## 1.5 GeV Damping Ring Design of the Test Accelerator Facility for Linear Collider

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Abstract    We present a 1.54 GeV damping ring design of the test accelerator facility for the Japan Linear Collider. It has normalized emittance of $\gamma\epsilon \lesssim 2.5$ $\mu$mrad. The damping time is $\tau \lesssim 2.5$ msec.

INTRODUCTION

The Test Accelerator Facility(TAF) consists of an 1.54 GeV S-band linear accelerator, an 1.54 GeV damping ring and an 1.0 GeV X-band linear accelerator. The TAF project will be carried forward in three phases. Through Phase-I and Phase-II, the S-band and X-band linacs will be constructed, and in Phase-III, the damping ring will be completed.[1,2,3]

The design parameters of the damping ring which are required from the design of the Japan Linear Collider(JLC) are as follows:

1) $1.0 \times 10^{10}$ particles/bunch,

2) 10 bunches/train with the bunch spacing of 1.4 nsec,

3) equilibrium normalized emittance is less than $\gamma\epsilon_x / \gamma\epsilon_y = 3.0 \times 10^{-6} / 3.0 \times 10^{-8}$ mrad,

4) transverse damping time/train is less than 0.5 msec.

One of the characteristics of the present design of JLC is to operate in a multi-bunch mode. The linac accelerates bunch trains where the bunches contained in a train are separated by about 42 cm and the particle per bunch is $1 \times 10^{10}$. 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.

We assume that the total time duration for the kickers to turn on, extract/inject a train, and turn off is less than 130 nsec. Thus the trains must be separated by at least 60 nsec. 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. Unfortunately, the damping times are increased by reducing the strength of the bend magnet or decreasing the energy of the ring.

The damping time is directly proportional to $\rho_B/\gamma^3$, where $\rho_B$ is the local bending radius of the bend magnets. On the other hand, the normalized emittance is inversely proportional to $\rho_B/\gamma^3$. In order to reduce both the damping time and the normalized emittance at the same time, we have decided to introduce long wiggler sections in zero-dispersion region. We also selected a racetrack configuration as a ring style for the reduction of dispersion suppression region.

We present a 1.54 GeV damping ring design of TAF for JLC. It has normalized emittance of $\gamma\epsilon\lesssim2.5$ $\mu$mrad. The damping time is $\tau\lesssim2.5$ msec. To achieve these extremely low emittances and fast damping times simultaneously, the ring contains 76 m of wigglers.


DECISION OF ENERGY

The type of lattice in the arc is a separated function FODO since simple lattices are favored for operational simplicity.

A computer program was written for the damping ring designs according to the conditions described above. In order to reduce the cost of the ring, the design parameters given by this program is optimized to obtain the smallest ring which can satisfy both requirements 3) and 4). Following parameters are given as the inputs of the optimization program: beam energy, length for RF, injection,extraction etc., drift space length in cell, bending field, horizontal and vertical phase advance per cell, half aperture, quad and sextupole pole tip fields, packing factor in wiggler section, wiggler field, vertical-horizontal emittance ratio, bunch train separation, quantum life time, RF frequency, and number of particles per bunch.

It was concluded by using this program that a optimum energy was near 1.5 GeV , considering longitudinal impedance threshold,

circumference, Touschek life, RF power, intra-beam scattering etc.. It
was decided that the energy of the damping ring should be 1.54 GeV
since it does not induce the depolarization of beam.

Requirements 5)~8) were added due to the technical consideration.

5) Length for RF, injection, extraction, feedback etc. is 14m.

6) Circumference is ranged 100 m to 200m.

7) Kicker rise/fall time is more than 60 nsec.

8) Normalized emittance of injected beam is $1.0 \times 10^{-3}$ mrad.

In next section we present a design which meets all of the
specified requirments.


## LATTICE AND OPTICS

A preliminary design of TAF for the JLC damping ring is illustrated in
figure 1. The optical functions $\beta_x$ and $\beta_y$ and the dispersion function
$\eta_x$ for a quarter of the ring are plotted in figure 2.

The two arcs are constructed of 27 separated function FODO cells.
The bending magnets bend an angle of 3.3°. The quadrupoles have
normalized gradients of 13.7 $m^{-2}$. Assuming a magnetic radius of
r=1.2cm, which is 2 mm greater than the beam pipe, the quadrupoles
have pole tip fields of 9.9 kG.


## COMPARISON WITH OTHER DAMPING RINGS

Table 1 shows the comparison of the parameters for typical damping
rings.[4,5] Our design has a longest circumference and a least number of
bunches among these rings. This result is due to producing enough
space for injection/extraction rise/fall time, RF cavities and
considering multi-bunch instability. Also, the magnetic field and the
drift space in the normal cell are relaxed on our parameters comparing
with other designs.

The design of the wiggler part is crucial in our design. We must
carry out enough R&D for developing the damping wiggler. It is
necessary for the wiggler to have enough field quality, which
statisfies the conditions of the effective field 1.8 T, the wiggler
period $\lambda_w$=13.67 cm and the length 76m with packing factor 0.6. The
loss in dynamic aperture, which is caused by realistic non-linear
fields of the wiggler, intensely disturbes the beam injection. The

simulation about this problem is in progress.


## THE STABILIZATION OF THE EXTRACTED BEAM

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
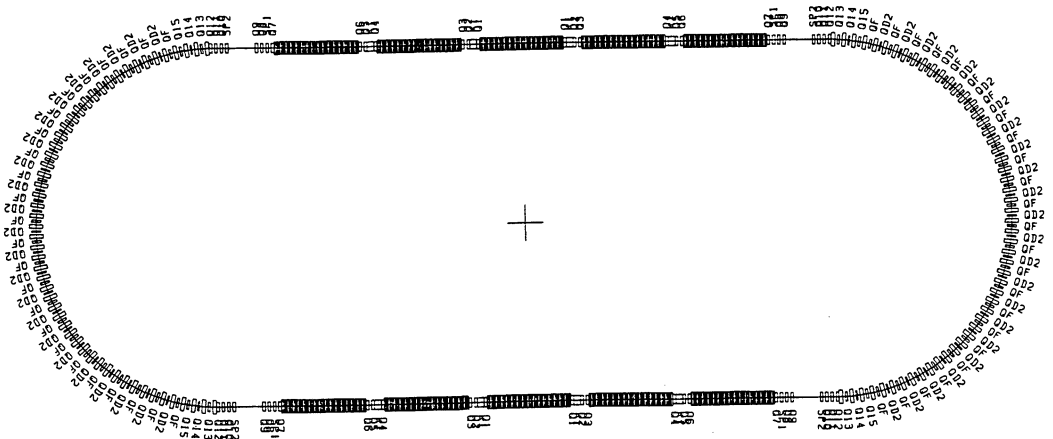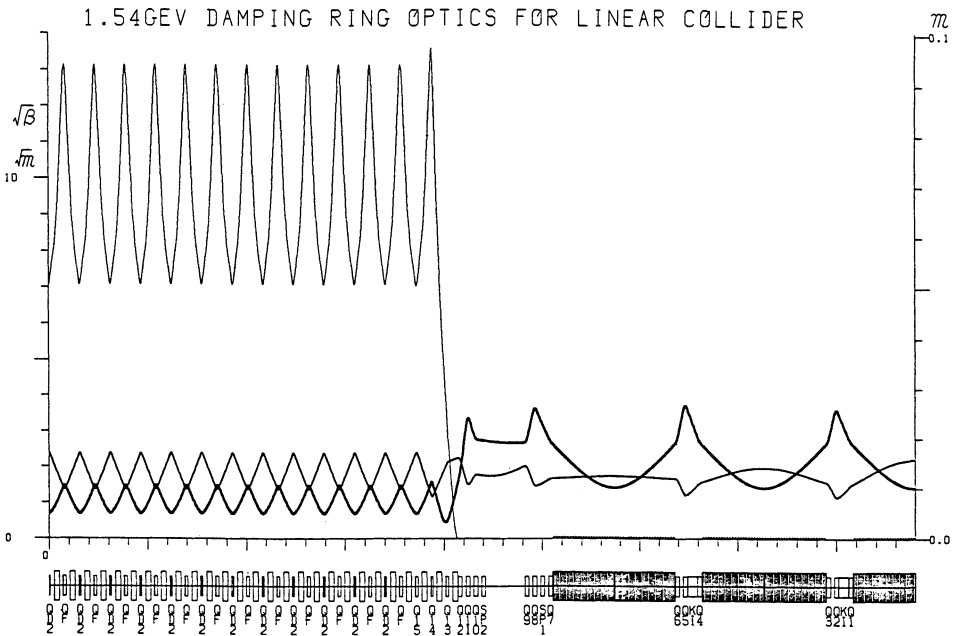


Figure 1. Schematic of the TAF damping ring.



Figure 2. Optical functions for a quarter of the ring.

Table 1. Damping ring parameters for linear colliders.

| | Units | JLC | TLC | CLIC |
|---|---|---|---|---|
| Type | | FODO&Wiggler | FODO&Wiggler | Alter. Bend |
| Beam Energy | GeV | 1.54 | 1.8 | 2.0 |
| Circumference | m | 176 | 155 | 162 |
| $N_{particles}$ | $10^{10}$ | 8x10x1.0 | 10x10x1.4 | 22x10x0.5. |
| $\tau_y$ | msec | 2.5 | 4.0 | 2.7 |
| f | GHz | 1.428 | 1.4 | 3.0 |
| $\Delta E/E$ | $10^{-3}$ | 0.76 | 1 | 1.7 |
| $\sigma_z$ | mm | 4.5 | 5 | 1.35 |
| $\alpha$ | $10^{-3}$ | 2.2 | 1.2 | 0.23 |
| $B_0$ | T | 1.15 | 1.3 | 1.6 |
| $L_{wiggler}$ | m | 76 | 22 | 0 |
| $B_{wiggler}$ | T | 1.8 | 2.4(peak) | 0 |
| $\gamma \varepsilon_{intra}$ | $10^{-6}$radm | 2.75 | 2.74 | 2.1 |

reproducibility in the total deflection angle(205 mrad) of the extracted beam is better than $\pm 3 \times 10^{-5}$. Each extracted beam is deflected about 4 mrad by a kicker magnet into the first septum magnet, which deflects the beam another 30 mrad so that it enters the second septum magnet. It deflects the beam another 170 mrad. 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 $5 \times 10^{-4}$. In order to achieve this tolerance, we need to use double kicker system, separated by a phase advance of $\pi$, 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 $5 \times 10^{-4}$ on the double kicker system.

Furthermore, if we are required more jitter tolerance, the feedforward control of the extracted beam will be necessary. The feedforward control system is consisted of an one turn extraction transport line around the damping ring which is necessary to increase the time duration between the beam extraction from the ring and injection to the linac, two pairs of the precise beam position monitors near the extraction point and two pairs of the correction kickers near the injection point to the main linac. The design of this system is in progress.


## CONCLUSIONS

In this paper we present a preliminary design for the damping ring of TAF. We have not yet taken into account the effect of alignment errors and realistic non-linear fields of the wiggler magnet on the dynamic aperture.

If the technical problems on the wiggler are solved, we believe that this design has enough performance as the first stage for the damping ring of JLC.

We can decrease the damping time and the normalized emittance, and increase the threshold of the longitudinal impedance by increasing the wiggler length. This feature is one of the characteristics of our design.


## Acknowledgements

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