SSRF MAGNET POWER SUPPLY SYSTEM

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Abstract

The primary design of the SSRF magnet power supply system is introduced in this paper. Schemes of the magnet power converters are presented. The performances of various prototypes for R&D subject are also described briefly in this paper.

1 INTRODUCTION

The accelerator of the Shanghai Synchrotron Radiation Facility (SSRF) is composed of a 300MeV linac, a 300MeV to 3.5GeV booster, 2 transfer lines, and a 3.5GeV storage ring. According to the operation character, the SSRF magnet power supply system is summarized with Table1.

Table 1 SSRF magnet power supply

Sub-System	P.S. Number	Capacity (KVA)	Op. Character
Transfer Line	52	200	Static
Booster	53	2800	1Hz Dynamic
Storage Ring	481	3564	Static

The design goal of the magnet power supply system is to meet the specifications required by the accelerator operation. The following design considerations are implemented in the design process:

(1) The power supply system must have high operation reliability and convenient machine repair access.

(2) Local and global EMC design.

(3) Optimize the power supply system design to reduce the construction and operation cost.

2 STORAGE RING MAGNET POWER SUPPLY

The specifications of the storage ring magnet power supply listed in Table 2 are designed to meet the requirements of the beam energy & position stability, and the allowable tune shift for the ring. The output current stability of the dipole and the quadrupole magnet power supply are ±0.005% and ±0.01% respectively under the interference conditions which include ±5% power lines fluctuation, load drift over the temperature range of 30 ± 3^{o} C. The output current ripple specification is set with considering attenuation on the field ripple caused by the magnet core and the aluminum chamber. The output rating is designed to be about 10% over the maximum operation current at 3.5 GeV.

Table 2 Storage ring power supply

P.S.	B	Q	S	Q_{T}, B_{HV}
No.	1	10	14	200 156
I_{out} rate (A)	850	360	340 300	±40 ±60 ±80
U_{out} rate (V)	900	620 385 315	185 160	10 20
Stability (24hrs)	±5E-5	±1E-4	±1E-3	±2E-4 ±1E-3
Repro-ducibility	±1E-4	±1E-4	±1E-3	±1E-3
Current Ripple	±1E-5	±5E-5	±1E-3	±1E-3

2.1 Dipole Magnet Power Supply

40 bending magnets on the ring are connected in series and fed by a single power supply. The power converter consists of a 12-phase SCR rectifier, a LC type main filter, a common mode filter and an active filter (see Fig. 1). The output voltage ripple components (peak-peak) from the rectifier are suppressed to 1-2% of DC output level by the main filter, the further 20dB attenuation is attained with the active filter. The regulator includes a current loop and a voltage loop connected in series to suppress the influence of load drift and power lines disturbance respectively.

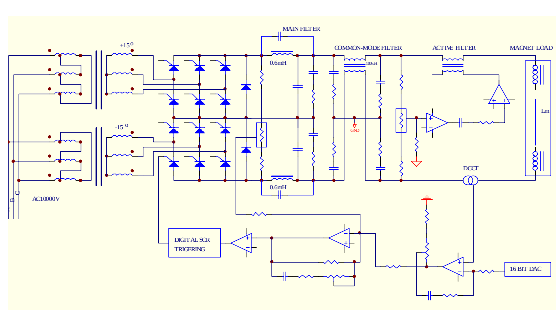

Fig. 1 The dipole power supply diagram

A prototype rated at 500A/100V has been built and tested for studies on the active filter, accurate regulation and other technique. The tested output current stability is $\pm 1\times 10^{-5}$ / 24hrs, and the current ripple is $\pm 6\times 10^{-6}$ (dummy load parameter L=55mH,R=0.2Ω).

2.2 Quadrupole Magnet Power Supply

200 quadrupole magnets on the ring are divided into 10 families, and the main windings of each magnet family are connected in series and excited by a single power supply while the trim winding of each magnet is fed by a individual bipolar power supply.

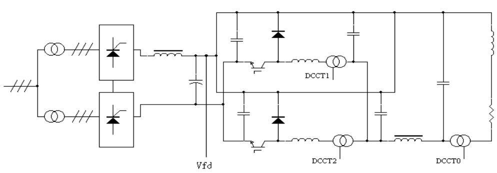

Fig. 2 The Q. magnet main winding power supply

A structure with SCR rectifier plus chopper type converter was designed for the main windings power supply (see Fig. 2). The chopper is composed of 2 IGBT branches connected in parallel through inductors, and both brunches are operated on pulse width modulation (PWM) mode at 20 kHz with 180° synchronization phase shift each other. With this structure, the converter has higher response speed and lower output ripple components compared with the single switch chopper. The output current regulation and branch current regulation loops are designed for the converter.

A prototype with full scale ratings of 360A/385V has been designed and built to study the parallel chopper topology and the EMC design technique. The stability of output current is $\pm 1\times 10^{-4}$ / 24hrs.

2.3 Sextupole Magnet Power Supply

140 sextupole magnets are divided into 14 families, the 10 windings of each family are connected in series and fed by a individual power supply. The full PWM bridge converter with ZVS (Zero Voltage Switch) mode was chosen as the power supply main circuit (see Fig.3).

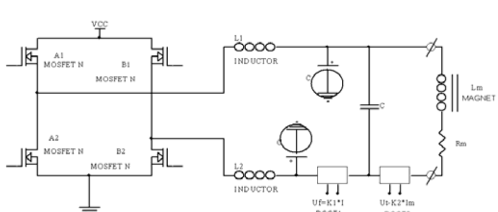

Fig. 3 The sextupole power pupply

To attenuate the ripple component caused by AC-DC rectifier in the output, the current feedback sampling point is set on the power bus before the output filter capacitor.

A prototype with 140A/210V rating has been designed and built for R&D. The output current stability is $\pm 6\times 10^{-4}$ / 24hrs; the output voltage ripple is $<\pm 1\times 10^{-3}$; the PS efficiency is > 95%.

2.4 Steering and Q. Trim Power Supply

All of the steering (B_{HV}) and Trim (Q_T) power supplies were designed with the bipolar bridge type scheme except their various output ratings. The circuit diagram is shown in Fig.4.

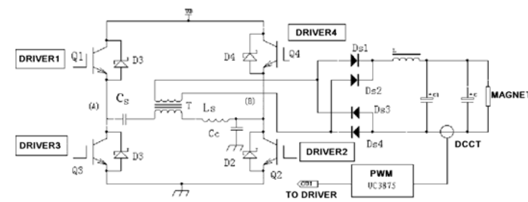

Fig. 4 The steering magnet power supply

All of the B_{HV} and Q_T power supply will be installed in 10 PS stations distributed along the ring, Two common DC sources were designed for B_{HV} and Q_T chopper in each PS station.

A set of B_{HV} and Q_T power supply prototype has been built and tested for R&D. The tested result are satisfactory for the designed requirement.

3 BOOSTER MAGNET POWER SUPPLY

The booster operating repetition rate is 1Hz, and both injection and ejection of beam are accomplished "on the fly". The booster magnet power supply system is designed to operate stably over the beam energy range 300MeV-3.5GeV. Both the ramp and return periods are set within 0.45 seconds, followed by 0.1 seconds rest time (see Fig. 5). The power supply specifications are listed in Table 3.

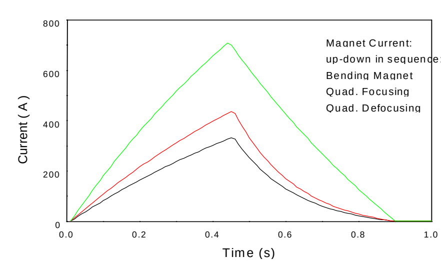

Fig. 5 The output current waveform of dipole & quadrupole magnet power supplies

The key techniques for the system design are:

(1) The dipole and quadrupole power supplies should be designed according to the dynamic characteristics and capable of tracking the 1Hz ramp reference accurately.

(2) An effective tracking control strategy should be chosen for the power supply ramp operation.

Table 3 Booster magnet power supply

P.S.	B	Q_F	Q_D
No.	2	1	1
I_{peak} (A)	694.2	442.4	447.4
U_{peak} (V)	825×2	295.4	236.9
P_{peak}(kW)	1145	130.7	160
P_{means} (kW)	178.4	38.59	31.46
Tracking Accuracy	0.1%	0.1%	0.1%

Note: Sextupole and steering magnet power supply are not included in Table 3.

3.1 Dipole Magnet Power Supply

36 dipole magnets are connected in series, and fed by 2 power supplies connected in series at the grounded middle point (refer to Fig. 6).

The power supply consists of a 12 phase SCR rectifier, a DC-DC converter and an energy storage circuit. To increase the response speed, the chopper is designed to be composed of 2 IGBT branches connected in parallel through inductors, and both branches are operated at 15kHz with 180° synchronization phase shift each other. The energy released by the dipole magnets during the booster return period will be stored in the capacitor bank through freewheel diodes and IGBT switches, and the stored energy will return to the magnets in the next ramping period.

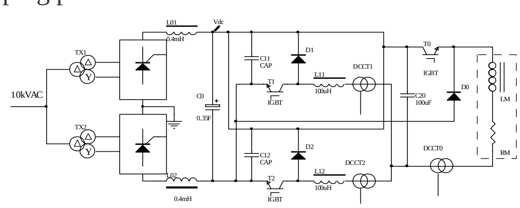

Fig. 6 The booster dipole power supply

The converter prototype has been designed and built for R&D. In the first stage, it was tested in DC mode at 500A/400V output level, the output stability of ±0.01% / 4hrs was achieved. The 1 Hz pulse operation mode was only test at low output level due to the lack of inductive load for full range operation, and 200A peak current was achieved**.**

3.2 Quadrupole Magnet Power Supply

48 booster quadrupole magnets on the booster are divided into 2 families of Q_F and Q_D. Each family has 24 magnets connected in series and employs a single pulse power supply for field ramp.

The power supply structure was chosen as the same as the one for storage ring quadrupole magnet except their regulator. A prototype with small scale was built for experimental study on the ramping control accuracy. The tested output current ramping error is less than 0.1% (refer to Fig. 7). This experiment result shows that the response speed of converter with 2 chopper branches meets the requirement of 1Hz ramp accuracy well.

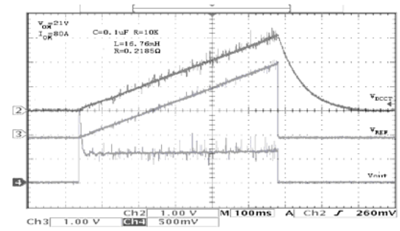

Fig. 7 The output current & error waveform of Q power Supply Prototype (I_p=80A, L=17mH, R=0.21Ω)

3.3 Strategy of Current Ramp Control

There are 5 sets of magnet power supplies (B, Q_F, Q_D, S_F, S_D) operated on the ramp mode, each of them has a built-in power supply controller (PSC) which communicates with the master computer through the fiber cable.

All current reference data of QF, QD, SF, SD are produced based on the dipole current curve and stored in the master computer as a "Ramping Table". The PSC downloads the ramping table from master. During the ramp period, the PSC will be synchronized by the accelerator timing signal and pick up the reference data from ramping table, and then send them to the respective power supply for current ramping. Meanwhile, all of the output currents will be read back in real time by PSC. With these current data information, the references are revised by master computer and sent back to the corresponding PSC for the future operation period.

4 CONCLUDING REMARKS

The primary design of SSRF magnet power supply system was accomplished in 2000, and various switching mode converter topologies were widely adopted for the power supply design. The R&D on the power converters were accomplished with prototypes effectively, that means a solid basis has been established for the equipment engineering design.

REFERENCE

[1] Shanghai National Synchrotron Radiation Center, "Primary Design of Shanghai Synchrotron Radiation Facilities", March 2000.