Recent Result in ATF Damping Ring

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The mission of the ATF at KEK is to test the feasibility of the production of multibunch beams with extremely low transverse emittance for future linear colliders. Until this summer the main goal had been to produce low emittance beams with single bunch operation. We established a tuning method of the damping ring for the small vertical dispersion and small x–y orbit coupling. Simulation studies indicate that low vertical emittance should be attainable with this tuning. At the zero intensity limit, the horizontal emittance and the vertical emittance are 1.1×10^{-9} rad-m and less than 1.1×10^{-11} rad-m, respectively, which correspond to normalized emittances of 2.8×10^{-6} rad-m and less than 2.8×10^{-8} rad-m at beam energy 1.3 GeV.

1. Introduction

ATF consists of an S-band linac, a damping ring and an extraction line [1]. The ring has been designed to produce extremely low emittance beam. The designed natural horizontal emittance is 1.1×10^{-9} rad-m and the target value of vertical emittance is 1% of that. History and summary of the beam operation are reviewed in references [2, 3]. The initial stage operation of ATF has been focussing on confirmation of low emittance beam production at a low repetition rate (1.56 Hz). Substantial commissioning experiences have been accumulated, and the target vertical emittance has been achieved at the bunch intensity of about 2×10^9.

2. Tuning for Low emittance Beam

Our tuning method of the damping ring for low vertical emittance is a series of corrections: COD correction, vertical COD + dispersion correction and coupling correction.

The strengths of a set of steering magnets is calculated to minimize

$$\sum_{\text{BPM}} x_{\text{meas}}^2 \text{ and } \sum_{\text{BPM}} y_{\text{meas}}^2 \tag{1}$$

in the COD correction and to minimize

$$\sum_{\text{BPM}} y_{\text{meas}}^2 + r^2 \sum_{\text{BPM}} \eta_{y,\text{meas}}^2 \tag{2}$$

in the vertical COD + dispersion correction. Here, x_{meas}, y_{meas} and $\eta_{y,\text{meas}}$ are beam horizontal position, vertical position and vertical dispersion measured at each BPM. In this COD + dispersion correction, both the vertical COD and vertical dispersion are considered simultaneously. The factor r is the relative weight of the dispersion and COD, and it was chosen to be 0.05 based on a simulation study. For the coupling correction, trim coils of all 68 sextupole magnets are wired so as to produce skew quadrupole fields. The strengths of these skew fields is calculated to minimize

$$\sum_{\text{steer}} [\sum_{\text{BPM}} (\Delta y_{\text{steer}})^2 / \sum_{\text{BPM}} (\Delta x_{\text{steer}})^2], \tag{3}$$

Here, Δx_{steer} and Δy_{steer} are measured horizontal and vertical position responses to each horizontal steering magnet. Usually, two horizontal steering magnets, which are apart by approximately $3/2\pi$ in horizontal and $1/2\pi$ in vertical phase advance, are chosen for this correction.

Simulations were performed to study this tuning method where realistic magnet misalignment and random errors of BPM are considered [4]. Transverse offsets of the all magnets are set as actually measured. In order to consider the error of the measurement, random offset, rms 30 μm , were added for all magnets. Random rotation errors, rms 0.3 mrad, of the all magnets, were also set. In order to consider the misalignment and the calibration error of BPM, each BPM was

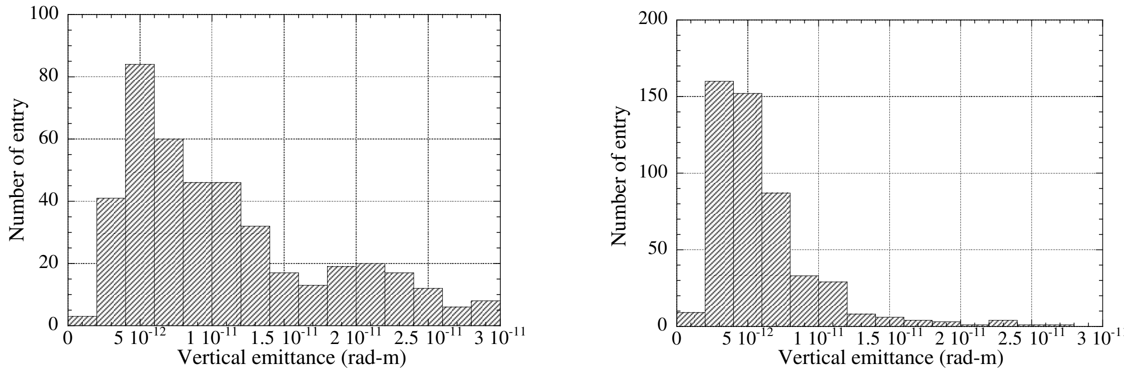

Figure 1: Distribution of the simulated vertical emittance (left) after the COD+dispersion correction and (right) after all the corrections.

assumed to have random offset and rotation error, rms 300 μm and 20 mrad. Figure 1 shows the distribution of the vertical emittance: (left) after the COD+dispersion correction and (right) after all the corrections, from 500 random seeds for magnet misalignment and BPM errors in the simulation. After all the corrections, the average was 5.8×10^{-12} rad-m, well below our target (1.1×10^{-11} rad-m) and 91% of the random seeds gave the emittance less than the target. Note that this should be regarded as emittance at zero intensity limit because the simulation did not consider intra-beam scattering, which could be significant for high intensity operation.

3. Beam size measurement

The beam size in the damping ring (DR) is measured using two kinds of monitors. One is an interferometer with two slits which allows to observe interference patterns created by the synchrotron radiation (SR monitor)[5]. Another is a laser-wire monitor that is newly commissioned [6]. A thin horizontal “wire” of light is created in an optical cavity, which consists of two mirrors. When the electron beam hits the wire, gamma rays are produced as Compton scattering and detected by a scintillation detector. The whole optical system is placed on a movable table, and the vertical beam size is measured in a manner similar to conventional wire scanners.

In the extraction line (EXT), the beam size is measured using tungsten wire scanners [7]. There are 5 wire scanners in the dispersion-free region of the beam line and the emittance is evaluated from the measured beam sizes and beam optics between the wire scanners.

In order to evaluate energy spread of the extracted beam, horizontal beam size is measured using a screen monitor at a high dispersion region in the extraction line.

4. Measured results

Figure 2 shows the emittance as a function of the bunch intensity (number of electrons per bunch). The left figure shows the horizontal emittance measured in the extraction line. The right figure summarizes measurement of vertical emittance using the laser wire monitor and the wire scanners on different days, where the ring optics and the tuning conditions of the extraction line were different. Figure 3 shows the energy spread measured in the extraction line as a function of the bunch intensity. The lines in these figures are from calculations using SAD program [8] assuming the emittance ratio (the ratio of the vertical emittance to the horizontal emittance) of 0.002, 0.004 and 0.008. The emittances depend on the bunch intensity due to intrabeam scattering.

At low intensity, the horizontal emittance and the energy spread agree well with the calculation. Since the effect of intrabeam scattering is large when the bunch density is high, the horizontal emittance and the energy spread is expected to be large at high intensity with small vertical emittance. Intrabeam scattering in the ATF damping ring was reported in another working group [9].

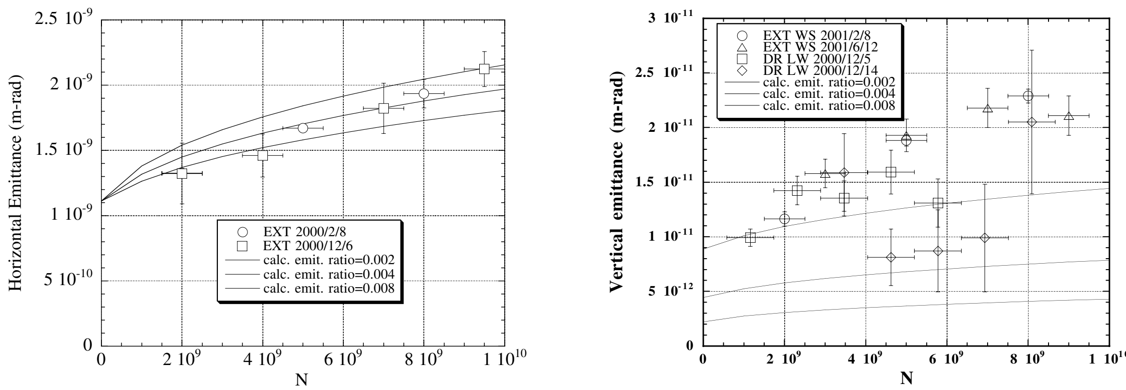

Figure 2: Left: Horizontal emittance measured in the extraction line versus bunch intensity. Right: Vertical emittance measured in the damping ring (DR) and in the extraction line (EXT) versus bunch intensity. The lines are from calculation assuming the emittance ratio 0.002, 0.004 and 0.008

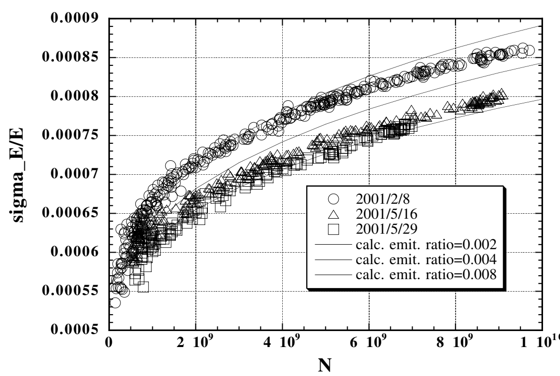

Figure 3: Energy spread measured in the extraction line (EXT) versus bunch intensity. The lines are from calculation assuming the emittance ratio 0.002, 0.004 and 0.008

There was a large variation in the measured vertical emittance on different days, suggesting different conditions in the damping ring or in the extraction line. Because unknown errors of the measurement are likely to make the apparent vertical emittance large, we concluded that the vertical emittance was smaller than 1.1×10^{-11} rad-m which corresponds to normalized emittance of 2.8×10^{-8} at beam energy 1.3 GeV. This satisfies the requirement of the linear collider designs (JLC/NLC [10]).

Acknowledgments

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[8] SAD is a computer program for accelerator design. http://acc-physics.kek.jp/SAD/sad.html.
[9] K. Kubo, "Intrabeam Scattering - Result from KEK-ATF", in Working Group T5.
[10] "International Study Group progress report on linear collider development", KEK Report 2000-7 (also SLAC R-559).
[11] ATF is an international collaboration for future linear colliders. Lists of the contributed institutes and members are available at http://atfweb/memberlist.html.