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Synchrotron of SPring-8

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Abstract

The specification and the layout of the synchrotron of SPring-8 were decided. The synchrotron is designed to accelerate electron or positron beams from 1 GeV to 8 GeV with the repetition cycle of 1 Hz. The injection method of the 1-GeV beam from the linac is adopted to be single-turn technique with on-axis into the synchrotron. The input power of 250 kW into the cavity was achieved in 1991, and the rise time of less than 100 nsec in kicker was succeeded in 1992. The construction of the synchrotron is started in the fiscal year of 1993, and it will be accomplished in 1997.

1. INTRODUCTION

Parameters of the synchrotron are listed in Table 1. An single-turn technique with on-axis is adopted as beam injection method from the linac to the synchrotron. For the single-bunch mode-operation in the storage ring, the 8 buckets of the synchrotron will be filled and ejected by the injection and extraction of 8 times, respectively. The interval of the two buckets which are neighborhood is 160 nsec. Then the rise time and fall time of less than 100 nsec in kicker is required in order to carry out the operation of the 8-buckets single-bunch for the single-bunch mode-operation in the storage ring. The synchrotron is located outside the storage ring and is constructed on ground having a grade level about 9 m lower than that of the storage ring. This necessitates a long beam transfer line about 300 m. Figure 1 shows the layout of the injector system.

Table 1 Parameters of the synchrotron

Injection energy	1 GeV
Maximum energy	8 GeV
Circumference	396.12 m
Repetition time	1 sec
Natural emittance (8 GeV)	230 nm.rad
Momentum spread (8 GeV)	1.26×10^{-3}
Number of cells/periodicity	40/2
Nominal tune (ν_x/ν_y)	11.73/8.78
Natural chromaticity (ξ_x/ξ_y)	-14.4/-11.5
Radio frequency	508.58 MHz
Harmonic number	672
Radiation loss (8 GeV)	12.27 MeV/turn

2. GENERAL DESCRIPTION

A. Lattice Design

The synchrotron has a twofold-symmetric lattice composed of 40 FODO cells. There are 30 normal cells, each having two bending magnets. Two straight sections are provided for injection, extraction and acceleration of the beam. The straight sections consist of these cells with no bending magnet. RF cavities and the devices for injection and extraction are installed into empty-dipole cells. The dispersion function at the straight section is suppressed by removing a bending magnet from a normal cell(dispersion-suppression cell) and selecting the optimum value for the horizontal tune suppress dispersion at the exit of the residual bending magnet. Horizontal and vertical tune values are 11.73 and 8.78, respectively. The natural chromaticities are ξ_x = -14.4 and ξ_y = -11.5. To correct the chromaticities, each normal cell contains a focusing and defocusing sextupole near the focusing and the defocusing quadrupole, respectively.

B. Injection and Extraction

At the injection energy of 1 GeV, a single-turn with on-axis technique is adopted as the standard injection method to provide good injection efficiency of the beam into the synchrotron. Two septum magnets and two kicker magnets are used for the on-axis injection. After leaving two septum magnets, the injected beam is inflected to the reference orbit by the focusing quadrupoles. Before entering the reference orbit of the synchrotron, the beam is kicked and placed smoothly in the reference orbit by the kicker magnets.

The duration when the kicker magnets are excited must be shorter than 300 nsec. Thus, the kicker waveform has 100-nsec rise-time, 40-nsec flat-top, and 100-nsec fall-time. For the operation with the long pulse mode, another PFN circuit for the kickers is used to generate a long flat-top. Figure 2 shows a short pulse waveform of the prototype kicker magnet for injection. Figure 3 shows a cross-sectional view of the kicker magnet.

The aperture of the vacuum chamber in the normal cells is determined by the size of the injected beam and the injection method. Substituting maximum beta and dispersion functions; β_x = 16.7 m, β_y = 17.9 m, η = 1.0 m, a maximum COD; COD_x = 9.0 mm, COD_y = 7.5 mm, and beam quality; 1.0 πmm.mrad, ΔP/P=0.01 into the following equations;

$$BSC_x = (\varepsilon_x\beta_x)^{1/2}+(2\Delta P/P)\eta + COD_x$$
$$BSCy = (\varepsilon_y\beta_y)^{1/2} + COD_y$$

The beam-stay-clear results in BSC_x = 33.5 mm and BSC_y = 11.7 mm. Presently the physical half aperture is designed to be A_x = 40 mm, A_y = 15 mm, to accommodate both cases.

The 8-GeV electron- or positron-beam is extracted from the synchrotron with four septum magnets, three kicker magnets and four bump magnets. The magnetic rigidity of these magnets is large but the empty space available for these magnets is limited, thus bump orbit must be used to assist the kicker and septum magnets.

C. Magnets

The magnets of the synchrotron are 64-dipole magnets, 80-quadrupole magnets, 60-sextupole magnets and 80-correction magnets. The core of each magnet is stacked with 0.5 mm thick, silicon steel laminations. The dipole magnet has a C type core and assembled by lamination stacking; this is curved with parallel end plates. The pole width is 140 mm with lateral shims 7.5 mm wide by 1 mm high. The pole length is 2870 mm. The maximum field strength of dipole magnets is 0.9 T. The Bohr radius and the length of the quadrupole are 70 mm and 0.57 m. And those of sextupole are 100 mm and 0.15 m. Quadrupole and sextupole magnets are constructed with two-piece core-structure. The maximum field strength of these magnets are 15 T/m and 200 T/m^2, respectively.

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D. Power Supplies for the Magnets

Power supplies for the magnets provide the pulsed current of 1 Hz. The waveform of the pulsed current has 150-msec flat-bottom, 450-msec rise-time, 150-msec flat-top and 250-msec fall-time. For the dipole magnet two 24-pulse thyrister-converters are used to reduce the direct current ripple. These two converters are connected in series to reduce the reactive power. One transfers the power from the mains to the magnet load and the other backs into the mains. A DC filter is installed which is composed of a passive filter and an active filter to bring the ripple down further. For the quadrupole and sextupole magnet, a 24-pulse and a 12-pulse thyrister converter are used, respectively. Transistor power supplies are used for correction magnets.

E. Vacuum System

The synchrotron has two types of vacuum chambers: an ordinary type which has a race-track cross-section with 1.5-mm wall-thickness and a rib-reinforced type that has 0.3-mm wall thickness with a race-track cross-section. The ordinary-type chambers are installed in the quadrupole magnets and the rib-reinforced-type chambers are in the dipole magnets. Both chambers are made of 316L stainless steel. The aperture of 80x30 mm^2 is requested. Under the condition of the present duct-aperture and the pressure of 1×10^{-6} Torr, the beam lifetime determined by the residual gases is estimated to be 100 sec at 1 GeV. Although it is sufficiently long compared to the lifetime, we have decided the design pressure should be less than 1×10^{-6} Torr throughout the synchrotron because of the gross reliability of the vacuum system.

F. RF System

The synchrotron uses 508.58 MHz RF system, the same frequency as that for the storage ring. The total required RF power is 1.69 MW. Two 1-MW KEK-type klystrons are used as the power source and provide for eight five-cell cavities. The RF power from a klystron is divided equally into the four cavities using three magic-T splitters. The required RF voltage is increased linearly during the ramping from 8 MV to 18.7 MV. The effective RF voltage is changed by controlling the phases of RF between two klystrons, keeping the output power of the klystrons constant. The phase differences between the two klystrons, 131 and zero degrees, correspond to the total RF voltages, 8 and 18.7 MV, respectively, at the constant klystron output power of 845 kW each.

Dissipation of RF power occurs mainly at the cavity walls, since the beam loading is very low because of the maximum beam current of 10 mA in the synchrotron. The design requirement for the cavity is to realize high shunt impedance to reduce the wall losses. A multi-cell type cavity, that consists of 5 cells was chosen. The cavity has inductive coupling slots. A large coupling-factor is required to stabilize the accelerating field against disturbances of the temperature-rise. A cross-sectional view of the prototype five-cell cavity is shown in figure 4. The total length is 1700 mm and the outer diameter is 492 mm. The cavity is constructed with OFHC copper with cooling channels machined into every component. The effective shunt impedance is about 21 MΩ/m. The maximum input power is 250 kW.

G. Beam Monitors

Table 2 shows beam monitors installed in the synchrotron. Beam position is measured at 80 locations around the synchrotron at every quadrupole magnet. Each beam-position monitor(BPM) consists of a set of four button electrodes mounted on the wall of the vacuum chamber. The signals from each BPM are transmitted through low-loss, high-frequency cables to the detector circuits via fast pin-diode switches. For real-time measurements of beam position during ramping, 4 detector circuits are used for 80-BPMs. Movable and rigid fluorescent screens are installed to see the position of the injection and extraction beam. The intensity of the beam current is measured by several types of current transformers. Horizontal- and vertical-beam excitation-electrodes are installed at the injection section to determine the tune values and the tune shift during acceleration.

Table 2 Beam monitors of the synchrotron

monitor type	quantity
Current transformer for short pulse	2
DCCT	1
BPM	80
Fluorescent screens	14
Photon monitor	1
RF-KO	1
Beam loss monitor	5

H. Beam Transport System

The injector system is located outside the storage ring and is at a lower elevation by about 9 m than the storage ring. It is necessary to construct a long beam-transport line(about 300 m) with vertical bending magnets. Thirteen bending magnets, 42 quadrupole magnets and 21 correction magnets are used in this beam transport line. The vacuum chamber of this transport line is made of stainless steel pipe with the inside diameter of 36 mm. The vacuum system is designed so that the pressure anywhere in the beam transport line will not exceed 1×10^{-5} Torr.

I. Timing System

To operate the accelerator complex of this facility, two systems for timing coordination are necessary. The first system is associated with beam transfer from the linac to the synchrotron. The second system is associated with beam transfer from the synchrotron to the storage ring. The RF systems of the synchrotron and the storage ring will be operated by the 508.58 MHz frequency of a master oscillator and the harmonic numbers of 672 and 2436, respectively. Since the time width of each RF bucket is 2 nsec, the timing accuracy required for beam transfer from the synchrotron to the storage ring must be less than 100 psec to suppress the beam loss due to the synchrotron oscillation of the injected beam. For single-bunch operation, it is necessary to select any one of the 2436 buckets as the single filled bucket in the storage ring into which the bunched beam from the synchrotron is transferred. Two concepts for the timing systems are being considered. One concept uses a synchronous timing table which has low jitters(lower than 100 psec) and the other utilizes is a phase control loop which has the accuracy of lower than 1 degree. The transfer line of the timing signal and the RF frequency consists of the optical fiber and the EO/OE transmitter and receiver which has low jitters and temperature dependence.

3. CONCLUSION

The specification of the synchrotron were decided. The construction of the synchrotron is started in the fiscal year of 1993, and it will be accomplished in 1997.

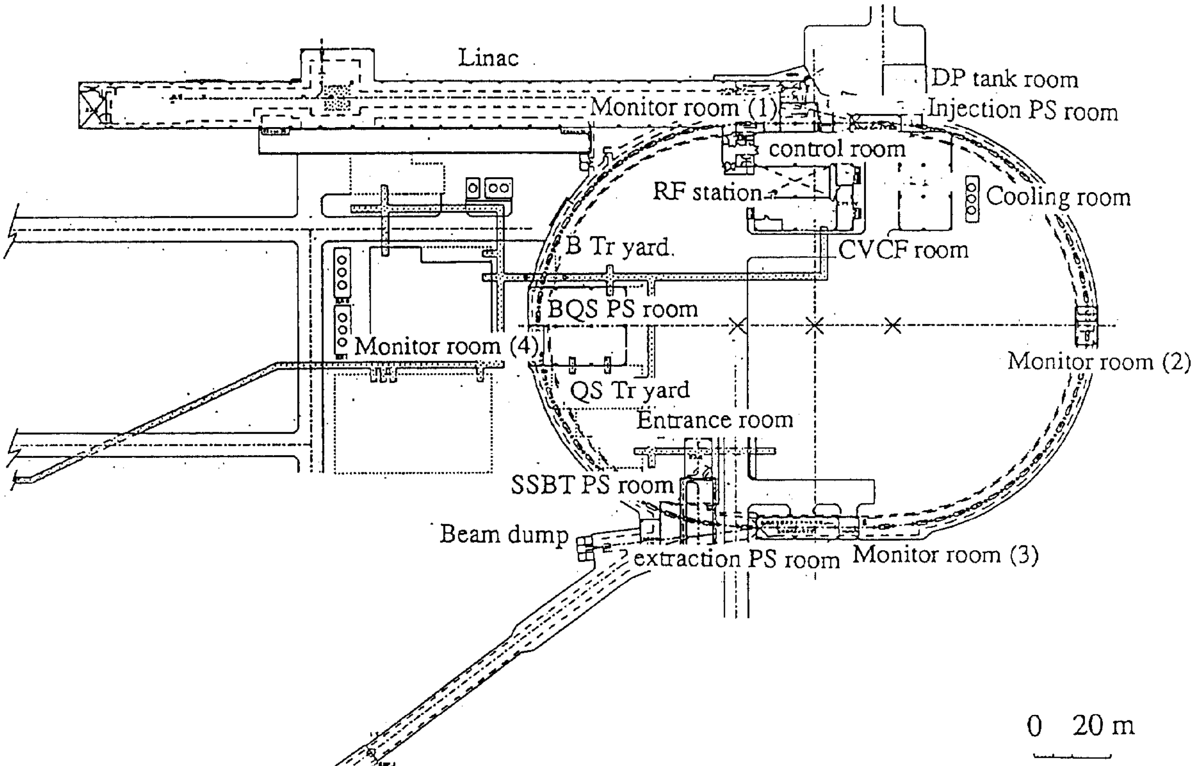

Figure 1. The layout of the injector system

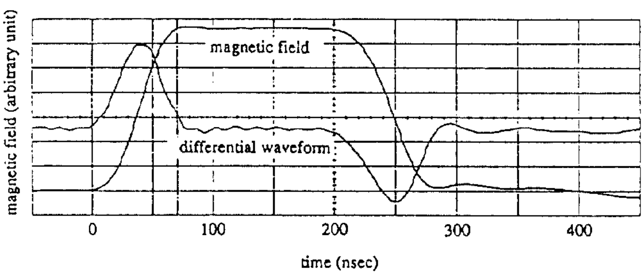

Figure 2. The short pulse waveform of the prototype kicker magnet

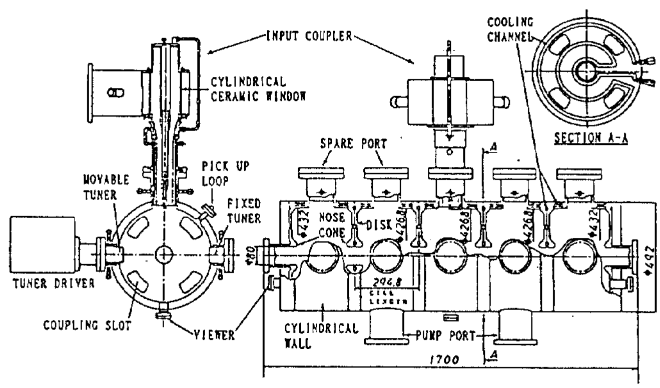

Figure 4. The cross sectional view of the prototype five-cell cavity

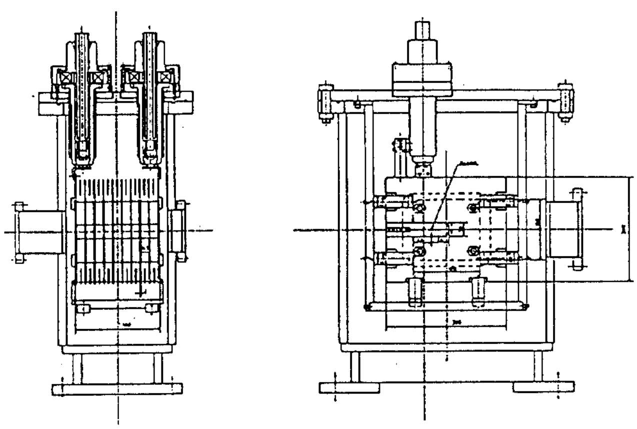

Figure 3. The cross sectional view of the kicker magnet for injection