2 Highlight

2-1 Twelve Years of SR Monitor Development at KEK

Synchrotron radiation (SR) monitors based on visible optics are one of the most fundamental diagnostic tools available for high energy circular accelerators [1]. These monitors allow the recording of parameters such as visible beam profile, beam size and longitudinal profile, greatly improving the efficiency of commissioning and operation of the accelerator. In these monitors, the visible SR beam is extracted by a mirror from the circular accelerator, then guided into the optical diagnostics systems.

I have worked on the development of SR monitors over the past twelve years at KEK. During these years, the development of the SR interferometer has been the most significant topic. The idea of the SR interferometer for measurement of beam profile and size struck me while I was performing experiments to investigate the coherence of synchrotron radiation in 1994 [2]. After basic investigation of beam profile and size measurements with the SR interferometer, this apparatus was applied to the daily monitoring of beam size [3]. Nowadays, the SR interferometer is recognized as a powerful tool for easily measuring small beam sizes [3].

The history of twelve years of development of SR monitors at KEK is summarized below.

1992-1994	Renovation of SR monitor for the Photon Factory. Development of deconvolution of the beam image by means of MEM.
1994	First experiment with interferometry. Demonstration of the possibility to apply the beam size measurement through interferometric method.
1994-1996	Development of SR interferometer.
1993-2000	Design, construction and commissioning of SR monitor for the KEKB-Factory. Development of beam profile measurement system by adaptive optics.
1996	Measurement of 10.5 µm beam size at the SR center of Ritsumeikan University.
1995-	Measurement of small beam sizes at the ATF, KEK. Development of SR interferometer based on reflective optics.
1997	Measurement of 6.2 µm beam size at the ATF.
1998	2D interferometer experiment at the Photon Factory.
1998-1999	Measurement of small beam sizes in the new low-emittance lattice at the Photon Factory.
1999-2000	Construction of profile monitor for KEKB injector Linac.
2000-2002	Construction of SR monitor for the Photon Factory Advanced Ring. Development of non-aplanatic SR interferometer.
2003	4.7 µm beam size measurement by SR interferometer with Hasherian reflective optics.
2002-2003	Development of intensity interferometry for the measurement of bunch length.
2003-2004	Development of Lyott optics for the measurement of beam tail and halo.
2002-2004	Measurement of instantaneous beam profile measurement by the use of high-speed gated camera.

To measure the spatial coherence of SR beams, a wavefront-division type of two-beam interferometer using polarized quasi-monochromatic rays was designed as shown in Fig. 1 [3] and a typical interferogram observed with the SR interferometer is shown in Fig. 2.

The beam profile can be recorded by making a Fourier transform of the spatial coherence. Fig. 3 shows the

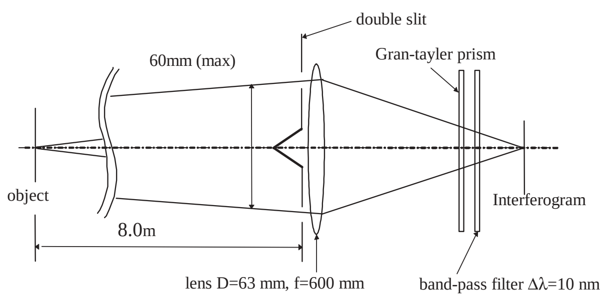

Figure 1
Outline of the SR interferometer.

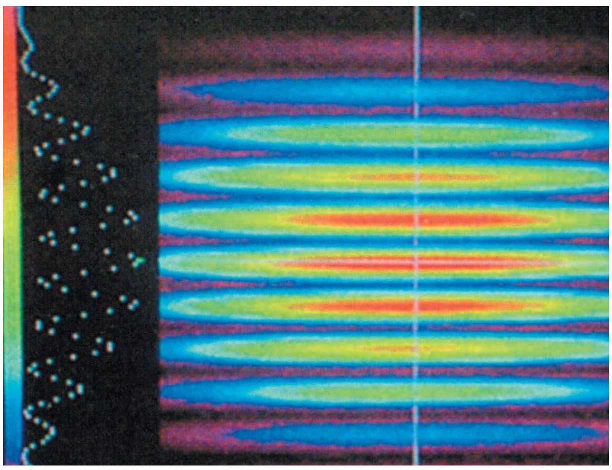

Figure 2
A typical interferogram observed with the SR interferometer.

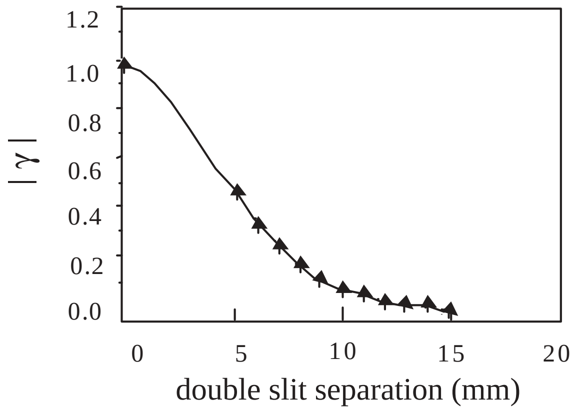

Figure 3
Result of |γ| at the Photon Factory.

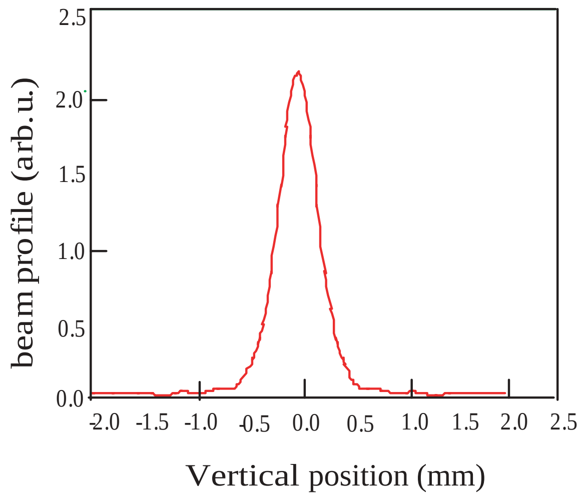

Figure 4
Beam profile by Fourier transformation of the spatial coherence at the Photon Factory.

absolute value of the complex degree of the spatial coherence (|γ|, visibility) as measured while changing the double slit separation from 5 mm to 15 mm at the Photon Factory [2].

The resulting beam profile calculated as the Fourier transform of the spatial coherence is shown in Fig. 4. The beam profile can often be approximated with a Gaussian shape. With this approximation, phase measurement can be skipped. The Fourier transform of an even function (Gaussian) is simplified to a Fourier cosine transform. The spatial coherence is also given by a Gaussian function. The RMS width of the spatial coherence can be evaluated by using a least-squares analysis. The RMS beam size σ_{beam} is obtained from the RMS width of the spatial coherence curve σ_γ as follows:

$$\sigma_{beam} = \frac{\lambda \cdot R}{2 \cdot \pi \cdot \sigma_r},$$

where *R* denotes the distance between the beam and the double slit. Experimentally, |γ| (the contrast of the interferogram) must be measured as a function of slit separation [3]. The difference between beam sizes of 3 μm and 4 μm can be obtained with a resolution of better than 1 μm.

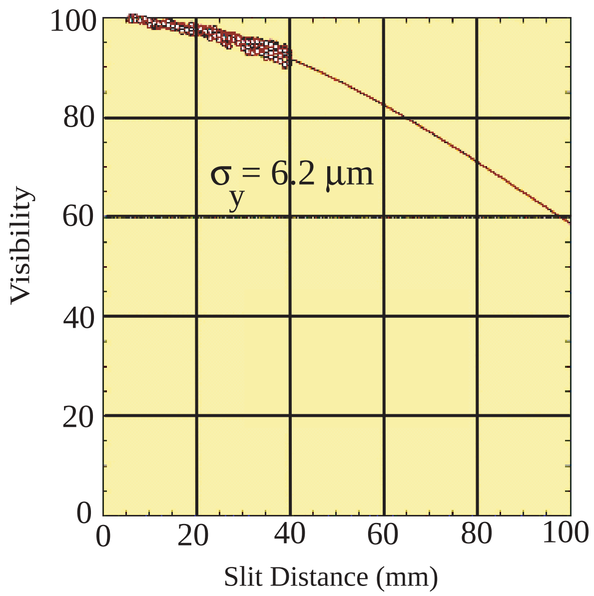

Figure 5
Absolute value of the complex degree of spatial coherence in the vertical direction at the ATF damping ring. The circles denote the measured |γ| (visibility), and the solid line denotes the best-fit beam size of 6.2 ± 0.6 μm.

Next I would like to introduce vertical beam size measurements made at the ATF damping ring at KEK [3]. The result of measuring |γ| as a function of slit separation in the vertical direction with a least-squares fitting by a Gaussian profile at the ATF damping ring is shown in Fig. 5. The beam size obtained from this fitting is 6.2 μm.

The RMS beam size can also be obtained from one measurement of visibility at a fixed separation of the double slits. The RMS beam size σ_{beam} is given by,

$$\sigma_{beam} = \frac{\lambda \cdot F}{\pi \cdot D} \cdot \sqrt{\frac{1}{2} \cdot \ln\left(\frac{1}{\gamma}\right)}$$

where γ denotes the visibility measured at a double slit separation of *D* [3]. Using this method, we can easily measure beam size automatically from an analysis of the interferogram taken at a fixed separation of the double slits *D* [4]. To find the visibility γ from the interferogram, we use the standard Levenberg-Marquart method for non-linear fitting. After image processing of the interferogram, the results are relayed to a computer in the control room for display and further analysis. Fig. 6 shows an example of the display panel for the two rings of the KEK B-Factory, the HER and the LER. The interferogram, best fit curve and beam size versus beam current graphs for the vertical and horizontal directions are shown in the panel. By using this automatic beam-size measurement system, we can measure the vertical and horizontal beam sizes every second, which is extremely useful for beam tuning. This system is also operated at the Photon Factory.

During twelve years of development of the SR monitor, the SR interferometer was developed to measure the spatial coherency of the visible region of the SR beam, and we have demonstrated that this method can be used to measure the beam profile based on the van

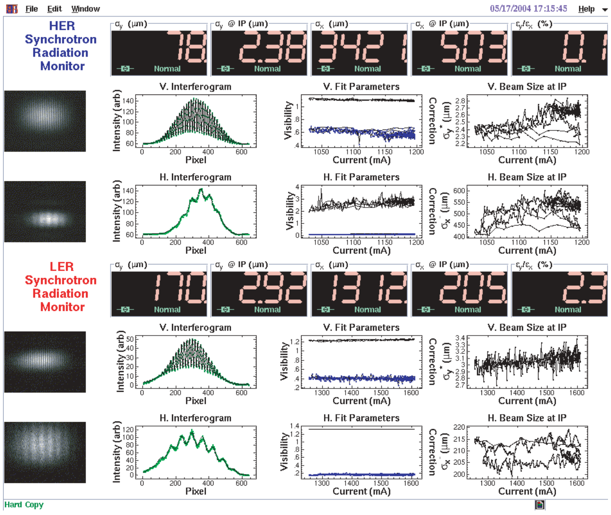

Figure 6
SR Monitor panel in control room, showing HER and LER vertical and horizontal beam sizes.

Cittert-Zernike theorem. Using a Gaussian beam profile approximation, we can measure beam sizes down to the µm range with a resolution of less than 1 µm. With an automatic analysis system, the SR interferometer is conveniently used as a continuous beam size monitor with a measuring interval of about 1 sec. A calibration method for the SR interferometer system having extra focusing power, such as a deformed mirror, was also developed to measure the absolute value of the beam size.

Finally, I would like to thank all of my KEK colleagues who were involved in the development of SR monitors at KEK. I would like to thank Emeritus Prof. Kobayakawa of KEK for strongly encouraging me to pursue the idea of beam size measurement with an interferometer. I would also like to thank Prof. Iwasaki of Ritsumeikan University, who invited me the SR Center to measure the beam size, and Professors Kurokawa and Hiramatsu of KEK, who gave me a chance to participate in the design and construction of the B-Factory SR monitors. J.W. Flanagan developed an excellent automatic analyzing system for the interferogram and he also organized the installation of the SR monitors in the B-Factory tunnel. T. Naitoh organized the installation of the SR interferometer in the ATF damping ring. Thanks are also due to M. Tadano for technical support of the system and for writing very useful application software. Last but not least I would like to thank the BIW2004 organizing committee for the selection of this work for the Faraday Cup Award of 2004.

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