DIAGNOSIS OF THE LOW EMITTANCE BEAM IN ATF DR EXTRACTION LINE

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Abstract

The ATF (Accelerator Test Facility in KEK) damping ring has been designed to produce the low emittance beam required by future linear colliders. In the design, the normalized vertical emittance of the ATF damping ring is 3.0E-8 radm which corresponds to the vertical beam size of about 10 micron in the extraction line. The emittance of the beam extracted from the ATF damping ring is measured with four wire scanners located in a dispersion free region of the extraction line. The optics of the extraction line is also studied. We will report the method and the result of the emittance measurement at the extraction line.

1 INTRODUCTION

The beam operation of the ATF damping ring started in January 1997. The first main target is to produce low emittance beams with single bunch operation. In order to measure the low emittance beam, the precise beam diagnostic and monitoring tools are necessary. In extraction line, four wire scanners and high resolution phosphor screen monitor system have been installed to measure the extracted beam of small transverse distributions. There are 16 beam position monitors (BPMs) and an integrating current transformer (ICT) which measure the beam orbit and beam intensity, respectively. Especially the measurement of small transverse emittance is difficult by the reason of a beam position jitter and contribution of dispersion to beam size, so the wire scanners and the high resolution screen monitor are located at dispersion free region in the extraction line to minimize the effect of error of dispersion. In measurement of beam qualities, it is also important to know the optics of the beam line. Strength error of quadrupole magnet affects the estimation of beta function at measurement point and dispersion correction. The lattice diagnostics have been performed by analyzing the extracted beam orbit with perturbations given by steering magnets.

2 ATF DR EXTRACTION LINE

2.1 Layout of Extraction Line

The layout of the extraction line is shown in Fig. 1. In the extraction line, a double kicker system was chosen to suppress a beam position jitter of extracted beam. The emittance of the beam extracted from the damping ring is measured with four wire scanners and a high resolution phosphor screen monitor located in a dispersion free region of the extraction line. The wire scanners are spaced about 2.1 m apart, and air Cerenkov detectors for γ-rays produced in beam-wire scattering are installed at down stream of the wire scanners .

2.2 Optics Diagnostics

There are 16 quads in the extraction line, and only one pair quads has common power supply. Errors of quadrupole magnet were estimated by changing strength of steering magnet and measuring beam positions. The measured values were 1-2 components of the transfer matrix from steering magnet to BPMs and compared with the model. Errors of strength of quads, BPMs and steerings are fit by the measured response coefficients. Fig. 2 shows estimated relative errors of k-values of

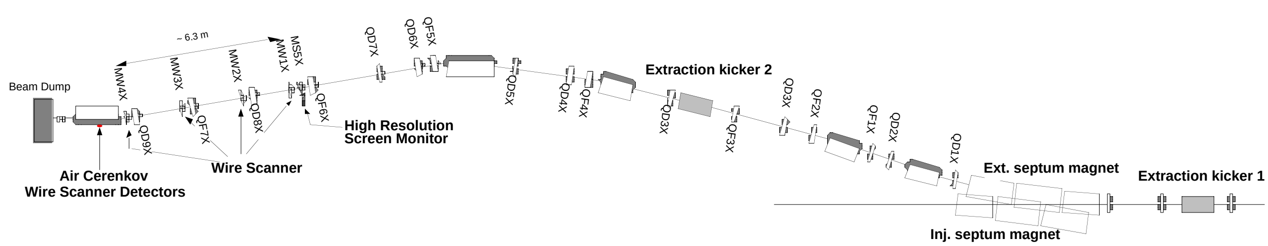

Fig. 1 Layout of the ATF-DR extraction line

magnets, $\Delta k_m/k_{m,mo}$. Large error bars in this figure correspond to quads whose strength are very small. These errors are larger than the errors of current setting of power-supplies which are estimated less than 0.4 %. The exact origins are not understood yet, however it is suspected that BPM responses were affected by beam loss at the middle region of the extraction line.

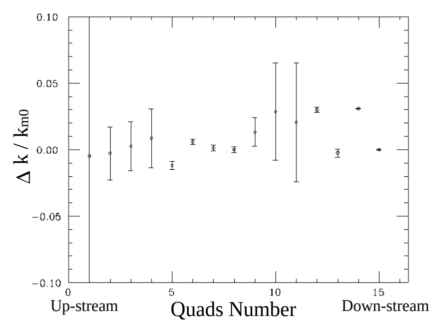

Fig. 2 Fitted relative errors of quads k-values

2.3 Diagnostic tools

In the extraction line a 130 μm thickness phosphor screen which was Alumina-ceramic with chrome doped was used and the CCD camera with high magnification lens was placed at 50 cm away from the screen. Resolution of monitor system is about ~30 μm due to granularity of material scattered light.

Beam-profile measurement around 1 μm accuracy is made using a wire scanning method. The measurement is performed using 50 μm gold plated tungsten wire. In each scanners, a wire is stretched in three directions (X,Y,U). The beam size determined by the U-wire is used for a coupling measurement between the X and Y directions. The vacuum chamber houses the wire mount, which is held at an angle of 45 degrees. One of the slider is the stepping-motor stage, which has a 0.5 μm step resolution and a 0.1 μm repeatability. For fine-resolution measurements, a thin carbon wire of 4 μm diameter will be used in ATF-DR extraction line. Air Cerenkov detectors have installed to detect γ-ray signal of bremsstrahlung produced by the beam passing through the wires[1]. In normal operation these detectors provide a signal-to-noise (S/N) ratio of at least 10 to one.

3 EMITTANCE MEASUREMENT IN EXTRACTION LINE

3.1 Dispersion Measurement

The dispersion in the extraction line is measured by detecting the orbit change induced by changing of rf frequency in the ring (Fig. 3). At injection into the ring, rf frequency has to be synchronized with the linac rf. A few 100 μs after the injection, the rf frequency is ramped over a time period of 50 ms. The beam is extracted from the damping ring about 450 ms after the end of the frequency ramp. The orbit change is proportional to $\eta\Delta f_{rf}/\alpha_c$, where α_c is momentum compaction factor. The η and η' at the extracted point from the ring and α_c are fit by the measured coefficients. The energy spread was measured using screen monitor at the place of large dispersion.

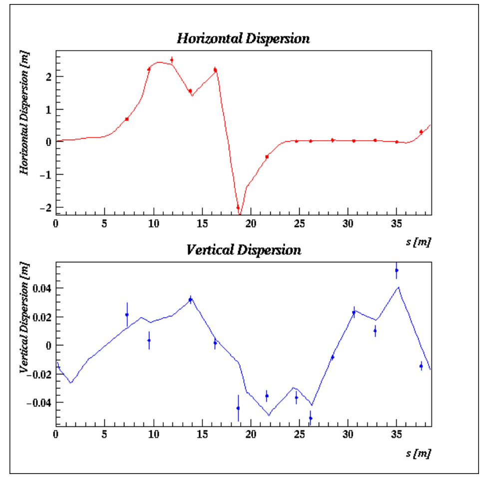

Fig. 3 Measured horizontal and vertical dispersion in the extraction line (plot) and fitted result (line).

3.2 Emittance Measurement

In the extraction line, transverse beam size measurements were performed using phosphor-screen monitor and wire scanner. As the damping ring beam development advanced such as COD correction and vertical dispersion correction, emittance became smaller and the transverse beam size ($\sigma_{x,y}$) reduced to about 20 μm in vertical and 200 μm in horizontal in the extraction line[2]. The resolution of phosphor-screen monitor was not enough for a few 10 μm beam-profile measurement. On the other hand, as shown in Fig. 4, the wire scanner provides a sufficient resolution down to several fraction of wire diameter. In this case the sigma of beam size was fitted assuming a Gaussian distribution. Since the wire has a finite thickness (50 μm), the measured beam size σ_m is expressed as $\sigma_m^2 = \sigma_0^2 + \sigma_W^2$, where σ_0 is a true beam size and σ_W is effective wire thickness which depends on the shape of the penetrated material. ($50^2/12$) was used as σ_W^2 in our analysis. Beam intensity of each pulse was measured using ICT placed between MW3X and MW4X to make corrections for variations of beam intensity.

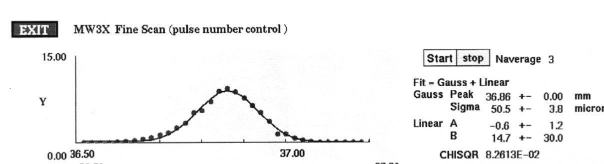

Fig. 4 Typical wire scan in Y

For beam size measurement using wire scanners, beam position at the wire is calculated from BPMs data for each pulse to subtract effect of beam position jitter from the data.

The contribution of the dispersion to beam size is not negligible. So it is also important to measure and correct the dispersion precisely at measurement point. The dispersion at each wire scanner was derived from the dispersion measurement at BPMs and the dispersion in horizontal is corrected by a correction software changing quadrupole's strength at large dispersion place. After the correction horizontal dispersion is reduced to less than 20 mm. However in vertical direction we need a high resolution BPM system for required dispersion correction. We subtracted the dispersion effect from measured beam size in our analysis.

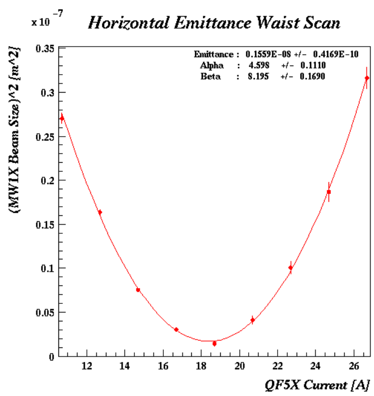

Fig. 5 Waist scan plot in *X* using QF5X

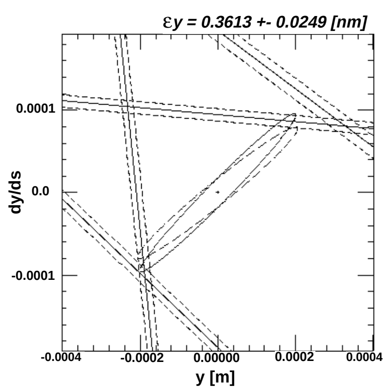

Fig. 6 Emittance plot in phase space and beam size

Two different method to measure emittance are used, one is waist scan method, that is, emittance and beta function at the monitor position are fitted from beam size changing strength of a quadrupole magnet at upstream of the monitor. Fig. 5 shows an example of waist scan plot in horizontal. As an another method of emittance measurement in the extraction line, beta function is fitted from beam size at 4 places of wire scanners, knowing the optics between them. As an example of measurement with 4 wires, vertical phase space distribution is shown in Fig. 6.

3.3 Data analysis and discussions

In our emittance measurement, the result of horizontal emittance is 1.3±0.2x10^{-9} radm which was averaged over waist scan measurements and 4-wires scan measurements.

This value is consistent with calculated values from the model which are 1.08x10^{-9} radm in case of no intra-beam scattering and 1.47x10^{-9} radm with intra-beam scattering of 8x10^{9} e^- beam intensity and 1% coupling.

As for vertical emitance measurement, several error sources have to be considered. One is wire tilt which is stretched in horizontally for vertical size measurement, because extracted beam is very flat. The second one is beam position jitter pulse-to-pulse coming from extraction kicker and instability of the ring. Observed vertical position jitter is around 20 μm which is comparable to beam size in case of small β. The third one is dispersion coupling. The x-y coupling could be observed on the screen (MS5X) which was close to the first wire scanner, and as changing a quadrupole (QD5X) at the middle of extraction line beam tilt angle changed. It is suspected that dispersion may leak from horizontal to vertical by small x-y coupling and $\eta_{x,y}$ at the screen were changed when QD5X was changed, because horizontal η' is very large at QD5X. So we need careful beam orbit tuning at large η' region to suppress the dispersion at diagnostic region. To estimate the vertical emittance precisely, it is necessary to correct η_y at the wire and to remove beam tilt. Preliminary result of vertical emittance measurement is 2.0~7.0x10^{-10} radm which is inconsistent with the SR interference monitor in the ring [3].

4 SUMMARY

Beam size and emittance were measured using wire scanners in the extraction line. The results were ε_x = 1.3±0.2x10^{-9} radm and ε_y = 2.0~7.0x10^{-10} radm. To reduce unknown errors of the measurements, it is necessary to improve diagnosis of the beam line and also the monitor system. Especially for very small beam size measurement it is important to correct the dispersion at measurement point and to refine position jitter subtraction.

4 ACKNOWLEDGMENTS

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