STUDY OF A MAGNET POWER SUPPLY FOR A MUSES BOOSTER SYNCHROTRON

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Abstract

A booster synchrotron ring (BSR) is proposed for RIKEN RI Beam Factory. The designed magnet power supply of BSR provides both an average power of 3.8 MW and a peak power of 13.2 MW at a repetition rate of 1 Hz. An effort concerning the design study was focused on the magnets, circuit and pattern simulation of the designed circuit. In the present paper, optimization of the circuit parameters and an evolutional ripple filter are studied to obtain the associated repetition rate and the ripple current below the sub ppm level.

1 INTRODUCTION

The proposed *"RIKEN RI Beam Factory "* [1] comprises a 6-sector Superconducting Ring Cyclotron (SRC), accumulator ring (ACR), booster synchrotron (BSR) and Multi USe Experimental Storage ring (MUSES). The BSR is a slow synchrotron used to boost the RI beam from SRC or to accelerate an electron beam from the 300-MeV linac. They are then injected into Double Storage Rings (DSR). The maximum energy of the BSR is designed at 2.8 GeV for protons and 350 MeV/u for 238U58 beams. The lattice structure of the BSR is four FBDB-FBDB-FBDO-FBDB-FDO structures. Thus the synchrotron magnet strings comprise 28 dipole magnets and 40 quadrupole magnets separated into four groups. In addition, one reference dipole magnet and four quadrupole magnets will be installed to measure the magnetic field, especially for B-clock detection. A current excitation pattern of lattice magnet has a trapezoid wave form, which has a flat bottom and a flat top. It is foreseen that a repetition rate of 1 Hz and third-order resonance-beam extraction at the flat-top current result in making a precision high-power magnet power supply. The betatron tune control requires a precise tracking control between the dipole and the quadrupole lattice magnets. The present paper discusses technical problems from the view point of the solution to encourage the construction of a precision power supply.

2 MAGNETS

The specifications of the lattice magnet are tabulated in Table 1.

Table 1: Specifications of a lattice magnet of BSR

Name	BM	QF1	QD1	QF11	QD12
Max. B $(T, T/m)$	1.5	22.4	-24.5	32.4	-33.1
Effect. l (m)	1.8	0.35	0.35	0.35	0.35
Hg or Rb (m)	0.07	0.053	0.053	0.053	0.053
Max. NI (AT)	83556	25035	-27382	36212	-36994
Turn No./pole	15	18	18	18	18
L (mH/u)	8.532	7.6	7.6	7.6	7.6
R $(m\Omega/u)$	4.677	5.276	5.276	5.276	5.276
Max.I (A)	2785	1391	-1521	2012	-2055

The dipole magnet is a H-type sector magnet with an effective length of 1.8 m. The quadrupole and sextupole magnets are normal-type magnets. All of the magnets will be produced using laminated punched steel like, the Shinnittetu 50H600A, with 0.5 mm thickness. A magnetic-field calculation has been performed using the computer code MAFIA to evaluate the magnet size and field distribution in the pole gap. The shape of the end-sim of the dipole gap is a hyperbolic-cosine. A saturation effect due to an over-drive of excitation current was simulated.

3 CURRENT PATTERN

The designed current pattern of the dipole magnet strings are shown in figure 1. The maximum time- derivative of the dipole magnetic field in the beam-acceleration phase was designed to be up to 5.99 T/s. The estimated power consumption at the full-excitation of the dipole magnet system is 7.614 MW. The var component at full-excitation was also estimated to be 10.768 MVA. The average dissipation power of the dipole magnet is 3 MW. The flat-top time will be expanded to five- or ten-times longer than that in given figure 1 in the case of slow extraction for the production of a long-spill beam. The maximum voltage and current of individual each magnet strings are tabulated in Table 2. An electricity estimation is also tabulated in Table 2.

4 POWER SUPPLY CONFIGURATION

Figure 2 shows a schematic diagram of the power supply for the BSR. The power supply comprises a 12-phase thyristor, symmetric double LC filter, a symmetric double dynamic filter and a current-regulation loop. The current-regulation loop comprises a voltage feed-forward as well as ACR and VCR loops. The feed-forward loop plays the role to boost the excitation current for an inductive load with a large time constant. A self-learning technique with

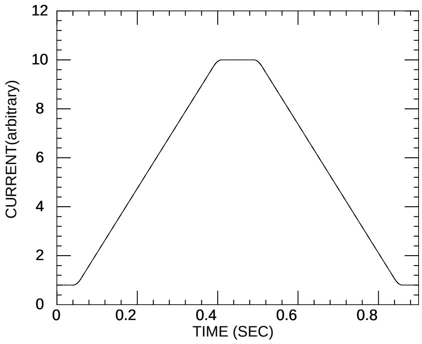

Figure 1: Designed Current Pattern of the MUSES-BSR

Table 2: Electric power requirements of BSR

Name	BM	QF1	QD1	QF11	QD12
No. of Mag	29	18	18	7	7
Cable L (mH)	10	10	10	10	10
Total L (mH)	257.4	146.8	146.8	146.8	146.8
Total R $(m\Omega)$	145.7	104.9	104.9	46.9	46.9
di/dt (A/sec)	9024	4506	4929	6158	6659
Max. I (A)	2785	1391	-1521	2012	-2055
Min. I (A)	77.98	38.94	42.59	56.32	57.54
Max. V (V)	2734	807.6	-883.3	585.6	-598.3
Max. P (MW)	7.164	1.1232	1.3436	1.1781	1.2296
Ave. P (MW)	2.866	0.673	0.806	0.707	0.738

a computer-feedback loop plays an important role so that the excitation-current error is minimized compared with a reference current pattern.[2] The voltage-compensation algorithm for self-learning control is as follows:

$$V_n(t) = V_o(t) + \sum_{i=1}^{n} k(I(t_i) - Id(t_i + t_r)).$$

The existing native synchrotron power supplies (KEK-12 GeV, HIMAC and Spring-8) are operated under a repetition rate of 0.5 Hz, or slower. These synchrotron power supplies show a difficulty to compensate a time-lag between the reference current pattern and the excitation current, since the response time is defined by the PI component in the ACR loop. The tracking error between the dipole magnet and the quadrupole magnet depends on that response time as a time lag. The time-lag results not only the evolution of a ripple power dissipation at a dynamic filter in the main current path, but also a tracking error between the bending magnet and the quadrupole magnet. A corrective voltage source is prepared and fed to the dynamic filter so as to reduce any ripple power dissipation at the dynamic filter. The time-lag, which causes a tracking error, is compensated for by a correction of the start timing of the current pattern at a reference input of the power supply. A computer study of a dipole magnet power supply was performed in order to evaluate the accuracy, response and reliability in the operation mode of a pulsed trapezoid wave form. The circuit model employed in the calculation, was similar to that of a synchrotron power supply of INSTARN2.[3]

5 COMPUTER SIMULATION OF THE POWER SUPPLY

The accuracy of the excitation current was evaluated as a function of the amplitude resolution of a current pattern generator, using a digital-to-analog converter. The current pattern at the acceleration phase comprises a linear or quadratic time dependence. In the quadratic region, a current change suddenly appears because of a bit-data change of the digital-to-analog converter. This step-wise current change must be smaller than 10^{-6} of the full excitation current. The error in the current pattern is exponentially decreased with the number of a self-learning process. The computer study shows that a small change in the circuit parameter is required in order to adapt the basic model to the MUSES-BSR power supply. The feed-forward time, gain of DCCT and damping time of the feed-back circuit have been searched in order to obtain a high- precision current control of up to 10^{-6}.

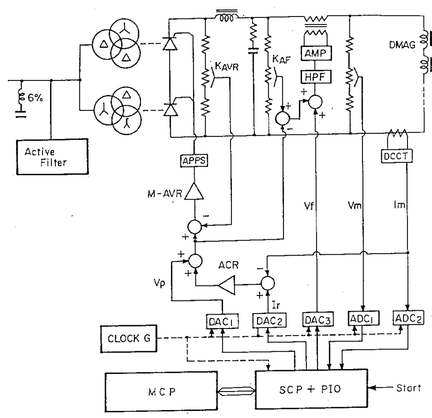

Figure 2: Schematic of the dipole power supply of the BSR

Figure 3 shows an example of the self-learning process. The vertical scale is a residual current defined as the subtraction of the reference current from a flowing current through the load magnet. For checking the circuit parameter, we first investigated the impulse response of the circuit in order to find the delay time of the power-supply circuit. An analysis of the impulse response also gave information concerning the component of oscillations against a rapid signal change, such as a step- wise reference signal from the digital-to-analog converter. Secondly, the delay time of the circuit was adjusted so as to reduce the ringing components which appeared in the residual signal.

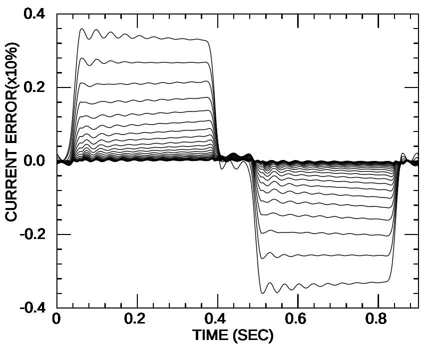

Figure 3: Current-pattern errors during the self-learning process

6 FREQUENCY RESPONSE OF THE LATTICE MAGNET

The magnet strings comprise a symmetric pai-pai mode L-C network having both normal-and-common mode admittances. These parameters were examined as for whether or not there is any resonance phenomena due to current ripples at a thyristor block. If the ripple current is coupled with the resonance of these admittances, an error in the magnetic field is excited. Figure 4 shows the calculated normal-mode admittance of the dipole magnet strings. We can see that the resonances appearing around the higher harmonics of the 50 Hz component. The resonance frequency, which coincides with the higher harmonics of the ripple current, must be shifted either upward or downward by additional capacitances at the magnet component.

7 OTHERS

We are making a small model of magnet strings in order to evaluate the winding structure of the magnet coils and the resonance detune method. The eddy-current loss in the vacuum chamber has been estimated and tested using a small piece of an aluminum chamber and a stainless chamber. The results show that a low ripple current is required to obtain a good field quality as well as to suppress any electromagnetic interference to the experimental apparatus. For example, the requirement concerning the ripple quantity is discussed from the view point of the stop-band stability at the third-order resonance extraction. We are taking into account the ripple-current quantity into the specification of the power supply. The estimation result shows that ripple current of sub ppm is required in the quadrupole-magnet power supply. A closed-orbit distortion will appear in the synchrotron ring. This closed-orbit distortion is to be compensated for by using the horizontal and vertical correction magnets in the magnet strings. The auxiliary correction coils are wound around the pole piece of each lattice magnet. The power supply for the sextupole magnet should be prepared in the power supply-system of the BSR.

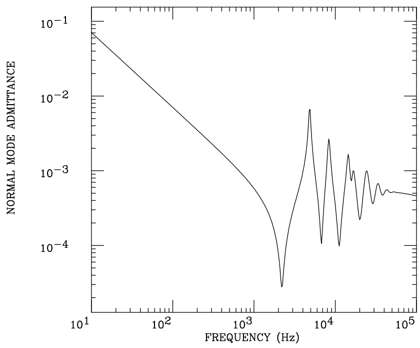

Figure 4: Calculated normal-mode admittance of the BSR dipole magnet strings

8 CONCLUSION

A study of the synchrotron power supply for the MUSES-BSR was carried out. The designed power supply provides both an average power of 3.8 MW and a peak power of 13.2 MW at a repetition rate of 1 Hz. The power converter with 12 phases thyristor block requires input power line stabilizer to compensate a var component. The lattice magnet provide separate connection coils to make a symmetric load-impedances. The two mode filters for common and normal mode ripples are used in the power supply.

Several kinds of computer codes are available for a design study of the magnet and power supply. The circuit simulator on the workstation is powerful for evaluating the circuit model of the lattice magnet strings. A small model of the magnet strings was constructed and tested in order to correct the computer-simulation model. To obtain the associated repetition rate and the ripple current below the sub ppm level, a search of optimum circuit parameters and a self-learning control are important.

9 REFERENCES

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