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REALIZATION OF TEMPERATURE COMPENSATED TPS CORRECTION MAGNET POWER SUPPLY

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Abstract

This report discusses the design of a current feedback component for a TPS correction magnet power supply. The component utilizes a low-cost and small-sized TI INA253 resistor combined with a temperature compensation control circuit to improve the output current thermal equilibrium time. With these measures, the system achieves thermal equilibrium quickly, resulting in improved performance. Ultimately, we successfully developed a TPS correction magnet power supply with temperature compensation control. The system is compatible with the existing TPS control interface, reduces the cost of current feedback elements, and achieves a better thermal equilibrium time, which is highly beneficial to power supply development teams.

INTRODUCTION

Currently, the fast correction magnet power supply used in the TPS storage ring is the Shunt version and DCCT version fast correcting magnet power supply jointly developed with the Industrial Technology Research Institute Measurement Group (ITRI). However, due to the continuous price increase of the main current feedback components, LEM ITN 12-P DCCT and Isabellenhutte RUG-Z-R001, it is necessary to find alternative current feedback components [1, 2].

To address this issue, we have developed a TPS fast correcting magnet power supply that incorporates the TI INA253 high-precision current transformer to replace the RUG-Z-R001 component. This approach not only reduces component costs but also adds temperature control functionality to enable the system to reach thermal equilibrium faster, thereby speeding up the power converter's attainment of a stable output current state [3, 4].

The system architecture diagram in Figure 1 includes several main units. The first unit is the circuit architecture, which includes a full-bridge DC-DC power converter composed of MOSFETs and an L-C lowpass filter at the output to filter out the harmonic current generated by PWM high-frequency switching.

The second unit is the temperature control box, which contains the current element TI INA253A1, the signal conversion gain and offset circuit, and the temperature control circuit. The related circuits are encapsulated in a temperature-controlled copper box and heated to maintain temperature stability, shorten the thermal equilibrium time, and make the output current converge to the stable value more quickly.

The third unit is used to process the error between the current command and reference. The P-I compensator and triangle wave are used to convert the four sets of PWM switching signals through two sets of UC3525A and then drive the MOSFET switch through HIP4081A to complete the hardware circuit design of the closed-loop control.

The fourth unit is the interlock protection circuit, including input side current overload protection (FUSE), output-side overcurrent protection (IOVL), auxiliary power supply ground protection (PWM POWER), power switch heat sink (T-SINK) protection, output oscillation protection circuit (T1-TEMP & T2-TEMP), input-side 48-volt low-voltage protection (HV POWER), and disable (DISABLE) protection signal. Through PCF8574N, the various protection signals are encoded into I2C timing for the controller to monitor the system status.

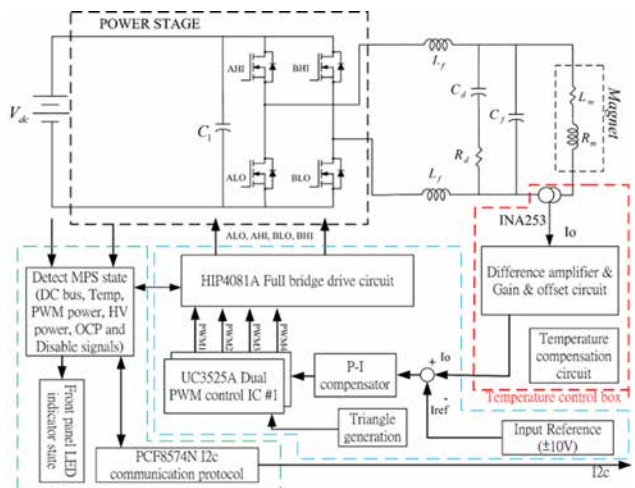

Figure 1: The system architecture diagram.

HIGH-PRECISION CURRENT SENSING COMPONENT

The current sensing element used in this version is the INA253A1 precision integrated shunt resistor. The INA253A1 is a high-precision current sensing amplifier designed by Texas Instruments, capable of accurately measuring current and providing an amplified output signal that is proportional to the measured current. With a wide operating voltage range and low offset voltage, it is suitable for use in various applications, including power supply and motor control systems. Its main specifications include a current measurement range of ±15 amperes, low temperature coefficient of 10 ppm/°C, shunt resistor of 2 mΩ, bandwidth of 350 kHz, and three output specifications of 100 mV/200 mV/400 mV for 1 ampere. It can withstand a range of -4 to 80 volts. Its functional block diagram is shown in Figure 2.

To provide a 5-volt power supply with 0.02% accuracy to INA253A1, the design also utilizes the MAX6250 high-

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precision voltage reference IC. By combining high-precision operational amplifiers with low-temperature drift resistors, a signal conversion circuit is formed that can convert the INA253A1 output voltage signal with high precision to full scaling. When combined with clever temperature control box design, it can reduce temperature drift and keep the internal circuit in a constant state, achieving stable output current characteristics.

The cost of this design is also more affordable compared to the constantly rising prices of similar products. The Isabellenhutte RUG-Z-R100-0.1-TK1, currently priced at 500 USD per piece, is a 100 mΩ shunt resistor. The cost of using this component is about 150 USD, still leaving considerable price space and advantages.

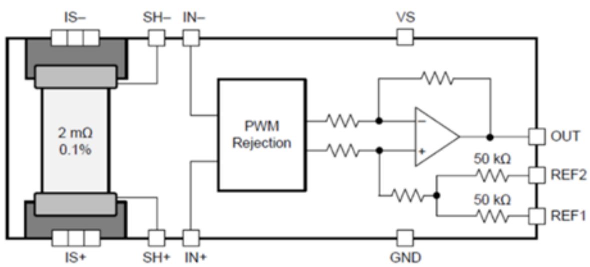

Figure 2: The TI INA253A1 functional block diagram.

TEMPERATURE-CONTROLLED COPPER BOX DESIGN

The temperature-controlled copper box design consists of a heat sink on top, which dissipates heat from the TES1-12703 in the middle to regulate the temperature stability of the copper box at the bottom. The material of the copper box is conductive copper, so the internal circuit components need to be arranged in the appropriate positions to ensure that they will not be touched during the installation of the copper box, which could cause damage to the circuit. The composition of the Copper box is shown in Figure 3.

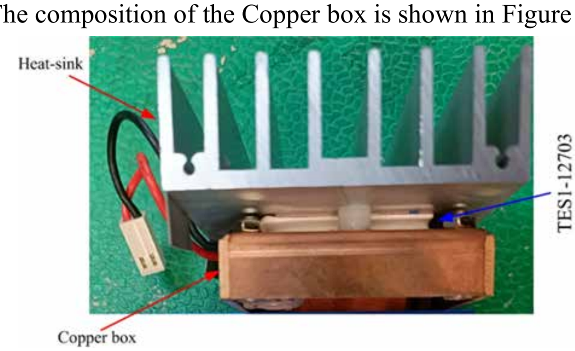

Figure 3: Component of the temperature regulation box.

In Figure 4, the Copper box and internal circuit are shown, mainly designed with SMD components for feedback and temperature control circuits, arranged in a compact manner. However, it is important to note that INA253A1 needs to operate within 51°C to maintain good impedance characteristics. To achieve stable operating conditions, the surface of INA253A1 must be carefully attached to the Copper box for heat dissipation and temperature stabilization. In addition, the temperature sensing element LM335AZ also needs to be attached to the Copper box, and the temperature feedback is promptly fed back to the system through copper columns for compensation, so that the TES1-12703 cooling plate can adjust and stabilize the Cop-per box temperature.

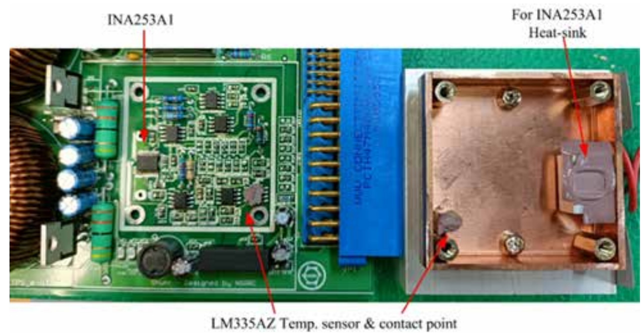

Figure 4: Inner circuit of the temperature regulation box.

In Figure 5(a), we replaced the old sensing elements with high-precision current sensing components and a temperature control box. The revised magnet power supply is designated e-SHUNT v.1 and can be easily used with the P-I compensation card and control interface. Additionally, in Figure 5(b), we show different angled side views of the e-SHUNT v.1 CPS, where it can be seen that the height of the temperature control box does not exceed that of the MOSFET heat sink. This allows for easy installation in the TPS CPS cabinet without interference, and it can be directly applied to the current TPS system.

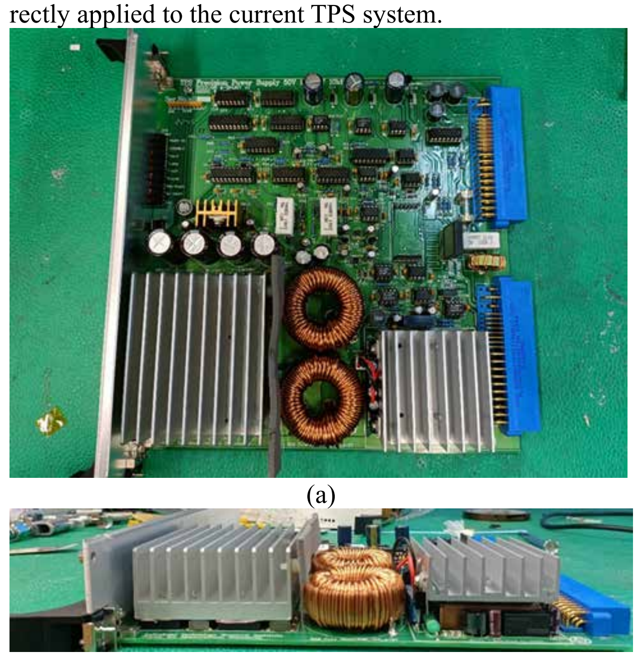

Figure 5: The e-SHUNT v.1 correction power converter :(a) Top view (b) Side view.

MEASUREMENT RESULT

We conducted output current thermal balance measurements on three different versions of the correction magnet power supply. In Figure 6, the top graph shows the SHUNT version, which requires 45 minutes of thermal equilibrium

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stabilization time from the set output current value of 10 A to reach stability. The middle graph in Figure 6 shows the CPS version with DCCT, which requires 25 minutes of thermal equilibrium stabilization time. Finally, the bottom graph shows the e-SHUNT v.1 with temperature compensation, which has a measured thermal equilibrium stabilization time of 5 minutes. It is clear that the temperature compensation function can significantly reduce the current stabilization time.

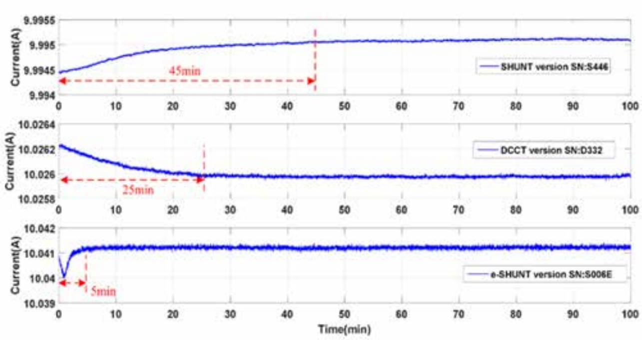

Figure 6: The output current thermal balance measurements of CPS.

In Figure 7, the output current spectrum analysis of three different versions of CPS is shown. The output current spectrum ranges from 0 to 1600Hz. It is evident that the e-Shunt v.1 version has higher current ripple, mainly because its internal impedance of INA253A1 is 2mΩ, while Isabellenhutte RUG-Z-R100-0.1-TK1 is 100mΩ. The Signal/Noise amplification ratio of the signal is positively correlated, which inevitably leads to a larger output current ripple for e-Shunt v.1, but it is still within 100uA. In addition, components with smaller Signal/Noise ratio will require larger impedance and better heat dissipation to achieve excellent output characteristics. However, the INA253A1 has significant advantages in small size and price, which allows us to have room to realize the development of the next generation of small-sized high-power density power supplies.

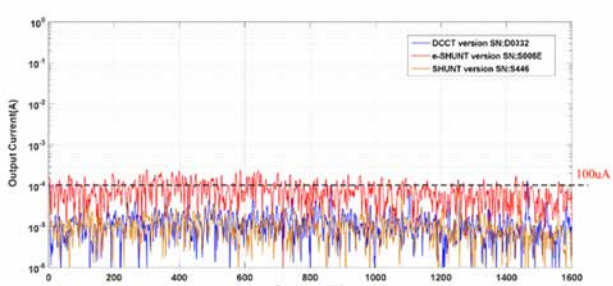

Figure 7: The output current spectrum analysis of three different versions of CPS.

CONCLUSION

In the final experiment, the thermal equilibrium time for different versions of the correction magnet power supply was measured. The version designed with temperature compensation only requires 5 minutes to reach thermal equilibrium, stabilizing the output current at the design value. However, the output current ripple is relatively large, which is a limitation inherent to the design. In the context of miniaturized integrated circuits and high-speed switching, there are still many challenges and compromises to be made in the future. I believe that these experiences are important for the development of the next generation of TPS correction magnet power supplies.

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