Activity at KEK-ATF

1 OUTLINE OF ATF AT KEK

The Accelerator Test Facility (ATF) at KEK consists of three major parts: an S-band injector linac, a damping ring, and a beam diagnostic system(EXT) (see Fig. 1). Each part directly contributes to the development of technologies relevant to high luminosity linear colliders(LC). The ATF has been designed to investigate the feasibility of the LC operation scheme and to develop beam-control techniques. 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”. The multibunch scheme is essential to boost the rf-to-beam transfer power efficiency in the accelerator. The ATF continues to help develop and test many techniques to handle the multibunch beam. One is the beam loading compensation system in the injector linac. A new idea using two rf side-bands was applied to compensate the bunch-by-bunch energy deviation due to beam loading. A newly developed damped cavity suppresses the coupled-bunch instabilities in the damping ring. A new simultaneous injection-extraction system for the damping ring will solve the problem of transient beam loading due to multi-train operation in the damping ring. The small emittance from the damping ring has been achieved by special design of a strong focusing lattice with precise alignment of components and beam orbit control. The nonlinear behavior of the beam has to be well understood to provide enough dynamic aperture under such strong focusing conditions. Table 1 summarizes the achieved accelerator performance of the ATF until the end of 2003.

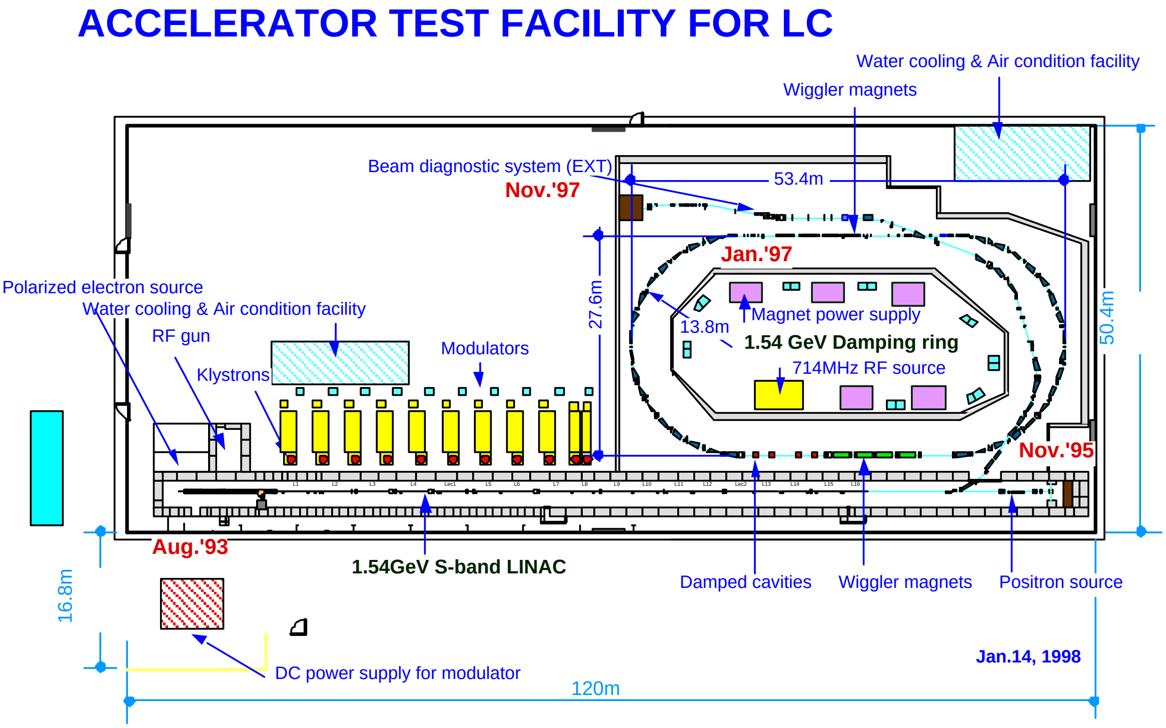

Figure 1: The Accelerator Test Facility (ATF) at KEK.

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	2.0×10^{10}	2×10^{10}
20 Multi-bunch Population	20×10^{10}	20×10^{10}
Energy Spread (Full Width)	< 2.0 % (90 % beam)	< 1.0 % (90 % beam)
Damping Ring Status		
Maximum Beam Energy	1.28GeV	1.54GeV
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	~ 9 mm	5 mm
Energy Spread	0.08 %	0.08 %
Horizontal Emittance	$(2.2 \pm 0.3) \times 10^{-9}$ m	1.4×10^{-9} m
Vertical Emittance	$(4.0 \pm 0.5) \times 10^{-12}$ m	1.0×10^{-11} m
Multibunch Population	8×10^{10} m	20×10^{10} m
Vertical Emittance	$(1 \sim 2) \times 10^{-11}$ m	1.0×10^{-11} m

2 EMITTANCE MEASUREMENTS AT THE EXT

Figure 2 shows the observed dependence of the measured emittance on the bunch intensity, which indicates the effects of intra-beam scattering. The error bar in the figure shows the statistical variation on repeated measurements. Intensive studies on the vertical emittance with the wire scanners in the EXT have been ongoing since March(2000). An important observation we made during this time is that there appears to be a source of x-y cross plane coupling somewhere between the extraction point of the damping ring (DR) and the wire scanner region in the EXT. The measured vertical emittance is approximately $(1.1 \pm 0.25) \times 10^{-11}$m for the beam intensity of $(2.0 \pm 0.2) \times 10^{9}$ electrons per bunch. This represents the best result so far obtained at the EXT in a single-bunch mode operation. The emittance is found to grow to $(2.2 \pm 0.33) \times 10^{-11}$m at the beam intensity of $(8.0 \pm 0.3) \times 10^{9}$ electrons per bunch, however. This could be partly due to effects of the intra-beam scattering, which according to a simulation can lead to an emittance growth of ~ 50 % at this bunch intensity. More careful theoretical and experimental studies are needed to fully understand the situation. In these measurements, the x-y beam profile showed a tilting of a few degrees, as observed by using 10 degree wires. The quoted vertical emittance in these plots might be further reduced by re-optimizing the setting of skew magnets. It appears that the following points play an important role.

1. Tuning with skew knobs in ARC sections of 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.

3 BEAM TUNING IN THE DR

We measured the R_{12} single-pass response matrix of each BPM to excitations of the different dipole correctors, with sextupole magnets turned off. From these data we calculated typical quadrupole

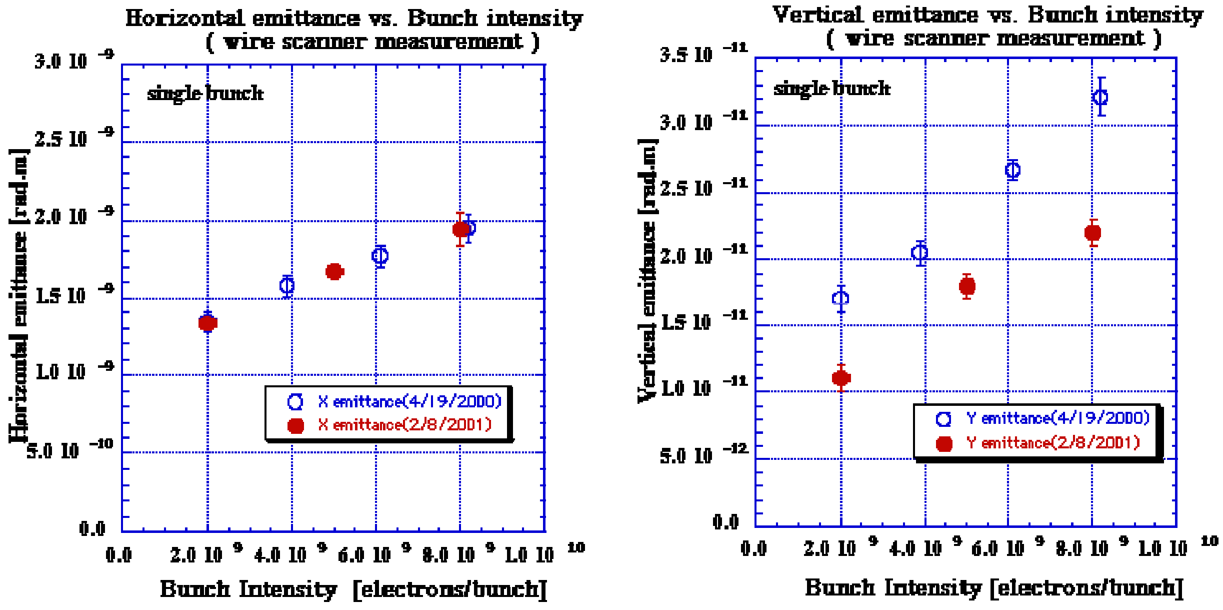

Figure 2: Recent results of emittance measurements using wire scanners at the EXT.

field-strength errors of about 1% and upgraded the optics model so as to account for these errors. The magnetic-field difference between the upgraded model and new beam-based measurements are less than 0.01%. The program SAD is used in orbit and dispersion corrections, for calculating new setting of the steering magnets. The orbit correction in the DR was satisfactory. The dispersion in the DR is measured as difference of the orbits with different RF frequencies. The dispersion correction in the ring worked and typical r.m.s. of the vertical dispersion after the correction was about 3 mm. To correct x-y coupling, trim coils of the all sextupole magnets are connected to produce skew quadrupole field. A global correction of the coupling is essential to achieve the smaller vertical emittance. We tried a global coupling correction minimizing vertical COD response to horizontal steering. The orbit coupling was clearly reduced and some reduction of the vertical emittance was observed after the correction.

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. A beam lifetime model which includes the effects of potential well distortion, intra-beam scattering, photo-desorption and Touschek effect was made. The effect of intrabeam scattering (multiple Touschek 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 $\sim 0.5\%$, assuming that the intra-beam scattering effect is the source of the beam-size variation.

4 FUTURE PLANS

Our goal is to confirm the stable operation with 3 trains in the DR towards the end of JFY2004. Each train should consist of 20 bunches with bunch spacing of 2.8 nsec. There are many study items on the multi-bunch beam physics. For example, transient beam loading, muti-bunch instabilities, fast ion instability and emittance blow-up issues due to the multi-bunch beam which should be overcome.

Future plans address the immediate goals of understanding the minimum achievable single bunch emittance and obtaining stable operation with 3×20 bunch trains. A program of theoretical and experimental studies has been planned that is focused on understanding the correction and optimization procedures, the stability of the ring component alignment, intra-beam scattering emittance growth and the multi-bunch beam dynamics mentioned before. The RF photocathode source, to be installed in late 2002, provided twice the present stored beam intensity, allowing more precise studies of single bunch intensity dependent phenomena, such as intra-beam scattering and impedance effects. International development studies are as follows;

1. Photo-Cathode RF Gun; Since $\sim 100\%$ beam injection efficiency was dramatically demonstrated during RF gun tests in 2001, we manufactured a photo-cathode RF gun with a Cs_2Te Cathode. Our photo-cathode RF gun is routinely operated and upgraded for ATF study program.

2. Beam Based Alignment; Using new, high-resolution ring BPMs we are developing a quick, accurate beam based alignment procedure that will provide insight into the nature of the optics corrections that are presently used for emittance optimization. We will be able to identify sources of instability and understand the physical limits on the minimum vertical emittance. This is one of the highest priority beam studies.

3. Laser Wire; 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 the cavity which produced a beam waist of 12μm (2σ) and an effective power of 100 W, with good long-term stability. The laser wire has been installed in the ATF DR at a location with a transverse electron beam size of $\sim 10\mu$m. We can measure the vertical and horizontal emittance of each bunch in the ring with sufficient accuracy.

4. Optical Transition Radiation; The linear collider needs a profile monitor that provides images of the low emittance beam with a resolution well below typical beam sizes in order to accurately determine x-y and y-z coupling and other phase space distortions. The required resolution $(2\mu m)$ is well below the state of the art for such monitors $(20\mu m)$ and we have a program to test and perfect such a monitor in the extraction. To date, beam sizes of $5\mu m$ have been imaged and tests of transition radiation target durability have been done.

5. 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. A preliminary experiment has been performed in the ATF extraction line. A polarized γ-ray yield of 3×10^6 photons/pulse has been measured.

6. Optical Diffraction Radiation Monitor; A ”proof-of-principle” experiment on the use of optical diffraction radiation (ODR) as a single pulse beam profile monitor has been done using the electron beam extracted from the DR. We are measuring the yield and the angular distributions of the optical diffraction radiation from a thin metal target at different wavelengths, impact parameters and beam characteristics. New beam diagnostic tool will be proposed for μm beam size measurement.

7. Stable Beam Extraction using Double Kicker Scheme; We already demonstrated in the single bunch operation that the stability of the beam orbit at the EXT was less than a few μm with double kicker system using cavity BPM. Regarding the multibunch operation, we need a precise bunch-by-bunch BPM with pulse-by-pulse to check the performance of the double kicker system.

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