Present Status of KEK-ATF*

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Abstract

This report describes the operation status and the results of the beam commissioning of the ATF at KEK. Recent progress on the studies on production of low emittance beam, multi-bunch beam operation and development on beam instrumentation are discussed. So far, a horizontal emittance of 1.7±0.3 nm was measured with wire-scanners in the extraction line and with the horizontal spatial coherence using an SR interferometer. In addition, a vertical emittance of 15 ± 7.5 pm was measured with a laser wire in the ring, the SR interferometer and 5 wire scanners.

1 INTRODUCTION

The ATF [1] has been designed to investigate the feasibility of the LC operation scheme and to develop beam-control techniques for the LC [2]. The purpose of the ATF is to develop accelerator technology that can stably supply to the main linear accelerator an extremely flat "multi-bunch beam". Presently, we are refining the beam-tuning techniques and are stabilizing the key machine components to supply the extremely small emittance beam stably into the extraction line (EXT). Table 1 summarizes the achieved accelerator performance of the ATF.

In the following sections we describe the operation status and the recent results on the emittance measurements in Section 2, results of the damping ring (DR) study in Section 3, our goal and the experimental plans in Section 4.

2 EMITTANCE MEASUREMENTS

We usually operate the ATF with the period of 22 weeks per year except for Sat. and Sun.. There are three months long shutdown in summer, one month shutdown in winter and many two weeks without the beam operation for the experimental set-up. Extracted beam is prepared in a few hours without hardware trouble. After that, we check the beam quality and start the beam studies to develop the beam-tuning techniques for the LC.

Figure 1 shows the dependence of the measured emittance on the bunch intensity, which indicates the effects of intra-beam scattering. The measurements have been done under following condition. The error bar in the figure shows the statistical variation on repeated measurements.

i) Vertical beam position jitter at the wire scanners is less than a few μm. ii) Horizontal beam position jitter at the wire scanners is less than several μm [3]. iii) Beam energy drift is less than 0.01 % within 8 hours.

It appears that the following points play an important role.

1. Tuning with skew knobs in the arc sections of the DR for reducing the betatron coupling in the ring.
2. Careful corrections for residual dispersion in the EXT.
3. Additional cross-plane coupling correction using a skew quadrupole magnet in the EXT, upstream of the wire scanners.
4. Careful examination of dependence of beam emittance on the stored bunch intensity in the ring.

3 RESULTS OF DAMPING RING STUDY

3.1 Beam Tuning

The SAD modelling program [4] is used to calculate settings for steering magnets in orbit and dispersion corrections. A COD correction algorithm and local-orbit bumps are used to correct the stored-beam orbit. After correction, the typical peak-to-peak COD is less than 2 mm in the horizontal plane and 1 mm in the vertical plane. The dispersion functions at the BPMs in the ring and in the EXT are measured from the orbit shift induced by a change in the RF frequency. The measured vertical dispersion in the arc section was reduced from 40 mm to 5 mm by an additional correction using vertical steerings. We thus established correction techniques for the COD and the dispersion, as well as a beam-based technique for measuring the quadrupole-field errors.

A global correction of the coupling using skew quads was also developed. The orbit coupling is measured as COD change due to change of strength of horizontal streerings. A set skew of quads (trim coils of sextupoles) is adjusted to make the orbit coupling minimum. The orbit coupling was clearly reduced after the correction. Setting many bumps one-by-one the vertical beam size was monitored using the SR-interferometer.

3.2 Turn-by-Turn BPM (Tune Monitor)

DR stored orbit stability was analyzed using 4 sets of turn-by-turn BPMs. This system can be used to monitor injection orbit error, damping after injection, stored orbit oscillation, and stored orbit stability. It can also be used as a precise tune monitor in combination with a strip line exciter at the South straight section in the DR. The FFT software showed that we can determine betatron and synchrotron tunes with an accuracy of 100 Hz (corresponding to 0.00005 in units of revolution frequency). Also, with this system we detected a 100-Hz betatron tune oscillation of amplitude 0.001.

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* Work supported by long suffering spouses and colleagues

Table 1: Achieved and design parameters at ATF.

Items	**Achieved Values**	**Design**
ATF Linac Status		
Maximum Beam Energy	1.42GeV	1.54GeV
Maximum Gradient with Beam	28.7MeV/m	30MeV/m
Single Bunch Population	1.7×10^{10}	2×10^{10}
20 Multi-bunch Population	7.6×10^{10}	20×10^{10}
Bunch Spacing	2.8 ns	2.8 ns
Repetition Rate	12.5 Hz	25 Hz
Energy Spread (Full Width)	< 2.0 % (90 % beam)	< 1.0 % (90 % beam)
Damping Ring Status		
Maximum Beam Energy	1.28GeV	1.54GeV
Circumference	138.6 ± 0.003m	138.6m
Momentum Compaction	0.00214	0.00214
Single Bunch Population	1.2×10^{10}	2×10^{10}
COD(peak to peak)	$x \sim 2$ mm, $y \sim 1$ mm	1 mm
Bunch Length	~ 6 mm	5 mm
Energy Spread	0.08 %	0.08 %
Horizontal Emittance	$(1.7 \pm 0.3) \times 10^{-9}$ m	1.4×10^{-9} m
Vertical Emittance	$(1.5 \pm 0.75) \times 10^{-11}$ m	1.0×10^{-11} m

3.3 *Laser Wire*

We have developed a new beam profile monitor which is suited for a low-emittance circulating electron beam. The monitor utilizes a CW laser and an optical cavity. It is a non-destructive device minimally interfering with the stored electron beam. A laser beam with a very thin waist is generated in an optical cavity formed by nearly concentric mirrors. The laser intensity is amplified by adjusting the cavity length to meet the Fabry-Perot resonance condition. We have already built and tested a prototype cavity, which produced a beam waist of 7μm (σ) and an effective power of 11 W, with good long-term stability[5].

3.4 *Wire Scanner*

The beam emittance can be measured independently in the EXT. The EXT is equipped with 5 wire scanners, an air Cerenkov γ detector, BPMs with single-pass signal processing and a current transformer (CT). We can measure a 5μm beam size with sufficient accuracy using a 10μm W(tungsten) wire scanner when the extracted beam is stable from pulse to pulse.

3.5 *Intra-Beam Scattering and Touschek Effect*

Given the extremely low emittance of the ATF-DR beam, it is difficult to directly and accurately measure the vertical beam size in the ring. On the other hand, the Touschek effect causes the beam lifetime to be approximately proportional to the bunch volume at equilibrium. We can take advantage of this fact to infer the beam size in the ring. Since the bunch volume, or equivalently the vertical emittance when horizontal and longitudinal beam sizes are known, can be evaluated from the measurement of the Touschek lifetime, a novel beam diagnostic technique was developed [6]. The effect of intrabeam scattering can also be used directly to infer the emittance in the ring via the increase of the energy spread. The measured dependence of the lifetime and the energy spread on the beam intensity recently both indicate an emittance ratio less than 1% [7].

3.6 *Performance*

Single-Bunch Operation The horizontal beam emittance, measured by using wire scanners in the EXT, agrees well with the theoretical calculation [8]. The vertical emittance has been measured both in the DR using the SR interferometer and in the EXT using wire scanners. We have also estimated the vertical emittance from the dependence of the energy spread and the beam lifetime on the bunch charge, which gives an apparent vertical emittance of approximately 0.006 nm with zero current, or 0.6% of the horizontal emittance [10].

Multi-Bunch Operation A $\pm\Delta F$ beam loading compensation experiment in the ATF linac was successfully conducted at 1.16 GeV with 23 bunches/pulse in 1996 [12]. A noteworthy requirement for beam instrumentation at the LC is the need to make measurements on a bunch-by-bunch basis. Other report [11] describes the status of the multi-bunch operation.

4 OUR GOAL AND EXPERIMENTAL PLANS

Our goal is to confirm the stable operation with 3 trains in the DR. Each train should consist of 20 bunches with bunch spacing of 2.8 nsec. There are many study items

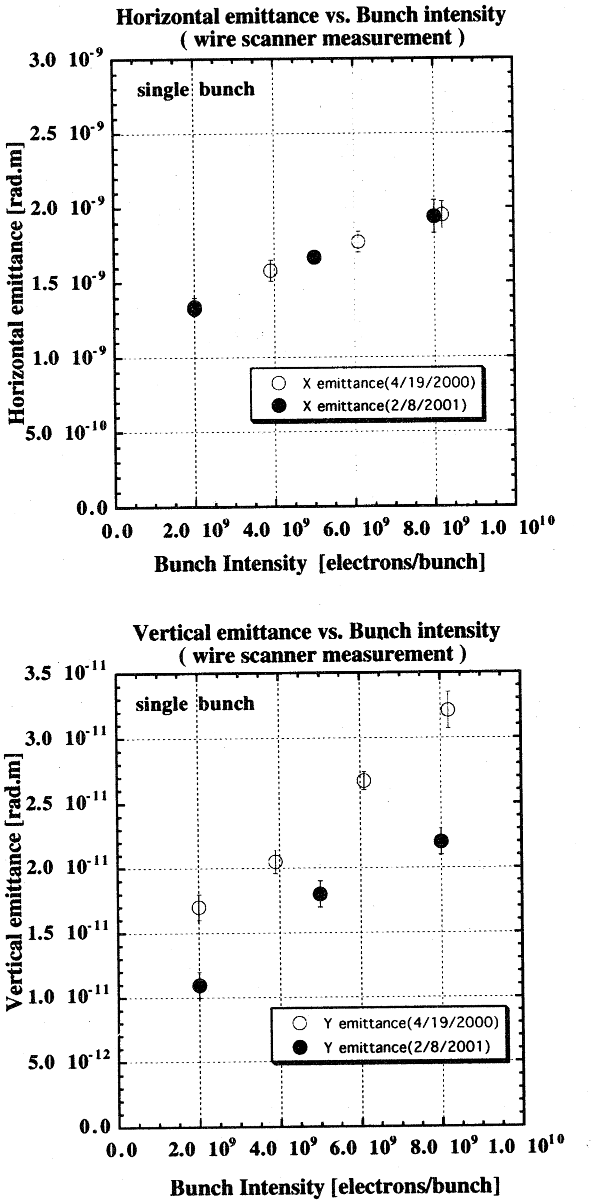

Figure 1: Recent results of emittance measurements using wire scanners at the EXT.

on the multi-bunch beam physics. For example, transient beam loading, muti-bunch instabilities, fast ion instability and emittance blow-up isuues due to the multi-bunch beam which should be overcome. The following development studies are under way in collaboration with Japanese universities and foreign accelerator physicists.

4.1 Polarized Positron Generation

We have proposed a new method of generating highly polarized positrons through Compton scattering of polarized laser light off relativistic electron beams and successive pair creation. We measured the intensity of the generated γ-rays and plan to measure the polarization of the positrons produced. A preliminary experiment was performed in the ATF extraction line on June 2001. A γ-ray yield of 6×10^5 photons/pulse was measured. Further optimization of laser and beam optics will be necessary [12].

4.2 Optical Diffraction Radiation Monitor

A "proof-of-principle" experiment on the use of optical diffraction radiation (ODR) as a single pulse beam profile monitor is planned by using the electron beam extracted from the DR. We already calculated that the ODR photon yield in 10% bandwidth for 500 nm is about 10^6 photons/bunch with the impact parameter of 100μm. This indicates that the ODR monitor is a promising candidate for single pulse beam profile measurements, and that it will be an extremely useful instrument for the LC [13].

4.3 Photo-Cathode RF Gun

We are manufacturing a photo-cathode RF gun with a Mg Cathode in collaboration with two Japanese universities. This RF gun is BNL type and the BNL-ATF made essential contributions to its development. Our target values are as follows [14, 15].

i) normalized emittance 3×10^{-5} m, ii) 1×10^{10} electrons/bunch, iii) 2.8 nsec bunch spacing, iv) 20 bunches/train, v) 25Hz operation.

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