



# A precision ADC sampling system design

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## Abstract

**Introduction** The high-energy photon source, which has been built in Huairou, Beijing, has high requirements on magnetic field dithering. Magnetic field dithering is mainly determined by the stability of the output current of the power supply. In order to ensure the stability of the output current of quadrupole magnet power supply, the power supply sampling control loop needs to be precisely designed. In this paper, a precision ADC sampling system based on internal temperature control is designed to carry out precise control of the sampling ADC.

**Materials** In this design, precise ADC chip is used to complete the precise sampling of the system. The precise sampling system contains a DAC system for high-speed settings.

**Methods** In order to verify the design of the system, high-precision quadrupole magnet power supply is used for measurement.

**Conclusion** The experimental results show that the temperature variation range of precision temperature control ADC system is  $\pm 0.1$  °C. By using the precise temperature control ADC system, the output current stability of the high-precision quadrupole magnet power supply is effectively improved.

**Keywords** HEPS · Precision ADC · Precision temperature control · Full-digital control · Low temperature drift

## Introduction

The high-energy photon source, which has been built in Huairou, Beijing, has high requirements on magnetic field dithering. Magnetic field dithering is mainly determined by the stability of the output current of the power supply [1]. In order to ensure the stability of the output current of quadrupole magnet power supply, the power supply sampling control loop needs to be precisely designed.

In this paper, according to the actual design requirements, a precision ADC sampling system based on internal temperature control is designed and developed. The whole system consists of the following three key components: high-precision ADC system; precision temperature control system; high-speed DAC output system. The design scheme of high-precision ADC part, temperature control system part

and high-speed DAC part is given. The simulation software is used to analyze and verify the feasibility of the scheme. The performance of the precision sampling system is tested to verify the feasibility of the design scheme.

## System design

The precision ADC sampling system consists of three key components: precision temperature control, precision ADC and precision DAC. System design block diagram is shown in Fig. 1.

### Precision temperature control unit design

The design requirements of precision temperature control system are shown in Table 1.

First of all, the structure design of the precise temperature control part is introduced. A delicate insulation system is designed for the on-board system, which includes an acrylic shell, thermal insulation system and an inner shell to ensure the internal temperature is evenly controlled. The shell is made of acrylic material, which is both light and strong. The interior of the shell is covered with insulating material for

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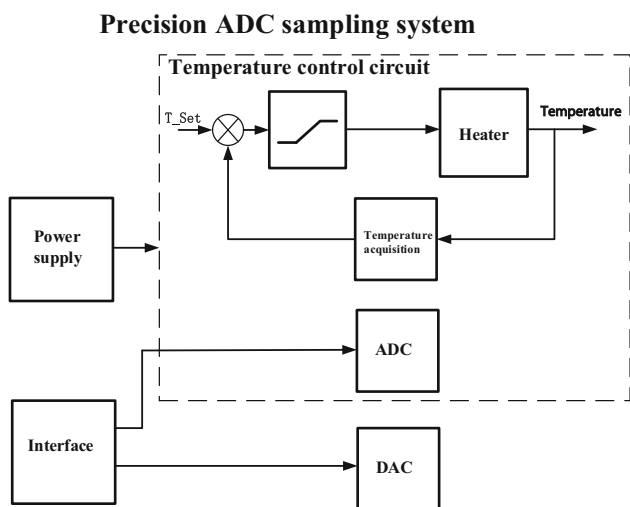


Fig. 1 System design block diagram

Table 1 Design requirements of precision temperature control system

Name	Value
Temperature set (°C)	60
Temperature set time (min)	≤ 18
Temperature control accuracy (°C)	±0.1 °C

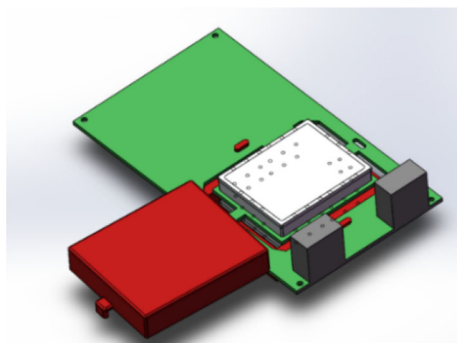


Fig. 2 Precise temperature control unit structure design

heat preservation. The inner shell is made of copper material with equal heat conduction to ensure the uniform control of the internal temperature of the system. The mechanical design of the temperature control part is shown in Fig. 2.

Secondly, the design of precise temperature control circuit is introduced. The design block diagram of the temperature control part is shown in Fig. 3, including precise reference, precise temperature feedback sampling and controller and heating circuit. The precision reference chip uses the AD581 chip from analog devices, has excellent long-term stability: 25 ppm/1000 h and trimmed temperature coefficient: 5 ppm/°C maximum, 0 to 70 °C; the precise temperature feedback sampling chip use the AD590 chip from analog devices, it has excellent linearity: ±0.3 °C over full range.

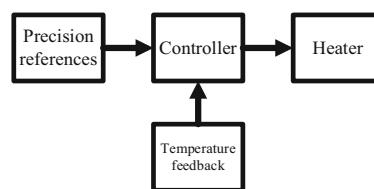


Fig. 3 Precise temperature control unit design

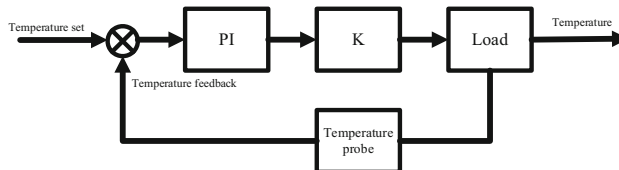


Fig. 4 Precise temperature control unit structure design

The control part of temperature control adopts analogy control mode. Compared with the digital control of discrete regulation, the analogy control belongs to continuous regulation, which has the advantage of high regulation speed and can effectively carry out precise temperature control. The specific control scheme design drawing is shown in Fig. 4.

Operational amplifier is actually used as the control core of the precision temperature control circuit. PI control circuit is built through the operational amplifier to complete the control function. In the circuit design, the temperature control function is completed by controlling the triode conduction. The schematic circuit diagram of the precision temperature control part is shown in Fig. 5.

### Precision ADC part design

Precision ADC part is used to complete accurate sampling of the output information of the power supply and assist the power control system to complete the closed-loop feedback of the entire power supply. Its performance is directly related to the performance of the entire power supply, so it needs to be carefully designed.

The precision ADC chip adopts the ADS8382 chip of TI Company. The ADS8382 is a high-performance 18-bit, 600-kHz A/D converter with fully differential, pseudo-bipolar input. The device includes an 18-bit capacitor-based SAR A/D converter with inherent sample and hold. The ADS8382 offers a high-speed CMOS serial interface with clock speeds up to 40 MHz. For precise ADC chips, a reference circuit is designed to provide accurate reference voltage. MAX6325 precision voltage with power conditioning circuit is selected to complete the benchmark setting of ADC chip. For the communication interface between ADC and the main controller, in order to ensure the reliability and safety of electrical performance, the high-speed digital isolation chip is actually used to complete the master control of ADC control and data read-back. In the analog input part of ADC, a precise voltage

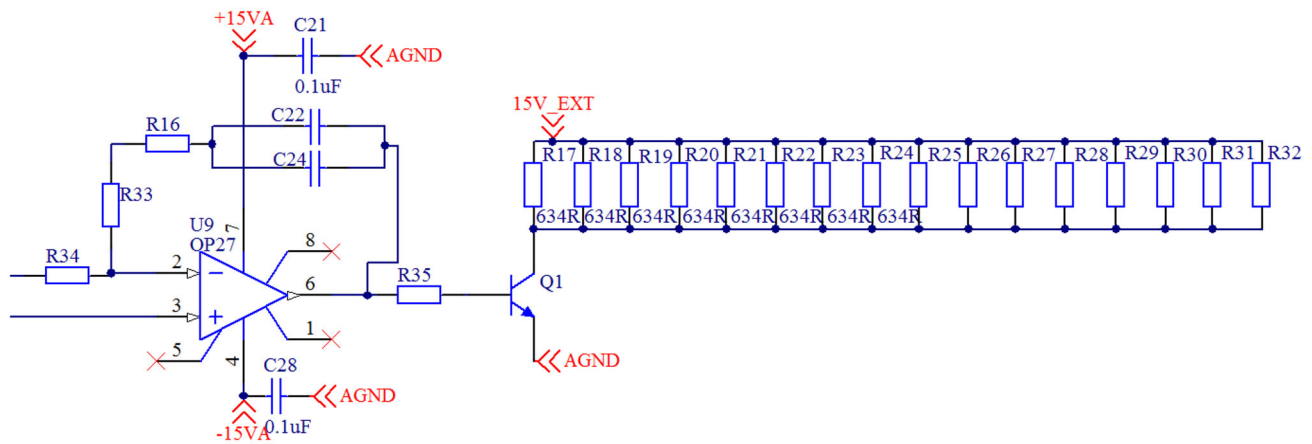


Fig. 5 Precise temperature control unit schematic design

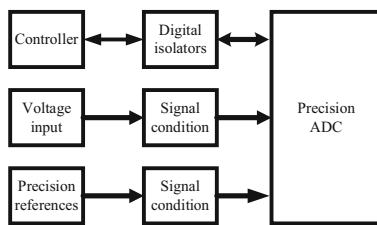


Fig. 6 Precision ADC design

conditioning circuit is actually designed to match the operating conditions under different input conditions. According to the ADS8382 chip data-sheet, the chip performs best at 60 °C [2]. The block diagram of precision ADC part is shown in Fig. 6.

### High-speed DAC part design

The high-speed DAC part is designed to be able to set the output of the power supply quickly and accurately. Meanwhile, the high-speed DAC system can also be used to extract the control system variables inside the digital controller when cooperating with the application of the digital controller, so as to facilitate the observation of the changes in the internal control parameters of the control system.

In fact, the AD5542A chip of analog devices is used as the high-speed DAC chip. The AD5542A is single, 16bit, serial input, unbuffered voltage output digital-to-analog converters that operate from a single 2.7 to 5.5 V supply. The AD5542A utilizes a versatile three-wire interface that is compatible with a 50 MHz SPI, and DSP interface standards. The AD5542A provides 16bit performance without any adjustments. The DAC output is unbuffered, which reduces power consumption and offset errors contributed to by an output buffer [3]. For precise DAC chips, a reference circuit is designed to provide accurate reference voltage. MAX6325 precision voltage chip from Maxim Company was selected to match the power

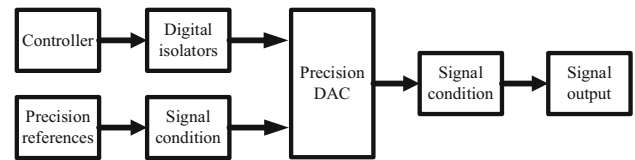


Fig. 7 High-speed DAC unit design

conditioning circuit to complete the benchmark setting of DAC chip. For the communication interface between DAC and the main controller, in order to ensure the reliability and safety of electrical performance, high-speed digital isolation chip is actually used to complete the master control of DAC control and data read-back. A precise voltage conditioning circuit is designed to achieve the precise and fast output of the DAC. The block diagram of high-speed DAC part is shown in Fig. 7.

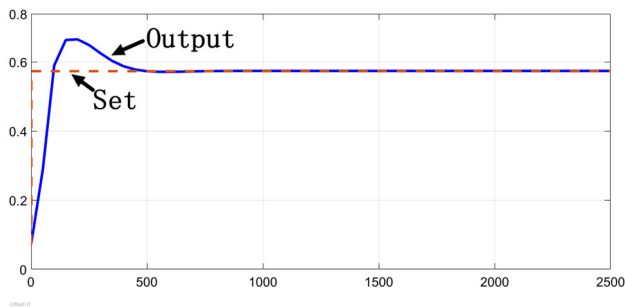
### Modeling and analysis of temperature control system

According to the design requirements of the temperature control system, MATLAB Simulink was used to model and analyze the temperature control system.

The difficulty of temperature control is that the inertia of the system is large and the hysteresis of the system is serious, which brings great trouble to the control system. The specific transfer function of the internal temperature in the temperature control box can be equivalent to the combination of the first-order inertia link and the delay link. In fact, based on the open-loop temperature sampling data, the transfer function of the internal model of the temperature control box system can be obtained. For the selection of control scheme, because PI control has the advantages of simple structure, good robustness, high reliability and easy parameter setting,



**Fig. 8** Temperature control system model



**Fig. 9** Simulation of step response of temperature control system

and the control method adopts PI control method. The actual model of the temperature control system is shown in Fig. 8.

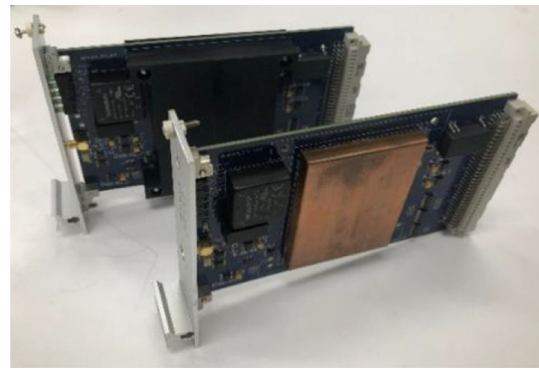
When adjusting the control parameters of the temperature control system, for the second-order control system, the control strategy of ensuring the adjustment time of the system is adopted to allow the control system to have overshoot under the condition of ensuring the adjustment time of the system. Since the temperature control is a large inertial system, the adjustment time of the whole temperature control system is set at 18 min. The step response of the temperature control system model was tested, and the step response curve of the system as shown in Fig. 9 was obtained. From the figure, it can be seen that the corresponding time of the temperature control system was 16.7 min, meeting the design requirements of 18 min.

## Prototype test

In order to verify the feasibility of the design scheme, a prototype of precision temperature control ADC sampling system was developed for testing. In the experiment, a HEPS quadrupole magnet power supply was used to test the precision ADC. The actual prototype is shown in Fig. 10.

## Precision temperature control unit test

In the temperature control unit test, in order to simulate the change of the external environment temperature, the temperature control box with controllable temperature is actually used as the actual test environment, and the prototype is put into the temperature control box for experiment. The 7-digit semi-digital voltmeter (KEITHLEY2010) was used to sample the data of the temperature sensor inside the temperature



**Fig. 10** Actual prototype



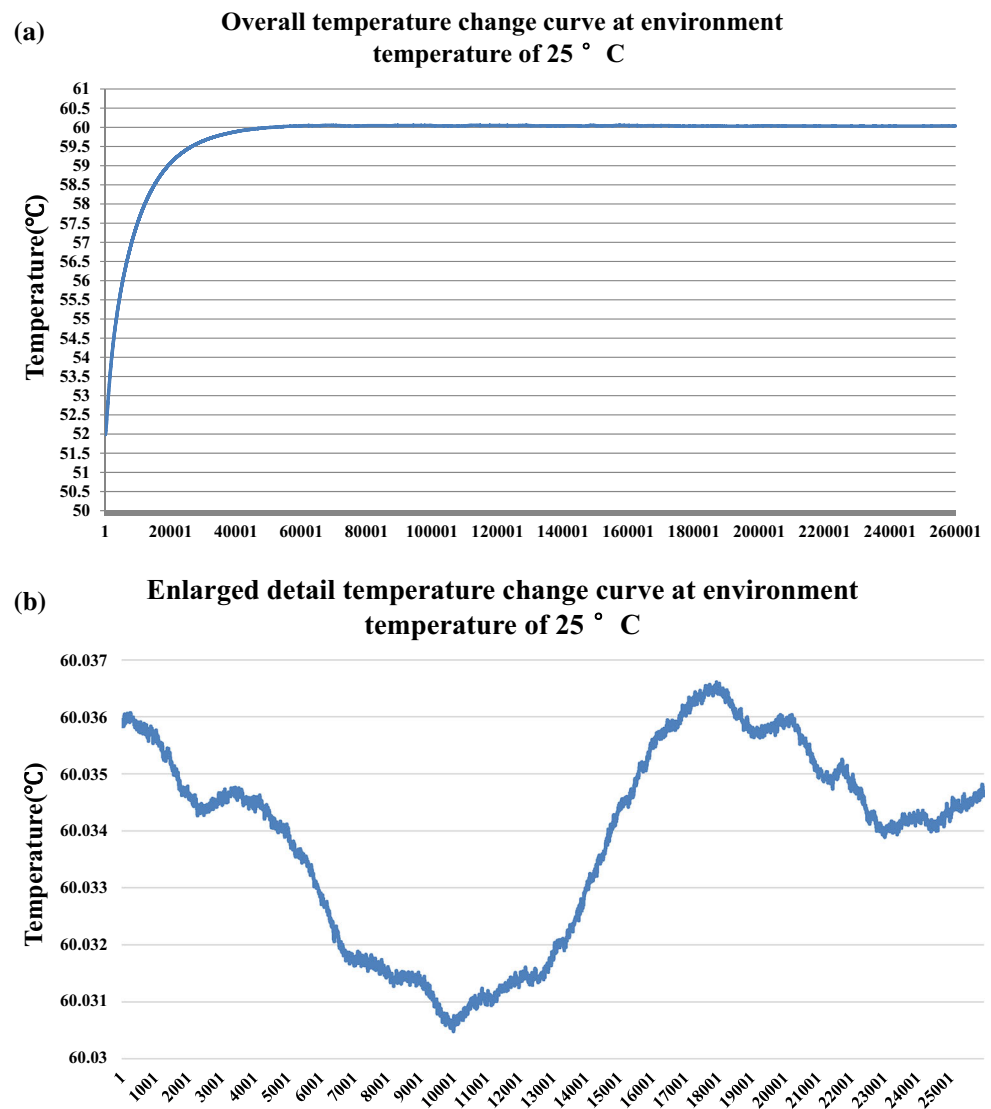
**Fig. 11** Temperature control test platform

control box and obtain the temperature change inside the temperature control box. The whole actual temperature control test platform is shown in Fig. 11.

First, the external temperature was tested at 25 °C, and the temperature of the temperature control box was set at 25 °C. After testing, the test curve inside the temperature control box is shown in Fig. 12a. The internal temperature of the temperature control box is set as 60 °C. After the actual test, in the temperature of 25 °C environment, temperature control box established time is 13 m, temperature curve without overshoot. By measuring the temperature in the control box, the maximum change in temperature control box is 0.0365 °C, which meet the design requirements of  $\pm 0.1$  °C. The specific curve is shown in Fig. 12b.

Considering that the operating environment temperature of the temperature-controlled ADC sampling system will change, the internal temperature of the temperature-controlled box will actually change when the external environment temperature changes. The temperature control box is used to change the environment temperature suddenly and increase the temperature disturbance artificially

**Fig. 12 a** Overall temperature change curve at environment temperature of 25 °C and **b** enlarged detail temperature change curve at environment temperature of 25 °C



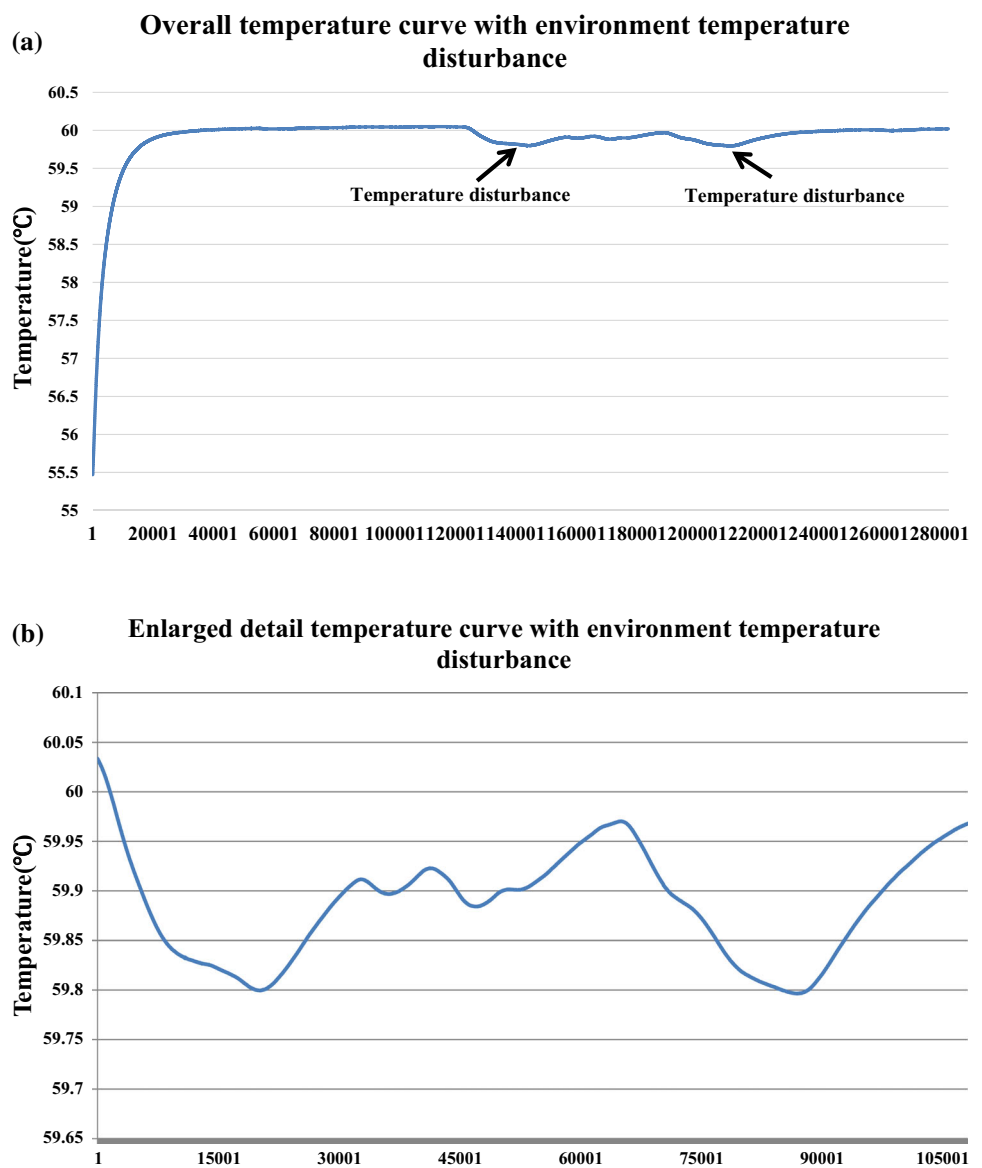
to test the reliability of the temperature control system. The actual temperature disturbance is set as a sudden drop in the environment temperature from 25 to 15 °C. Two environment temperature disturbance tests were actually carried out. Through these conditions, the adaptability of the temperature control system to the external environment is investigated. The actual temperature disturbance test curve is shown in Fig. 13a.

In fact, two sections of the environmental temperature disturbance curve were analyzed, and the temperature control system adjusted the environmental temperature disturbance for each time for 3 min. During the whole adjust process, the maximum change of internal temperature of the temperature control box was 0.2 °C. This set of tests is a limit test, and the specific curve is shown in Fig. 13b.

### Precision ADC unit test

Precision ADC unit test is actually conducted by using HEPS quadrupole magnet power supply. The power supply system of HEPS includes two parts: the booster power supply system and the storage ring power supply system [4]. In physical design, the stability and ripple of the storage ring quadrupole magnet power supply output current are highly required. Another important factor affecting the long-term stability of the current is the temperature drift of the power supply, that is, the device parameters generated by the temperature change [5]. The temperature drift characteristics of ADC devices are particularly critical in this power supply. Therefore, the developed precision ADC sample system is actually used as the closed-loop current feedback unit of HEPS quadrupole magnet power supply. The actual power test environment is shown in Fig. 14. During the system test, the temperature sensor is actually used to give the test environment tempera-

**Fig. 13** **a** Overall temperature curve with environment temperature disturbance and **b** enlarged detail temperature curve with environment temperature disturbance



ture change, as shown in Fig. 15. The power supply system actually outputs 200 A current and tests the stability of the power supply output current, as shown in Fig. 16.

After the actual test and analysis, the power supply output current stability is lower than 8 ppm. In this design, the developed precision ADC sample system as the closed-loop feedback system of the power supply, which can reduce the temperature drift of the closed-loop system due to the change of external environment temperature, improves the stability of the output current of the power supply and improves the performance of the power supply.

**High-speed DAC part test**

The DAC part is designed to be able to set the output of the power supply quickly and accurately. Meanwhile, the DAC



**Fig. 14** Power supply test platform

### Environment temperature Curve

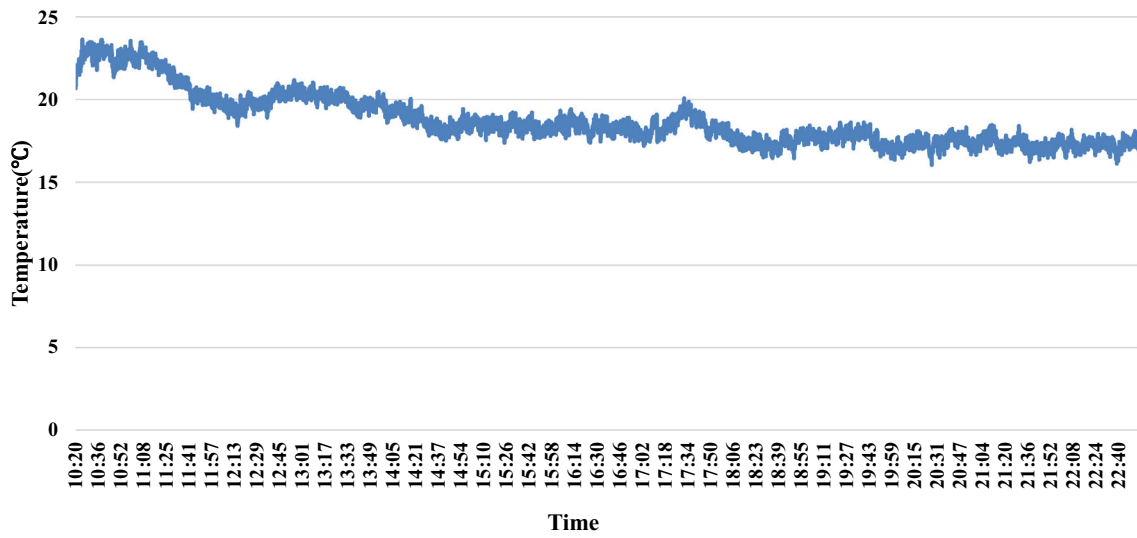


Fig. 15 Environment temperature curve

### Output Current stability curve of HEPS quadrupole magnet power supply

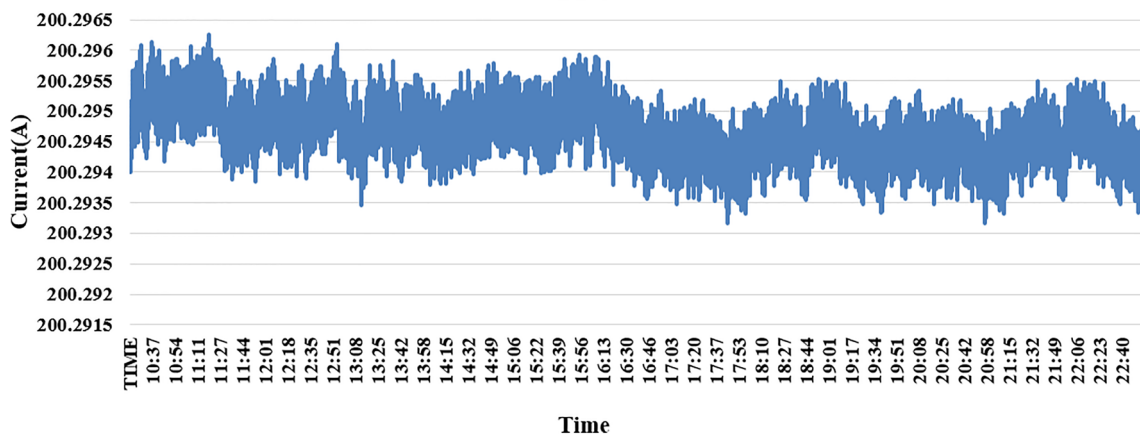


Fig. 16 Output current stability curve of HEPS quadrupole magnet power supply

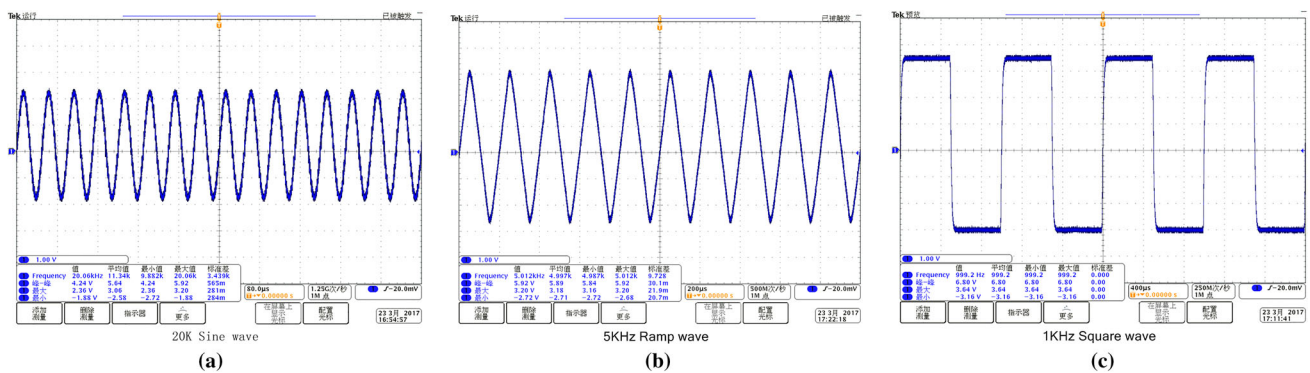


Fig. 17 a 20 kHz sine wave, b 5 kHz ramp wave and c 1 kHz sine wave

system can also be used to extract the control variables inside the digital controller when cooperating with the application of the digital controller, so as to facilitate the observation of the changes in the internal control parameters of the control system. In actual test, through online programming, DAC outputs waveform curves of different types and different frequencies, verifying the feasibility of high-speed DAC part design. The specific waveform is shown in Fig. 17.

## Conclusion

After fully tested, the precision ADC sampling system satisfied the design requirements. The overall structure of the design is reasonable. This system can meet the requirements in high stability output current of power supply in high energy

photon source. The precision ADC sampling system can be applied in the actual construction of high energy photon source.

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