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Upgrade of the Pulsed Magnetic Field System with Flat-top at the WHMFC

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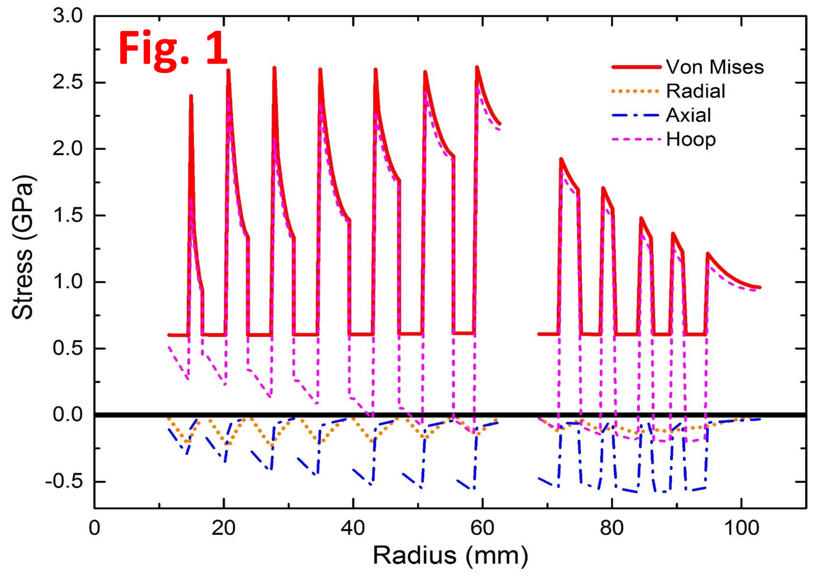
I. Introduction

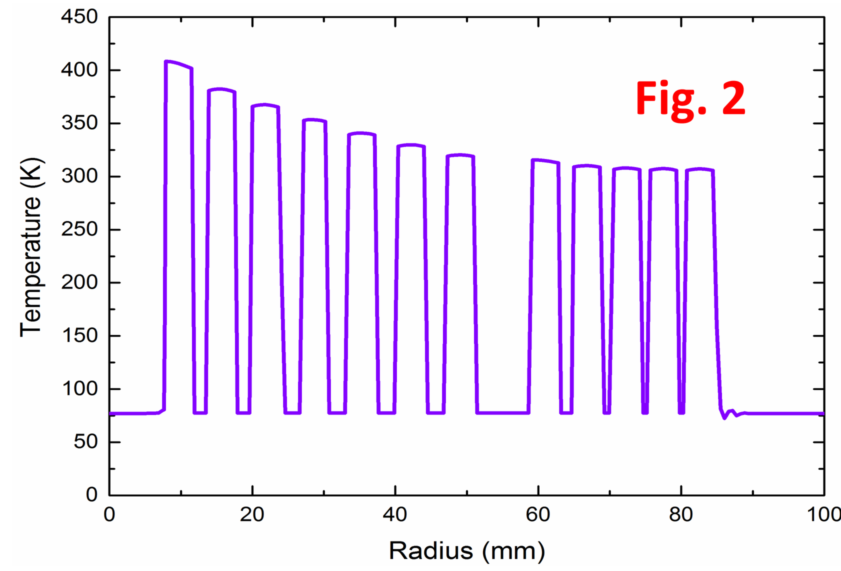
- The 65 T pulsed magnetic field with 10 ms flat-top has been achieved at the Wuhan National High Magnetic Field Center (WHMFC). This is an upgrade based on the 41 T with 6 ms flat-top system. Both the magnet and the coupling transformer were newly designed and fabricated. The magnet circuit and the auxiliary circuit were driven by ten and two 1 MJ capacitor bank modules, respectively. At the voltage of 19.1 kV for the magnet circuit and 8.5 kV for the auxiliary circuit, peak field of 64 T with 10 ms flat-top and 0.3% flatness was obtained. The primary specific heat measurement of sample $CeRhIn_5$ was successfully performed.

II. System Design

1) Magnet Design

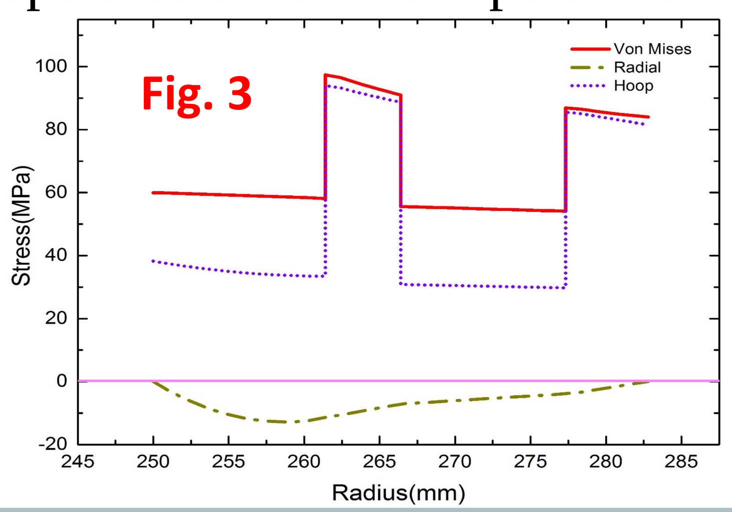
- In order to produce 65 T peak field reliably, a monolithic pulsed magnet aiming at 70 T was designed based on the Bochvar CuNb wire with cross section of 3.2 mm × 5.5 mm. The ultimate tensile strength (UTS) is 1200 MPa at a strain of 2.2% at room temperature.
- The magnet coil consists of 12 layers of conductor with 180 mm height and 21 mm bore. The Zylon/epoxy composite with optimized thickness is used to reinforce all the conductor layers. The fast cooling technology is applied to reduce the cooling time between every two pulses. The calculated stress distribution at 70 T is shown in Fig. 1. The peak von Mises stress in the Zylon/epoxy layers is 2.62 GPa, which is much lower than the measured UTS of Zylon/epoxy composite. The calculated temperature distribution at the end of the 65 T PMFFT is shown in Fig. 2. The effects of eddy current and magnetoresistance are negligible because of the long pulse duration. As a result, the temperature distribution inside one conductor layer is almost uniform. The maximum temperature in the conductor is 427 K after the discharge is completed.





2) Design of the Coupling Transformer

- Both the primary winding and the secondary windings were designed to have two layers of copper conductor with cross-section of 5.3 mm × 14.5 mm and were reinforced by 5 mm thick layer of Kevlar/epoxy composite on the outer surface. The detailed parameters of the magnet and the transformer are listed in Table I. The calculated stress distribution of the coupling transformer is shown in Fig. 3. The peak von Mises stress in the Kevlar layers is only 97 MPa. Figure 4 shows the temperature distribution in the coupling transformer at the end of the pulse. The maximum temperature of the primary and the secondary windings is 308 K and 319 K, respectively, although the transformer is operated at room temperature



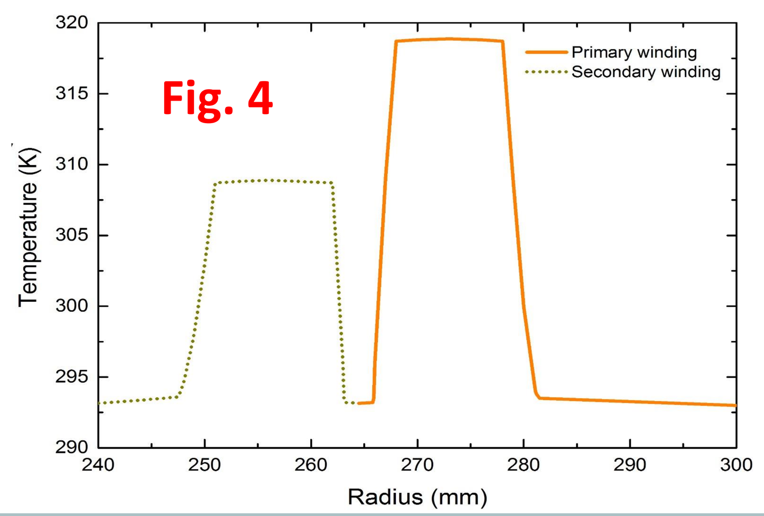
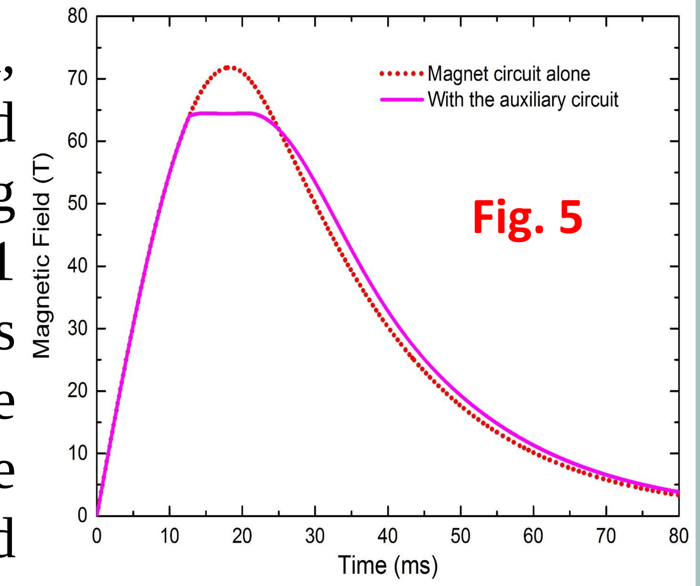


Table I

	Magnet	Secondary winding	Primary winding
Bore (mm)	21	500	545
Height (mm)	180	656	656
Conductor (mm×mm)	CuNb (3.2×5.5)	Cu (5.3×14.5)	Cu (5.3×14.5)
Conductor layers	12	2	2
Resistance (mΩ)	36.8 (77K)	31.72 (300K)	33.75 (300K)
Inductance (mH)	3.82	2.21	2.47
Mutual inductance (mH)	2.19		

3) Magnetic Field Simulation

- When the magnet circuit is triggered alone, the typical pulsed field waveform is obtained, as shown in Fig. 5. As soon as the auxiliary circuit is introduced, a flat top magnetic field can be generated. As the magnet current increases quickly in the magnetic field rising stage, accurate trigger delay is critical to obtaining the flat-top. The adjustment step of 0.01 ms is required. The charging voltage of the capacitor bank of the secondary circuit affects the flatness as well. Voltage adjustment of 50 V each pulse is desirable. The increase of the conductor resistance caused by Joule heat was also calculated. The simulation result of the magnetic field waveform with flat-top is shown in Fig. 5. It is evident that magnetic field of 65 T with 12 ms flat-top and flatness of 0.3% flatness can be achieved.

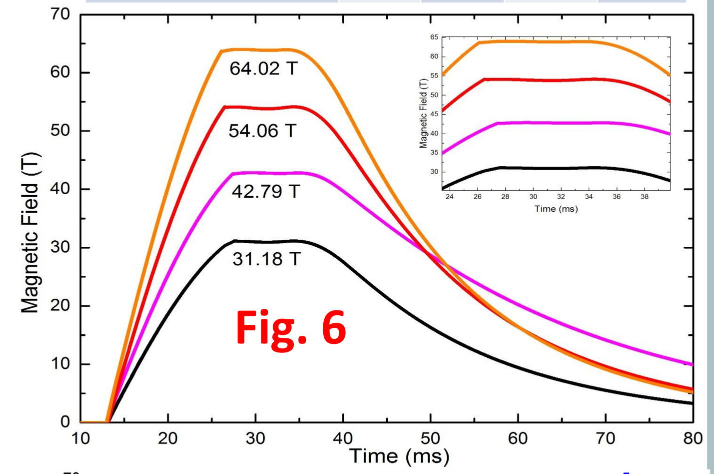


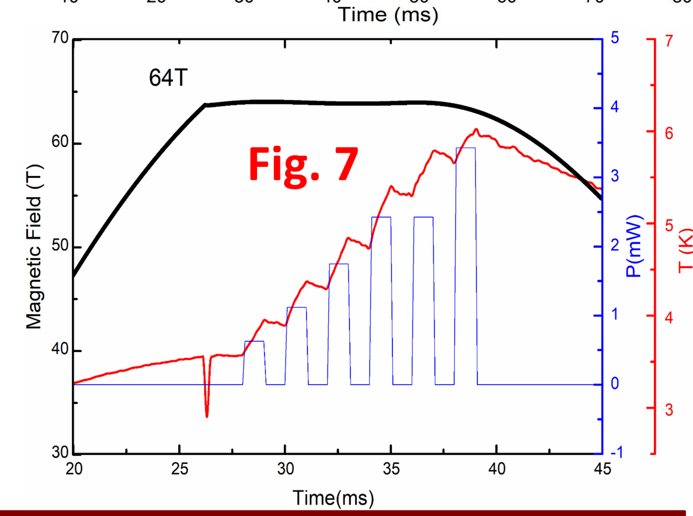
III. Result and Discussion

- The power supply of the magnet circuit and the auxiliary circuit is 10 MJ (10×3.2 mF) and 2 MJ (2×3.2 mF), respectively. The magnet coil was immersed in liquid nitrogen and the coupling transformer was operated at room temperature. Before and after discharge, the resistance of the magnet coil and the coupling transformer were measured with the 4-wire method to monitor the temperature rise. A calibrated pick-up coil was used to measure the magnetic field.
- The test procedure proceeded with gradual increase of the discharge voltage, and finally stopped after the 64 T peak field was obtained. The measured magnetic field waveforms are shown in Fig. 6. The data of the test are listed in Table II. With the increase of the peak field, the trigger delay is shorter. The reason is that the magnetic field is reduced and the pulsed rise time becomes shorter due to the increase of conductor resistance caused by Joule heat. The trigger delay during the test is only 0.31 ms less than that of the simulation and the measured field is only 0.2 T smaller than the calculated value. In a word, the measured results agree well with the simulation.
- During the magnet test, the primary measurement on the specific heat of sample $CeRhIn_5$ was carried out. Six heat pulses were applied to the sample during the 10 ms flat-top. The temperature rise of the sample are shown in Fig. 7. More specific heat and NMR tests will be performed in the next step.

Table II

Test sequence	1	2	3	4
Discharging voltage of the magnet circuit (kV)	9.52	12.63	16.25	19.12
Discharging voltage of the auxiliary circuit (kV)	4.14	5.48	7.36	8.51
Trigger delay (ms)	13.58	13.57	13.52	13.51
Maximum field (T)	31.18	42.79	54.06	64.02
Flat-top duration (ms)	8.2	9.1	9.8	10.01
Flatness	0.36%	0.41%	0.43%	3.10%





IV. Conclusions

- We developed the unprecedented PMFFT of 65 T with 10 ms and 0.3% flatness system with the coupling transformer at the WHMFC. The system consumed only 7 MJ energy. Compared with the previous method, the system can be easily built with capacitor banks that are available at most laboratories in the world and the waveform is flatter. It is one of the promising methods to produce magnetic field with flat-top for specific heat and NMR measurement.

References

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