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ELECTRON BEAM DIAGNOSTICS USING SYNCHROTRON RADIATION AT THE ADVANCED LIGHT SOURCE*

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Recycled Paper

Electron Beam Diagnostics Using Synchrotron Radiation at the Advanced Light Source*

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Abstract. Synchrotron light emitted from a bend magnet is being used to diagnose the electron beam stored in the main accelerator of the Advanced Light Source (ALS) at Berkeley Lab. The radiation has maximum intensity in the soft X-ray region and is imaged by a Kirkpatrick-Baez mirror pair from the source point inside the ring onto a Bismuth/ Germanium-Oxide (BGO) crystal, converted into visible light and magnified by an attached microscope. The final image is captured by a TV camera-tube and digitized by a frame- grabber device to obtain records of parameters such as beam size, center location and profile. Data obtained from this Diagnostic Beam Line have been very useful in day-to-day operation of the ALS storage ring to assess the quality and repeatability of the stored beam. The line has further been utilized in several dedicated research activities to measure bunch lengths under various conditions and observe transverse beam instabilities. A summary of obtained results is given in this paper, together with a description of the technical features of the Diagnostic Beam Line.

INTRODUCTION

The main accelerator of the Advanced Light Source (ALS) is a third-generation electron storage-ring that produces synchrotron radiation in bend magnets and insertion devices over the spectral range from ultraviolet to the soft x-ray region. One of the bend-magnet photon beam-lines is exclusively used to obtain on-line information about the electron beam to provide quality assurance in day-to-day operations as well as support for beam development activities and trouble shooting in case of a malfunction. The synchrotron-light image of the beam cross-section carries information on horizontal and vertical beam sizes, positions, and density profiles. With time-resolved measurements dynamic effects such as bunch lengthening and instabilities can be observed.

The design features of the diagnostic beam line have been described in detail elsewhere (1). In this paper, after giving a brief overview of its characteristics we

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concentrate on discussing applications of the beam line to accelerator diagnostics and the main results so far obtained. Currently some minor modifications are being implemented that will allow faster and safer switching between various observation modes and reduce the setup time for infrequently used special detectors such as streak camera and single-photon counting system.

BEAM-LINE LAYOUT AND ELEMENTS

A schematic of the diagnostic beam-line layout is given in Figure 1. The source point, representing a cross-section through the electron-beam, is located inside a storage-ring bend magnet. A Kirkpatrick-Baez (K-B) mirror pair (2) images this object plane into the image plane where a Bismuth/Germanium-Oxide (BGO) single-crystal scintillator converts the soft x-ray radiation to visible light. This visible-light image is magnified and recorded by a CCD camera. A set of carbon foils of different densities is inserted in front of the BGO crystal to absorb low-energy photons and to attenuate the transmitted soft x-ray radiation to a level suitable for the CCD camera. In this way the full resolution of the CCD camera can be utilized, without being subject to the larger diffraction effects of the visible or ultraviolet fractions. A pair of silicon mirrors, retractably mounted in front of the carbon-foil attenuator, can deflect the visible light into a second optical axis to perform time-resolved measurements with either a streak camera, or a fast photo diode, or a single-photon counter.

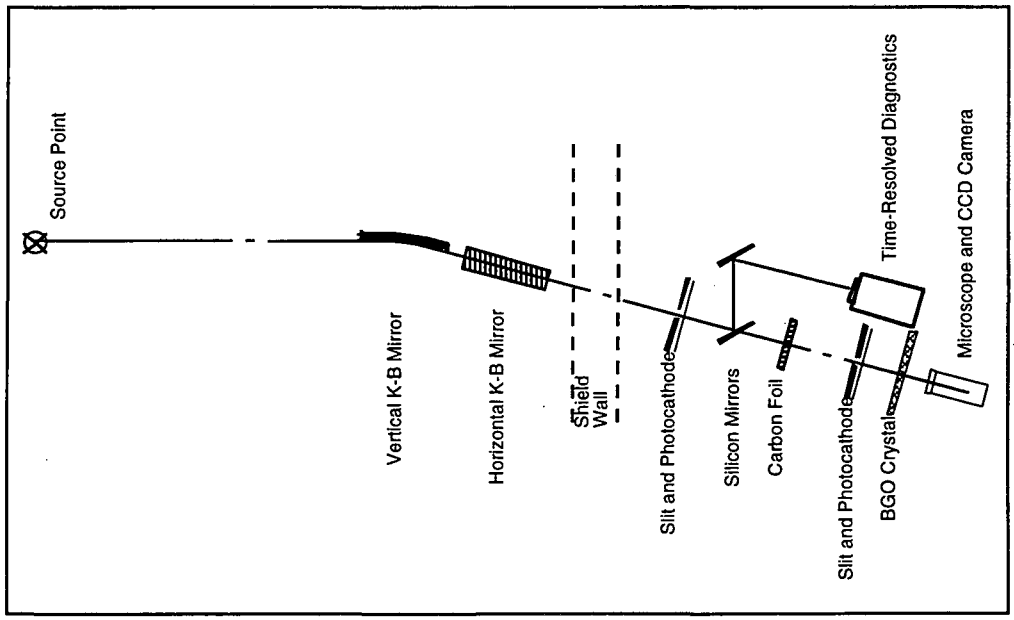

FIGURE 1. Schematic elevation view of the diagnostic beam line.

The actual object-mirror and mirror-image distances are 6.1 and 6.1 m, horizontally, and 5.7 and 6.5 m, vertically, resulting in magnification factors of 1.00 and 1.14, respectively. The horizontal grazing angle is 1.5° and the vertical one 2.0°. Both mirrors are mounted inside a common vacuum tank that can be pivoted around

the transverse symmetry axis of the vertical mirror. The first of the two silicon mirrors can be retracted manually to allow passage of the radiation to the end station for the standard operating condition when no time-dependent measurements are being performed.

The two slit/photocathode assemblies in front of the silicon mirrors and in front of the BGO crystal consist of two orthogonal, 200-μ wide slits and AL_2O_3 scintillator screens. The slits can be moved across the light beam in horizontal or vertical direction to generate intensity profiles, and both assemblies can be completely retracted when they are not in use. The first slit assembly is used to verify the alignment of the K-B mirrors with respect to the incoming photon beam, and the second one serves to monitor the electron-beam density-profiles.

The carbon foils are mounted on a manually operated wheel and range in thickness from 0.1 μ through 20 μ in steps of about a factor of two, corresponding to about a factor of 10 in transmission reduction for every step. Foils thicker than 5 μ are made from pyrolytic graphite, the thinner ones consist of evaporated carbon. The filter system allows one to work at optimum signal-to-noise ratio for a wide range of electron beam currents and energies without saturating the charge-coupled-device (CCD) camera. The limiting aperture of the beam line admits photons within an angle of 1.0 mrad, and under diffraction-limited conditions the desired spatial resolution of 10 μ implies that the wavelength of the utilized radiation be shorter than 12.5 nm, corresponding to photon energies above 99 eV. The carbon foils actually transmit at energies above 280 eV, and thus the resolution requirement is fulfilled.

The end station elements, consisting of the second slit assembly, the BGO crystal, and the CCD camera with its imaging optics, can be moved longitudinally on a common stage. In this way the beam line can be made to provide a stigmatic image of the source point by slightly rotating the vertical K-B mirror. Adjusting a grazing-incidence mirror angle mostly changes its effective focal length; the slight vertical shift in image position can be accommodated by mechanically adjusting the end station.

Time-dependent measurements can be performed along the secondary photon-beam axis, with the first silicon mirror inserted into the main axis. We have performed measurements using a fast photo-diode (18 GHz frequency limit) and a streak camera.

OBSERVATIONS AND MEASUREMENTS

For most of the time, when the ALS is running for synchrotron-light users, the CCD camera is providing an on-line image of the electron-beam cross-section on a TV monitor in the ALS control room. Operators can observe the stability of beam shape and position and take the necessary actions if the storage ring performance is not adequate. Quite often, sudden changes in the beam conditions are noticed first on this beam image and can then be verified with other diagnostic elements such as capacitive beam-position monitors. Based on its usefulness for operations, the on-line beam image is now being patched to the various experimental stations in the

storage-ring building to help the users distinguish between photon beam-line and electron-beam motion.

The monitor image can also be captured by frame-grabbing utilities and digitized for post-processing. Correlating beam-size or center-location variations off-line with archived data such as power supply currents helps identify defective accelerator components. The processed frame-grabber data are also very useful for a multitude of beam studies performed in dedicated accelerator development-shifts. Some examples of observed beam shapes are given in Figure 2.

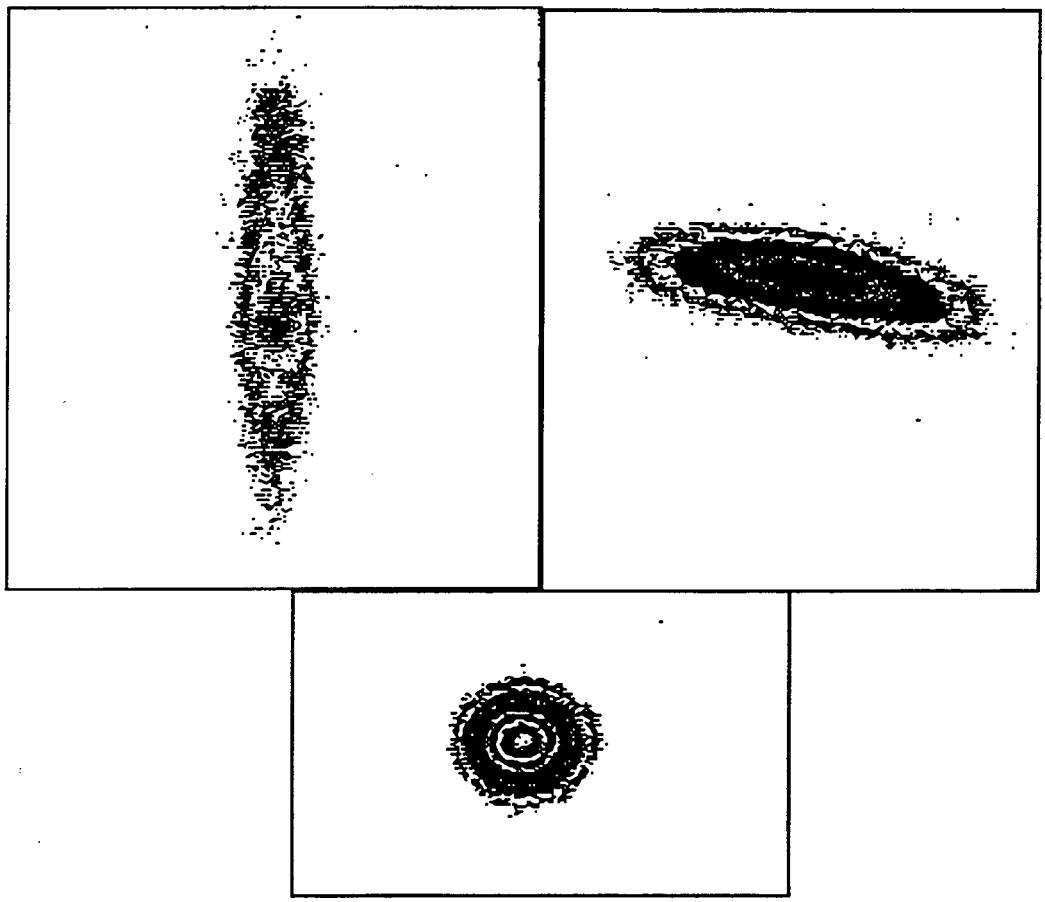

FIGURE 2. Digitized electron beam images as recorded by the CCD camera for various conditons of the fast feedback systems (3). Top left, vertical feedback OFF, horizontal and longitudinal feedback ON. Top right, vertical and horizontal feedback ON, longitudinal feedback OFF. Bottom, all feedback systems ON; in this case the horizontal beam size is $\sigma_x = 51\ \mu$. All three shapes are reproduced in the same scale. The original monitor images are displayed in false colors representing zones of different intensities; this explains the rings seen on the black-and-white reproductions of this paper.

Figures 3, 4, and 5 show measured horizontal and vertical beam sizes as functions of beam current for different feedback conditions and bunch filling patterns.

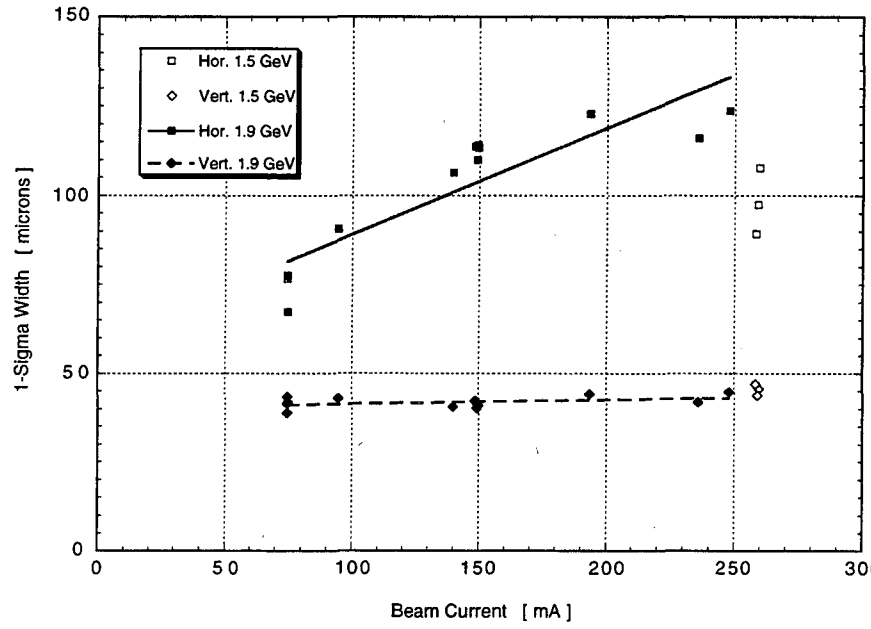

FIGURE 3. ALS beam sizes for multibunch fills (320 out of 328 buckets filled) and energies of 1.522 and 1.9 GeV. The feedback systems were switched OFF for this measurement series. Linear fits are applied to the 1.9-GeV data.

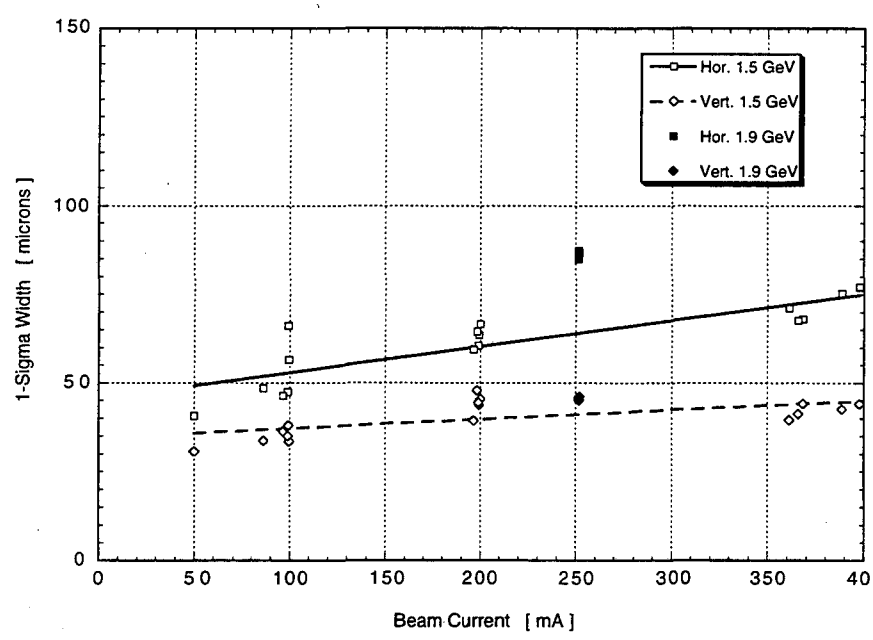

FIGURE 4. ALS beam sizes for multibunch fills (320 out of 328 buckets filled) and energies of 1.522 and 1.9 GeV. The feedback systems were switched ON for this measurement series. Linear fits are applied to the 1.522-GeV data.

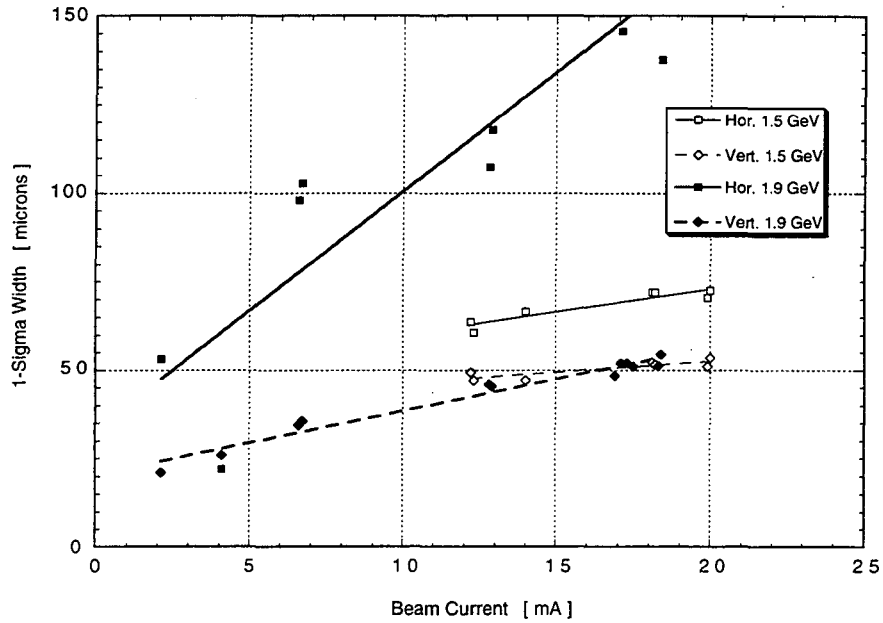

FIGURE 5. ALS beam sizes for single-bunch fills and energies of 1.522 and 1.9 GeV. The feedback systems were switched OFF for this measurement series. Linear fits are applied to all data.

Examples of time-dependent measurements are given in Figures 6 and 7.

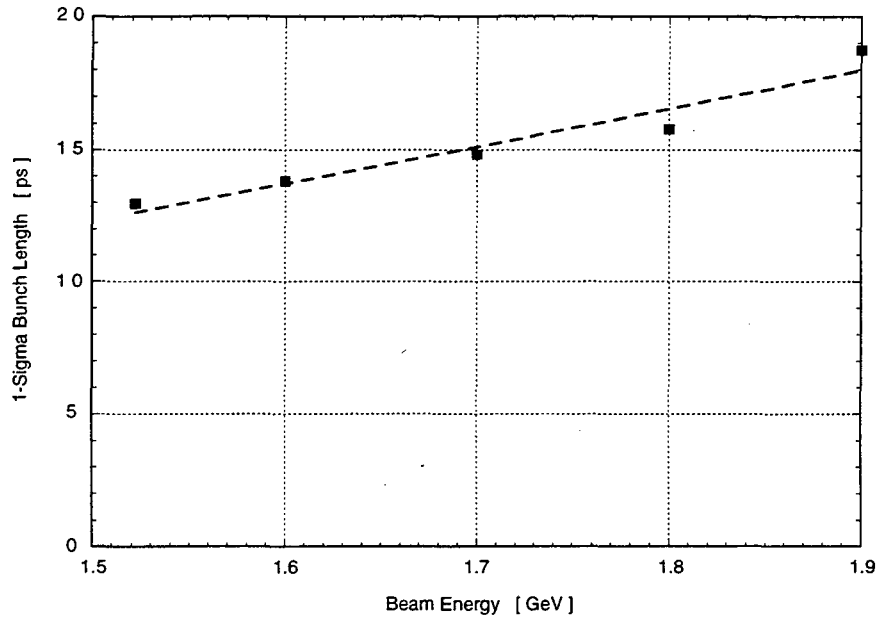

Figure 6. Bunch lengths as a function of electron beam energy as measured by a streak camera for a 200-mA multibunch fill, 0.625 mA per bunch, (4).

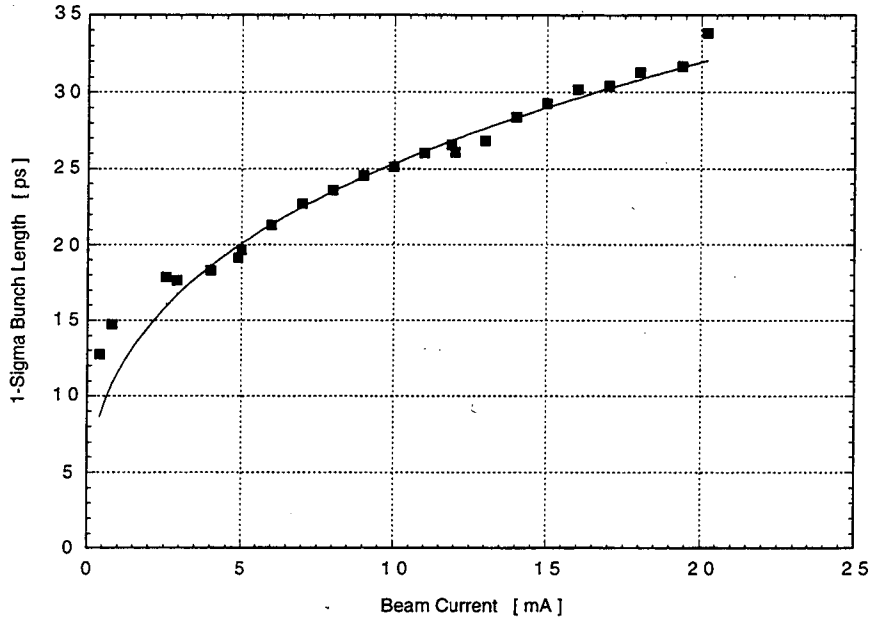

Figure 7. Bunch lengths as a function of electron beam current, **I**, as measured by a fast photodiode for a single-bunch fill at 1.522-GeV energy. 20 ps are subtracted from all measured lengths to account for the cable delay in the measurement circuitry. A curve proportional to $I^{1/3}$ is fitted to the data with $I \geq 2.9$ mA.

The bunch-length data, σ_l, in Figure 7 are well fitted by a curve $\sigma_l \propto I^{1/3}$, as is expected when the threshold for turbulent bunch lengthening is exceeded (5). The deviation of the data from the fit at very low currents is due to increasingly poor signal-to-noise ratio, whereas the deviation at 20 mA marks the onset of another effect, the transverse mode-coupling instability (6) that represents an absolute current limit for the ALS storage ring with single-bunch fills.

IMMINENT UPGRADES

The diagnostic beam line already has proven its usefulness for day-to-day operations as well as for accelerator development and trouble-shooting activities. Some of its present features, however, are either somewhat uncomfortable to work with or even pose a risk for the machine safety. Therefore, three upgrade projects have been devised and are currently being implemented. The first one regards the danger that a carbon filter might break when high photon intensity is transmitted through the beam line. In that case, our calculations show that the BGO crystal will be overheated and might break as well, leaving the rather thin exit window to absorb most of the radiation power. A failure of this window will expose not only the beam line itself but also parts of the ALS storage ring to humid air at atmospheric pressure, a clearly undesirable prospect. The remedy consists in mounting a mirror behind the BGO crystal which will absorb or pass the x-ray component of the incident

radiation straight through while deflecting the visible light 90° upwards into the CCD camera.

Secondly, rotating the filter wheel to accommodate different electron beam intensities presently requires insertion of a photon shutter because the wheel has empty spaces between the filters. A protective mask will circumvent this problem and ultimately allow remote control of the wheel orientation.

A third modification affects the mounting of the first silicon mirror that can deflect visible light into the secondary beam line axis reserved for time-resolved measurements. With the new mount, the mirror can be precisely inserted into its previous operating position, without need for realignment as is presently required. This upgrade will also allow remote control of the insertion and retraction tasks.

ACKNOWLEDGMENTS

We would like to thank Howard Padmore and Alan Jackson for their leadership shown in the effort to bring the diagnostic beamline into its present configuration. It is also a pleasure to express our gratitude towards the ALS operators for their help in carrying out all beam measurements and towards Pat McKean for technical assistance. Jim Hinkson and Mike Chin gave valuable support with the time-dependent measurements, and John Byrd contributed some material and advice regarding the bunch-length measurements.

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