BEAM DEVELOPMENT IN ATF DAMPING RING

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Abstract

The Accelerator Test Facility (ATF) at KEK is a test accelerator for future linear colliders. Its purpose is to test the feasibility of the production and diagnostics of multibunch beams with extremely low transverse emittance. The beam operation of the damping ring started in January 1997 as an international collaboration. While installations and improvement of many components has been continued, the main target so far is to produce low emittance beams with single bunch operation. The status of the recent beam experiment, methods and results of the beam tuning and diagnostics will be reported.

1. INTRODUCTION

ATF consists of a 1.54 GeV S-band Linac, a damping ring and an extraction line[1]. The ring has been designed to produce extremely low emittance beam. The design emittance are 1×10^{-11} radm in vertical and 1×10^{-9} radm in horizontal. Though operation of multibunch beam with high repetition rate is very important for future linear colliders and should also be tested in ATF, it was decided that our first target should be to achieve and confirm the low emittance beam production with single bunch and low repetition rate. For this purpose, the beam energy has been chosen to be 1.29 GeV because the S-band injector linac could be more stable than at higher energies.

Table 1. Typical operation condition and design parameters of the damping ring.

	Typical condition	Design
Beam Energy	1.29 GeV	1.54 GeV
Repetition Rate	0.78 Hz	25 Hz
Bunch trains	1	4
Bunch/train	1	20
Circulating time	640 msec	160 msec
Wiggler magnets	Off	On
RF voltage	~300 kV	~500 kV
Bunch Population	$6\sim8\times10^{9}$ e/bunch	2×10^{10} e/bunch

Recent typical operation condition of the damping ring is listed in the Table 1. History of the beam operation was reviewed in references [2][3].

2 UNDERSTANDING OF THE RING

2.1 Beam Position and Close Orbit

The single pass beam positions are measured using 96 BPMs in the ring where turn number to be measured can be selected. In repetition rate of 0.78 Hz, data can be taken once per one beam filling using present system. Position resolution is estimated to be about 40 microns and recent studies for improvement are reported in another paper.[4]

Orbits just after an injections are monitored for injection tuning and also used for optics test as described later.

After many (~100000) turns, the orbit becomes stable turn by turn and is considered as the closed orbit.

A COD correction routine is available, in which a set of strength of the dipole correctors are calculated to make the apparent beam offset at BPMs small. Local orbit bumps are also used for orbit corrections. Typical COD (peak to peak) is about 2 mm in horizontal and 1 mm in vertical .

2.2 Optics Test and Correction of the Model

Change of one-pass orbit by changing dipole correctors (R_{12}) have been measured as a test of the first order optics [5][6]. In the measurement, sextupole magnets were turned off to avoid nonlinear responses. Errors of strength of quadrupole magnets and quadrupole component of combined bending magnets were estimated from the data as typically 1% and maximum 3% where the accuracy is estimated to be about 0.5 %. The source of the error is suspected to be error of field measurement or interference between magnets close each other. But it has not been clear yet. Fig. 1 shows R12 of the original model and the corrected model vs. measured R_{12}. Each point corresponds to a pair of a dipole corrector and a BPM. It is obvious that the original model should be modified.

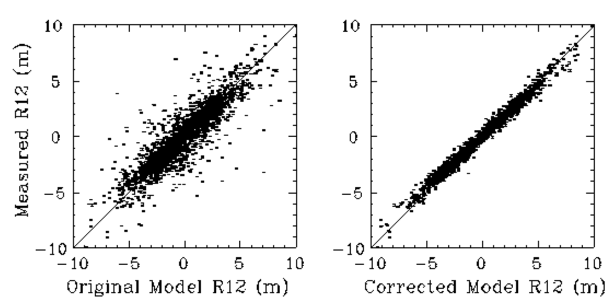

Fig. 1, Measured R_{12} vs. calculated R_{12} using the original model (left) and the corrected model (right).

Responses of the closed orbit to dipole correctors have been also measured. For each corrector, the amplitude of the orbit change has some difference from the corrected model. The discrepancies are about 20 % for the horizontal and 10 % for the vertical orbit changes. Also tunes, beta function and dispersion function have some discrepancies with the model though they are not large. The source of the discrepancies has not been clear but errors related to the sextupole magnets or small error of the quadrupoles, which are not sensitive in the R_{12} test, are suspected.

2.3 Transverse Oscillation and Tune

Turn by turn beam position monitor (the oscillation monitor) is used for injection tuning observing the beam oscillation at injections. It is also used for transverse tune measurement. There is the other system to monitor transverse tunes in real time.

To make transverse oscillations for tune measurement, an excitor which consists of four electrodes has been installed. Beam oscillation is excited also by shifting the extraction kicker timing so that the beam is slightly kicked by the tail of the pulsed field.

In the typical operation condition, measured horizontal tune was different from the calculation based on the optics model by about 0.03 while the difference of the vertical tune was less than 0.01 as shown in the Table 2.

2.4 Beta function

Beta-functions (β_x and β_y) at positions of all quadrupole magnets have beam estimated by changing the strength of the magnets one by one and measuring the change of transverse tunes[7]. As an example of recent measurements, β_y is shown in Fig. 2.

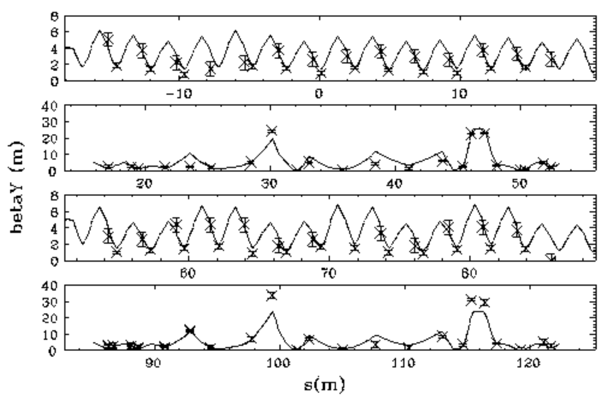

Fig. 2, Measured (plots) and model (lines) vertical beta function.

2.5 Dispersion

Dispersion function (η_x and η_y) at BPMs in the ring and in the extraction line are measured as the orbit difference for different RF frequencies. The frequency of the ring RF, whose frequency and phase are locked with the injector linac at the injection timing, are changed gradually after the injection and beam positions are measured. An example of the measured η_x in the ring is shown in Fig. 3 with the model.

To reduce the vertical dispersion in the arc section is essential to produce low vertical emittance. After COD correction, additional correction using vertical dipole correctors has been tested. An example is shown in Fig. 4, η_y before and after the correction. Relation between the change of dispersion and emittance is to be studied.

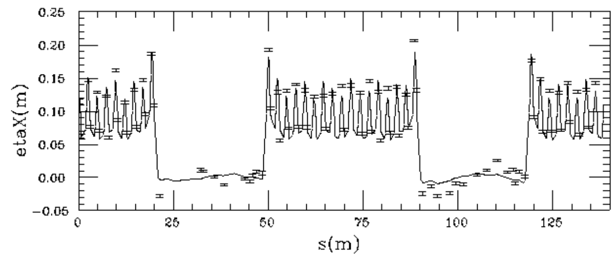

Fig. 3, Measured horizontal dispersion in the ring (plot) and model calculation (line).

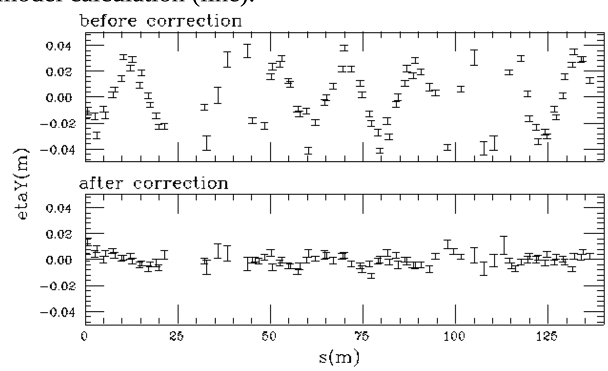

Fig. 4, Measured vertical dispersion in the ring before dispersion correction (top) and after correction (bottom).

2.6 Longitudinal Oscillation

Longitudinal oscillations are monitored using a bunch phase detector. It is also used to measure the synchrotron frequency. Dependence of the synchrotron frequency on the total RF voltage is shown in Fig. 5. The line in the figure shows calculation using fitted momentum compaction factor from the data (see Table 2).

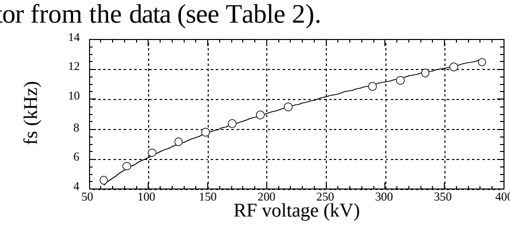

Fig. 5, Measured synchrotron frequency vs. RF voltage (plot), the line shows calculation from the model using fitted momentum compaction factor.

2.7 Other Measurements

Energy spread is estimated from the beam size on a screen monitor at large η_x region of the extraction line.

Bunch length in the ring is measured detecting synchrotron light using a streak camera. Longitudinal damping time is calculated from the measurement. Studies concerning bunch lengthening and impedance of the ring are reported in other papers[8][9].

The beam life time is measured turning off the extraction kicker and the following injections. The life time data is used to study the ring aperture and vertical emittance. Recent studies are reported in other papers[10][11].

Physical and/or dynamic aperture has been studied from beam life time and beam loss at injection.[12][13].

3 BEAM SIZE AND EMITTANCE

3.1 In the Ring

In the damping ring, the transverse beam size is measured detecting synchrotron light emitted in a bending field using two methods[14][15]. One is observing the beam profile using gated camera. The other uses interferometer with two slits where the beam size is estimated from the 'visibility' of the interference and the distance of the two slits. The profile monitor is used for damping time measurement and the interferometer is used to measure the equilibrium beam size. Emittance is estimated from the beam size and $\beta_{x,y}$ and $\eta_{x,y}$ at the source point and the energy spread .

The estimated emittance is listed in Table 2 with calculated and design values. The main sources of the big errors are ambiguities of $\beta_{x,y}$ and $\eta_{x,y}$ because these parameters and the beam size were not measured at the same time. The horizontal emittance is close to the model calculation and the vertical emittance is around 4% of the calculated horizontal one where our target is 1%. The measured damping times are also listed in the table.

Table 2, Summary of beam measurement

	measured	model
COD in the arc section (peak-to-peak)	x : <2.0 mm y : <1.0 mm	
η_y in the arc section	< 5 mm	
Tune	x : 15.17 y :8.72 z :0.00485	x : 15.145 y : 8.715 z : 0.00480
Momentum compaction	2.22×10^{-3}	2.173×10^{-3}
Energy spread	$6.0\pm0.3\times10^{-4}$	5.56×10^{-4}
ε_x measured in the ring extraction line ($\times10^{-9}$ radm)	$0.9^{+1.8}_{-0.9}$ 1.3 ± 0.2	1.08 (1) ~ 1.47 (2)
ε_y measured in the ring ($\times10^{-11}$ radm)	$3.6^{+5.0}_{-3.6}$	$\varepsilon_x\times10^{-2}$ (3)
Damping time	x : 19.5 ms y : 29.9 ms z : 20.6 ms	x :17.0 ms y : 27.3 ms z : 19.5 ms

(1) Calculation without intra-beam scattering.
(2) With intra-beam scattering, $N=8\times10^9$ and $\varepsilon_y=\varepsilon_x\times10^{-2}$.
(3) Design value.

3.2 Extracted Beam

There are four wire scanner monitors for beam size measurement in the extraction line. Knowing beta function and dispersion at the monitor positions are necessary to calculate emittance from beam size. Beta function is fitted from beam sizes at 4 places. The other method is measuring beam size changing strength of a quadrupole magnet upstream of the monitor. Dispersion is measured by changing frequency of the ring RF.

The horizontal emittance is estimated using the different methods and the average is shown in Table 2, which is close to the model calculation. The vertical emittance has not been confidently estimated yet because the vertical beam size is much smaller than the horizontal size so that possible x-y coupling could affect the vertical measurement and effect of measurement error of the dispersion is large. Another paper reports the measurement in detail[16].

4 SUMMARY

In recent operation, the optics model was modified based on the measured beam orbit and various parameters have been compared with the model. There is still a little discrepancy between them and the error sources are being studied. The measured horizontal emittance was close to that of the model calculation and the vertical emittance was around 4% of the horizontal one where our target is 1%

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