MEASUREMENT OF DYNAMIC BEAM-BEAM EFFECTS ON HORIZONTAL BEAM SIZE AT KEKB USING SR INTERFEROMETER EQUIPPED WITH RETROFOCUS OPTICS

J.W. Flanagan, H. Fukuma, S. Hiramatsu, T. Mitsuhashi, KEK, Tsukuba, Japan

Abstract

Transverse beam-size enlargement due to dynamic beta and emittance effects has been observed in the KEKB Low Energy Ring (LER) and High Energy Ring (HER). In order to observe these effects, a retrofocus optics system has been developed and installed in the horizontal SR interferometers at the HER and LER. This system allows us to vary the apparent beam size to match the dynamic range of the interferometer. We report on the retrofocus optics system and measurement results, and compare the measured effects with those expected from dynamic beta simulations.

INTRODUCTION

KEKB is an energy-asymmetric, two-ring collider. Positrons are circulated in the 3.5 GeV Low Energy Ring (LER), and electrons in the 8 GeV High Energy Ring. The beams collide at the Interaction Point (IP), inside the Belle detector. Beam sizes are measured by the use of SR interferometers.[1] During collision, the transverse beam sizes of the LER and HER typically change as compared to the single-beam (non-colliding) beam sizes in each ring. Beam-beam effects due to the collision can lead to emittance growth, which enlarges the beam size around the ring. Dynamic beta effects can also occur, leading to larger or smaller beam sizes at different places in the ring, depending on change in the betatron phase advance from theIP to the observation point. The horizontal beam sizes of the HER and LER at the SR source points are particularly sensitive to dynamic beta effects, with the observed beam sizes at those points increasing by a factor of two or three. As a result of this increase in beam size, the beam size exceeds the dynamic range of the horizontal interferometers, making it impossible to measure the beam sizes in collision. Several possibilities exist for changing the dynamic range of the horizontal interferometers to accommodate larger beam sizes. One method is to reduce the separation, D, between the double slits. However, the slit separation at the HER is already only 5 mm, and making the separation much smaller would make the precision requirements more severe. In addition, the slit width would need to be reduced, which would reduce the available light level below that which can be easily measured with the cameras currently in use at the HER. Another possibility would be to change the frequency of the detected light. However, this could not be shifted much more than about 20% below the current 500 nm without encountering sensitivity limits of the CCD camera. Another possibility is to employ a technique from camera optics called inverted telephoto, or retrofocus optics, wherein a concave lens is introduced in front of the interferometer slits. In this way, the apparent beam size can be reduced by an arbitrary amount to match the dynamic range of the interferometer system. Such a system has been installed at KEKB.

RETROFOCUS OPTICS

A retrofocus, or inverted telefocus, lens consists of a concave (negative focal length) lens placed in front of a convex (positive focal length) lens.[2] The difference between a simple convex lens and a retrofocus lens is illustrated in Figure 1. Figure 1a shows a simple lens, and Figure 1b shows a retrofocus lens with the same effective focal length as the simple lens in Figure 1a, but with a longer back focal length. Retrofocus lenses are used in wide-angle, short focal length lenses for SLR cameras, where a long back focal length is desired while maintaining a short effective focal length. By placing a pair of slits in front of the convex lens, we create a double-slit SR interferometer with retrofocus optics.

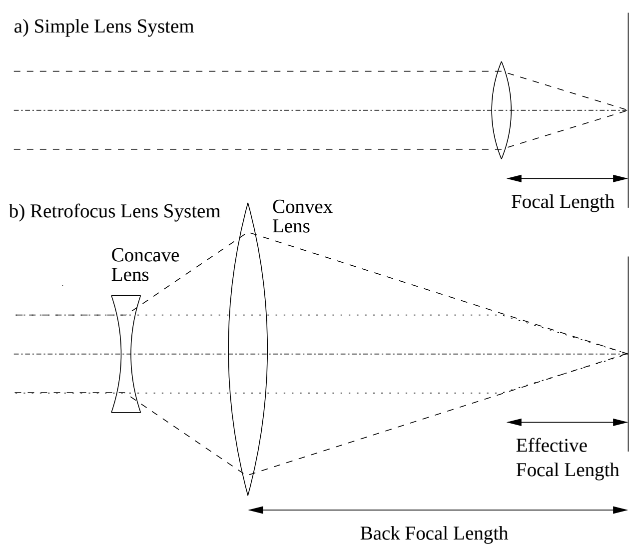

Figure 1: A) Simple lens system. B) Retrofocus (inverted telephoto) lens system with same effective focal length as a) but longer back focal length.

The interferometer using retrofocus optics is shown in Figure 2. A concave achromat lens, of focal length -150 mm, is placed in front of the double slits of the interferometer. This reduces the effective slit separation. The focal

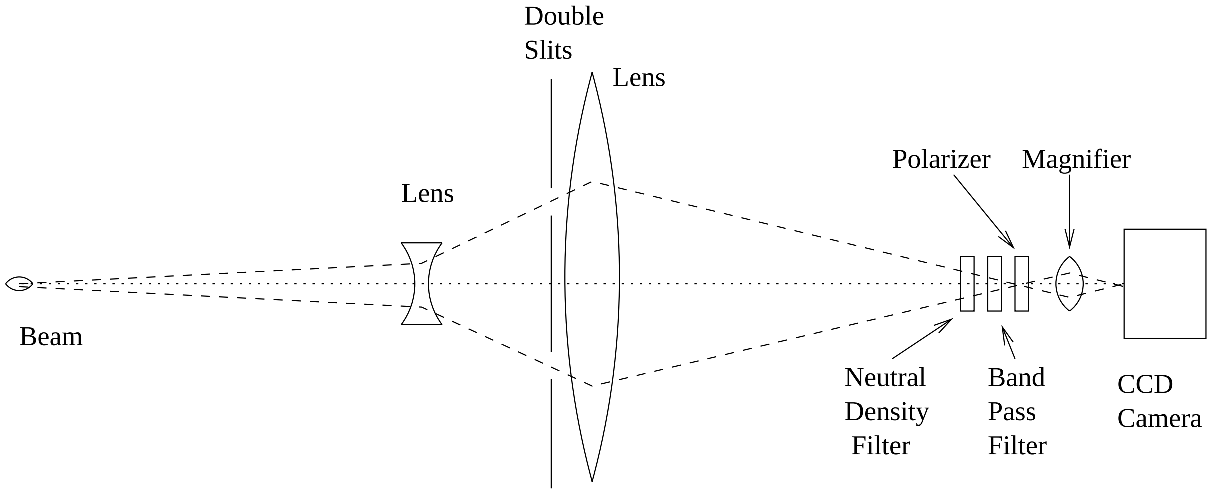

Figure 2: Retrofocus optics-equipped SR interferometer beam line.

length of the lens after the double slit must be shortened as a result, so two 500-mm focal-length lenses are placed just after the slits, replacing the 1000-mm focal-length lens that was originally used in the simple-lens configuration of the interferometer.

The results of installing the retrofocus optics are shown in Figures 3 and 4. Figure 3 shows a typical interference pattern for the HER horizontal beam size during physics running, while the HER bunches are in collision with the LER bunches. As can be seen, the visibility (difference between the peaks and the troughs in the pattern) is extremely low, measuring only 0.05, which is beyond the reliable dynamic range of the system. Figure 4 shows a typical interference pattern after the installation of the retrofocus optics. Here, the visibility is around 0.27, which is well within the usable range of the system. The single-beam image, with a higher visibility, is also well within the usable dynamic range. From the ratio of the visibilities in single-beam and colliding conditions, the ratio of the beam sizes in collision to that out of collision appears to be approximately 2:1; this ratio is approximately in agreement with the results of dynamic beta simulation, however, after the installation of retrofocus optics, it is necessary to performa an absolute calibration of the system before these sizes can properly be compared to the simulations.

OBSERVATIONS

After installation of retro-focus optics, we measured the distortion of the HER mirror using a pinhole mask, as described in [1] and [3]. This corrects for distortions in the absolute beam size measured by the SR monitor due to mir-

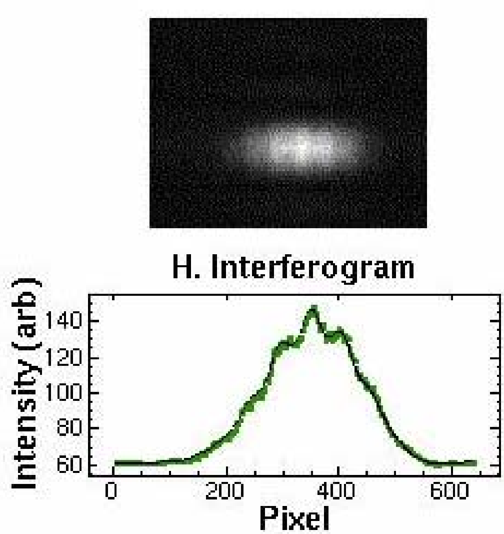

Figure 3: HER horizontal interferogram before addition of retrofocus optics.

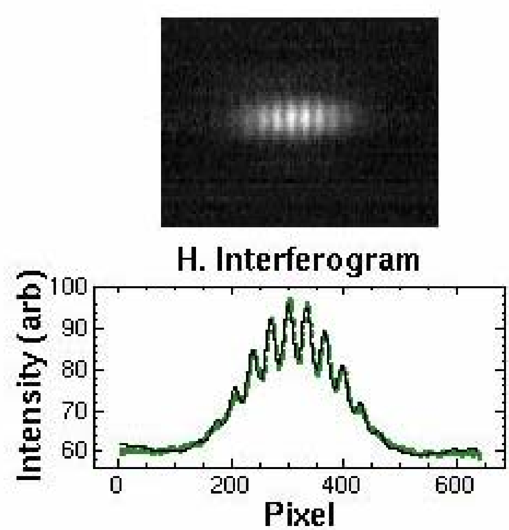

Figure 4: HER horizontal interferogram after addition of retrofocus optics.

ror heating, and also corrects for changes in the effective slit separation due to the introduction of the retrofocus optics.

To observe the horizontal beam-beam effects in the HER, we look for events where the LER beam was aborted during regular physics operation, but the HER beam remained circulating, and we compare the measured horizontal beam sizes of the HER just before and after the LER abort. An example of such an event is shown in Fig. 5. The data shown were logged on 31 October 2004. The green line shows the measured HER horizontal beam size, and the red line shows the LER beam current. Before the abort, the HER horizontal beam size is fluctuating between $\sim 1650\mu$m and $\sim 1700\mu$m. When the beam aborts at 1:30, the HER horizontal beam size simultaneously drops from $\sim 1660\mu$m to $\sim 850\mu$m.

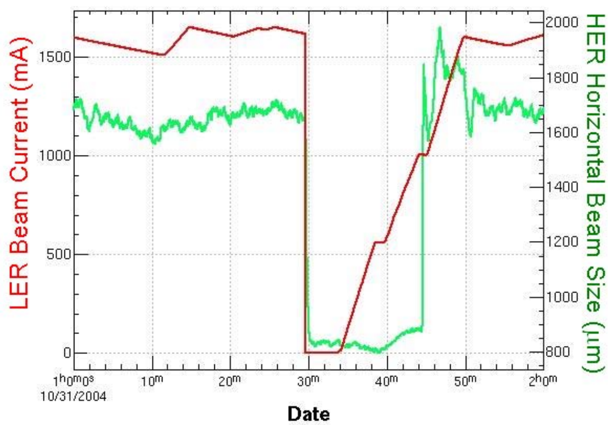

Figure 5: Measured HER horizontal beam size in collision and out of collision. The LER beam current (in red, left axis) is 1600 mA just before an LER abort at 1:30. The HER beam size (in green, right axis) is about 1650μm in collision just before the abort, dropping to 850μm out of collision, just after the abort.

To compare this change in the beam size with the expected dynamic beam-beam effects, we used the SAD tracking software, loaded with the optics settings used in the machine on 31 October, and simulated a beam-beam kick at the interaction point,

$$\Delta k = \frac{4\pi}{\beta^*}\xi, \tag{1}$$

from which we then solve for the perturbed emittance and beta function at the SR monitor source point, using as unperturbed values the design value of the emittance and the calculated value of the beta function for the given optics. The beam size at the source point is then calculated for various values of the beam-beam parameter ξ.

The predicted horizontal beam size as a function of beam-beam parameter ξ is plotted in Figure 6. The horizontal beam size in the absence of collision ($\xi = 0$) is 800μm, which is in good agreement with the measured value after the LER abort. The maximum beam size before the abort of 1700μm corresponds to a beam-beam parameter of ~ 0.06.

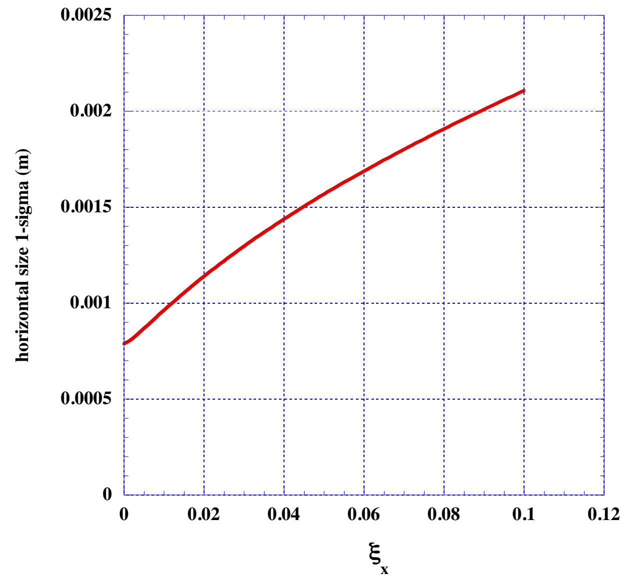

Figure 6: Calculated horizontal HER beam size at the SR monitor source point as a function of horizontal beam-beam parameter.

SUMMARY

A retrofocus optics system has been installed at the KEKB horizontal SR interferometers. Tests indicate that it increases the visibility of the horizontal SR interference pattern to be within the dynamic range of the interferometer system, with no change to the rest of the system. After absolute calibration, the single-beam horizontal beam size agrees well with the predicted beam size using the design emittance and measured and calculated beta functions. From comparing the measured horizontal beam size to the results of simulation, HER horizontal beam-beam parameter of around 0.06 has been estimated. We plan to make further measurements using retrofocus optics at both the HER and LER.

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