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Development of 10kA Standard DC Constant Current Source

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Abstract:

The traditional high-precision DC large current sensor has the problem of direct calibration, so 10kA standard DC constant current source device is developed. The device make use of modular design and is composed of 18 constant current sources in parallel, and each constant current source is 600A. The 600A constant current source designed a deep negative feedback loop, and the self-developed 600A zero flux sensor was used as the feedback element of the output current. Each 600A constant current source is designed with a high-power diode as a fixed load, the diode can not only ensure the stability of the output current of a single constant current source, but also eliminate the mutual interference between the constant current sources in parallel. The output current structure of the device uses the form of copper bars. It is shown by tests that the current accuracy of the device is better than 0.01 %, and the current relative stability is better than 10ppm/min, which fully meets the calibration requirements of high precision current sensors.

Keywords*: constant current source, zero-flux current sensor, negative feedback, high-precision, stability, Parallel circuit.*

I. INTRODUCTION

In the study of physical science, The particle collider usually gives a magnetic field of above 8T to the dipole magnet to accelerate particles, so it needs a DC current of up to 10kA and there are high requirements for the precision measurement of large DC current and the accuracy of current sensor Also in industrial production ‘DC current of 10kA’ is widely used in electrolysis, electroplating, non-ferrous metal coloring and other industries. In order to ensure the production process, high-precision current sensors are widely used. These high precision DC high current sensors in the field of scientific research and industrial production need accurate calibration to ensure the accuracy of their measurement. The traditional DC high current sensors are calibrated by the equal-ampere-turn method, but this method has the defects that the magnetic field cannot be uniformly distributed, and the repeatability of the verification results of high-precision sensors is poor, so it is impossible to calibrate the DC current sensor with accuracy below 0.05 level. Therefore, it is urgent to develop a 10 kA standard DC constant current source for the

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calibration of high-precision sensors.

II. OVERALL DESIGN

There are two designs for 10kA standard DC constant current source. One is to make use of the traditional design method, including high-power thyristor rectification and filtering, DC-DC conversion, and maintains the constant current output by sampling feedback control[1]. It is very difficult to realize, and the ripple of current is large [2]. So it can not be used for the calibration of high-precision sensors; Another is to use the modular idea, decompose the 10kA standard DC constant current source into multiple constant current source modules, and then realize the output of high current by parallel connection of modules. Compared with the first design, the second plan does not need to design ultra-high power inverter circuit, and has the advantages of low design difficulty, simple manufacture and small output current ripple. The 10kA standard DC constant current source consists of 18 constant current sources and each constant current source is 600A [3], It is connected in parallel through special design to prevent mutual interference between constant current sources as shown in Fig 1. The console controls each individual constant current source by RS485 communication interface. When current output is required, the console controls 18 constant current sources for current output according to the current setting [4].

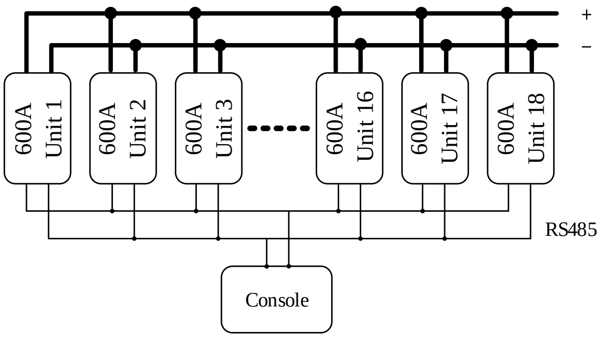

Fig 1: Structure Diagram of 10kA Standard DC Constant Current Source

III. RESEARCH ON KEY TECHNOLOGIES

3.1 600A Constant Current Source

600A constant current source is an important part of 10kA standard DC constant current source, and its performance directly determines the performance of the whole device. The 600A constant current source uses low noise circuit architecture and deep negative feedback loop to ensure the stability of the constant current source [5]. The principle block diagram of the 600A constant current source is shown in Fig 2.

The 600A constant current source uses a 32-bit microprocessor as the core controller to communicates with the main control box by the RS485 communication interface. External EEPROM is stored calibration data [6], etc. The 32 - bit microprocessor realizes range switching and adjusts the DA output according to the output current emitted by the console. Also, the processor converts the feedback sampling current into digit, and transmits the AD sampling data and the alarm information of circuit failure to the console.

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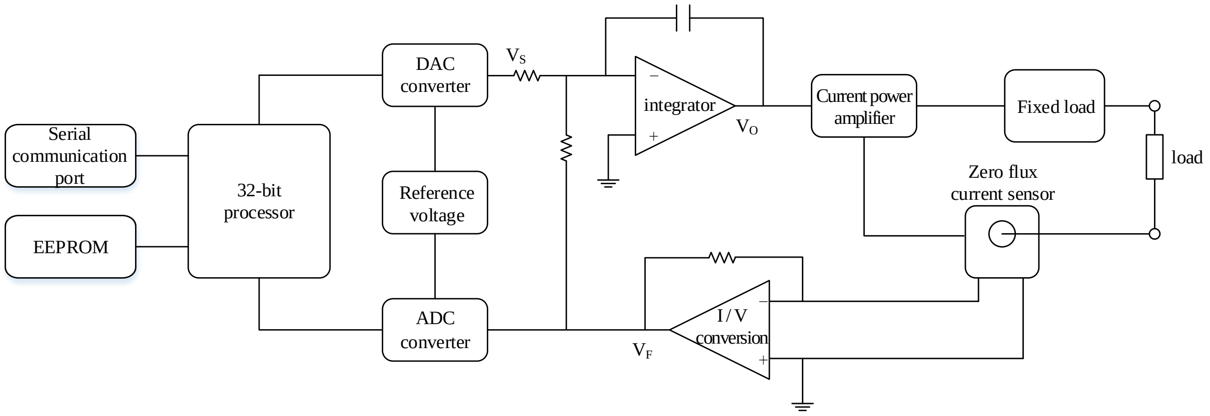

Fig 2: Principle block diagram of 600A constant current source circuit

A deep negative feedback circuit is designed for the analog circuit of the 600A constant current source to ensure the constant output current [7]. When the constant current source outputs current, the 32-bit processor controls the DAC to output corresponding voltage V_S. The signal V_S is added with the feedback sampling signal V_F and sent to the integrating circuit [8], the integrator reaches a stable voltage value V_O, and the voltage signal V_O controls the power amplifier to output DC large current. The load current is converted to a secondary small current according to the designed standard ratio by a zero flux current sensor [9]. The small current is converted into a voltage signal into a feedback circuit by the I/V conversion circuit, a closed-loop negative feedback system is set up. When the current increases due to the load change, which will cause the feedback signal V_F to be amplified in proportion, resulting in the integrated voltage V_O decreases, and the current is reduced by adjusting the current power amplifier; When the current becomes small due to load change, the feedback signal V_F will be reduced in proportion, resulting in increasing the integral voltage V_O, adjust the current power amplifier to reduce the current. The whole feedback loop is in a dynamic balance state to maintain a constant current output [10].

3.1.1 zero-flux current sensor

The most important current feedback component of the 600A constant current source is the zero flux current sensor [11]. The sensor performance determines the accuracy and stability of the constant current source. The sensor converts large current into small current proportionally by the principle of self-balancing zero flux [12]. The principle block diagram of zero flux sensor is shown in Fig 3.

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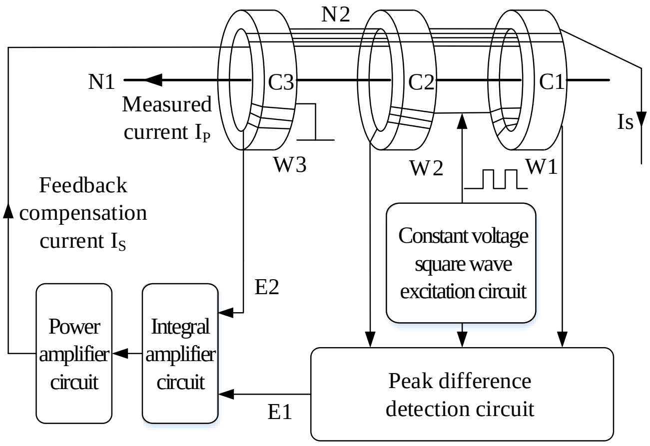

Fig 3: Principle block diagram of zero flux sensor E1 E2

The sensor uses the structure of three magnetic rings to measure the current. Firstly, the winding with the same number of turns is wound on two high permeability cores C1 and C2 with the same geometric size and permeability. The excitation circuit is used to make the cores in a deep saturation state [13]. The measured current I_P is modulated into the second harmonic signal. The peak difference detection circuit converts the second harmonic signal into DC signal E1. The integral amplification circuit amplifies the signal E2 induced in the magnetic ring C3 and the signal E1. The power amplifier generates the magnetic flux opposite to the measured current I_P by the feedback winding N2 until the magnetic flux produced by I_P is equal and the magnetic ring is in zero flux state [14]. As shown in formulas (1) and (2).

$$I_P \times N1 = I_S \times N2 \tag{1}$$

$$I_S = \frac{N1}{N2} \times I_P = \frac{1}{1500} \times I_P \tag{2}$$

The number of turns of the current measured is N1 = 1, and the number of turns of the secondary winding is N2 = 1500 [15]. The measured current can be obtained by measuring the size of I_S. The linearity of the sensor is better than 10 ppm.

3.1.2 Current power amplifier

The system uses commercial programmable power module with high reliability and high stability. The power module makes use of broadband modulation high frequency switching power supply technology [16], which can continuously output constant current for a long time. It can not only meet the requirements of EN/UL60601 and other safety standards, but also meet the requirements of electromagnetic interference B level.

The power module uses voltage-controlled output, with the maximum output of 200 A. Therefore, three current units are connected in parallel to realize the output capacity of 600A, as shown in Fig 4.

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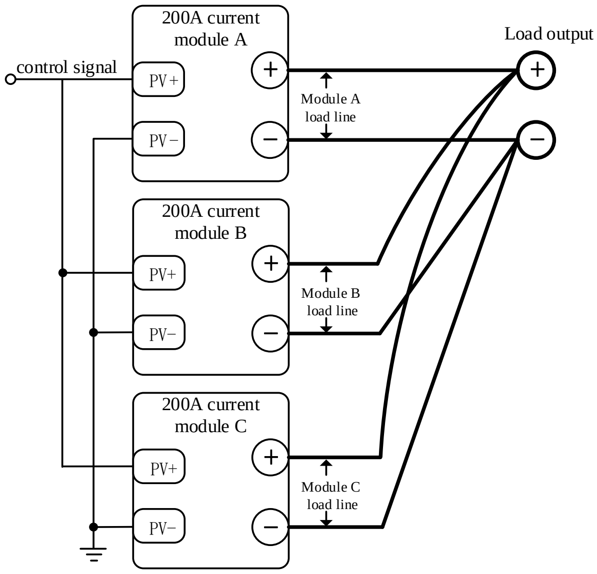

Fig 4: Current power amplifier power supply

3.2 Design of non-interference between power modules

When the 18 constant current sources of the whole device are connected in parallel, high-power diodes and large-capacity relays are designed inside each constant current source, as shown in Fig 5. The forward current of the diode can stably flow through 1000 A, the diode has high anti-surge current tolerance. Due to the unidirectional conduction of the diode, it can ensure that 18 constant current sources are not affected each other; the diode also provides a fixed load for the constant current source, which is more conducive to the stable output of the current. Large capacity relay can control the number of constant current source to access to the whole system. When a constant current source fails, the main circuit of 10kA standard DC constant current source can be completely disconnected electrically, and other constant current sources can be put into use normally. The whole device will not be affected and the redundancy of the whole device will be improved.

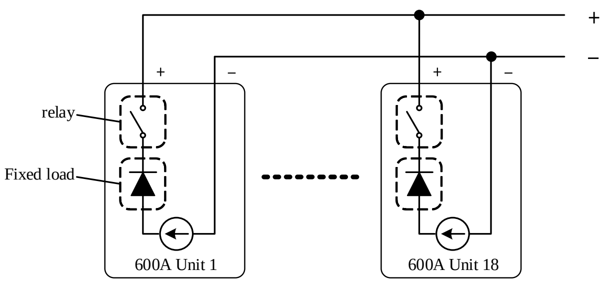

Fig 5: Parallel Structure Diagram of Constant Current Source

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3.3 control strategy

The console of 10kA standard DC constant current source device communicates with 18 constant current sources by RS485. The console is the control core of the whole constant current source device, and 18 constant current sources are controlled by it. When the 10kA standard DC constant current device to output current I, the console according to the number of access to the constant current source N, controls each constant current source output current I/N by RS485 ; at the same time, each constant current source feedbacks its output current and alarm information to the console by RS485 [17]. The console accumulates the output current value of each constant current source to obtain the total output current of the whole device.

3.4 Design of busbar

Since the current of 10kA standard DC constant current source device is very large at full load, considering the loss and heat dissipation [18], the traditional cable connection is no longer feasible. Compared with the cable, the copper bar has the advantages of large carrying capacity, good heat dissipation, less loss, easy processing, forming and convenient installation. Therefore, the device makes use of the copper row structure as the connection mode of the device, as shown in Fig 6.

Fig. 6: Current copper bar structure

IV. PERFORMANCE TESTING

10kA standard DC constant current source is tested by zero flux sensor with linear error less than 1ppm 、standard resistance and high precision digital multimeter 3458A.

4.1 current error

The relative error of current is shown in TABLE I.

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TABLE I. DC Current error

Set value (A)	Actual value (A)	Relative error (%)
1000	1000.063	-0.0063%
2000	2000.056	-0.0028%
3000	2999.961	0.0013%
4000	3999.942	0.0015%
5000	4999.95	0.0010%
6000	5999.96	0.0007%
7000	6999.94	0.0009%
8000	7999.96	0.0005%
9000	8999.99	0.0001%
10000	9999.98	0.0002%

The result shows in the TABLE I: the lower the current the greater the relative error. That is because when the whole device outputs 1000 A, each 600A constant current source outputs only 55.555 A, which is less than 10% of the maximum load capacity of single constant current source, at this time the accuracy of the constant current source itself is low. Conversely, when each constant current source works close to full range, the accuracy index is the highest, so the relative error is the smallest when the whole device outputs 10000 A.

4.2 Current stability

10kA standard DC constant current source set output 1000 A, 2000 A, 3000 A, 4000 A, 5000 A, 6000 A, 7000 A, 8000 A, 9000 A, 10000 A, observed current output relative stability of 2 minutes. The test data are shown in TABLE II.

TABLE II. Current Stability Test Data

Current (A)	Maximum value (A)	Minimum value (A)	Relative stability (ppm/min)
1000	1000.067	1000.061	6
2000	2000.068	2000.054	7
3000	2999.964	2999.958	2
4000	3999.951	3999.94	2
5000	4999.97	4999.95	4
6000	5999.98	5999.96	2
7000	6999.95	6999.93	2
8000	7999.96	7999.94	3
9000	8999.99	8999.97	2
10000	9999.99	9999.96	3

The result shows in the TABLE II: the greater the current, the better the relative stability of the current. It is that the whole constant current device uses the structure of 18 constant current sources in parallel, which is conducive to the stability of the current output of the whole device, which is equivalent to averaging and smoothing the stability of a single current source. Therefore, compared with a single 600A constant current source, the current stability of the whole device is better.

V. CONCLUSIONS

The device uses the modular design, and 18 constant current sources of 600A are designed in parallel to form a 10kA constant current source. For each 600A constant current source, a deep negative feedback constant current source circuit architecture is designed, a voltage controlled programmable power supply is used as the power amplifier, and a current sensor based on the principle of zero magnetic flux is developed for the sampling feedback of 600A current, which ensures the stability and accuracy of each 600A constant current source. High power diodes and high-capacity relays are designed inside each constant current source to eliminate the mutual interference between constant current sources and improve the redundancy of the whole device. In addition, the whole device uses the copper bar structure as the connection mode to reduce the heat loss. The test results show that the current accuracy of the device is better than 0.01%, and the relative stability of the current is better than 10ppm / min. The successful development of the device solves the problem of tracing the source of high-precision DC large current value, and provides a basis for improving the transmission of DC large current value.

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