DESIGN OF POWER SUPPLY SYSTEM FOR SPRING-8 STORAGE RING MAGNETS

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Abstract

Detailed design for the SPring-8 storage ring magnet power supply system had been made in a view point of production and operating cost reductions. An eddy current effect of the vacuum chamber and ripple current was measured. Current control system for the large number of small power supplies was investigated in this report.

Introduction

Final designs of the dipole (B), quadrupole (Q), sextupole (Sx), and steering (St) magnets for the SPring-8 storage ring have recently been revised to reduce the production and operating costs. The bore radius and length of the Q and Sx magnets were reduced. Steering magnet is separated from the Sx magnet[1]. The configuration of magnets, for one cell, is shown in Fig.1. Ten operating modes for the SPring-8 were adopted by the lattice group. Q magnets in the long straight sections are adjusted in less than a few percent using an auxiliary power (QA) supply system.

A high stability and low ripple current is required for the B, Q, and Sx magnets. Magnetic field ripple, induced by current ripple, can be reduced by an aluminum vacuum chamber. This ripple fields were measured inside the vacuum chamber of the B, Q, and Sx magnets, in order to decide a current ripple tolerance of the power supply[2]. Results of these measurements will be described later.

Table 1 shows the parameters of the power supply system, maximum currents, voltages, required current stability, ripple, magnet resistances and inductances, power consumption and the numbers of the cubicles, connection type and the number of connected magnets and PS's in the PS rooms A,B,C and D. The magnet operating current may be selected for either an 8 GeV or 3 GeV beam, and the minimum currents of the Sx magnet power supplies are 20 % of the maximum currents for the ten operation modes. Four connection modes of the magnets and PS are shown in Fig.2. Further description of these connection modes will be appear later.

Power Supply

<u>Bending Magnet Power Supply</u>

The maximum BM current for 8 GeV (0.679 Tesla) is 1230 A. All the BM's are connected in series, and excited by one power supply. The total resistance of the 89 magnets, including one reference magnet, is 0.783 ohm and that of the cable is 0.099 ohm; thus, the total voltage of the power supply is 1176 V. Eight BM's of four cells are excluded from the 48 cells to make a four long straight sections. In order to reduce the potential difference between the terminal of the magnet and cable, and the earth, the voltage is divided into two (~580V). The connection cable consists of a pair of two parallel 500 mm^2 CV cables (total=1000 mm^2). The magnets in every other cells are connected in series. The current stability and ripple are both 1×10^{-4}. Temperature controlled cooling water ($30 \pm 1°C$) is supplied to the power supply's shunt resistance. The reference voltage for current control is given by a hi-precision 16 bit DAC (Digital to Analog Converter). This DAC and amplifier are enclosed in a temperature controlled housing.

Table 1. Required current stability, ripple, power consumption, and connection type for Bending, Quadrupole, Q-auxiliary, Sextupole, and Steering magnet power supplies. Four connection types of the magnet and PS are introduced as seen in Fig.2.

PS Name	No.Mag /P.S.	Induct (mH)	Total (mH)	Max.Curr (A)	Stability /Curr.	Ripple /Curr.	V (PS) *(V)	DAC /PS	Pow/P (kW)	Cnct. Type	No.of PS in Room A	B	C	D
BP	89	9	801	1270	1*10E-4	1*10E-4	1176	1	1540	A	1			
							5%up							

PS Name	No.Mag /P.S.	Induct (mH)	Total (mH)	Max.Curr *(A)	Stability /Curr.	Ripple /Curr.	V (PS) (V)	DAC /PS	Pow/P (kW)	Cnct Type	No.of PS in Room A	B	C	D
QP1	48	10	480	400.7	1*10E-4	1*10E-4	432	1	184	A	1			
QP2	48	26	1248	392.4	1*10E-4	1*10E-4	822	1	341	B-2	1			
QP3	48	14	672	409.9	1*10E-4	1*10E-4	533	1	232	A	1			
QP4	48	11	528	520.2	1*10E-4	1*10E-4	604	1	333	A	1			
QP5	48	14	672	549.0	1*10E-4	1*10E-4	714	1	415	B-2	1			
QP6	48	14	672	549.0	1*10E-4	1*10E-4	714	1	415	B-2	1			
QP7	48	11	528	520.2	1*10E-4	1*10E-4	604	1	341	A	1			
QP8	48	14	672	561.4	1*10E-4	1*10E-4	730	1	434	A	1			
QP9	48	26	1248	568.6	1*10E-4	1*10E-4	1165	1	699	B-2	1			
QP10	48	10	480	557.2	1*10E-4	1*10E-4	600	1	354	A	1			
				3%up			3%up	10	3748		10			

PS Name	No.Mag /P.S.	Induct (mH)	Total (mH)	Max.Curr *(A)	Stability /Curr.	Ripple /Curr.	V (PS) (V)	DAC /PS	Pow/PS (kW)	Type	No.of PS in Room A	B	C	D
QA1	1	10	10	16.4	3*10E-3	3*10E-3	18.5			B				
QA2	1	26	26	4.0	1*10E-2	1*10E-2	27.0			B				
QA3	1	14	14	5.0	1*10E-2	1*10E-2	23.4			B				
QA4	1	11	11	10.6	1*10E-2	1*10E-2	39.9			B				
QA5	1	14	14	11.2	1*10E-2	1*10E-2	44.0			B				
QA6	1	14	14	11.2	1*10E-2	1*10E-2	44.0	10	5.80	B	1	1	1	1
QA7	1	11	11	10.6	1*10E-2	1*10E-2	39.9			B				
QA8	1	14	14	8.6	1*10E-2	1*10E-2	36.9			B				
QA9	1	26	26	5.8	1*10E-2	1*10E-2	39.1			B				
QA10	1	10	10	22.7	3*10E-3	3*10E-3	25.6			B				
				5%up				10	5.80		1	1	1	1

PS Name	No.Mag /P.S.	Induct (mH)	Total (mH)	Max.Curr *(A)	Stability /Curr.	Ripple /Curr.	V (PS) (V)	DAC /PS	Pow/P (kW)	Cnct Type	No.of PS in Room A	B	C	D
SP1	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
SP2	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
SP3	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
SP4	48	15	720	300.0	1*10E-4	1*10E-4	858	1	272	A				1
SP5	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
SP6	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
SP7	48	10	480	300.0	1*10E-4	1*10E-4	704	1	223	A				1
							5%up	7	1610					7

PS Name	No.Mag /P.S.	Induct (mH)	Total (mH)	Max.Curr (A)	Stability /Curr.	Ripple /Curr.	V (PS) V	DAC /PS	Total (kW)	Cnct Type	No.of PS in Room A	B	C	D
StP	1	200	200	5.0	1*10E-2	1*10E-2	38-103	3	27.09	C/D	4	4	4	4

PS-Room	Air	kW	kVA	PS-No. in Room A	B	C	D
-A	52.1	5420	7742				
-B	39.0	131.6	188				
-C	39.0	131.6	188				
-D	43.5	1742	2488				
Total	174	7424	10606	16	5	5	12

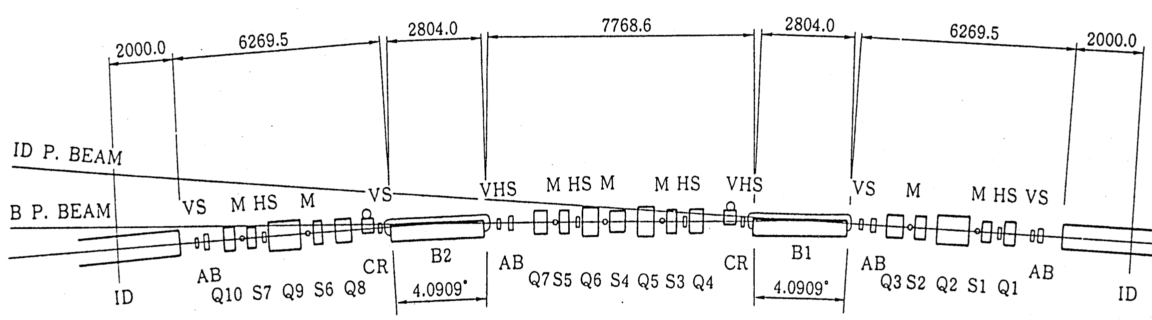

Fig.1. Configuration of storage ring (SR) magnets for one cell.

ID : Insertion device
AB : Absorber
CR : Crotch
M : Monitor
B : Bending magnet
Q : Quadrupole magnet
S : Sextupole magnet
HS(STH), VS(STV), VHS(STVH) } Steering magnet

Quadrupole Magnet Power Supply

Required maximum currents and voltages for the Q-magnets are listed in Table 1. The minimum current is 20 ~ 81% of maximum values.

To reduce the number of the PS's and power consumption, the similarly designated Q-magnets, amongst the 48 cells, are connected in series (see Fig. 2; connection type A). The Q magnets in long straight sections are adjusted by auxiliary (QA) PS circuits (Fig. 2; connection type B). Current corrections for the insertion devices can be installed in future[3]. The efficiency of a large current and low voltage power supply is not good, therefore, an auxiliary PS with series connection type will save power consumption and cost. However, if we use an independent connection type, for the above Q magnets, the total power consumption will increase by about 2 MW.

The shape of the QF5 magnet yoke of even cell is different from that of odd cell, because of beam line vacuum chamber. So, the Q magnet current must be adjusted in a few percent. The QF6, QF2, and QF9 are the same situation. Fig. 2, connection type B-2, shows this adjusting system using one PS with bypath circuits.

Sextupole Magnet Power Supply

The magnets for Sx-1 to Sx-7 are connected in series for all cells (Fig. 2. type A). If the voltage exceeds 600V, the terminal voltage polarity will be split and center grounded, similar to the BP and QP. The field level of some Sx magnets must be almost zero, but the de-gauss power supply system (bipolar small power supply) will not be taken.

Because of two fold symmetry of the thick aluminum chamber and three fold symmetry of the magnetic field, the large ripple current can not be allowed[3]. Both the current stability and ripple are 1×10^{-4}.

Steering Magnet Power Supply

All coils of the steering magnets have independent power supplies. The total number of St-PS's is so large (672), that the maximum current of the St-PS's must be small to reduce manufacturing cost. 12 or 36 PS's are installed in one PS cabinet (cubicle) and controlled by VME extension I/O card (RIO). All the St-PS's are bipolar (or have fast polarity switches). Both the current stability and ripple for the St-PS are less than 1×10^{-2}. The DAC interface operates using 15 or 16 bits. For the analog feedback system[4], some of the correction magnets PS's comprise a fast control circuit (1~ 25 Hz), which is added to the main reference voltage.

As not all the St magnets are operated at once, a matrix switch can connect the designated steering magnet coil. 36 steering coils in 3 cells are operated selectively by 12 PS's as seen in Fig. 2 type-D.

Computer Control System for Power Supply

Huge number of the DAC's (250 ~1100) is needed for the SR magnets PS's. Half of them (~ 480 for QA type) needs voltage floated system from the ground level. So, optically linked remote I/O system (RIO) must be employed (Fig.3). The RIO master controller, which has a dual port RAM, is a VME module. Interface of the master and slave (RIO card) is RS485 and HDLC protocol (or eLAN) with a speed of 1 Mbps. This system consists of following devices,

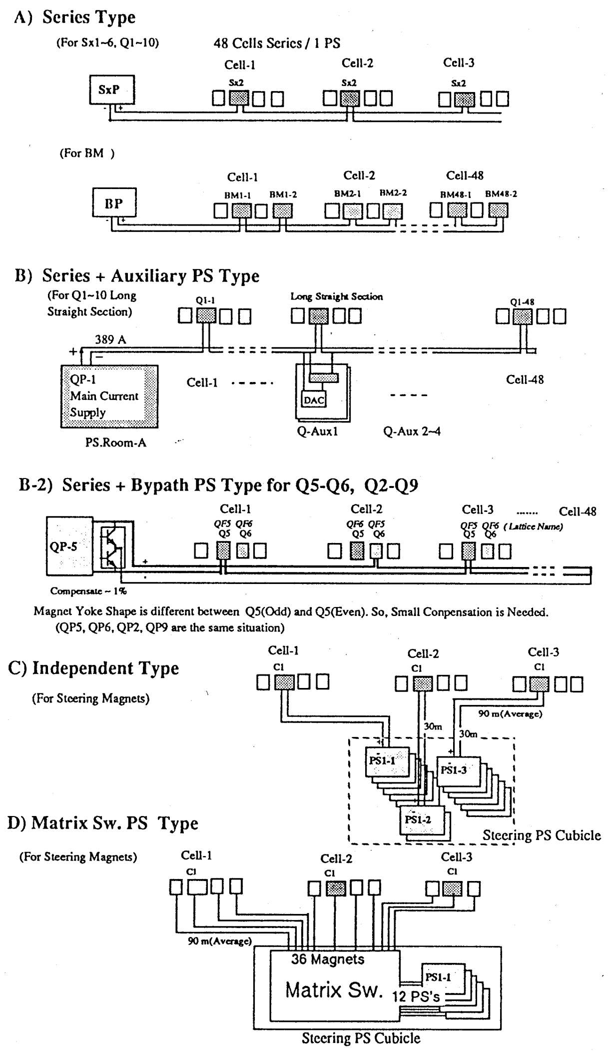

Fig.2. The four connection types of magnets and power supplies. Type A; series connection between 48 cells for BM, Q and Sx magnets. Type B; PS's with auxiliary-PS type, series connection between 48 cells for Q-magnets. Type C; independent type for correction magnets. Type D; steering coils are connected to the PS's by Matrix switches.

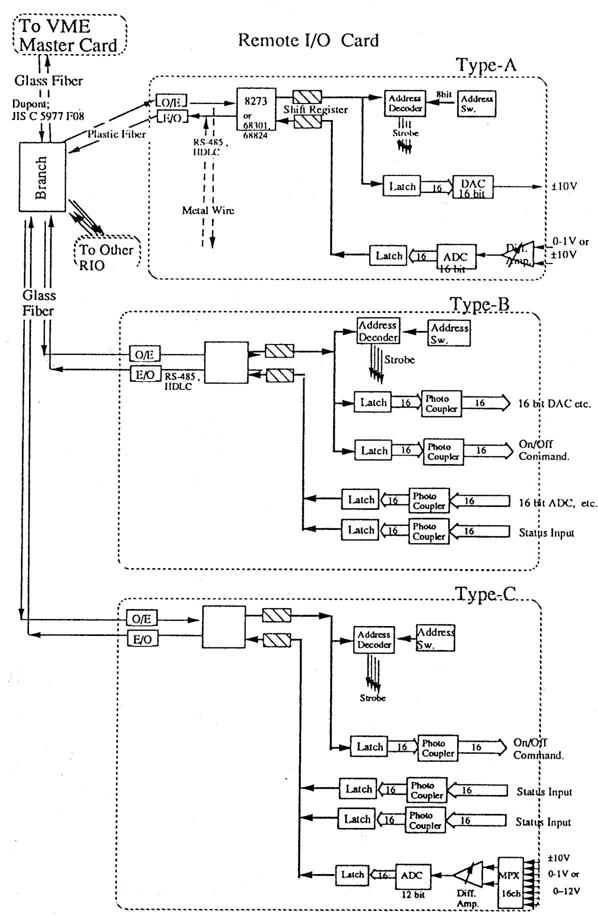

Fig.3. Remote I/O cards (type-A and B). VME master controller sends data and address to register (Latch) for the ADC, DAC, DIO through a glass fiber and a star coupler. An integration type ADC has an accuracy of 1×10^{-5}.

1) Master card; VME module,
2) Star branch; glass fiber cable from the master to slave cards (1 : 62),
3) RIO (slave card), which has three types as follows,
Type-A ; 16 bit DAC, 16 bit ADC
(input ; 0-1V, 0-10V, ±1V, ±10V).
Type-B ; 32 bit digital output, 32 bit digital input
(photo isolated).
Type-C ; 16 bit digital output, 32 bit digital input,
16 bit ADC + 16 ch MPX.
4) Optical glass fiber cable (Dupont Co.Ltd) with a connector : JIS C 5977 F08.

The transistor regulator reference voltage of the PS is supplied by a 16 bit DAC. DAC's for the B, Q, Sx PS's are controlled by 16 bit digital output of the RIO card as seen in Fig.3-(type B). The St and QA PS's are controlled by an analog signal (-10 ~ +10V). The RIO type-A has also an ADC, monitors the actual current thought a shunt resistance output. 12 or 36 steering magnet and 10 or 40 QA power supplies are enclosed by one power supply cubicle, respectively. A 24 bit status (power on/off, fuse, transistor break down, temperatures, oven, polarity, ext-interlocks, door, water flows, etc.) is read by the RIO type-B.

A VME system with a 68030 or 68020 CPU and MAP I/F (or TCP/IP) can be employed for the device (magnet) controller. And a UNIX work station will be used for the program development host computer and for a local control terminal. Because the application program will be developed using the host computer, a program down-load system must be employed. Furthermore local operation on by panel switches are not necessary.

When a digital feedback (DFB) system[4] is used to set the multiple PS's current, since this must be achieved simultaneously, one VME CPU can control any combination of four St-PS's in any PS room. So, the trigger (Timing signal) system for the COD correction will not be necessary. An analog feed back (AFB) signal (1-25 Hz) can be added to the DAC reference voltage.

Cabling and Power Supply Rooms

A total input power for the magnets is estimated to 10.5 MVA. Electronic noise levels must be suppressed inside the power supply cabinets and power supply room.

Connection cables from the PS to the magnets for the B, Q, Sx , and St are led on the "upper rack" above the SR cave (tunnel). Fifteen hales (100 A and 125A) for these cables are bored in the cave ceiling. A water cooling pipes also pass through this ceiling.

Cables for the FFB magnets, interlock signal cables, and other control cables (vacuum, cooling, beam line, beam monitor's system) are laid in a "cell duct" under the cave, and led to a "outer rack" above the maintenance corridor.

Four separate sector PS rooms are located on the 2nd floor of the machine cooling building. The input transformer (6600V) yards for these PS's are placed beside the PS rooms. Cubicle size when carried into the PS room is smaller than 2 x 2.5 x 2.4 m. And weight is less than 1 ton /m^2.

Magnetic Field induced by Current Ripple in the Vacuum Chamber

The magnetic field ripple has been measured inside the vacuum chamber to decide the current ripple tolerance of the power supply. Figure 4 shows cross sectional view of the Sx magnet and the vacuum chamber. The length of the model chamber is 40 cm, and the model magnet is 45 cm length. The schematic diagram of the measurement is shown in Fig.5. A ripple current is ±0.85 ~ ±3.4 A (0 to peak) and 30 ~ 480 Hz, supplied to the exciting coil by a bipolar amplifier and a frequency generator. A pick up coil (200 turn, 5 mm dia.) is connected to an FFT (Frequency Fourier Transfer) analyzer, and moved in X and Y directions.

Figure 6 shows obtained ripple field distributions of the Sx magnet. The field distribution without the chamber is same to the sextupole DC field. But the field inside the chamber is induced by an eddy current in the aluminium vacuum chamber. This is decreased with the frequency. The field strength at I=±3.4 A (0 to peak , 60 Hz) is 4.2 gauss, which perturbs the electron beam position in 0.2 mm. In order to suppress this beam displacement within 0.002 mm, the ripple current (Sx) must be less than 10^{-4}. Similar measurements were done in the B and Q magnets. The ripple field in the bending magnet is reduced less than 1/100 of the field without the chamber.

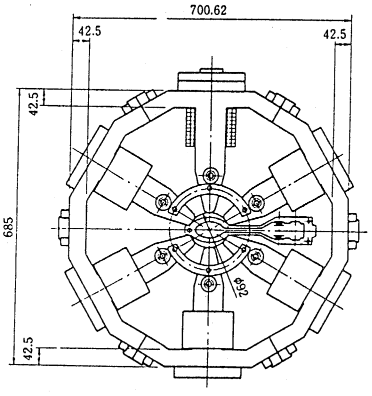

Fig.4. Cross sectional views of the Sx magnet and the vacuum chamber. The length of the model chamber is 40 cm, and the model magnet is 45 cm length.

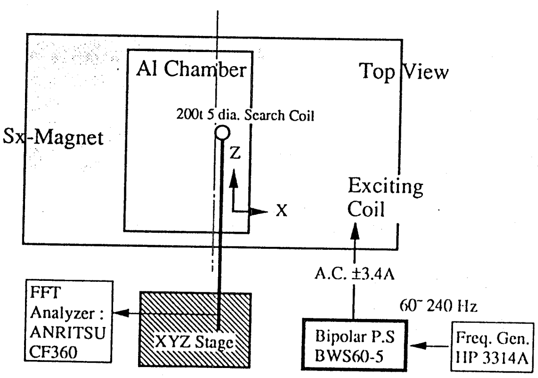

Fig.5. The schematic diagram of the measurement for magnetic ripple field induced by a vacuum chamber.

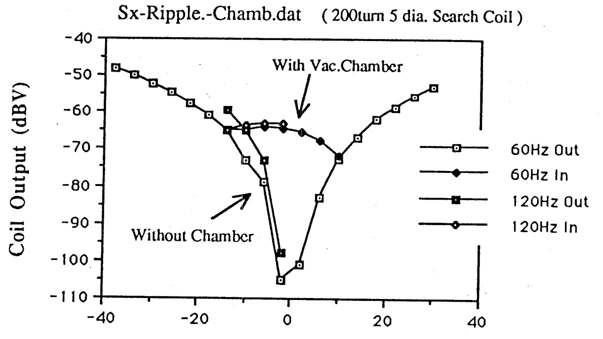

Fig.6. Magnetic ripple field distribution of the Sx magnet (±3.4A, 60 Hz) with / without a vacuum chamber.

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