Design of Power Supplies for SPring-8 Storage Ring Magnets

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Abstract

Machine parameters for seven operating modes of the SPring-8 storage ring were decided. Final design of magnets; dipole, quadrupole, sextupole, and correction magnets, have been made. A fundamental design of the power supplies system and connection of the magnets are investigated in this report.

Introduction

Seven operating modes of the SPring-8 were decided by Lattice group[1]. Final design of the dipole (B), quadrupole (Q), sextupole (Sx), and correction (Co) magnets have been designed. Table 1 shows a required strength for Hybrid, middle-β, high-β and Detuned Chasman Green (DCG) modes. Currents for magnets are calculated from these values, magnetic effective field lengths and excitation factors[2]. Maximum and minimum currents of the power supplies for the magnets will be listed later. To reduce the power consumption and an initial cost, total number of the power supplies must be as small as possible because large currents are required for a small coil space in the Q and Sx magnets. Connection and operation of the Q and Sx magnets are to be investigated. The circumference of the storage ring (SR) is 1436m. Figure 1 shows the layout of the SR, injection accelerators and power supply rooms. All the power supplies for the SR magnets are DC power supplies. A high stability and a low ripple current are required especially for the bending magnets (BM). A rising up time of the current is not necessary to be short (a few minutes). The operation current of the magnets power supply is designed for 8 GeV and 3 GeV beam also. The minimum currents of the Sx magnet power supplies are 18 % of the maximum currents for the seven operation modes. For an operation of the positron beam, (changed from the electron), the polarity switch of the PS's are installed. As a magnetic field ripple (induced by a current ripple) is reduced by an aluminum vacuum chamber, the allowance of the current ripple is about three times larger than that of the current stability.

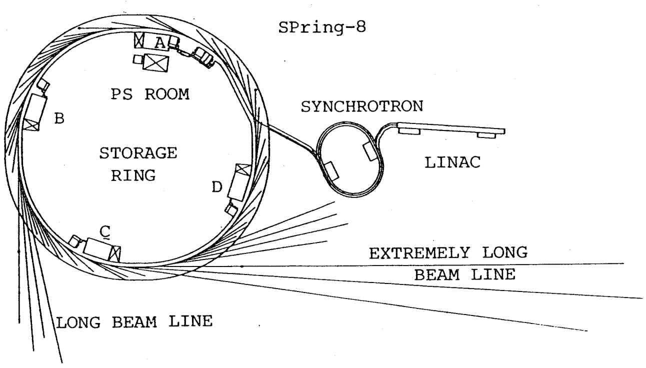

Fig.1. A layout of the SPring-8 storage ring, injection accelerators and power supply rooms.

Table 1. Required values of the Q and Sx magnets for seven operation modes

Magnet	Hybrid	middle ß	high ß	DCG 8	DCG 6	DCG 4	DCG 3	Max	Min	Min/Max
				(Detuned Chasman Green)				(Absolute Value)		
QD1	-0.2422	-0.4354	-0.2348	-0.3365	-0.2829	-0.2992	-0.3005	0.4354	0.2348	54%
QF2	0.3759	0.4121	0.3711	0.4077	0.3720	0.3409	0.3140	0.4121	0.3140	76%
QD3	-0.3905	-0.2531	-0.3906	-0.4094	-0.4081	-0.3552	-0.3319	0.4094	0.2531	62%
Q4	-0.5077	-0.6000	-0.5077	-0.3870	-0.4105	-0.3765	-0.3581	0.6000	0.3581	60%
Q5	0.5555	0.5799	0.5555	0.4213	0.3334	0.3165	0.2969	0.5799	0.2969	51%
Q6	0.5555	0.5799	0.5555	0.3850	0.3608	0.3213	0.2970	0.5799	0.2970	51%
Q7	-0.5077	-0.6000	-0.5077	0.4074	-0.2877	-0.3095	-0.3074	0.6000	0.2877	48%
QD8	-0.5297	-0.2531	-0.3906	-0.4536	-0.4412	-0.4489	-0.4237	0.5297	0.2531	48%
QF9	0.5749	0.4121	0.3711	0.3506	0.3632	0.3591	0.3489	0.5749	0.3489	61%
QF10	-0.4309	-0.4354	-0.2348	-0.2875	-0.3467	-0.3234	-0.3091	0.4354	0.2348	54%
Sx1	3.5463	0.0000	2.0800	0.0000	0.0000	0.0000	0.0000	3.5463	0.0000	0%
Sx2	-4.0383	0.0000	-2.0616	0.0000	0.0000	0.0000	0.0000	4.0383	0.0000	0%
Sx3	-4.3757	-3.3593	-3.5308	-1.4909	-2.0060	-1.1570	-1.2709	4.3757	1.1570	26%
Sx4	7.7652	2.9091	3.1285	1.9722	2.4202	1.4021	1.5019	7.7652	1.4021	18%
Sx5	-4.3757	-3.3593	-3.5308	-1.4909	-2.0060	-1.1570	-1.2709	4.3757	1.1570	26%
Sx6	-3.0021	0.0000	-2.0616	-1.4909	-2.0060	-1.1570	-1.2709	3.0021	0.0000	0%
Sx7	4.8322	0.0000	2.0800	1.9722	2.4202	1.4021	1.5019	4.8322	0.0000	0%

Emit	5.3		5.7	23.1	36.8	53.3	81.7	nm.rad
Tune (Vert.)	19.2	18.3	16.2	21.1	21.1	21.1	20.9	
(Horiz.)	51.2	42.3	42.2	31.2	28.2	25.2	22.8	

Bending Magnet Power supply

The maximum current of the BM for 8 GeV (0.66 Tesla) is 1320A. All the BMs are connected in series, and excited by one power supply. The total resistance of the 97 magnets, including one reference magnet, is 1.57 ohm and that of cable is 0.095 ohm. The total voltage of the power supply is 2233V. Table 2 lists these parameters for the bending magnets. In order to reduce the terminal voltage of the magnet and cable against the earth, the PS is divided into two devices and the voltage is divided by four (~550V) as shown in Fig.2. BP-0 has a current control circuit, and BP-1 has a voltage control circuit. Connection cable is a pair of two parallel 400 mm^2 CV cable (total=800mm^2). Every pair of the BM's of the alternating cells are connected. The two separated cabinets of the BPs are located in the same PS room (see Fig.3). The current stability and the ripple are 1 x 10^{-5} and 3 x 10^{-5}, respectively. A temperature controlled cooling water (25 ± 0.5 °C) is supplied for the power supply's shunt resistance. The reference voltage for the current

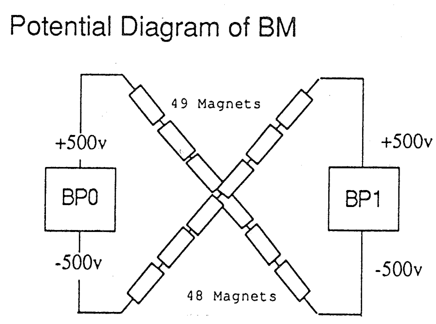

Fig.2. Potential diagram of the bending magnets and power supplies.

Table 2. Designed parameters for the bending magnets.

Magnet Name	PS Name	length (m)	Max.Curr. (A)	R(Mag.) Ω	No.Mag. / P.S.	Rm Ω	Cable km	mm2	Ω	Rm+Rc Ω	V (PS) V	P(mean) (kW)	No.PS	Total Power (kW)	Connect Type
BM	BP0-1	2.81	1340	0.0162	97	1.571	4.200	800	0.095	1.667	2233.43	2992.80	1	2992.8	B

control is given by a hi-precision 16 bit DAC (Digital to Analog Converter). This DAC and amplifier are enclosed in the temperature controlled housing.

Quadrupole-Magnet Power supply

Required maximum currents and voltages for the Q-magnets are listed in Table 3. To reduce the number of the PS's and a power consumption, the same Q-magnets of the each cells are connected in series (connection type A). The Q4,Q5,Q6 and Q7 magnets are just connected in series with 48 cells, respectively (Fig.4; connection type A). The other same named Q-magnets, (Q1, Q2, Q3, Q8, Q9, and Q10) are connected in series, respectively, but are adjusted by bypass control circuits[3] to correct the insertion device distortions (Fig.5; connection type C). The current corrections for the insertion devices are needed for 0.5% (Q2,Q3, Q8 and Q9), 4% (Q1) and 2% (Q10) to the maximum current[4]. In this Table 3, the bypass voltage is the magnet voltage. The minimum voltage is 48~76% of those values (see Table 1). Because it is better to reduce an isolation voltage between each bypass circuit (less than ~100 V), 48 cells magnets will be divided into four or eight groups. An efficiency of a large current and low voltage power supply is not good, therefore, the bypass type will save the power and cost. The current stability and the ripple are 1 x 10^{-4} and 3 x 10^{-4}, respectively. The shunt resistance and the DAC/Amp. housing of the Q-PS main current supply is cooled by the temperature controlled water (25 ± 0.5 °C), but the bypass control circuits (and other transistor bank, transformers, etc.) are cooled by a normal (de-mineralized) water (25 ± 3 °C) .

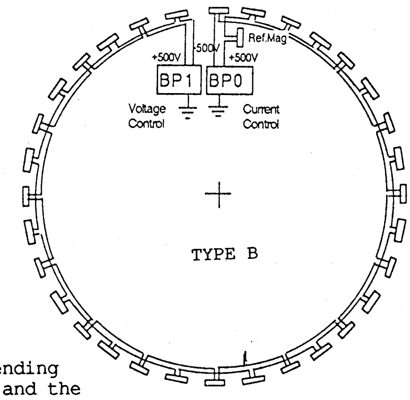

Fig.3. Bending magnets and the power supply connection.

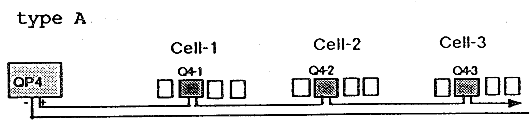

Fig.4. 48 cells magnets series connection for Q4 ~Q7.

Table 3. Designed parameters for the Q-magnets.

Quadrupole Magnet	P.S.	length (m)	Max.Curr. (A)	R(Mag.) Ω	Bypass 0.2-4% V	I(A)	W	No. / P.S.	Rm Ω	Cable km	mm2	Rc Ω	Rm+Rc Ω	V (Main) V	P(Main) (kW)	No.PS	Total Power (kW)	Connect Type
QD1	QP1	0.5	676.30	0.0110	7.4	27.1	201.2	12	0.132	1.05	400	0.049	0.181	122.36	85.2	4	340.7	C
QF2	QP2	1.1	640.80	0.0242	15.5	1.3	19.9	12	0.290	1.05	400	0.049	0.339	217.44	139.6	4	558.3	C
QD3	QP3	0.6	636.00	0.0132	8.4	1.3	10.7	12	0.158	1.05	400	0.049	0.207	131.86	84.0	4	336.0	C
QD4	QP4	0.5	932.80	0.0110				48	0.528	4.20	500	0.157	0.685	638.65	595.7	1	595.7	A
QF5	QP5	0.6	901.90	0.0132				48	0.634	4.20	500	0.157	0.790	712.74	642.8	1	642.8	A
QF5	QP6	0.6	901.90	0.0132				48	0.634	4.20	500	0.157	0.790	712.74	642.8	1	642.8	A
QD4	QP7	0.5	932.80	0.0110				48	0.528	4.20	500	0.157	0.685	638.65	595.7	1	595.7	A
QD6	QP8	0.6	823.80	0.0132	10.9	1.6	17.9	12	0.158	1.05	500	0.039	0.198	162.75	134.3	4	537.2	C
QF7	QP9	1.1	893.80	0.0242	21.6	1.8	38.7	12	0.290	1.05	500	0.039	0.330	294.57	263.7	4	1055.0	C
QD8	QP10	0.5	676.30	0.0110	7.4	13.5	100.6	12	0.132	1.05	400	0.049	0.181	122.36	84.0	4	335.8	C
																28	5640.0	

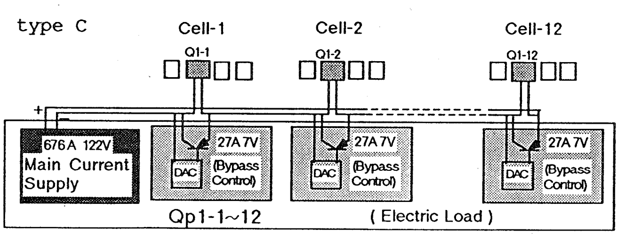

Fig.5. Bypass control circuits for the Q-magnets power supply.

Sextupole Magnet Power supply

Table 4 shows the required currents, voltages, resistances, etc. for the Sx-magnets. Magnets for the Sx-1 to 7 are connected in series in all cells, respectively (same as Fig.4). Sx3 and Sx5 magnets are operated by the same PS (SP3). If the voltage of the SP3 is exceed 600V, the terminal voltage will be divided into + and - , and take similar center grounded type to the BP. The total number of the Sx PS's is 6. For the operation mode of the Detuned Chasman Green as shown in Table 1, if the field level is needed to be zero quitely small, a de-gauss power supply system or a bi-polar small power supply can be switched. The current stability and the ripple are 1 x 10^{-4} and 3 x 10^{-4}, respectively.

Table 4. Required currents, cables and voltages for the Sx-magnets.

Sextupole Magnet	P.S.	Length m	Max.Curr. (A)	R(Mag.) Ω	No.Mag. / P.S.	Rm Ω	Cable km	mm2	Rc Ω	Rm+Rc Ω	V (PS) V	P(mean) (kW)	No.PS	Total Power (kW)	Connect Type
Sx1	SP1	0.45	577	0.0097	48	0.467	4.200	500	0.157	0.623	359.60	207.49	1	207.5	A
Sx2	SP2	0.45	656.8	0.0097	48	0.467	4.200	500	0.157	0.623	409.33	268.85	1	268.8	A
Sx3-5	SP3	0.45	710.5	0.0097	96	0.933	5.600	500	0.209	1.142	811.39	576.49	1	576.5	A
Sx4	SP4	0.60	948.4	0.0115	48	0.550	4.200	500	0.157	0.707	670.27	635.69	1	635.7	A
Sx6	SP5	0.45	489	0.0097	48	0.467	4.200	500	0.157	0.623	304.75	149.02	1	149.0	A
Sx7	SP6	0.45	787.2	0.0097	48	0.467	4.200	500	0.157	0.623	490.60	386.20	1	386.2	A
													6	2223.7	

Correction Coil Power supply

All coils for correction magnet (steering magnet) have independent power supplies. The total number of the Co-PS's are 672. The maximum current of the Co.PS's must be small. Table 5 shows required currents for the Co-coils. Some Co-coils are installed in the Sx magnets. Six horizontal correction coils in one Sx magnet are connected in series.

12 PS's are installed in one PS cabinet and controlled by one micro processor. All the Co-PS's are bi-polar system or have polarity switches. The current stability and the ripple for the Co-PS are 1×10^{-3} and 3×10^{-3}, respectively. The DAC interface is 12 or 14 bits.

Table 5. Required currents, cables and voltages for the Co-magnets.

Steer/Correction Magnet	P.S.	Length m	Max.Curr. (A)	R(Mag.) Ω	No.Mag. / P.S.	Rm Ω	Cable km	mm2	Rc Ω	Rm+Rc Ω	V (PS) V	P(mean) (kW)	No.PS	Total Power (kW)	Connect Type
Sx1	CP1	0.5	20.0	0.573	1	0.573	0.100	14	0.130	0.703	14.05	0.28	48	13.5	D
Sx2	CP2	0.5	20.0	0.920	1	0.920	0.100	14	0.130	1.050	21.00	0.42	48	20.2	D
Sx3	CP3	0.5	20.0	0.573	1	0.573	0.100	14	0.130	0.703	14.05	0.28	48	13.5	D
Sx5	CP4	0.5	20.0	0.573	1	0.573	0.100	14	0.130	0.703	14.05	0.28	48	13.5	D
Sx6	CP5	0.5	20.0	0.920	1	0.920	0.100	14	0.130	1.050	21.00	0.42	48	20.2	D
Sx7	CP6	0.5	20.0	0.573	1	0.573	0.100	14	0.130	0.703	14.05	0.28	48	13.5	D
C1H	CP7	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
C1V	CP8	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
C2	CP9	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
C3	CP10	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
C4H	CP11	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
C4V	CP12	0.5	40.0	0.229	1	0.229	0.100	14	0.130	0.359	14.36	0.57	48	27.6	D
B-C1	CP13	2.9	15.0	0.520	1	0.520	0.100	14	0.130	0.650	9.75	0.15	48	7.0	D
B-C2	CP14	2.9	15.0	0.520	1	0.520	0.100	14	0.130	0.650	9.75	0.15	48	7.0	D
													672	273.7	

All PS.No.	Total Power
707	11103.7 kW

Control by Computers

A reference voltage to the transistor regulator is supplied from a 16 bit DAC. This DAC is controlled by 15 or 12 bit registers through isolation devices. This register is strobed in a local processor (L-CPU) which communicate to the host processor[5] (see Fig.6). A 24 bit status (power on/off, fuse, transistor break down, temperatures, oven, polarity, ext-interlocks, door, water flows, etc.) is read by this L-CPU. An actual current (shunt voltage) is monitored by an ADC and checked by the L-CPU in every a few tens second. If the difference between the ADC and the DAC values exceeds some allowance, or if an error is occurred in the status, an error flag is send to the host computer.

Hardware

Except the BM power supply, all PS's are thyrister pre-regulated and transistor series regulated type (Fig.6). As a huge number of the devices are used in the PS's, many common devices must be the same unit, in order to provide an easy maintenance. For the isolation between the high voltage circuit and control circuit, highly reliable devices must be used. A DAC and a differential amplifier are enclosed in a temperature controlled housing (T < 40 °C). This housing is cooled by a conditioned air or a water, because higher temperature is not good for the lifetime of the semi-conductor devices. This must be also common device to get a easy maintenance. The power supply rooms are located in four sections as seen Fig.1 and the layout of the power supplies are shown in Fig.7. Only one PS room (A) includes 48 cells series connected power supplies (BP, Q4 ~ Q7, Sx1 ~ Sx6).

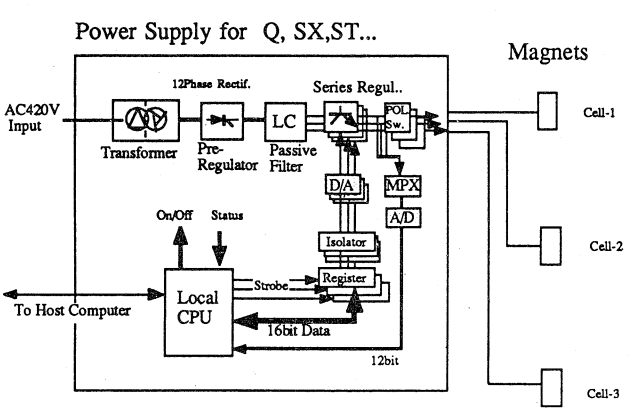

Fig.6. Power supply control system using a micro-processor.

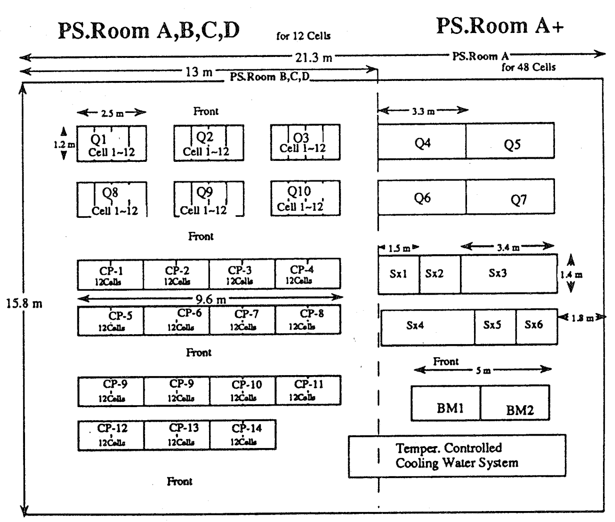

Fig.7. The power supply layout of PS.room-A,B,C,D.

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