AMELIORATION OF SR EXTRACTION WINDOW TRANSMISSION LOSS VIA ELIMINATION OF ANTI-REFLECTIVE COATING

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Abstract

Synchrotron radiation (SR) diagnostics are used at KEKB for beam size and other diagnostics. As beam currents have increased, the SR extraction windows have become contaminated more quickly, to the point where they must be replaced more often than once per year. The contamination is in the form of a black substance on the vacuum side of the window. A new extraction window has been tested, which has no anti-reflective coating on the vacuum side. This window shows a much slower rate of contamination. We report on the new window design, and show contamination rate data for the old and new windows.

INTRODUCTION

KEKB consists of two colliding storage rings, the Low Energy Ring (LER), holding 3.5 GeV positrons, and the High Energy Ring (HER), holding 8 GeV electrons. SR diagnostics are used for bunch size and other measurements[1]. In each ring there is an SR source bend, from which the SR is extracted after reflection off a beryllium mirror mounted in the beam pipe approximately 10 meters downstream of the source bend, and passing through a fused-silica extraction window at the interface between vacuum and atmosphere. From there, the SR beam is passed by a series of mirrors to the optics hut (one for each ring) above ground, about 30 meters downstream of the extraction window. In each optics hut, there are interferometers for average transverse beam size measurements, and streak cameras and gated cameras for bunch-by-bunch, turn-by-turn beam profile diagnostics.

DESIGN OF SR EXTRACTION WINDOW

The extraction window is an optical flat made of fused silica, with a diameter of 100 mm and a thickness of 19 mm. To prevent wavefront distortions due to mechanical stress in the window, it is mounted using metal O-rings (Helicoflex from Le Carbone K.K.) on both sides[2]. The slope error of the surfaces are polished to better than $\lambda/10$ on one side, and $\lambda/4$ on the other side. The two sides are parallel to within 2”. To minimize the risk of overlapping images from multiple reflections between the vacuum-side and atmospheric side faces, which destroy the measured spatial coherency of the SR light by which the beam size is measured using the SR interferometer, a single layer of MgF_2 is applied to each side.

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This design has been used from the early stages of KEKB commissioning in 1998, and has generally worked quite well, with the window needing occasional replacement as it became contaminated over time. The windows have generally been replaced once per year, as a maintenance item, along with other periodic maintenance of the system. However, in order to increase the luminosity of KEKB, the beam currents of both the LER and the HER have increased over time; the peak currents of the LER and HER are 2000 mA and 1350 mA respectively, with regular operating currents over 1700 mA and 1300 mA respectively. Concomitant with this rise in operational beam currents, the rate of contamination has accelerated, to the point that the HER window required replacement two times in the past year (in August 2005 and March 2006), and the LER three times (August 2005, and January and March 2006). Since even higher beam currents will be required in the future for further luminosity upgrades, it became necessary to study the problem of window contamination and seek ameliorative measures.

ANALYSIS OF WINDOW CONTAMINATION

The LER window was replaced in January 2006; a photo of the window is shown in Figure 1.

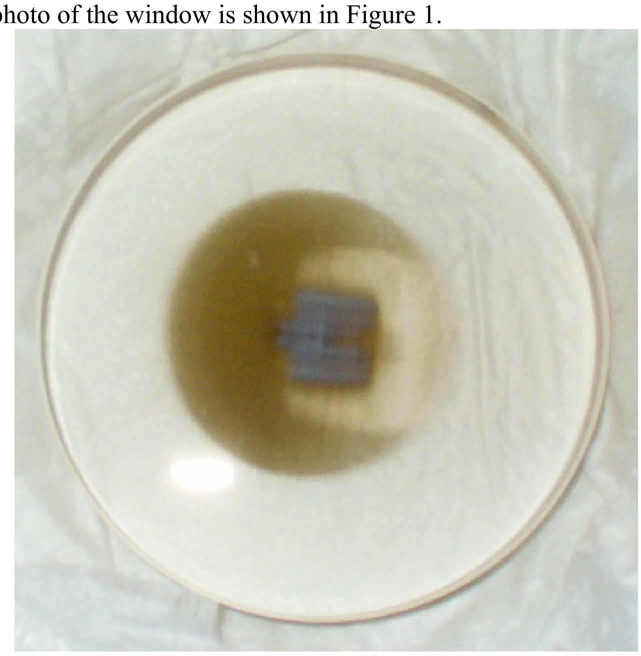

Figure 1: Contaminated extraction window. Darker region in center shows where the SR beam hit directly.

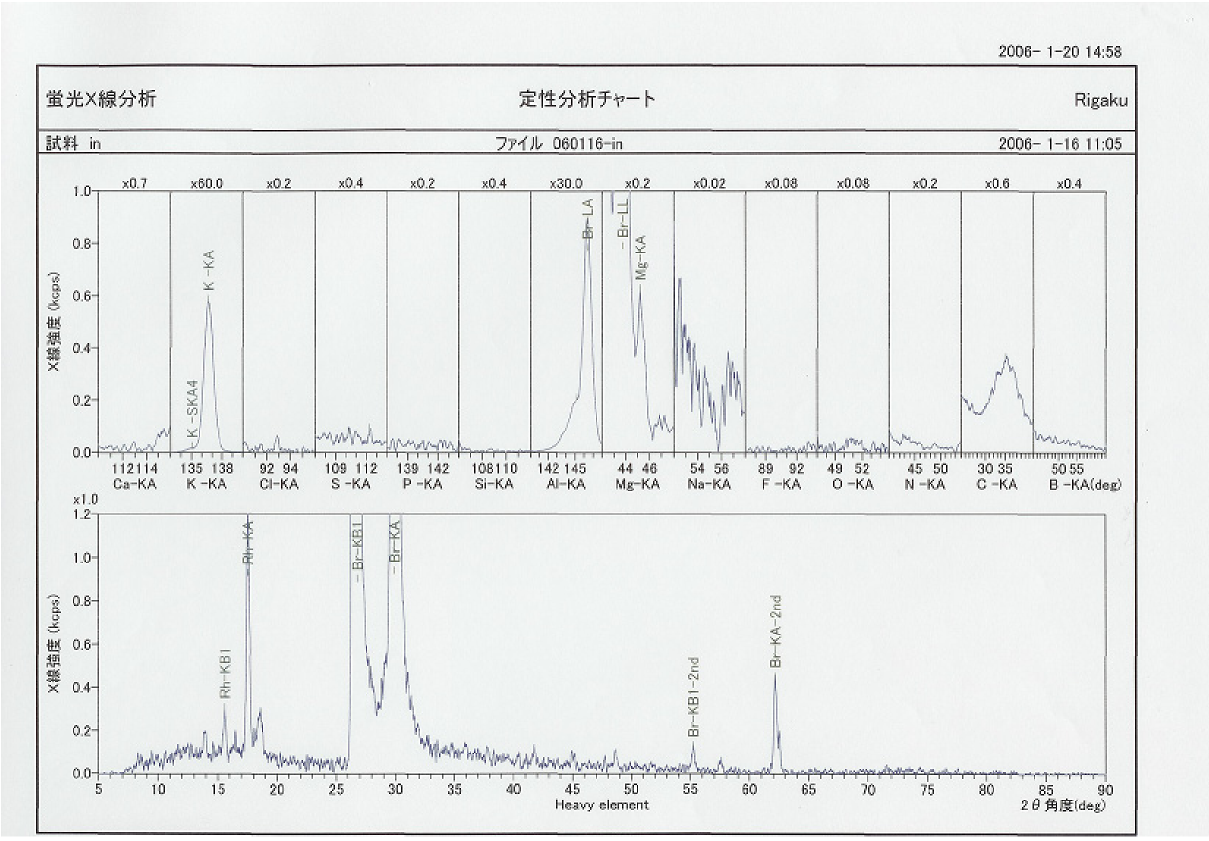

Figure 2: Elemental analysis by X-ray fluorescence spectroscopy of the black material in the center of the extraction window.

Two regions of contamination can be seen in the photograph. The darker, rectangular central region is where the SR beam impinges directly on the window. Surrounding this is a lighter, copper-colored region, with a circular border of the same diameter as the beam pipe. The clear region around that was protected by the mounting flange.

X-ray fluorescence spectroscopy of the black substance (See Figure 2) shows the presence of magnesium. Magnesium is a known getter material, chiefly effective at capturing oxygen to make magnesium oxide. It was commonly used in early vacuum tubes, though was later superceded by better materials such as barium, which capture a broader range of contaminants. It was theorized that the magnesium in the anti-reflective coating may be activated by the strong SR hitting it, causing it to act like a getter pump, resulting in the build-up of contamination on the window.

The lighter ring of contamination surrounding the central region was also analyzed, and in addition to magnesium and oxygen, silicon an copper were also found. The surface of the outer ring of contamination is also conductive, whereas the black region is non-conductive. It is possible that the presence of copper is due to some kind of sputtering from the copper beam pipe, though the exact mechanism is not clear. If the surface of the window is wiped, the black substance can be removed, but the copper-colored discoloration cannot be. This suggests that the black substance builds up first, and prevents the copper-colored material from contacting the window surface directly in the very center of the window.

It was decided to try eliminating the anti-reflective coating on the vacuum side only, to prevent the getter pump effect while not impacting the light quality significantly. One such window was installed in the LER in April, 2006. At the same time, the extraction window in the HER was replaced with a regular window with both sides coated. Over the following weeks, the light levels of both the LER and the HER were observed.

LIGHT INTENSITY

The interference pattern has the form:

$$y(x) = I_0 \left[\frac{\sin\left(\frac{2\pi}{\lambda}\frac{w}{f}x + \Phi\right)}{\frac{2\pi}{\lambda}\frac{w}{f}x + \Phi} \right]^2 \left(1 + \gamma \cos\left(\frac{2\pi}{\lambda}\frac{D}{f}x + \Psi \right) \right),$$

where I_0 is the light intensity through the slits, D is the separation between the double slits, w is the slit width, f is the distance between the secondary principal point of the lens and the camera CCD plane, and λ is the wavelength of light used. Φ and Ψ are phase offsets depending on the position of the beam off-axis from the slit-camera system. The interference pattern is fit using the above formula, and the fit parameters are logged permanently.

The light intensity as a function of integrated beam current (Amp hours) are shown in Figures 3, 4 and 5. Figure 3 shows the HER with the double coated window, taken in April and May of 2006. Figure 4 shows the LER in January-March 2006, with the double-coated window, and Figure 5 shows the LER with the single-coated window in April and May of 2006. The light intensities with the double-coated window drop dramatically over the time periods shown, with the HER dropping somewhat more rapidly (by more than a factor of 10) than the LER (by a factor of about ~5). However, the single-coated window in Figure 5 shows a much slower rate of transmission loss.

The uncoated window shows superior transmission characteristics over time. Note that the transmission does still drop, though more slowly. This may be due to the

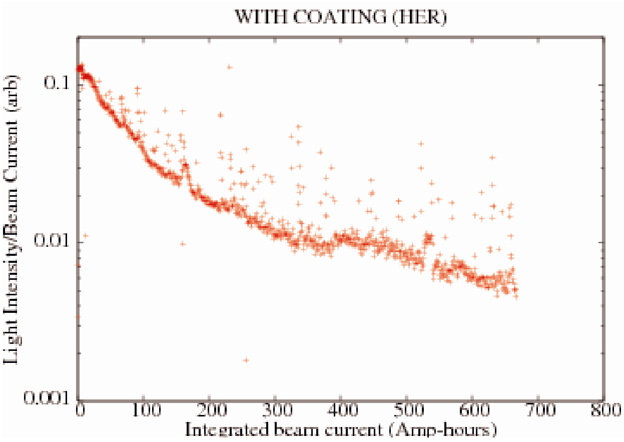

Figure 3: Dependence on integrated beam current of HER light levels seen using the extraction window treated with an anti-reflective coating of MgF_2 on both sides.

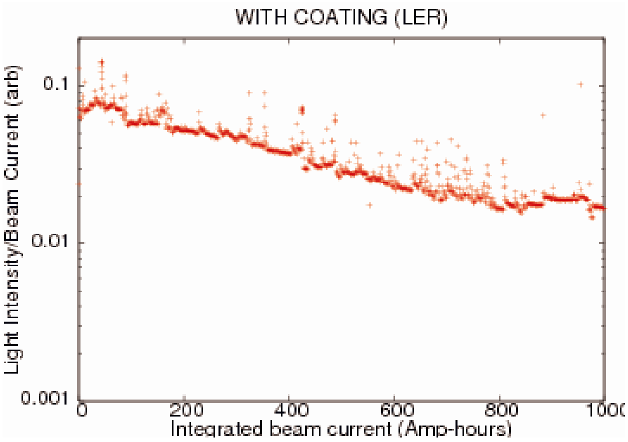

Figure 4: Dependence on integrated beam current of HER light levels seen using the extraction window treated with an anti-reflective coating of MgF_2 on both sides.

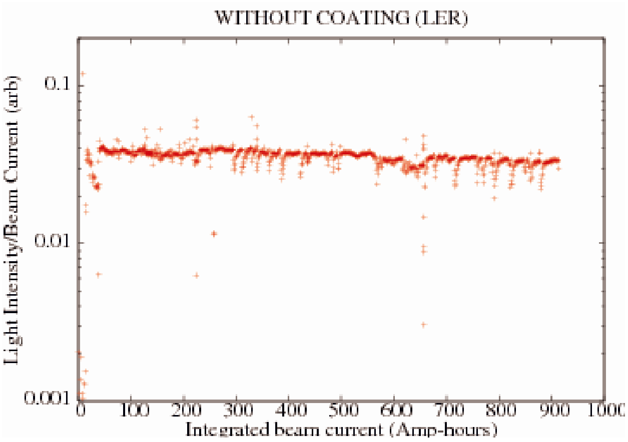

Figure 5: Dependence on integrated beam current of light levels seen using the extraction window treated with no anti-reflective coating of MgF_2 on the vacuum side.

build-up of the copper-colored contamination which, if it is due to sputtering, would be expected to develop even without the MgF_2 coating. The windows will be replaced this summer, and will be examined then.

Finally, no evidence of harmful reflections has been seen. However, to be safe, the next set of windows will be created having a slight wedge shape, with a 10 mrad angle between the vacuum- and atmosphere-facing sides.

CONCLUSION AND FUTURE PLANS

We have tested the performance of a light-extraction window with no MgF_2 anti-reflective coating on the vacuum side, and have found that the rate of contamination as a function of integrated beam current is greatly reduced compared to that of a window with coatings on both sides. Though no evidence of harmful reflections were found in the beam-size measurements, slightly wedge-shaped window will be tested in the fall of 2006 in both the old LER and HER beam lines, as well as in the new LER beam line.

ACKNOWLEDGMENTS

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