EMITTANCE MEASUREMENT AT KEK-ATF DAMPING RING

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Abstract

In order to achieve an extremely low emittance down to ε_y~1x10^{-11}m-rad, the beam development has been continued at KEK-ATF for future linear collider. The emittance measurement in the damping ring is a key point to confirm the low emittance beam. The beam size measurement is done by SR interferometer using visible light (~500nm) at ATF damping ring. The measured beam sizes were already reached less than 14µm(vertical) and 37µm(horizontal), respectively. The beta function was also measured by applying a perturbation on the quadrupole magnet. The dispersion function was measured by means of rf frequency modulation method. Combining these measured values, the emittance was measured as ε_x=1.8x10^{-9} m-rad, ε_y=6.1x10^{-11} m-rad. The measurement technologies are described.

1 INTRODUCTION

To establish a low emittance beam is one of the significant milestone for the future linear collider. The ATF was designed to develop the low emittnce beam, and it's designed emittance is ε_y~1x10^{-11}m-rad and ε_x~1x10^{-9}m-rad[1]. The measurement of an emittance such a small beam is not easy by using the ordinal methods such as an imaging of Synchrotron radiation(SR). At the beginning of the ATF commissioning, the beam size monitor by means of the imaging of the SR was used for an observation of the damped beam size. The predicted beam size at source point is 6µm for the vertical and 30µm for the horizontal, however the diffraction limit of the imaging system is about 50µm. The resolution of the beam size measurement is limited by the diffraction in this monitor[2].

The SR interferometers for horizontal and vertical beam size measurements were installed to solve the problem of the resolution those can be measure down to ~5µm with 1µm resolution[3]. The SR interferometer measures the degree of complex spatial coherence of visible-SR beam. Under the assumption of gaussian distribution of the electron beam profile, the absolute value of the degree of complex spatial coherence(visibility) is also gaussian. The beam size is easily obtained by a least squares fitting for the visibility curvature by using a beam size as the free parameter[3]. In practical, the measurement is done by observing the visibility through the intensity of the interferogram. The beta function and the dispersion function were also measured from the perturbation on the quadrupole magnet and the rf frequency modulation method, respectively.

2 BEAM SIZE MEASUREMENT BY SR INTERFEROMETER

The set up of the SR interferometer is shown in Fig.1. The synchrotron light is split into four lines, 1)the line for the imaging system by using a fast gate camera for the observation of the damping phenomena, 2)the line for the streak camera for measurement of the bunch length, 3)the line for horizontal SR interferometer, 4)the line for the vertical SR interferometer.

The SR interferometer is basically a wavefront-division-type two-beam interferometer using a polarized quasi-monochromatic rays. A double slit assembly having a aperture size of 1mm(width) x 3mm(height) which can be changed the separation of the slits. A diffraction limited doublet lens(f=600mm) is used as a objective to make the interferogam . A band-pass filter which has 80nm band width at 500nm and a polarization filter are used to obtain the polarized (select a σ-polarization) quasi-monochromatic rays. The interferogram is observed by the CCD camera(SONY SSC-M370) after the magnifier lens(x5). The visibility is evaluated by using an image

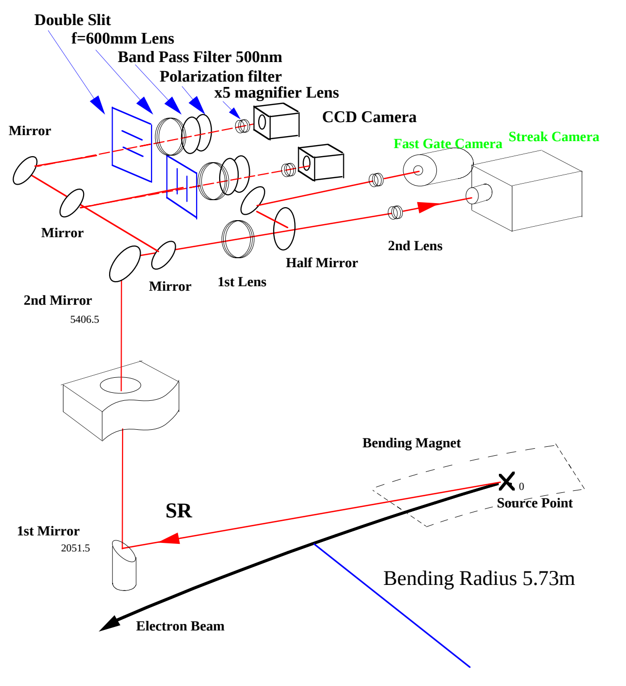

Fig.1 Layout of SR monitor - There is four monitor shared the synchrotron light, 1)Streak camera, 2)fast gate camera , 3)SR interferometer(H) and 4)SR interferometer(V).

processor.

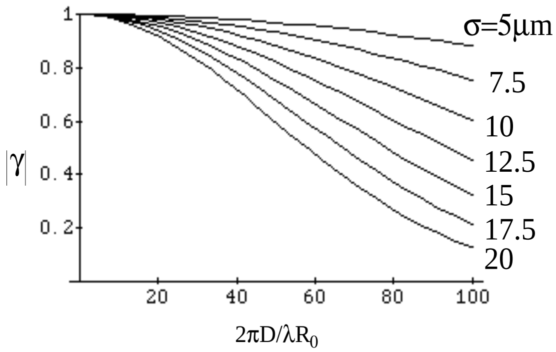

Fig.2 Calculation of the visibility at each beam size

2.1 Vertical Beam Size Measurement

With the assumption of gaussian beam profile, the visibility γ, as a function of spatial frequency ν, is given by the Fourier transform of beam profile *f*, as a function of position y_0, as follows;

$$\gamma(\nu) = \int f(y_0) \bullet \exp\{-i2\pi\nu \bullet y_0\} dy$$

$$\nu = \frac{2\pi}{\lambda R_0} D$$

where R_0 is the distance between the object beam and the double slit, λ denotes the wave length and D is a slit separation. The observed interferogram is given by,

$$I(y_1) = I_0\left[\operatorname{sinc}\left(\frac{2\pi a}{\lambda R_1} y_1\right)\right]^2 \bullet \left[1 + |\gamma(\nu)| \cos\left(\frac{2\pi D}{\lambda R_1} y_1 + \varphi\right)\right]$$

where *a* denotes the half of slit height of the double slit, R_1 denotes distance between the interferogram and the back principle point of objective lens of the interferometer, and φ denotes the phase of the interference fringe.

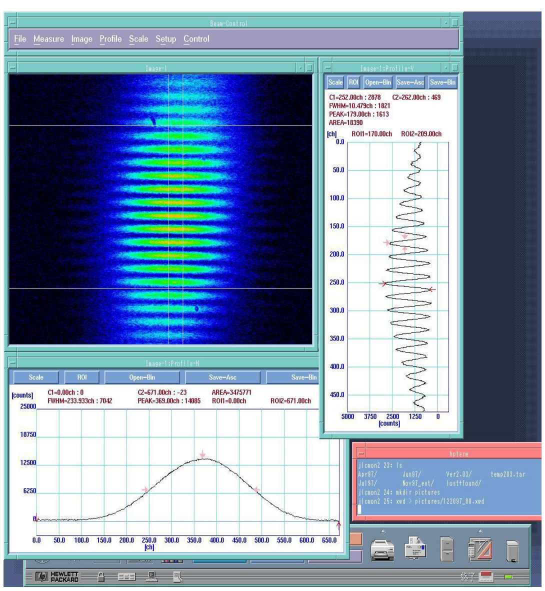

Fig.3 Example of the vertical interferogram. Double slit separation is 35mm.

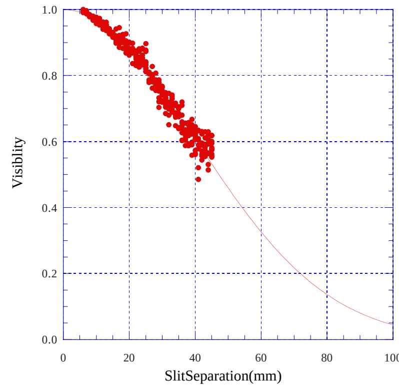

Fig.4 The result of vertical visibility. The horizontal axis is converted to the slit separation. Dotted line denotes measured visibility, and solid line is the best-fit value of 14.0μm

To demonstrate the sensitivity of the interferometer, we make a simulation of the visibility curve in case of the beam size from 5μm to 20 μm by 2.5 μm step. The results are shown in Fig. 2. The useable slit separation is limited to 40mm due to the opening angle of the aperture of the vacuum duct . In case of 5 μm beam size, the visibility reduces by 6.1% at the slit separation 40mm. 1μm difference at the beam size of 5μm makes 2.8% difference in the visibility. Since we can measure easily the visibility better than 1%, the sensitivity and the resolution of the SR interferometer is sufficient for a small beam size measurement.

An example of measured interferogram is shown in Fig.3 and the visibility as a function of double slit separation is shown in Fig. 4. In this case, the vertical beam size is measured as 14.0μm by the least squares fitting.

2.2 Horizontal Beam Size Measurement

The horizontal visibility was measured in the same way as the vertical direction, except for the double slit assembly rotated by 90degrees. For horizontal measurement, the optical beam line of the SR was switched by a flat mirror manually. In the horizontal direction, including the effect of the field depth, the visibility γ is given by,

$$\gamma = \iint \frac{2\sqrt{I_1(\psi) \bullet I_2(\psi)}}{I_1(\psi) + I_2(\psi)} f\left(x - \rho(1 - \cos(\psi))\right) \bullet g(\psi) \bullet \exp\left(-i\frac{2\pi D}{\lambda f} x\right) d\psi dx$$

where g is the angular distribution of the SR in the horizontal plane as a function of the observation angle ψ, I_1 and I_2 are intensity of the two modes of the SR at the double slit, *f* is the beam profile distribution, ρ is the bending radius[3].

The result of measured plot is shown in Fig. 5. In this case, the horizontal beam size is measured 36.8 μm by the least squares fitting.

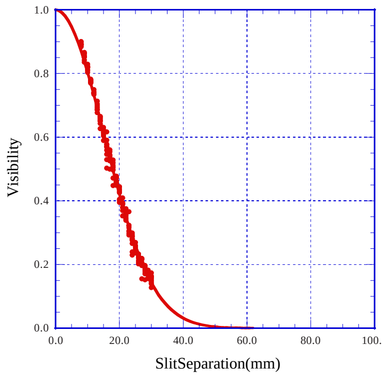

Fig.5 The result of horizontal visibility. Dotted line denotes measured visibility, and solid line is the best-fit value of 36.8 μm

3 BETA FUNCTION MEASUREMENT

Because there is no BPM at the source point, the β-function at the SR source point was obtained by measuring a shift of the betatron-tune during changing the magnetic fields of three quadruple magnets located in the upstream and the downstream of the SR source point. The betatron tune was measured by the spectrum of the orbit oscillation due to injection error. The value of β−function was obtained by a fit of the β-function at each quadruple magnet. The measured β-function is shown in

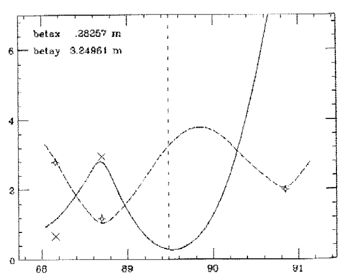

Fig.6 β-function plot near the SR source point (dotted line)

Fig. 6.

4 DISPERSION FUNCTION MEASUREMENT

The η-function at the SR source point is measured from the change of the closed orbit due to change of the rf frequency. The change of the closed orbit is measured at every BPM position. The η-function at the SR source point is obtained by the least squares fitting. The measured η-function is shown in Fig. 7. In order to reduce the vertical emittace, the vertical dispersion correction software has been developed[4].

5 CONCLUSION

The beam size measurement was performed in the ATF damping ring by the use of SR interferometer. We conclude the beam sizes reached less than 14μm(vertical) and 37μm(horizontal), respectively. The beta function was also measured by applying a perturbation on the quadrupole magnets. The dispersion function was measured by means of rf frequency modulation method. Combining these measured values, we conclude the emittances are as ε_x=1.8x10^{-9} m-rad, ε_y=6.1x10^{-11} m-rad. From this conclusion, the vertical-horizontal emittance coupling is 3.4%.

The emittance of extracted beam was also measured by wire scanners at the extraction line[5]. The comparison of two emittance measurements are listed in table 1. The result of these two measurement is well agreed. The emittance tuning is underprogressing by using of SR interferomter.

Table 1: Comparison of the measured emittance with SR interferometer and with wire scanner

	SR interferometer	Wire Scanner
Vertical	6.1+/-2.0 x10^{-11}	5.8+/-0.4 x10^{-11}
Horizontal	1.8+/-0.5 x10^{-9}	1.5+/-0.2x10^{-9}

6 ACKNOWLEDGMENT

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7 REFERENCES

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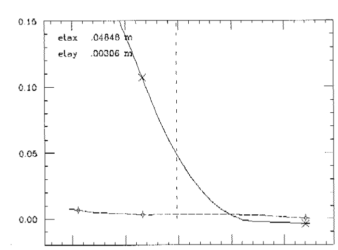

Fig. 7 η-function plot near the SR source point (dotted line)