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DESIGN OF DIGITAL CONTROLLER FOR MULTI MODULE SERIES-PARALLEL ACCELERATOR POWER SUPPLY

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Abstract

With the development of accelerators, Accelerator physics require power supply output high voltage and current (Peak power reached MWs). And the current stability requirements better than 10ppm. Therefore, the power supply is mostly used in the mode of module series-parallel. However, during actual commissioning, the power supply often does not run at rated current. If the power supply is running at less than 30% of the rated current, the power output current stability will drop sharply. This topic designed a set of digital controller for multi-module serial-parallel control. The digital controller can automatically adjust the number of input modules according to the current setting, and can automatically allocate the required PWM number of the module. While taking into account the synchronization between the various modules, Ensure the power supply is always running at an optimal working condition. Through a special AD conversion hardware design and advanced closed-loop controller algorithm, the digital controller can provide up to 20 high-resolution PWM signals to drive power conversion devices.

INTRODUCTION

According to the new requirement of accelerator physics for power supply, power supply design is developing towards high power or super high power. Due to the limitation of electronic components, multi-module series-parallel connection is widely used to improve the output voltage capability of power supply and the output current capability of power supply by parallel connection. And the ordinary medium and small power supply is also changing to modular power supply. In the past, the accelerator power supply was customized one by one according to the physical needs, and each power supply was different [1]. A large amount of R&D and design costs are needed, and there are many kinds of spare parts for power supply. With a modular power supply, it is only necessary to develop a modular power supply that can be connected in series with the module power supply to the required output current and voltage.

This topic intends to design an adaptive control system of modular power supply, which can judge the number of modules to be put in by detecting the actual output voltage and current of the power supply through program control. The module is switched on and off according to different power levels to realize on-line module switching, and the precise control of the algorithm ensures that the switching process is stable and controllable and does not affect the overall output stability [2]. At the same time, the automatic exit function of the failed module is designed. When individual modules fail, the controller can automatically cut off the driving signal of the module. Through the self-adaptive control of modular power supply, some modules do not output power when the accelerator is running, which invisibly increases the redundancy of power supply system and improves reliability, through the automatic withdrawal function of fault module, the failure time of power supply can also be reduced and the operation efficiency of accelerator can be improved.

Firstly, the multi-module series-parallel circuit simulation system is built by the simulation software of MATLAB, and the multi-module power supply circuit is designed to verify the PWM automatic allocation algorithm and adaptive control program. Then, the hardware of the multi-module series-parallel circuit digital controller is designed, and the main board, AD board and backboard of the digital controller are drawn, and the debugging is completed. Finally, the algorithm is debugged on the hardware circuit.

MATLAB SIMULATION OF MULTI-MODULE SERIES-PARALLEL POWER SUPPLY

A set of 10-module power supply is built through the simulation software of MATLAB. The power supply module can be connected in series and parallel. In order to verify the program, the module is initially connected in series with 10 modules. As shown in Fig. 1.

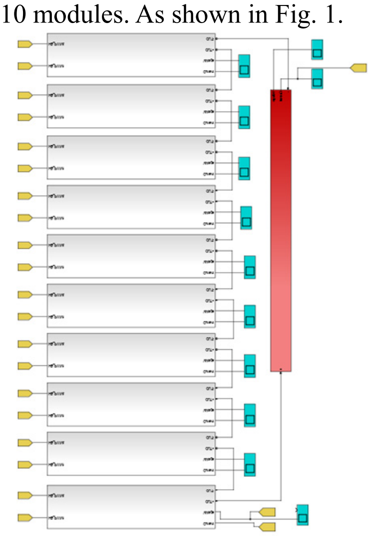

Figure 1: MATLAB simulation diagram.

The internal connection diagram of the module is shown in Fig. 2. The ideal DC source is used as the bus voltage, the H bridge circuit composed of IGBT is used

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for the latter DC-DC conversion, and the low-pass filter composed of inductance and capacitance is used for the output of the module. The output voltage ripple can be reduced and the output current stability can be improved by changing the characteristics of the system.

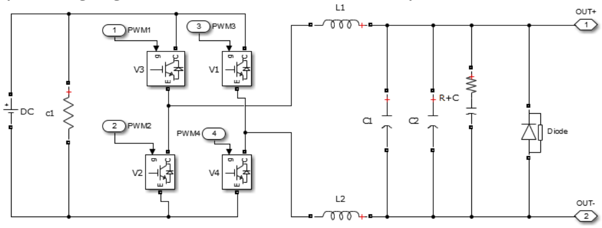

Figure 2: Internal simulation diagram of module.

The output PWM pulse width of the adaptive digital controller can be automatically allocated and phase shifted. For example :

Running 10 modules, 20 PWM pulse widths are output, each pulse width is staggered by 18 degrees.

Running 9 modules, 18 PWM pulse widths are output, each pulse width is staggered by 20 degrees.

Running 8 modules, 16 PWM pulse widths are output, each pulse width is staggered by 22.5 degrees

…

…

Running 1 module, output two PWM pulse widths, each pulse width staggered 180 degrees.

Module failures occur randomly, so module exits will also be random. The adaptive digital controller program must be able to cover all these random changes.

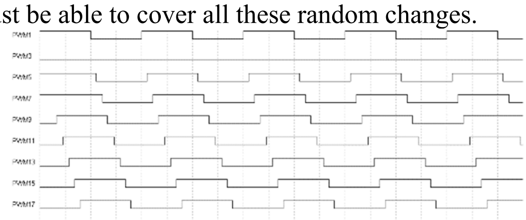

Figure 3: Module 2 does not work to output PWM waveform.

If running modules is nine. The module that does not run may be any one between module 1 and module 10, so there are 10 kinds of PWM allocation possibilities. Figure 3 is a sequence diagram of output PWM waveform when module 2 is not working. For display convenience, only the first PWM signal of each module is given. Because Module 2 does not work, the delay of Module 3 to Module 1 is 20 degrees and that of Module 4 to Module 3 is 20 degrees. Module 10 has a delay of 20 degrees relative to Module 9.

Figure 4 is Using MATLAB Function to Build Automatic Distribution PWM Algorithms Module. With a MATLAB Function block, you can write a MATLAB function for use in a Simulink model. The MATLAB function you create executes for simulation and generates code for a Simulink Coder target.

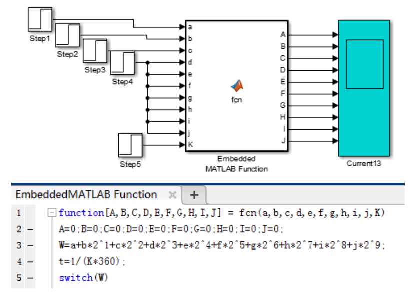

Figure 4: MATLAB Function.

This method can enumerate all the modules by enumerating, but the program is very cumbersome and the code is more than 10000 lines. The author has designed another set of streamlined program, only 16 lines of program can complete the automatic pulse width allocation algorithm.

After building a complete simulation model, the appropriate parameters are designed, and then the system simulation is carried out. The simulation results are as shown in Fig. 5.

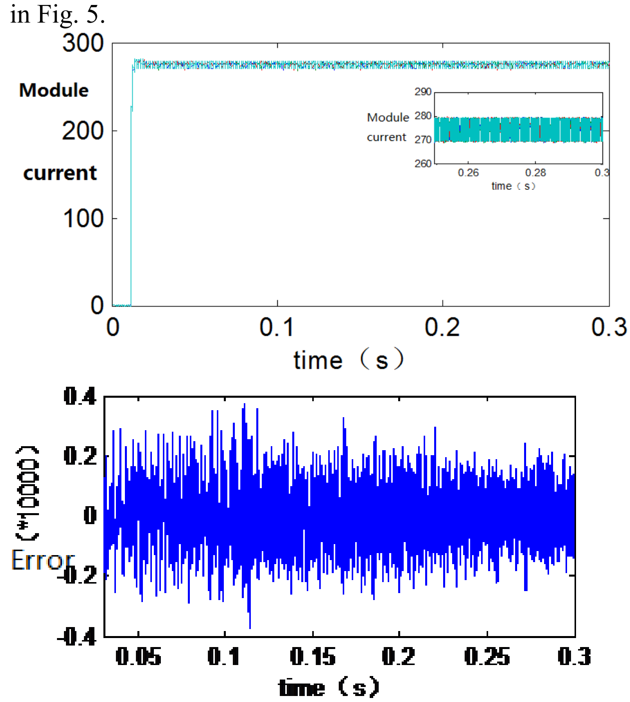

Figure 5: Simulation results.

The correctness and feasibility of the design are verified by simulation, which provides theoretical support for hardware design.

HARDWARE DESIGN

Based on Intel's Cyclone V chip, the hardware of the main board of the digital controller is developed. The hardware circuit diagram is shown in Fig. 6.

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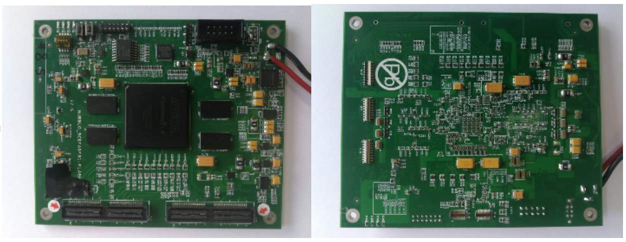

Figure 6: Digital controller motherboard.

Cyclone V is a relatively new processor launched by Intel, which has rich logic resources. By configuring appropriate external memory chips and power chips and designing IO ports according to the needs, we have completed the work of chip plate making, welding and principle testing.

Figure 7 is a screenshot of the software interface of Quartus 17.1 system.

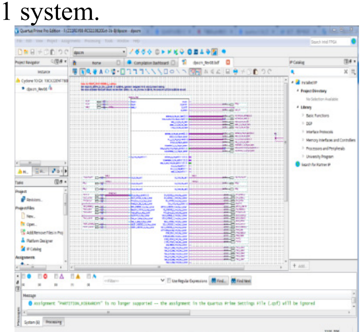

Figure 7: Screenshot of the software.

Single module design power is 400A/35V, water-cooled design. In order to reduce power consumption, soft switch design is adopted. Module height is 2U, AC power supply is 380V. The module is divided into two stages, AC-DC and DC-DC. AC-DC adopts PFC control circuit to reduce bus voltage fluctuation. The PWM signal output by the adaptive digital controller is used in the closed-loop control of the post-stage high frequency DC-DC. The circuit schematic diagram is shown in Fig. 8 and Fig. 9, and the mechanical diagram is shown in Fig. 10.

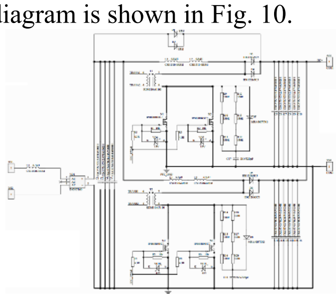

Figure 8: AC-DC Circuit diagram.

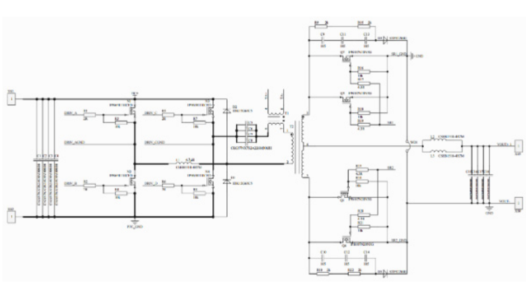

Figure 9: DC-DC Circuit diagram.

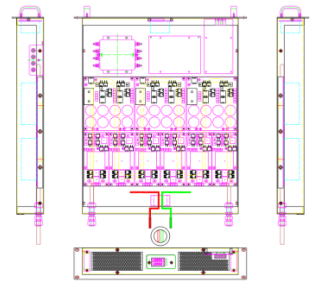

Figure 10: Modular mechanical drawing.

The power cabinet is a 19-inch standard cabinet. The single cabinet can install up to 10 power modules. As shown in Fig. 11, the power supply adopts the connection mode of down-in and out-of-line, and the cooling water is connected to one module through the water-cooled drain.

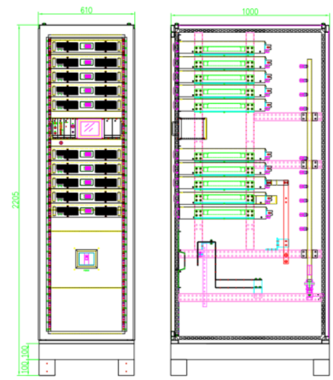

Figure 11: The power cabinet.

CONCLUSION

Firstly, this paper analyses the application prospect and market demand of multi-module series-parallel power supply in accelerator industry, then simulates the working principle of multi-module series-parallel power supply, designs the algorithm of automatic pulse width distribution and parameter self-tuning, finally designs the prototype of power supply, and completes the design of prototype schematic diagram and structure diagram. Next, the prototype will be produced and debugged.

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