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Optical Beamlines for the KEK B-Factory Synchrotron Radiation Monitors[*]

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Abstract

We have designed and constructed two optical beamlines for the KEK B-Factory synchrotron radiation monitors, one for each ring. Each beamline transports the SR beam 30-40 meters to an external optics hutch along two parallel paths. One path is used for direct imaging with adaptive optics[1], the other is used for transverse beam size measurements via SR interferometer[2] and longitudinal profile measurements via streak camera. We designed and installed relay lens systems for the adaptive optics paths. We also provide remote alignment control for components which are inaccessible during beam operation (14 mirrors and 2 pairs of lenses total), with monitoring provided by a set of remote-controlled optical screen monitors. We describe the design of the relay lens and alignment systems along with performance results.

1 INTRODUCTION

The KEK B-Factory is an asymmetric electron-positron collider with two intersecting storage rings: the High Energy Ring (HER) for storing 8 GeV electrons, and the Low Energy Ring (LER) for storing 3.5 GeV positrons. Each ring has a complete, independent SR monitor system, consisting of a 5 mradian bend SR source magnet, water-cooled beryllium extraction mirror, closed optical beamlines and above-ground optical hutch. The beamline for the LER is shown in Fig. 1; the HER beamline is similar, except for having one less bend in the tunnel. The beamline is split into two paths soon after the extraction mirror. One path, the imaging line, contains two pairs of relay lenses which are used to transport the SR wavefront at the extraction mirror to a deformable mirror in the optics hutch for wavefront correction prior to imaging. The other path, the direct beamline, has no focusing optics.

The mirrors for both imaging and direct beamlines are custom ground and coated with aluminum for a surface flatness of $\lambda/10$.

2 OPTICAL PATH DESIGN

2.1 Imaging Beamline

The principle features of the imaging beamline are shown in Fig. 2. The optical path begins at an SR extraction point on the beam line, reflects from a beryllium extraction mirror in the beam pipe, and then passes to an optical hutch aboveground outside the tunnel, where the image is captured via camera and processed. The surface of the beryllium mirror is deformed by heating from the X-ray component of the synchrotron radiation. The deformation, which varies as a function of the SR beam intensity, introduces a corresponding wavefront distortion in the SR beam. The surface deformation of the mirror will be continuously monitored in the tunnel with a Shack-Hartmann wavefront measurement system to be installed during the machine shutdown for physics detector roll-in, and the wavefront distortion corrected by the use of a deformable mirror (CILAS BIM31) in the optical hutch. This adaptive optics system[3] should permit the wave front distortion to be corrected to within $\lambda/10$ in RMS.

Because of the distance between the hutch and the beamline, the optical path between the two mirrors is constrained to be at least 30 meters. A set of relay lenses is used to transport the SR wavefront from the extraction mirror to the deformable mirror, which is located at the conjugation point of the relay lens system.

2.2 Relay Optics Design

The requirements for the relay lenses are:

- Provide plane-to-plane focusing for the extraction and correction mirrors: each mirror sits at a conjugation point of the relay lens system, to map the surface of the extraction mirror onto that of the correction mirror;
- Match the active area of the correction mirror to that of the extraction mirror: the 15x15 mm usable surface of the extraction mirror needs to be magnified by a factor of 2 to make the most effective use of the clear aperture (active area) of the 5 cm diameter correction mirror;
- Minimize aberrations at the wavelengths of interest; a bandpass filter in the optical path sets this range to 550 nm ± 5 nm;
- Use commercially available lenses where feasible.

The basic design uses two pairs of doublet lenses. Each pair consists of a concave lens and a convex lens with focal lengths of equal magnitude but opposite sign, which minimizes the dependence of focal length on errors in focal lengths of the two lenses. The convex lenses are common, commercially available lenses (Melles-Griot achromatic doublets). Concave lenses are not commercially common, so they have been custom ordered.

To reach the factor of two magnification between the front focal plane (extraction mirror surface) and the rear focal plane (correction mirror surface), the focal length of the first pair of lenses is taken as $1/3$ of the total distance

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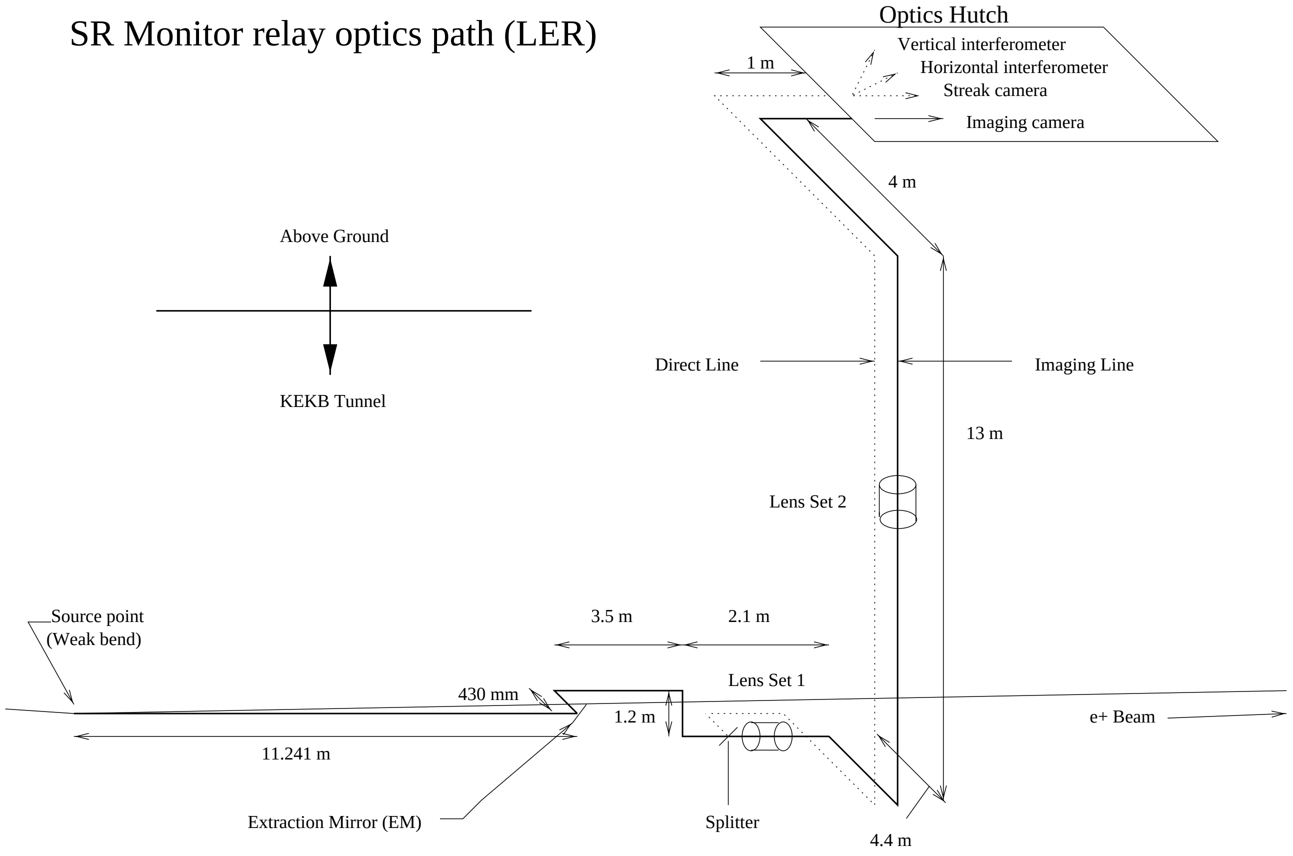

Figure 1: SR Monitor optical beamlines (LER)

between the mirrors (5100 mm), while that of the second pair is taken as $2/3$ of the distance (10200 mm). The resulting set of design parameters is shown in Table 1.

Table 1: Relay Lens Specifications

Pair/ Lens	**Eff. Foc. Len. (mm)**	**Edge Dia. (mm)**	**Thick-ness (mm)**	**Pair Foc. Len. (mm)**	**Lens Sep. (mm)**
Pair 1:				5100	187
Convex (Melles Griot LAO366)	1000	80	10		
Concave (custom)	-1000	80	10		
Pair 2				10200	373
Convex (Melles Griot LAO379)	2000	150	23.27		
Concave (custom)	-2000	150	23		

As a starting point, the concave lenses are specified as being identical to the convex lenses, but with opposite radii of curvature. The glasses used in the custom lenses are then changed to more common types (BK7 crown and F2 flint), and optimized for the required focal lengths. Commercially available lenses are optimized for minimum aberrations at infinite conjugate ratios; the curvatures of the custom lenses were optimized with the use of optical design software (Zemax) for minimum aberrations in combination with the commercial convex lenses at the finite conjugate ratios needed and at the required magnification on the surface of the correction mirror.

In addition to the above, an additional MG LAO366 is used after the correction mirror to bring the image to a final focus at the video camera input. This final focus lens is added to the simulated system, and the spacings between lens pairs in the end-to-end design re-optimized.

The resulting design shows a wavefront distortion of $\lambda/10$.

2.3 *Direct Beamline*

In addition to the imaging beamline described above, a direct (non-imaging) optical beamline is split off from the imaging beamline before the first lens, and proceeds parallel to the imaging beamline into the optical hutch. This direct beamline is used for precise transverse beam size mea-

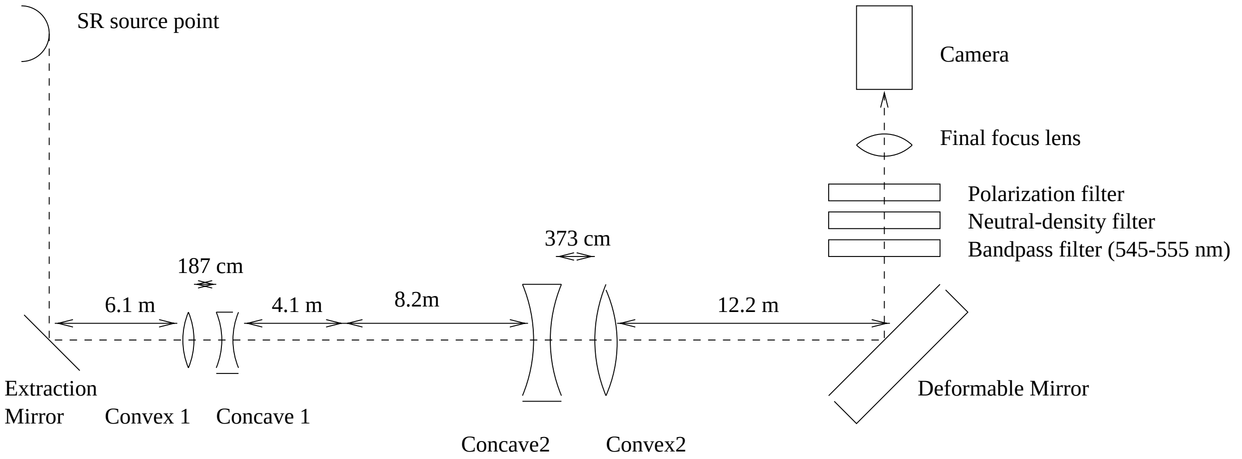

Figure 2: Relay lens optics. Extraction and deformable mirrors sit at conjugation points of the lens system.

surement via interferometry, as well as for longitudinal profile measurement via streak camera. The direct beamline contains no focusing optics between the SR source point and the hutch, only mirrors, in order to preserve both the spatial coherence for the SR interferometer and the temporal structure for the streak camera.

3 MECHANICAL DESIGN

All mirrors which are below ground (8 in the LER ring and 6 in the HER ring) are movable in two degrees of freedom with pulse motors. The pulse motors are remotely controlled from the optical hutches to permit alignment while the rings are in operation, by both manual control and GPIB interface.

In addition to the mirrors, the second set of lenses in each SR beamline are remotely movable as well, to adjust the focal length and magnification of the mapping of the surface of the extraction mirror onto the surface of the correction mirror. The alignment of the beamlines before particle beam commissioning was carried out using a laser auto-collimation method: a laser beam is sent down the beamline from the optics hutch, and the mirrors adjusted sequentially to deliver the beam to the SR extraction port, where a temporary mirror reflects the beam back up both beamlines.

For alignment with the SR beam itself, when the laser auto-collimation method can not be used, a set of "optical screen monitors" were designed and installed in the system at several locations in each beamline. These monitors consist of remotely operable guillotine-like semi-opaque screens, which are monitored via cameras from the optics hutch to facilitate optical path alignment using the SR beam.

To reduce image fluctuations due to air currents, the beamline is closed with a minimum diameter of 200 mm. Some fluctuations are still visible and further work remains to be done in this area, but the system works successfully for streak camera measurements and for beam profile measurements using both the imaging and direct lines. An measurement output example is shown in Fig. 3.

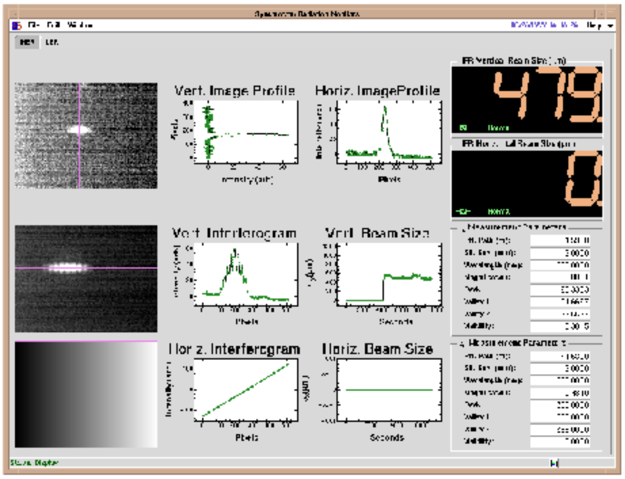

Figure 3: Example of SR measurement system output. Beam size (LER, vertical only in this example) is monitored continuously.

4 RESULTS

The direct and optical beamlines for the LER and HER have been designed, installed and commissioned, and are working well to deliver initial SR beams for imaging, interferometry, and streak camera use. Refinements to the measurement methods are underway, and commissioning of the adaptive optics components is scheduled to begin shortly.

5 REFERENCES

[1] N. Takeuchi et al., Tech. Digest of Nonastronomical Adaptive Optics (NAAO' 97), (1997) p. 26.

[2] T. Mitsuhashi et al., Proc. EPAC 1998, p. 1565.

[3] T. Mitsuhashi et al., Proc. APAC 1998, p. 698.