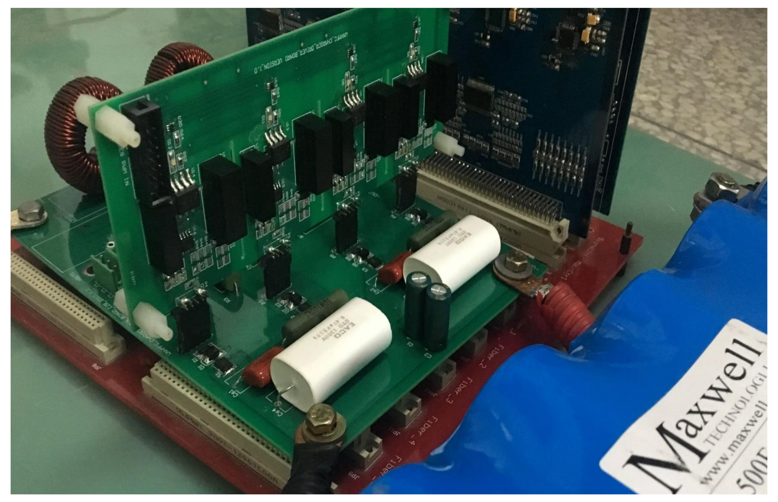

Fig 2. Active ripple compensator.

III. Compensation Coil

A. Design of Compensation Coil

The compensation coil has a same height with the 50 T dual-coil magnet. The compensation coil is placed into the inner coil coaxially and the magnetic field is the resultant magnetic field of the compensation coil and the 50 T dual-coil magnet. The pure copper wire with a diameter of 1mm is wound around an epoxy tube coil. The copper conductor is wrapped with a layer of Kapton film to ensure insulation. The outer diameter and the thickness of the epoxy tube coil are 13.5 mm and 0.5 mm respectively.

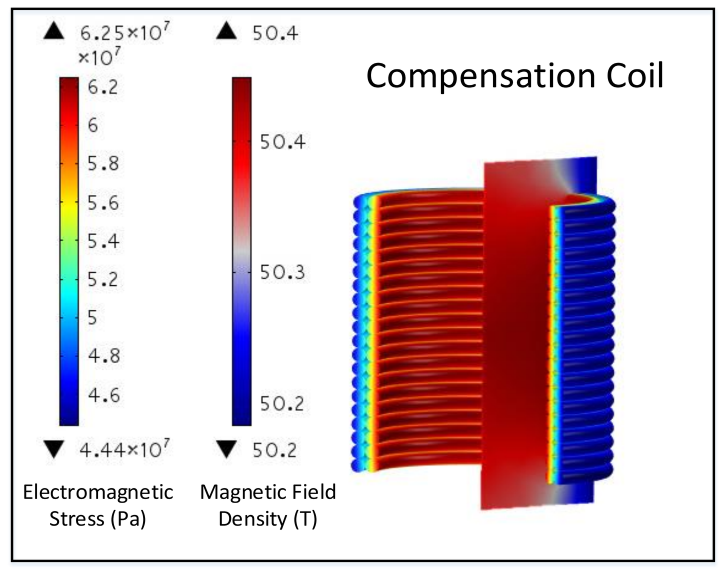

Fig. 3. Electromagnetic stress and magnetic field density of compensation coil. The coil passes through 100 A DC current and the background field is 50.2 T.

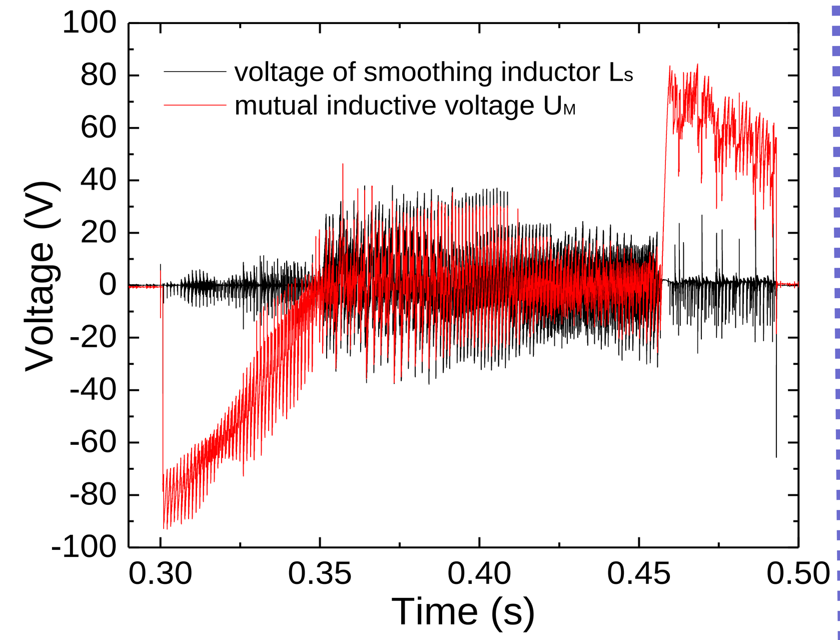

Fig. 4. Voltage of smoothing inductor Ls and mutual inductive voltage U_M..

B. Mutual Inductance Coupling

The change of 50 T dual-coil magnet current will cause high induced voltage U_M on compensation coil which brings difficulties to the control of flat-top. A smoothing inductor Ls is proposed to eliminate the current coupling and limit the change rate of current in a reasonable range. Fig. 4 shows the voltage of smoothing inductor Ls and mutual inductive voltage U_M. Because of the large inductance of smoothing inductor Ls, the mutual inductive voltage U_M is almost equal the voltage of Ls during the flat-top process.

During the flat-top process, TRIAC T_1 is in conduction state and U_M is smaller but still larger than the voltage of C_{su}. The circuit equation of active ripple compensator is

$$U_P + U_M = L_s(di_3/dt) + R_c i_3 + L_c(di_3/dt) + R_0 i_3 + L_0(di_3/dt)$$

IV. Control System

A. Control System of Generator-rectifier

The generator-rectifier control system has been built and designed at the WHMFC [5]. The outer coil of 50 T dual-coil magnet is powered by 12-pulses rectifier RE_1 and the inner coil is powered by 12-pulses rectifier RE_2. The coil current is changed by adjusting the trigger angle of rectifiers.

B. Control System of Active Ripple Compensator

The control system of active ripple compensator is designed and built based on FPGA (type EP3C55F484). The coil current is regulated by controlling the turn-on and turn-off of the four MOSFETs.

At the beginning, the two TRIACs T_1 and T_2 are both in OFF state. When B_{m2} reaches 49.95 T, the TRIAC T_1 is triggered. When T_1 is in conduction state, the bipolar PWM controller G_{PWM} begins to work.

The function of G_{PWM} is achieved by comparing the triangular carrier wave with the modulation wave. The amplitude and period of triangular carrier is 1 and 16μs respectively.

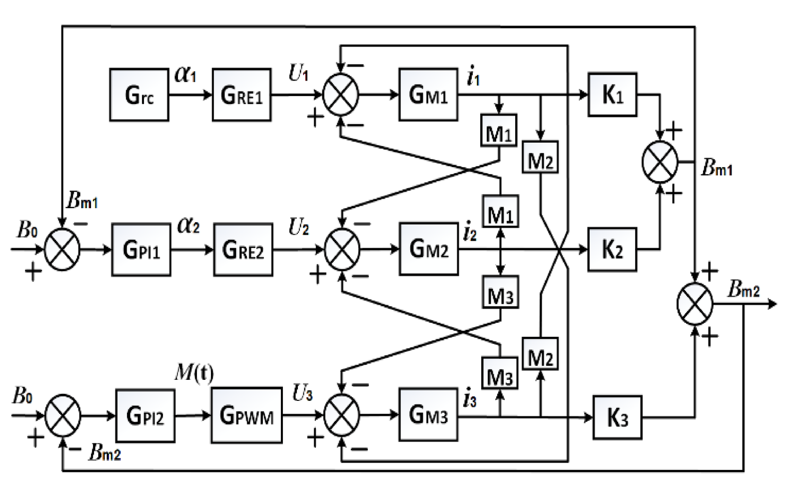

Fig 5. Control block diagram of the magnetic field system. B_{m2} is measured by pick-up coil. M_1, M_2, M_3 represent the mutual coupling effect.

V. Simulation Results

An integrated model of the magnetic field system is built on MATLAB/Simulink. The models of magnets include the self-inductance, the mutual inductance and the increase of resistance due to the Joule heat. The model of MOSFET include the drain-to-source on-resistance, input capacitance, turn-on delay time, rise time, turn-off delay time, fall time and diode forward voltage.

The output current of full-bridge is shown in Fig. 6. The consumed energy of C_{su} during discharge process is only about 2 J. As shown in Fig. 7, when the active ripple compensator starts to work, the ripple is quickly suppressed. The red line shows the flat-top accuracy of resultant magnetic field is less than 100 ppm.

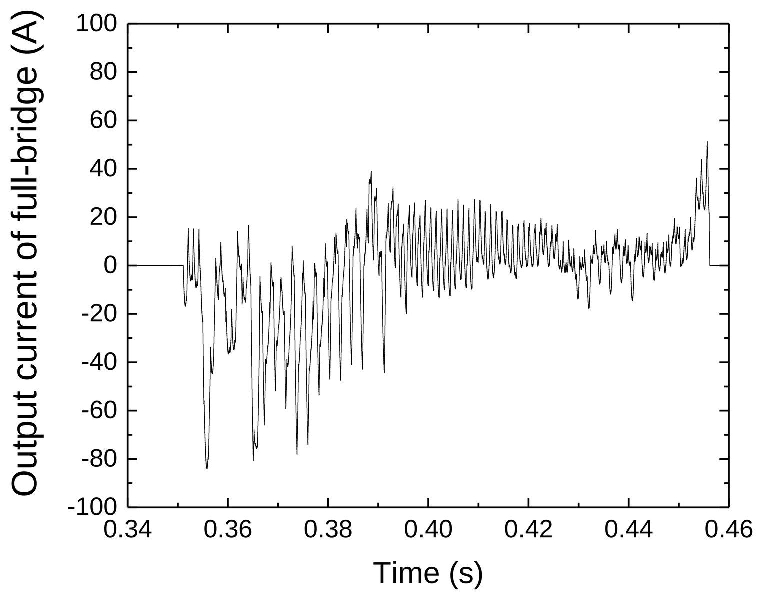

Fig. 6. Output current of full-bridge.

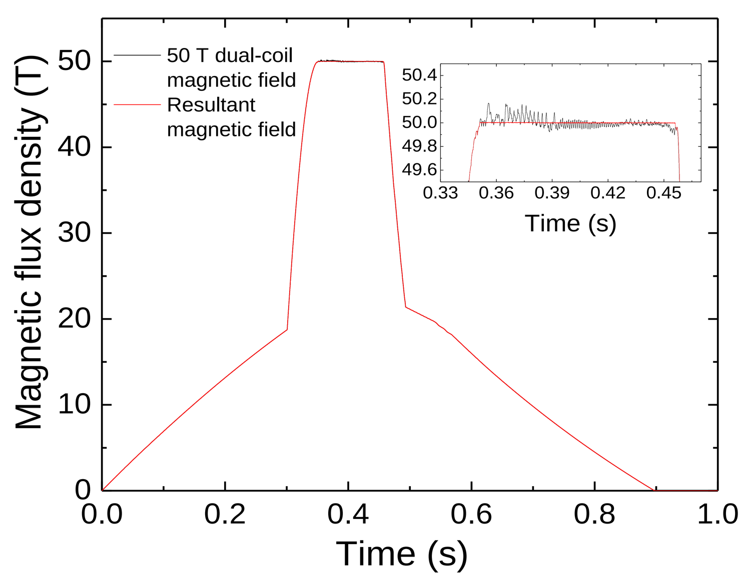

Fig. 7. Magnetic flux density.

VI. CONCLUSION

With the application of active ripple compensator, the ripple of 50 T magnet system is reduced from 1500 ppm to 60 ppm. The experiment platform is under construction and the system is scheduled to be completed in the autumn of 2018. A more effective control strategy for the active ripple compensator is under study. The application of the active ripple compensator for other flat-top magnetic field system, such as the 41 T flat-top magnetic system at the WHMFC, is also under study.

References

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