Operation of the SPring-8 SR Main Magnet Power Supplies and Control System

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Abstract

After installation of the power supplies (PSs) of the main magnets in the SPring-8 Storage Ring (SR) in 1995, cable connections between the PSs and the magnets were completed in October of 1996. The final test operation and inspection of current stability, ripple measurement and control, interlock sequence and operation program were successfully carried out by March of 1996. During the SR beam commissioning and operations for the beam line users from March to July of 1997, the magnet power supply were operated successfully.

1. Introduction

SPring-8 storage ring consists of 48 cells of Chasman-Green type. Each cell has two Bending Magnets(B), ten Quadrupole Magnets(Q), seven Sextupole Magnets(S). Total numbers of Steering magnet PSs (StP) and auxiliary quadrupole PSs (QA) for the SR are 576 and 40, respectively. Eighteen sets of B, Q, S PSs, 40 QAs and 576 St-PSs are used. The power supplies for the magnets are controlled by the VME and remote I/O system.

2. Power Supply System

The maximum current, voltage, power and cubicle number for the B-PS[1] are 1270A, 1157V, 1470kW, and 1, respectively. Those for Q-PS[2] are 394A ~ 570A, 480 ~ 1281V, 192 ~ 728kW and 10. And those for S-PS[3] are 300A, 650~ 750V, 195 ~ 225 kW and 7. Total inductance of the B, Q, S magnets over 48 cells are 0.76 H, 0.45 ~ 1.25 H, and 0.62~0.72 H, respectively[4][5][6].

Each steering magnet(St) is connected to one PS of ±5 A and ±60 V. Total number of the St-PS is 192. Thirty-six sets of St-PS are mounted in 1 cubicle and are supplied a DC bus together.

The total numbers of the large PS's for B, Q, S is 18. Some Q-magnets, which are connected in series, are adjusted by auxiliary PS circuits (QA) to correct the modulation of the beta function and phase advance[7].

Forty QAs were installed for the long straight sections[8] in 1996. The other QAs are to be installed in future). These QAs are floated from the ground level with a few hundreds volts. They are 11~17A and 19~33V floating PSs.

The B-PS has four input transformers for 6.6kV, 24th phase thyrister diodes and a passive filter system.

Q-PS has 12th phase thyrister diodes and a reactor transformer active filter system. Figure 1 shows a block diagram of the Q-PS system. Input voltage for the Q-PS is 400 V.

QP-2,5,6,9 have bypass (2%) circuits to compensate a small difference of the excitation factors caused by the magnet yoke shape difference. This bypass circuits are connected to the terminal of Cell#5 magnet (Fig. 2).

Input voltage of the Sx-PS is 400V. A twelve phase thyrister diode system is stacked with a 33.3 kHz switching regulator system.

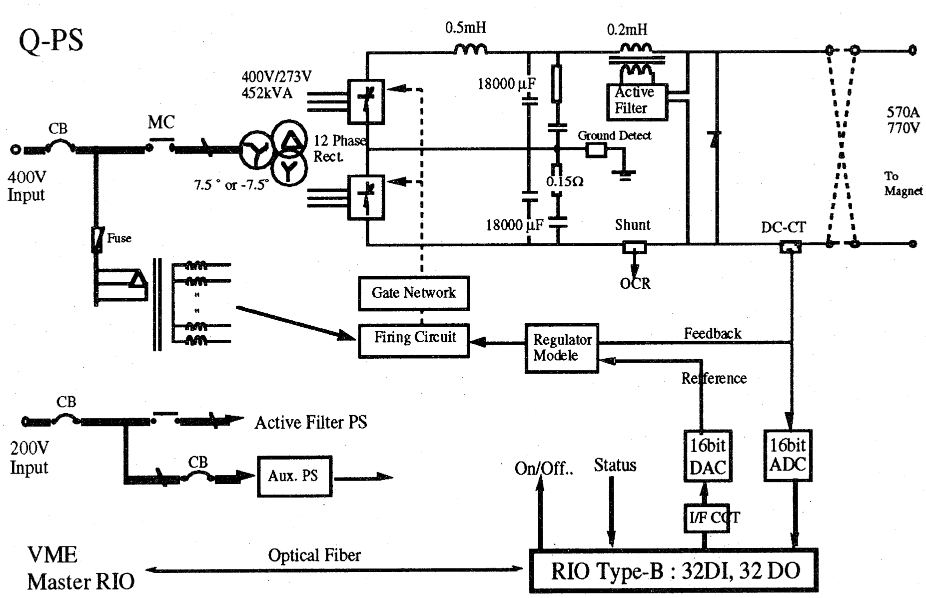

Fig. 1. Block diagram for the Quadrupole Magnet Power Supply.

Input voltage of the St-PS is 200V and a 100 kHz switching regulator system is used.

B, Q, S, QA and St-PSs are located in PS room-A. PS room-B, C, and D only have 192 sets of StPs and 10 sets of QA-PSs. The area for St-PS is air-conditioned (26°±2° C). The other area for BP, QP and SP is only air circulation (10° ~ 35°C).

3. Power Supplies and Cabling

Installation of the power supplies at the PS rooms and cabling to the magnets was settled in 1994 and 1995. Fig. 1 shows the cabling system between the QP and the Q-magnets, with an earth line. A CV-S (shielded cross-linked polyethylene insulated) cable is used for connecting between the PS and terminal board in the accelerator tunnel. A LMFC (flame retarding, flexible insulated wires) cable is used between the terminal board and the magnets.

Test operations for four QPs, ten QAs and two SPs with 14 cells QMs and SMs started in September 1996. The tasks of this test operation included surveying the alignment distortion of the magnets due to the heat of the cables (LMFC) under the girder of the QM and SM. During the test operation, the alignment distortion on the magnet girder was less than 30 microns with the maximum current excitation for 24 hours, and the maximum temperature of the LMFC cables was 40 °C.

A programmable logic controller (PLC) was adopted as a magnet power supply external interlock system for the BP, QP and SP. Magnet water flow switches and coil temperature switches are connected to 24 stations of local PLCs input modules in the maintenance hall, and concentrated interlock signals are fed to the PSs via a master PLC in the PS room-A.

4. Stability and Ripple Inspection

The final test operation, stability, ripple and power consumption measurement, control sequence and I/F (to RIO) inspections and cabling checks were done by the end of 1996. Three external DC-CT (Holec Co., Ltd. TOPACC) were adopted to the PS output cable for the measurement of long time stability. The actual current data calibrated the DAC and ADC data as a final database. Table 1 shows the measured stability and ripple ratio for BP, QP and SP. The stability was achieved better than 7 x 10^{-5} for 8 hours.

Table 1. Stability and ripple of the PS.

PS Name	Stability (8 Hr)	Ripple 60 Hz ~1 kHz
BP	0.6 * 10-5	1.0 * 10-5
QP1	5.4 * 10-5	1.1 * 10-5
QP2	6.3 * 10-5	0.8 * 10-5
QP3	4.8 * 10-5	1.0 * 10-5
QP4	7.3 * 10-5	0.8 * 10-5
QP5	4.3 * 10-5	1.0 * 10-5
QP6	5.6 * 10-5	1.1 * 10-5
QP7	6.7 * 10-5	0.8 * 10-5
QP8	7.3 * 10-5	0.7 * 10-5
QP9	3.4 * 10-5	0.3 * 10-5
QP10	5.3 * 10-5	1.0 * 10-5
SP1	2.8 * 10-5	3.3 * 10-5
SP2	7.4 * 10-5	2.7 * 10-5
SP3	4.0 * 10-5	3.4 *1 0-5
SP4	6.8 * 10-5	4.7 * 10-5
SP5	4.8 * 10-5	2.6 * 10-5
SP6	7.0 * 10-5	2.6 * 10-5
SP7	4.1 * 10-5	2.4 * 10-5

Figure 3 and a table 2 show the frequency spectrum of the QP's current ripple. The current ripples were measured by the DCCT (Holec) and an FFT at the magnet terminal of Cell#6, Cell#5 and at the PS output.

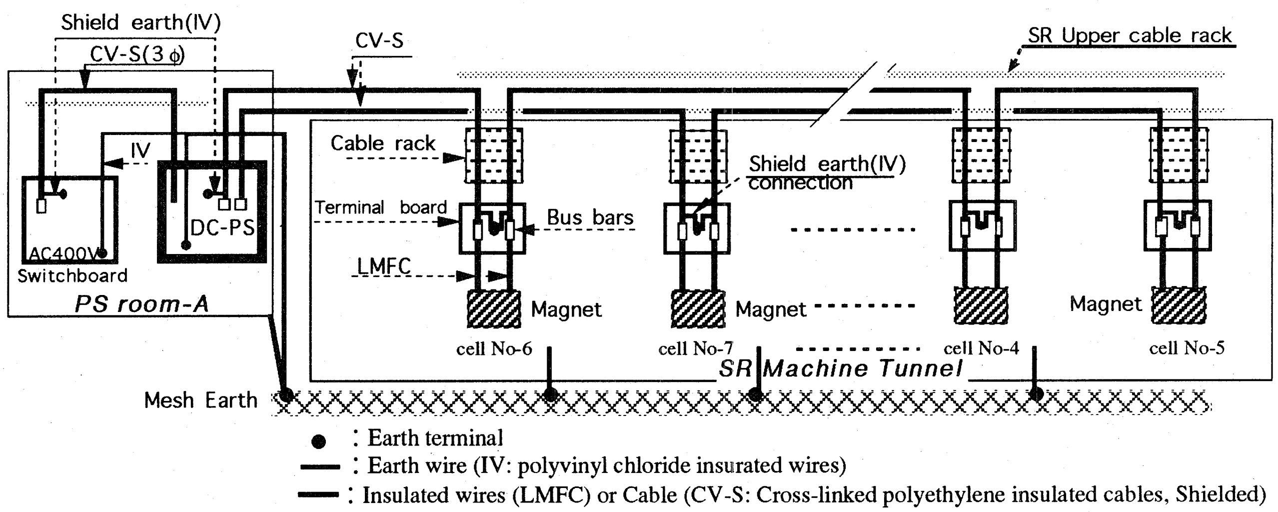

Fig. 2. The power supplies (QP, SP), magnet (QM, SM) cabling system and the earth line.

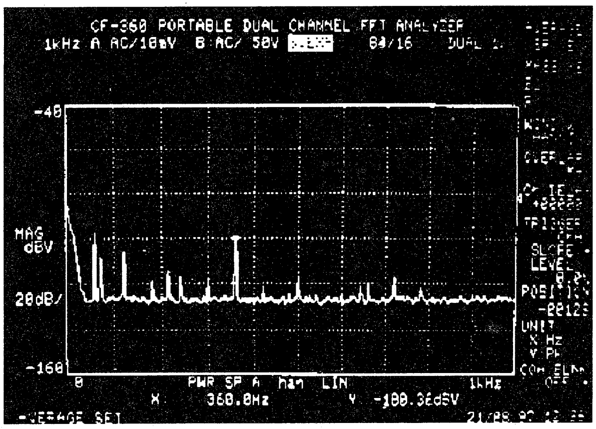

Fig. 3. Current ripple spectrum of the QP6, magnet in the Cell #6.

Table 2. Ripple frequency spectrum of the QP6 DCCT at Cell#6 (550A).

Hz	dBV	Ripple(A)	Ratio to 550A
60	-97	1.91E-03	3.47E-06
120	-104	8.57E-04	1.56E-06
180	-120	1.36E-04	2.47E-07
240	-118	1.71E-04	3.11E-07
300	-120	1.36E-04	2.47E-07
360	-100.4	1.30E-03	2.36E-06
420	-120	1.36E-04	2.47E-07
480	-118	1.71E-04	3.11E-07
600	-124	8.57E-05	1.56E-07
720	-118	1.71E-04	3.11E-07

For a bending magnet PS, four input transformers for 6.6 kV are located in an outer yard and connected by four sets of bus ducts with 24 phase rectifiers.

A 33.3 kHz MOS-FET switching regulator for the SP, is piggy-backed by the 12 phase thyristor regulator. This higher order ripple noise was not observed in the magnet terminals.

576 sets of steering magnet PS's were tested. And the current stability and ripple were better than 1.8×10^{-4}.

Table 3 shows the PS specifications, power consumption for the maximum operation mode and 2-cell mode Lattice operation. An AC 6.6 kV - 400V transformer connection are also indicated in this table 3. "R8" and "R9" are the titles of the transformer (AC 6.6kV to AC400V). Each sign (+/-) of these titles indicates a phase shift of +15 or -15 degree of the QP internal transformer.

In order to reduce the harmonic current distortion, input transformer phase of the five QPs (QP-1, 3, 4, 5, 10) are shifted. The QP has 12 phase thyristor diodes and a reactor transformer with an active filter system.

To reduce a heat effect for the magnet girder, the current density of the LMFC cables was suppressed to be small. Therefore, the magnet connection cable loss became smaller.

Table 3. QP and SP output specification, power consumption, and AC 400V inlet transformer connection for a maximum operation and a 2 cell mode Lattice operation.

	Designed Spec.			Actual Volt. & Power				AC Inlet		2 cell Mode Operation			Input
96.Dec.	(A)	(V)	Power	(V)	Ratio-V	Ohm	kW	KVA	Ratio	(A)	(V)	kW	Trans.
BP	1270	1157	1469	1053	0.910	0.836	1337	1627	0.82	1236	1033	1277	
QP1	410	480	192	367	0.765	0.895	150	256	0.59	220	193	42	R9+
QP2	394	918	360	821	0.894	2.084	323	483	0.67	318	632	201	R9-
QP3	410	578	237	444	0.768	1.083	182	303	0.60	-347	373	129	R9+
QP4	521	619	322	477	0.771	0.916	249	440	0.56	-487	439	214	R8+
QP5	549	726	399	568	0.782	1.035	312	497	0.63	523	535	280	R8+
QP6	549	726	399	562	0.774	1.024	309	540	0.57	523	534	279	R8-
QP7	521	619	322	476	0.769	0.914	248	440	0.56	-487	437	213	R8-
QP8	562	743	417	584	0.786	1.039	328	554	0.59	-451	460	208	R9-
QP9	569	1281	728	1123	0.877	1.974	639	947	0.67	498	970	483	R8
QP10	558	619	345	484	0.782	0.867	270	456	0.59	-376	313	118	R9+
SP1	300	650	195	590	0.908	1.967	177	254	0.70	232	455	106	R8
SP2	300	650	195	590	0.908	1.967	177	250	0.71	-266	506	134	R8
SP3	300	650	195	590	0.908	1.967	177	248	0.71	-244	465	113	R9
SP4	300	750	225	680	0.907	2.267	204	288	0.71	256	578	148	R9
SP5	300	650	195	590	0.908	1.967	177	252	0.70	-244	467	114	R9
SP6	300	650	195	590	0.908	1.967	177	251	0.71	-146	287	42	R9
SP7	300	650	195	590	0.908	1.967	177	254	0.70	256	510	131	R9

The QM coil resistance and the output voltage was achieved smaller than the designed value. In contrast, the power factors increased due to a decreasing output voltage. Accordingly, the QP input voltage (AC 420V) was decreased 5% by changing the transformer tap.

5. Remote Control and Program

The PSs of the SR magnets are controlled by a VME - RIO (Optical fiber distributed field BUS) system. The RIO type-A is used for StP, QA. It has a 16 bits DAC (Digital to Analog Converter) and a double integration type ADC (Analog to Digital Converter), which monitors the actual current using a shunt resistance output[10][11][12].

The reference voltage for the large (B, Q, S) PS current control is given by a 16 bit DAC, controlled by the digital output of the RIO type-B. These DAC's for the BP, QP and SP are installed in a temperature controlled box in the PS cubicle.

The ADC data is transferred to the RIO card via a 16 bits parallel signal. A cyclic time for ADC read out and status read out for the 22 RIO slave cards (for the BP, QP, SP and QP's bypass) is 5 ms. A VME controlled remote I/O card is connected to this PS using an optical fiber cable.

Fig. 5 shows a time chart of DAC data set and strobe signal for BP, QP and SP. The DAC set step time is within 50 ms. This current data bits control and I-DAC calculation program is run in the VME computer (EM: Equipment Manager). 576 set of current control can be achived simultaneously. The current and step number are ordered by UNIX RPC's command string (ex: "set/sr_mag_ps_q_main_1/200.00A", " put/exec_20.0sec ") from an operation WS to the EM.

A current set database, and Man-Machine control panels with a GUI (Graphical User Interface) are developed. They send the RPC command from the console GUI panel. Fig. 6 shows a BQS-PS's sequential current set program panel from the database and files. Fig. 7 shows a magnet initialing sequence used before new beam injection.

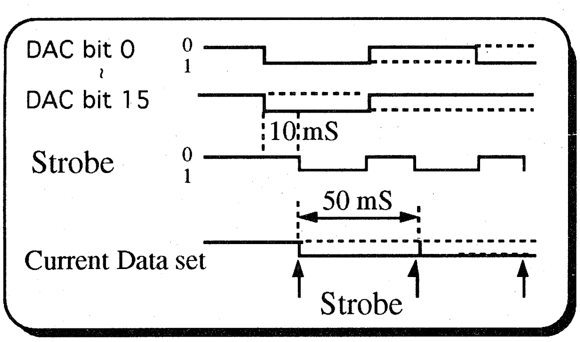

Fig. 5. Time chart of DAC data and strobe for BP, QP and SP.

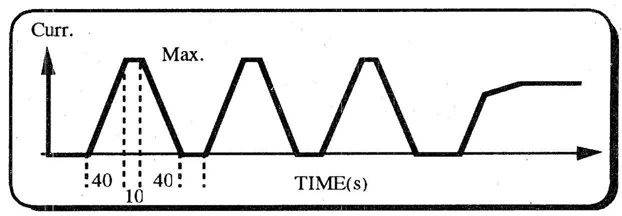

Fig. 7. Magnet Initializing Sequence.

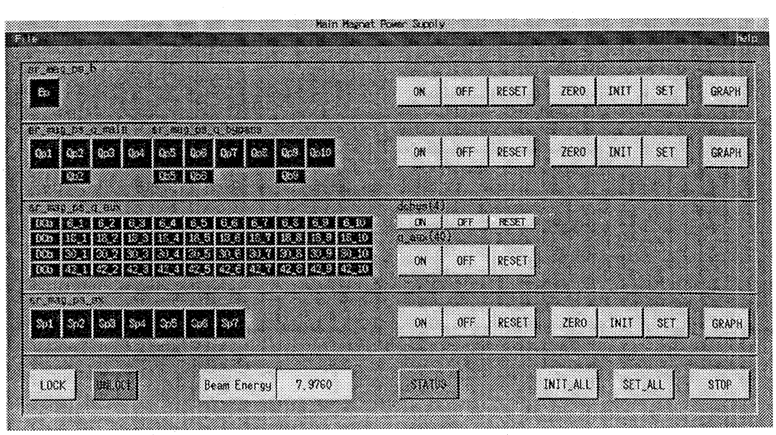

Fig. 6. BQS Control Panel of Operation Console.

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