Linac and Booster Synchrotron for SPring-8 Injector

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Abstract

The construction of the injector system for SPring-8 is almost completed. The machine components were carefully fabricated with good qualities. The magnets and accelerator columns of the linac were precisely installed within the accuracy of ±0.15 mm. A computer-aided automatical aging system was developed and successfully operated for the microwave aging inside the waveguides and accelerator columns. The bending magnets for the synchrotron were arranged in consideration of COD analysis with measured field data.

1 INTRODUCTION

The injector system for SPring-8 is composed of a 1 GeV linac and a 8 GeV booster synchrotron. The linac consists of a 250 MeV high current linac and electron/positron converter, and a 900 MeV main linac with the frequency of 2856 MHz. In order to avoid the ion trapping in the storage ring, SPring-8 linac is able to provide the positron beam with the energy of 900 MeV. The electron beam is also able to be accelerated up to 1.15 GeV by means of extracting the target of the electron/positron converter from the beam line.

The booster synchrotron of Spring-8 is able to accelerate the beam from 1 GeV to 8 GeV with the operation rate of 1 Hz. The synchrotron ring has a racetrack shape with a circumference of 396.12 m containing 40 cells of FODO lattice. It consists of 30 normal cells and two straight section including 5 cells each. This straight section has 3 dispersion-free cells and 2 dispersion-suppressing cells with missing bending magnets. The main parameters of the injector system are shown in Table 1.

The fabrication of the linac and synchrotron components was started in 1990 and 1992, respectively. Installation in site was started in April, 1995.

Table 1: Injector Parameters

Linac		
Energy	Positron	0.9GeV
	Electron	1.15GeV
Repetition rate		60Hz
RF frequency		2856MHz
Total length		140m
Electron gun	Thermionic assemble	Y796
	Voltage	200kV
Accelerator column	Number	26
	Traveling wave	$2\pi/3$ mode
Klystron	Number	13
	Maximum power	80MW
Synchrotron		
Injection energy		1GeV
Maximum energy		8GeV
Circumference		396.12m
Repetition rate		1Hz
Number of cells	FODO lattice	40
Periodicity		2
RF frequency		508.58MHz
Number of klystron	1MW output	2
Number of cavity	5-cell type	8
Harmonic number		672

2 LINAC

2.1 Preinjector

The preinjector of the linac consists of the electron gun, prebuncher, buncher, beam monitors. This was fabricated in 1992 and temporarily installed in Tokai site to examine its performances. The maximum beam current was achieved 22 A at the condition of the high voltage of 200 kV. The stability of the beam current was obtained to be less than $\pm1.5\%$. The pulse length from 1 nsec to 1 μsec was adjusted by changing the three different types of the grid pulser. The pulse length of 1nsec was achieved by means of using a 4 kV rapid rise-time pulser with a short-stub circuit. The pulse transfer line between grid pulser and the gun was designed to have an impedance of 12 Ω matched with a cathode assemble to prevent the pulse shape deformation. The bunching efficiency through the prebuncher and buncher was obtained 65% which is agreed with the calculation. The energy spread was obtained to be less than $\pm2\%$ at the exit of the buncher with an energy of 9 MeV. The normalized emittance was measured to be about 130 mm·mrad at the exit of the buncher.

2.2 Magnets and alignment

The beam focusing magnets are composed of triplet-quadrupole magnets, which are placed in between accelerator columns. The steering magnets are used for beam position adjustment in combination with the beam position monitors.

The precise alignment of the magnets and accelerator columns were carried out using the laser system. The tolerance of the precise alignment of the linac is expected to be less than 0.15 mm along the straight line through the total length of 140m. The laser is set on the axis of the

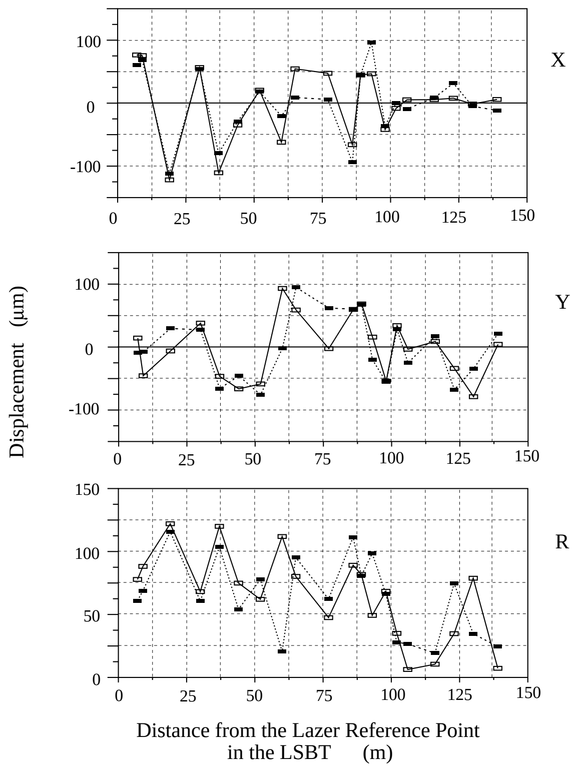

Figure 1: *Displacement of 20 sets of magnets along the beamline. Three data were measured in series. X is horizontal, Y is vertical, and R is radial direction.*

beam. The laser is expanded to 12 mm diameter just after the laser head and focused to 2.4 mm diameter at the end of the linac. Its pointing stability is less than 1 arc-sec. The laser beam was measured by the position sensitive detector with the resolution of $\pm15\ \mu$m, which was set at the center of the quadrupole magnets. The precise alignment of the each magnet was achieved to be less than 0.15 mm of the deviation from the beam center as shown in Fig. 1. After the precise alignment on axis of quadrupole magnets, off-axis measurement of the top of each magnet was carried out to know the original coordinates for the future reference.

2.3 Accelerator column

The linac has 26 accelerator columns. One accelerator column is 2.835 m long containing 81 cells, and $2\pi/3$ traveling-wave constant-gradient type. Borediameters of an exit iris are slightly different in three types; 20.0 mm, 20.5 mm and 20.95 mm. They are randomly arranged to prevent multi-sectional beam-breakup. The average accelerating field is designed $\sim$16 MV/m, and the energy gain per each column becomes $\sim$45 MeV when RF power is fed 26MW. The accelerator columns are designed to operate in the constant temperature of 30 ℃, and their temperature is controlled by the water cooling system with an accuracy of ±0.1 ℃. The disks and cylinders of the accelerator column are carefully machined and brazed in the vacuum furnace. The phase deviations of each cell were achieved good enough within 2 degrees.

2.4 Microwave system and aging

The 13 high-power klystrons of 80 MW are used with 4 μsec pulse-length and 60 pps repetition-rate. This klystron feeds the microwave to two accelerator columns. One low-power klystron of 7 MW is used in a microwave booster system for driving high-power klystrons. Another medium-power klystron of 35 MW is also used at the positron converter section.

The 190 MW pulse modulator for high-power klystron has 4 parallel and 14 series line-type PFN. This modulator is required to produce the pulse of 49 kV, followed by the pulse transformer of 1:16. The voltage fluctuation was achieved to be less than $\pm0.5\%$ during the flat-top of 2 μsec among the full width of 5 μsec. The reproducibility of the output voltage was obtained good within $\pm0.5\%$. To reduce the effect of the leakage inductance in the PFN condensers, coils of PFN were designed to have the mutual inductance between the neighboring coils. The new type of De'Qing circuit, which regulates the PFN voltage, was designed to recover an energy through the De'Qing circuit.

Computer-aided aging system was developed for saving man-power to carry out the aging of the wave-guides and accelerator columns with a high power microwave. This system automatically controls the output voltage of the modulators by means of observing the vacuum condition at several locations. The vacuum condition of 1 x 10^{-5} Pa is set to be an interlock values to cut the modulator output. When the vacuum condition is good, then the modulator voltage is gradually increased in every minute. The vacuum condition becomes worse than 4 x 10^{-6} Pa, then the modulator is forced to keep the output voltage constant, and the vacuum becomes worse than 8 x 10^{-6} Pa, then the output voltage is reduced immediately by a small amount to avoid time loss due to shutdown of the modulator by interlock. This automated aging system was successfully operated and saved time to reach the maximum microwave power.

3 SYNCHROTRON

3.1 Magnets and arrangement

The synchrotron has 64 bending magnets, 80 quadrupole magnets, 60 sextupole magnets and 80 steering magnets. The bending magnet has C-type core which is stacked with 0.5 mm thick, silicon steel laminations. The pole length is 2.87 m, and the maximum field strength is 0.9 T at the energy of 8 GeV. The pole width is 140 mm with the lateral shims 7.5 mm wide by 1 mm high. The magnetic field was measured by means of NMR probe at the center of the pole, and the linearity was obtained within 0.2% in proportion to the excitation current. Field distribution was measured using a hall-probe, and the variation of the field distribution was found to be less than 0.02% in the area of 60 mm width.

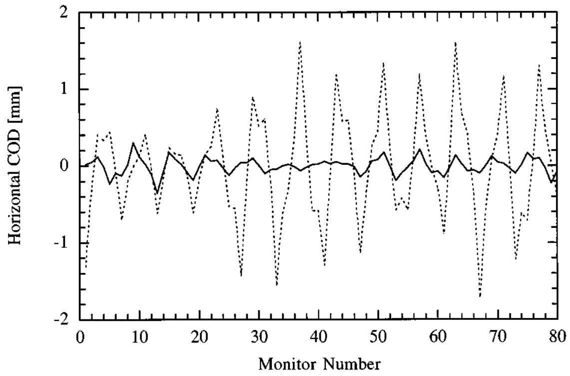

Figure 2: *Horizontal COD at every monitor location. The solid line is the case of the final setup, and the dotted line is the case of a random setup.*

The integrated magnetic field was measured along a straight line at the 18 mm outside from an electron orbit at the pole edge because a sagitta of the bending magnet is 35.6 mm. The deviation from the average magnetic field was obtained to be less than $\pm 0.08\%$.

To reduce the COD (closed orbit distortion) caused by field error of the bending magnets, an arrangement of the bending magnets are analyzed using RACETRACK code with the measured magnetic field data as the source of the field error. While an initial setup of the random arrangement has 1.71 mm and 0.69 mm of maximum and r.m.s. COD, the final setup of the analyzed arrangement provides 0.35 mm and 0.10 mm of maximum and r.m.s. COD. Calculated COD data are shown in Fig. 2 in two cases of the random setup and the final setup for comparison.

3.2 Power supplies

The power supplies of the synchrotron magnets are required to have high tracking accuracy and high reliability because the synchrotron operates in a ramping pattern of 1 Hz. The tracking accuracy of the power supply is required to be less than 1 x 10^{-4} for the bending magnet. Active filter coupled with a reactor-transformer was used in the power supply circuit in combination with a passive filter. Voltage ripples produced by the thyristor converter are sufficiently suppressed in the passive and active filters. The delay time following the ramping pattern was obtained to be 1 msec, and the tracking error was achieved less than the requirement. 24-pulse and 12-pulse thyristor converters are used for quadrupole magnets and sextupole magnets, respectively. Transistor power supplies are used for steering magnets.

3.3 RF system

Synchrotron uses 508.56 MHz RF system, the same as one of the storage ring. The maximum RF power is required 1.69 MW at 8 GeV. Two 1 MW klystrons are used with eight five-cells cavities. The RF voltage is required from 8 MV to 18.7 MV during the ramping pattern. The effective RF voltage is supplied by controlling the microwave phases from 0 to 135 degrees between two klystrons which are kept at the constant output power of 845 kW each. A 5-cells cavity has an effective shunt impedance of 21 MΩ/m, total length of 1640 mm, a diameter of 492 mm, and is composed of OFHC copper.

3.4 Monitors

The beam position monitors (BPM) are located at the upstream positions of 80 quadrupole magnets. Each BPM consists of four button-type electrodes with 18 mm diameter, which are mounted on the rigid wall of the 80 mm x 30 mm racetrack-shaped vacuum chamber. Output signals from BPM are processed in a detection system including fast PIN-diode switches and amplifiers. Four detection systems are simultaneously used for 80 BPMs, and it is expected that it takes less than 30 msec to obtain all position data. The relationship between the BPM and the center of the vacuum chamber was calibrated using an antenna simulating an electron beam. The antenna was mounted on a stage which is able to drive x, y and s directions. The output signals were measured by a spectrum analyzer.

4 CONCLUSION

The components of the injector system were fabricated and their characteristics were observed to have good qualities. The installation of the machine is almost completed on schedule, and the final performance test is under way. The aging of the waveguides and accelerator columns of the linac was carried out using a computer-aided automatic system, which is effective to operate a large facility such as SPring-8 linac by quite a few peoples for a short time.