KEK / ATF DAMPING RING

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Abstract

One of the major challenges in the next-generation electron-positron linear colliders is to produce and control multi-bunch beams with extremely small transverse emittance. The Accelerator Test Facility (ATF) at KEK is a test accelerator that has been built to study the feasibility of production, damping, control and diagnosis of such beams. The facility consists of a multi-bunch capable thermionic gun, bunchers, followed by a 1.54 GeV S-band injector, beam transport and a test damping ring. This paper reports the preliminary results from commissioning and accelerator studies of the test damping ring that has started in January, 1997.

1 INTRODUCTION

Next-generation electron-positron linear colliders, such as JLC [1], must collide multi-bunch trains of electrons and positrons with extremely small transverse and longitudinal emittances. This is an absolutely essential requirement for obtaining the desired collision luminosity. Typically, the beam to be accelerated in a linear collider is a bunch-train which consists of ~ 100 bunches, whose invariant emittance should be $\gamma\epsilon_x \sim 3 \times 10^{-6}$ m and $\gamma\epsilon_y \sim 3 \times 10^{-8}$ m. The bunch length should be $\sim 100\,\mu$m, and a typical bunch intensity should be 1×10^{10} or less.

The ATF (Accelerator Test Facility) project [2] was launched in 1990 as a test facility for investigating the technical feasibility of the low-energy portion of such a linear-collider, which is responsible for producing multi-bunch beams with extremely low emittance. At present the ATF consists of:

- A multi-bunch capable thermionic gun that can produce a bunch train with up to 20 bunches spaced by 2.8 ns with an intensity $< 5 \times 10^{10}$/pulse,
- A 1.54 GeV S-band injector linac equipped with multi-bunch beam-loading compensation system based on the $\pm\Delta F$ scheme [3],
- An injection beam line,
- A 1.54 GeV damping ring, and
- An extraction beam line.

In addition, a variety of beam diagnostic instruments are implemented throughout the facility.

After completing the injector linac, a series of experiments were conducted on producing and diagnosing multi-bunch trains by using the gun, pre-injector and the 1.54 GeV linac, prior to building the damping ring (DR), [4,5]. Construction of the ATF DR was started in November of 1993. The hardware commissioning of the ATF DR began in December of 1996, and the beam commissioning in January of 1997. This paper reports the preliminary results from the commissioning work of the ATF DR and presents the plans for the near-future.

2 DESIGN OF THE DAMPING RING

As mentioned earlier, the beam to be produced at ATF is a multi-bunch beam with up to 20 bunches, whose spacing is 2.8 ns. The ATF DR has been designed to operate at 1.54 GeV and can store up to five such bunch trains. The ring has a race-track shape, consisting of two arc sections and two straight sections. The ring cirumference is 138.6 m.

The target equilibrium emittance is $\gamma\epsilon_x = 5 \times 10^{-6}$ m and $\gamma\epsilon_y = 3 \times 10^{-8}$ m. For this purpose, a special design of a strong-focusing FOBO lattice is implemented using combined-function bending magnets in the arc sections. The two arcs have 36 FOBO cells in total. The horizontal phase advance per cell can be varied from $100°$ to $160°$, leading to the equilibrium horizontal emittance of $\gamma\epsilon_x = 6.6 \times 10^{-6} \sim 4.3 \times 10^{-6}$ m.

The two straight sections are dispersion-free, and they accommodate injection and extraction septa, RF cavities, and 20.4 m of damping wigglers which reduce the radiation damping time by a factor of 1/2. The expected damping time is 9.1 ms, when operated at 1.54 GeV.

The apertures in the injection and extraction septum magnets region are 7 mm vertically and 14 mm horizontally. In the early stage of the beam commissioning a significant beam loss often occurred in this region due to the jitter originating in the linac. The physical apertures in the wiggler section are 12 mm vertically and 24 mm horizontally. The aperture in the arc section is 24 mm diameter and the 5 m long straight section in the ring near the injection and the extraction lines has the physical aperture of 14 mm diameter.

In total 96 sets of beam-position monitors (BPMs) are installed in the DR for measuring the beam orbit in an arbitrary turn. For beam profile measurements, a synchrotron radiation monitor has been installed near the exit point of one of the arc sections. In addition, a “laser-wire” system is under development to measure the profile of several micron sized beam.

As a study machine, the ATF DR has several operation modes in terms of the bunch structure. For example, the number of particles per bunch, the bunches per train and

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the trains per ring, and the train spacing can be flexibly chosen under the restriction that the total stored current should not exceed 600 mA due to the limitation of radiation safety requirements and the cooling of the vacuum chamber.

The control system for ATF has been built based on the commercially-available V-system[6]. It allows to implement graphical user interface that lets physicists without the inner knowledge of the hardware system easily operate the device from an X-window terminal.

3 FIRST BEAM COMMISSIONING

The beam commissioning started on Jan. 21. The first beam revolution (two-turns) in the damping ring was observed on Jan. 27. A beam profile in the first turn was measured by synchrotron radiation monitor, and many turns of beam circulation was confirmed on Jan. 30 with a wall current monitor[7]. The effect of the radiation damping was observed on Feb. 15.

As of May 1997, the ATF DR is operating with a beam energy of 0.96 GeV at a repetition rate of 1.56 Hz in a single-bunch mode. The stored beam current is up to 6×10^9 electrons/bunch. The measured beam lifetime is about 50 s, consistent with the estimated Touchek lifetime assuming the ring momentum acceptance of ± 0.5 %.

In the following, we present some highlighting items from the initial commissioning experience of the ATF DR.

3.1 Alignment

The damping ring is built on support girders that are equipped with active position controls for applying the beam-based alignment technique. Full implementation of this system is expected to complete in September, 1997.

One active-girder in the arc section supports one combined bending magnet, two quadrupole and two sextupole magnets. The magnets on each girder have been installed with a relative position accuracy of $\sim 30\mu$m (rms). The girder-to-girder alignment accuracy resulting from the initial installation in January of 1997 is estimated to be $\pm 200\,\mu$m (peak-to-peak). The scatter plot of the x-y setting errors, and distribution of the measured longitudinal setting errors are shown in Figure 1[8].

The closed orbit distortion (COD) has been measured on the stored beam and the COD amplitude was found to be less than ± 1 mm, peak-to-peak. This is consistent with the currently-conceived quality of the transverse alignment.

Conducting beam-based alignment measurements on quadrupole magnets and combined-function bending magnets, and applying the results would significantly improve the alignment accuracy. This work is planned for the near-future run. During the initial run, the alignment of SF sextupole magnets has been quickly checked by observing the dependence of the tune on the strength of SF magnets. It is estimated that the position accuracy of 34 SFs is 120μm (r.m.s.), or better.

When the wiggler magnets are turned-on, the beam is captured by using the rf frequency of 714 MHz, which is

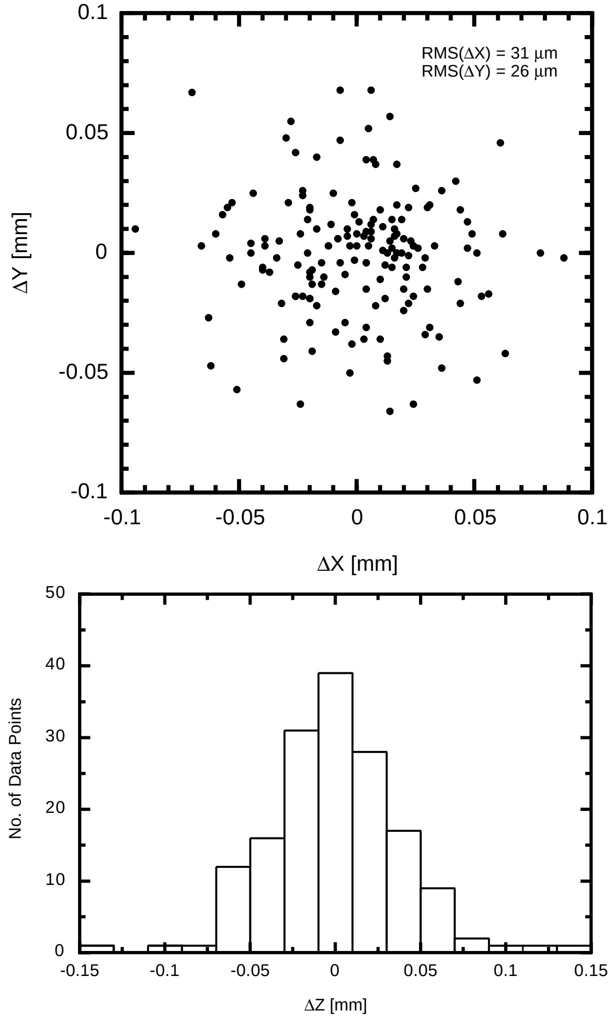

Figure 1: Scattered plot on transverse setting error and longitudinal setting error which were measured on magnets of the ATF 14 active girders using a 3D mobile tracking system

the design value. This indicates that the longitudinal alignment is fairly good, too. When the wiggler magnets are not excited for machine study purposes, the orbit length becomes shorter by 1.95 mm. To cope with this condition, the ring rf frequency needs to be increased by 10 kHz in such cases.

Estimation of COD in the injection septum region is shown in Figure 2. With the use of the energy feedback system (pulse by pulse) for the linac beam, and by applying an optical matching between beam transport and the damping ring, the beam loss in the injection septum region has become negligible.

3.2 BPM Response versus Steering Kick

The beam trajectory in the ATF DR is measured with 96 sets of BPMs. A simple and inexpensive circuit has been developed for signal processing. At present the beam or-

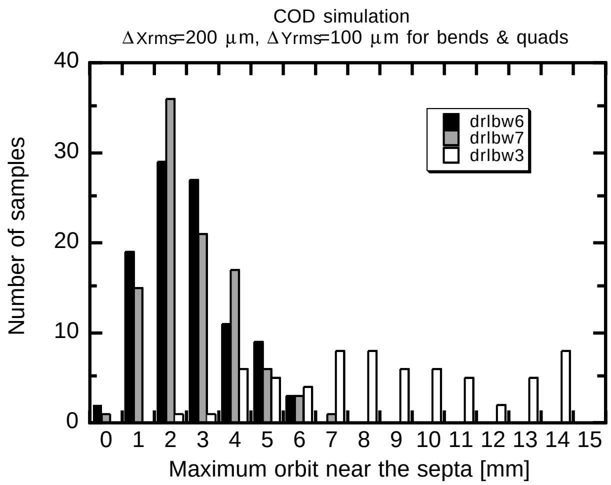

Figure 2: Simulation results of COD in septum region

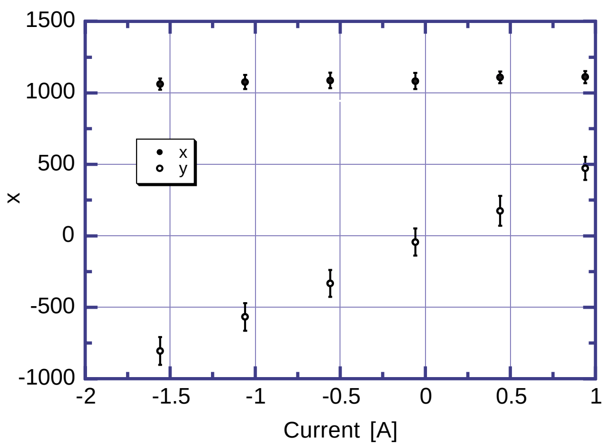

Figure 3: Response of BPM

bit can be measured every 20 ms[9]. The working of the BPM system has been checked by analyzing the response of the measured orbit with respect to perturbations applied by varying the excitation of steering dipole magnets. By comparing the current on the steering magnets and the response of the BPM data in their immediate neighborhood, the BPM resolution was found to be 90μm at 3×10^9 electrons/bunch. Figure 3 shows an example of the response of a BPM right next to the steering dipole magnet whose excitation is varied. There, the excitation current of one of the vertical steering magnet is varied while observing the variation of the beam orbit on a BPM near-by is measured.

3.3 Field Errors of Quadrupole Magnets

Field errors of quadrupole magnets in the ATF DR have been studied by creating π-bump orbit perturbations[10]. If no "leakage" orbit distortion is found to be originating from the bump, it indicates an absence of optical errors. If a "leak" orbit distortion is observed, its magnitude is related to the magnitude of focusing field errors in the region where the π-bump is created.

Quadrupole field errors are also estimated by measuring the orbit distortions, which are induced by varying the strength of steering magnets, and comparing them with model calculations[11].

In the initial phase of the study errors of a few % level were found on quadrupole magnets used in the ATF DR. All quadrupole magnets and combined-function bending magnets are equipped with individual trim-coils and small power supplies associated with them. Small quadrupole magnets are installed near the combined bending magnets. By using these trim coils, the overall quadrupole field errors can be reduced to a $\sim 0.2\,\%$ level.

3.4 Field Error on Combined and Wiggler Magnets

For each type of magnets used in the ATF DR, magnetic field measurements were conducted on representative prototype models only. Not all magnets in the ATF DR had their field map data collected, due to the budget constraint and the desire to reduce the production period.

However, provisions are made to allow surveys of magnetic field qualities using the beam. All combined-function bending magnets and major quadrupole magnets have trim windings whose currents can be individually controlled.

It has been found that the combined bending magnets (36 units in total) can be grouped into three families according to their field strength for a given excitation current. A group of six bending magnets has the field strength weaker than the average by 0.86 %, while another group of 15 is stronger by 1.02 %.

In addition, an uncanceled error kick that amounts to 3 mrad was found on the wiggler magnet. To quickly reduce this error, the cabling of the wiggler magnets have been temporarily revised, so that these error kicks form a chicane orbit which roughly cancels the orbit distortion. As a more definitive solution, four horizontal steering magnets will be installed at both sides of the wiggler section during a long shutdown period this summer[12].

3.5 Beam Size and Damping Time Measurements

An SR (Synchrotron Radiation) monitor, which is installed near the end of the first arc[13], has been used to study the beam profile and beam damping within the ATF DR. An image spot size of 76 μm (horizontal) was measured after damping. This corresponds to an actual beam spot size of 45 μm, when corrections are applied for the diffraction effects and the depth of focus. This horizontal spot size is in rough agreement with the expected value for operation at $\sim$ 1 GeV. Considering the intra-beam scattering effects at 0.96 GeV, β- and η-functions at the light source point of the SR monitor, diffraction effects, the depth of focus, and other issues, very preliminary estimates of on the beam parameters in the first beam commissioning are quoted as:

- Horizontal emittance $\sim$ 2 nm,

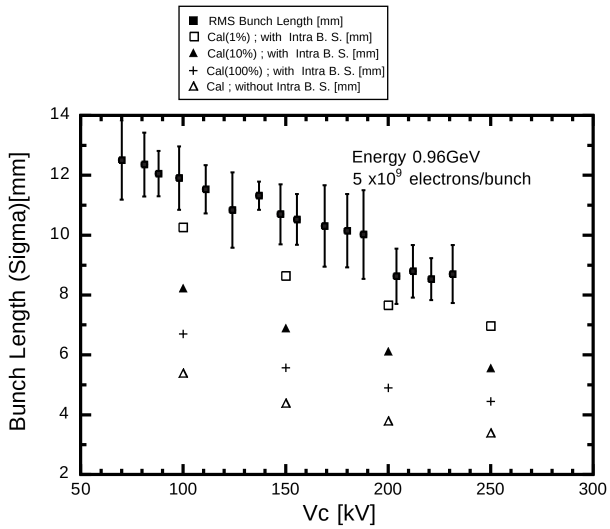

Figure 4: Bunch Length Measurements and Calculation with intra-beam Scattering

- Vertical emittance $\sim$ 0.5 nm,
- Bunch length $\sim$ 9 mm, and
- Energy spread $\sim 6 \times 10^{-4}$ at 0.96 GeV.

At present, the observed vertical size of the SR image is bigger than the expectation by factor 2. Detailed studies on possible set-up errors in the ATF DR as well as plausible systematic errors in the SR monitor optics system are being done. The vertical deformation of the first mirror was found. It enlarges the vertical image size. To measure the beam size directly, new beam instrumentation like the laser wire with a optical cavity in the ring and 5μm carbon wire scanner in the extraction line is necessary.

The damping times have beem measured in cases with the wiggler magnets turned on and off. The horizontal damping time has been measured to be about 40 ms with the wiggler off, and 30 ms with the wiggler on. They are in good agreement with expectations at ~ 1 GeV.

The SR monitor is also equipped with a streak camera which can be used to measure the bunch length. The result of a bunch length measurements is shown in Figure 4, together with the calculated values which takes into account intra-beam scattering effects. This is indicative of effects of potential-well distortion and an x-y coupling (emittance ratio) of several $\%$. Also, synchrotron frequency was measured as function of the cavity voltage, by using a bunch phase monitor. The measurement was found to agree with theoretical values within 1%[14].

4 PROSPECTS

The ATF DR has been operated at the beam energy of 0.96 GeV, limited by the hardware condition of the injector linac until now. The beam energy will be gradually increased up to 1.54 GeV later this year.

For the next few months our focus will be on the development of the beam handling techniques to stably operate the entire ATF complex with a 1.0 GeV beam. The specific work item list includes: transient beam loading at high current beam injection, fast ion instability, beam loading effect due to train gap, nonlinear beam dynamics, intra-beam scattering, long beam tail due to beam-gas scattering, investigation of Touchek lifetime, and so on.

The next-stage beam commissioning will be started on May 20. Beam energy will be increased to 1.3 GeV. Then, a series of precise measurements on the image size, the bunch length, possible field errors and so on will be continued in a single-bunch operation until the summer shutdown. Hardware upgrades for the rf system and multi-bunch operation are scheduled for the next year (1998)[15,16]. Many experiments with the extracted beam from the damping ring are under consideration. Precise measurement of wake-field is also planned at the ATF extraction line next year[17].

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