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The Damping Ring of Accelerator Test Facility for Linear Collider

J.Urakawa,M.Akemoto,K.Egawa,H.Hayano,T.Higo,K.Kanazawa,M.Kikuchi,K.Kubo,T.Kubo,
S.Kuroda,H.Matsumoto,T.Naito,H.Nakayama,K.Oide,Y.Sakamoto,S.Sakanaka,S.Takeda,Y.Takeuchi,
M.Tejima,N.Terunuma,T.O.Raubenheimer*,N.Yamamoto,K.Yokoya and M.Yoshioka
KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan
* *SLAC, Stanford University, Stanford, CA 94309*

Abstract

The ATF(Accelerator Test Facility) is being constructed at KEK. The ATF has been designed to test the experimental feasibility of the accelerator sub-systems and to confirm the specification of the total accelerator system for JLC(Japan Linear Collider). A 1.54GeV damping ring is the main accelerator sub-system of the ATF. The construction of the damping ring will be started from November 1993. The beam parameters of the damping ring are as follows: 1) 3.0×10^{10} particles/bunch, 2) 20 bunches/train with the bunch spacing of 1.4nsec, 3) normalized emittances are less than horizontally 5.0×10^{-6}, vertically 5.0×10^{-8} radm and longitudinally 4.5×10^{-6} m, 4) repetition frequency 25Hz. This paper gives the details of the design and describes the status of the R&D works.

1 Introduction

One of the characteristics of the present design of the JLC[1,2] is to operate in a multi-bunch mode. The linac accelerates bunch trains where the bunches contained in a train are separated by about 42cm and the number of particles per bunch is 2×10^{10}. The proposed KEK-ATF consists of a 1.54GeV S-band linear accelerator, a 1.54GeV damping ring, a bunch compressor, a 0.5GeV X-band linear accelerator, a final focus system and a test station for positron production[3]. The ATF has been designed to investigate the feasibility of linear collider operation scheme and to accumulate beam control technics for linear collider.

The 1.54GeV damping ring is the main sub-accelerator system of the ATF. In order to prevent multi-bunch instabilities we need to use a specially designed RF system. In addition, we would like to operate the ring below the longitudinal microwave instability threshold. To achieve this without increasing the longitudinal emittance significantly, the damping ring must have a very low impedance and a large momentum compaction. In the section 2 the 1.54GeV damping ring design of the ATF is presented. The status of the R&D works is described in the section 3. Finally, the construction schedule is given in the section 4.

2 Design

2.1 Design considerations

The emittance of a ring can be reduced by reducing the dispersion in the bend magnets, reducing the strength of the bends, or decreasing the energy of the ring. The damping time is directly proportional to ϱ_B/γ^3, where ϱ_B is the local bending radius of the bend magnets. On the other hand, the normalized emittance is inversely proportional to ϱ_B/γ^3. In order to reduce both the damping time and the normalized emittance at the same time, we have decided to introduce two wiggler sections in zero-dispersion region. We also selected a racetrack configuration as a ring style for the reduction of dispersion suppression and matching regions. The lattice of cell in the arc is a combined function FOBO to minimize the dispersion in the bend magnet.

The ratio of the equilibrium normalized emittance and the impedance threshold, $(Z/n)_t/\gamma\epsilon_{x0}$, is inversely proportional to the cell length[4]. While decreasing the main bending field increases the cell length, it still decreases the emittance without decreasing the impedance threshold. Therefore it is desirable to maximize the wiggler fields and minimize the normal bending field. Since we introduce wiggler sections in zero-dispersion region, we can require 1.18m as the drift space length per cell. This length allows realistic space for sextupole magnets, steering magnets and position monitors.

2.2 Lattice and optics

Following requirements were added due to the technical consideration. 1) Length for RF, injection, extraction, feedback etc. is 16m. 2) Kicker rise/fall time is 60nsec. 3) Normalized emittance of injected beam is 3.0×10^{-4}radm.

The ring has a superperiodicity of two. The optical functions β_x and β_y and the dispersion function η_x for a half of the ring are plotted in Fig.1. The intrabeam scattering contribution to the emittance is about 40% of the ring emittance. The damping times are $\tau_x =$ 5.75msec and $\tau_y = 7.52$msec. This allows each train to remain in the ring for 26 vertical damping times when

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operating at a repetition rate of 25Hz. The parameters of the damping ring are shown in Table 1.

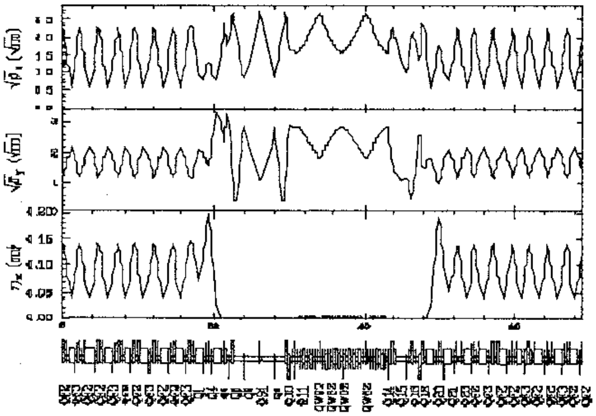

Figure 1: Lattice parameters of half of the damping ring.

Table 1: Parameters of the damping ring

Circumference	138.6	*m*
Harmonic number	330	
Number of trains	5	
Bending field	0.896	*T*
Horizontal phase advance/cell	131	*degree*
Cavity voltage	0.77	*MV*
Cavity frequency	0.714	*GHz*
Number of cavity cells	4	
Momentum compaction	0.00217	
Synchrotron radiation/turn	0.190	*MeV*
Longitudinal impedance threshold	0.11	Ω
Bunch length	4.88	*mm*
Longitudinal damping time	4.45	*msec*
Energy spread	0.0757	%

The two arcs are each constructed of 18 combined function FOBO cells. The bending magnets bend an angle of 10.00°. The quadrupoles have normalized gradients of 9.0m^{-2}. Assuming a magnetic radius of r=1.6cm, the quadrupoles have pole tip fields of 7.4kG. The magnet positions are plotted with the lattice functions of a single cell in Fig.2.

It is necessary for the wiggler to have high field quality. The effective wiggler field is 1.88T with a period of 40.0cm. The total length is 24.5m and the packing factor is 0.4. The cell lattice of a damping wiggler is shown in Fig.3. We use 4 cell wigglers. The wiggler system decreases the vertical damping time from 16.3msec to 7.52msec and the natural emittance from 1.69nradm to 1.22nradm.

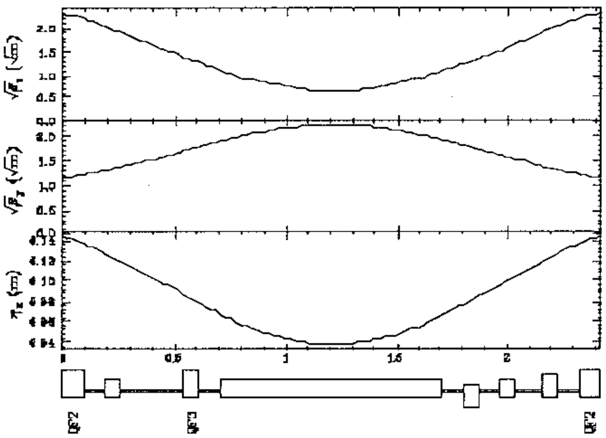

Figure 2: Lattice parameters of a single normal cell.

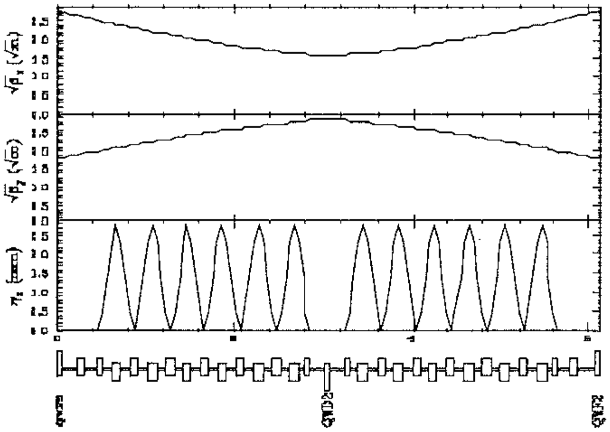

Figure 3: Lattice parameters of a wiggler cell.

3 R&D Status

3.1 Dynamic aperture and alignment tolerances

It is necessary that the dynamic aperture is more than three times the beam size of an injected beam. Since damping the bunch for seven damping times($\sim 53msec$) reduces the emittance of the injected beam by six orders of magnitude, this aperture gives sufficient beam life time. The damped normalized emittance $\gamma\epsilon_0$ is 5.0×10^{-6}radm. The beam size of the injected beam σ_i is obtained from $\sigma_i=\sqrt{\beta\epsilon_i}$. Therefore,

$$3\sigma_i=3\sqrt{\beta\epsilon_0 \times 300/5} \sim 24\sigma_0 \sim 3.1mm,$$

where σ_0 is maximum equilibrium beam size. Then, the dynamic aperture more than 4mm($\geq 30\sigma_0$) gives sufficient beam life time. The planned beam pipe in the arcs has a 13.5mm inner radius and is approximately 13 times the beam size of an injected beam.

We correct the chromaticity with only two families of sextupoles located in the arcs. The integrated sextupole strengths are: $K_{2SF} = 41.7m^{-2}$ and $K_{2SD} = -57.2m^{-2}$. The results from computer code SAD(KEK original code) with only two families and MAD indicate that the dynamic aperture is more than $60\sigma_0$ without the nonlinear fields from wigglers. The dynamic aperture will decrease when errors and wiggler induced nonlinear field are included. The results of tracking sumilation(SAD and RACETRACK) with a sinusoidal nonlinear field from wigglers indicate that the dynamic aperture is more than $30\sigma_0$. The dynamic aperture is enough for beam injection.

The results of simulation(SAD and ref.5) indicate that the tolerances of the quadrupole misalignment and rotational misalignment, the sextupole misalignment, the magnetic field error and the monitor setting error are less than $50\mu m$ vertically, $60\mu m$ horizontally, 0.5mrad rotationally, 0.1% and 0.1mm to obtain the required emittance, respectively.

3.2 Vacuum, magnets, position monitor and rf

The aperture of a beam duct is $\phi 27mm$ in the normal cell and $15mm \times 47mm$ racetrak in the wiggler section. We choose the antechamber for the bending magnet to localize the area that is irradiated by synchrotron radiation. Beam gas interaction causes emittance growth and momentum spread. The elastic scattering requests the pressure less that $6 \times 10^{-6}Pa$ if the vertical emittance growth is less than 10%[6]. Ionization, excitation and bremsstrahlung processes are not severe. Vacuum system less than $6 \times 10^{-6}Pa$ was designed.

Conceptual designs have been made for damping wigglers, combined function bendings, quadrupoles and sextupoles. The magnet specifications were determined with consideration for the available space and the cost of the magnets and power supplies.

The beam position monitor are electrostatic type with four button-like electrodes. The position monitor system is designed to achieve the resolution of $3\mu m$(rms) in order to correct the $1mm$-dispersion in the wiggler section.

To ease the multibunch instabilities due to wakefield of rf cavities and the shift of bunch positions due to beam loading an rf freq. of 714MHz was adopted. Instabilities caused by the higher-order modes will be suppressed by using a damped cavity(low Q cavity) and bunch-to-bunch betatron tune spread of about 1×10^{-3}.

3.3 Beam injection and extraction

Considering transverse wakefields in the main linac, the stabilization of the extracted beam from the damping ring is extremely important. We would like to achieve a jitter tolerance of one tenth of the beam size at the interaction point. DC septum magnets are designed, because a pulsed septum will introduce more jitter problems. The pulse-to-pulse reproducibility in the total deflection angle(291mrad) of the extracted beam is better than $\pm 3 \times 10^{-5}$. Each extracted beam is deflected about 4.65mrad by a kicker magnet into the first septum magnet, which deflects the beam another 44mrad so that it enters the second septum magnet. It deflects the beam another 132mrad. Third septum magnet deflects the beam another 110mrad. The first septum plate is 90° in phase downstream of the kicker. Assuming $\beta_x \cong 10m$ according to ref.4, the jitter tolerance on the kicker is less than 7×10^{-4}. In order to achieve this tolerance, we need to use double kicker system, separated by a phase advance of π, to cancel the jitter. The first kicker will be placed in the damping ring and the second kicker located in the extraction line. We obtain the estimation of the jitter ranges from 10^{-4} to 5×10^{-4} on the double kicker system.

4 Construction schedule

Test vacuum chamber with the position monitors is investigated to confirm the performance. Test magnet system and the support table with movers are designed and will be made until the end of FY1992. In the case of best schedule, the construction of the damping ring including the reconstruction of the floor will be started from June 1993. The ATF damping ring will be completed by the end of 1994.

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