CORONAGRAPH MEASUREMENTS ON THE AUSTRALIAN SYNCHROTRON STORAGE RING OPTICAL DIAGNOSTIC BEAMLINE

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Abstract

A coronagraph was constructed on the Optical Diagnostic Beamline at the Australian Synchrotron to observe the tails of the stored beam and the injected beam on the first few turns. Some results are presented with special emphasis on the limitation of the sensitivity due to the quality of the synchrotron light extraction mirror.

BACKGROUND AND MOTIVATION

The Optical Diagnostic Beamline (ODB) [1] at the Australian Synchrotron is designed for experiments to monitor and develop the electron beam in the storage ring. A range of instruments have been developed to measure and observe the storage ring electron beam using the visible part of the synchrotron radiation (SR) spectrum. The visible light is extracted with a vertical from a bending magnet source point using a mirror that intercepts the top part of the SR beam fan. The extraction is not optimal since a port that was designed for x-rays had to be used and only 1.2 mrad of the vertical opening angle passes into the beamline. The light is extracted from the top of half of the RS beam to allow the x-rays to pass below the mirror to avoid unwanted heating, following the design at the CLS [2]. Previously measurements where made using the coronagraph to block the stored beam and observe the injected beam [3], however this type of measurement did not push the limits of the coronagraph. These measurements were conducted to test the limits of the sensitivity of the system and to gain experience with the apparatus for making measurements in hadron machines where the measurement and control of the beam halo is critical for operation.

SETUP AND METHOD

An apparatus was constructed on the ODB based on a stellar coronagraph adapted for a particle accelerator by Mitsuhashi [4]. The objective lens at the entrance to the coronagraph has to be highly polished to reduce the Mie scattering of light into measurement plan at the exit. Baffles are used along the length of the coronagraph to block as much of the scattered light as possible to prevent it from entering back into beam path (See Fig. 1). An opaque disk for blocking the beam core consists of a metal cone with a base diameter of 100 μm (See Fig. 2). The cone shape reflect the core transversely away from the acceptance of the coronagraph to eliminate noise from scattered light.

Two flat mirrors were introduced for practical reasons since the optical table is too short compared with the focal length of the objective lens. These mirrors bend the optical axis across two 90 degree left turns after the field lens behind the opaque disk. The relay lens then images the plane where the opaque disk sits and a ocular enlarges the image on an intensified CCD (ICCD) (See Fig. 3).

Figure 1: Optical table layout of the coronagraph.

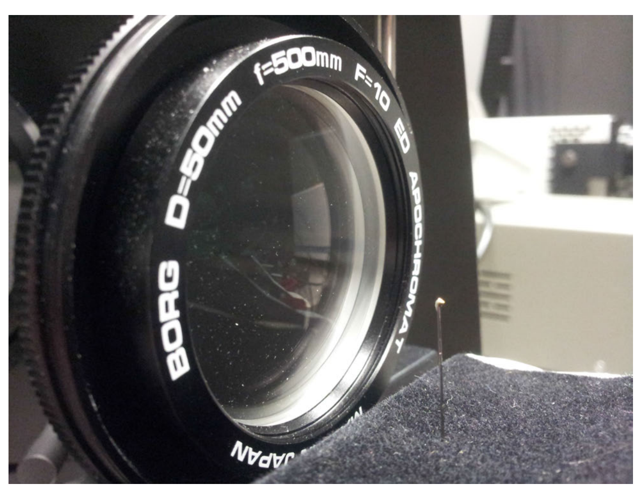

Figure 2: Opaque disk with a cone shape and a base diameter of 100 μm.

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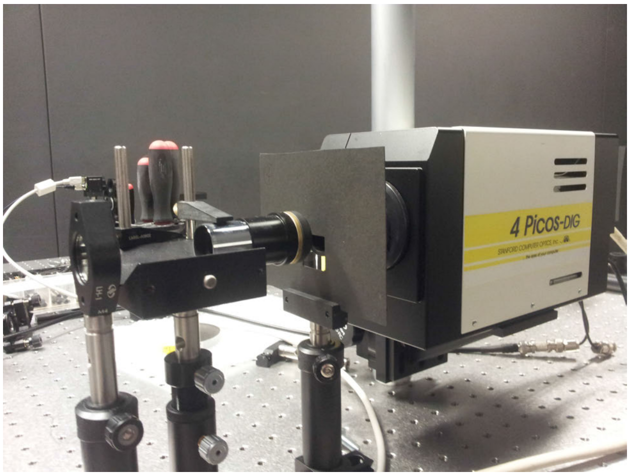

Figure 3: Intensified CCD camera for recording the coronagraph images.

METHOD AND RESULTS

To explore the sensitivity of the system a range of ICCD gain and exposure times were tested. For short exposures the beam profile can be measured with a sensitivity of about 10^{-3} with no beam block in place (See Fig. 4 and the top trace in Fig. 7).

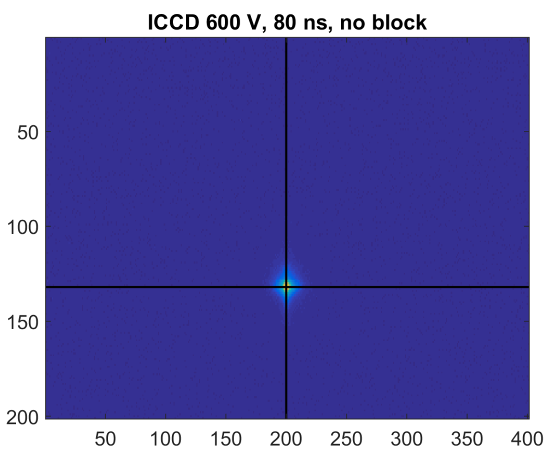

Figure 4: Image of the beam core without the beam block in place.

With the beam block in place and using different exposure times it is possible to extend the range apparently to 10^{-6}. However, when taking longer exposures where better statistics of the background can be captured, the sensitivity seems to plateau at 10^{-4}. This can be understood in terms of photon counting statistics and the background scatter. For short exposures, the background regions in the image receive very few background photons, rather the data shows the noise in the ICCD system resulting from the noise in the intensifier and the CCD readout. Only with longer exposures is it possible to get high enough statistics to get the true photon background coming from the coronagraph apparatus.

Figure 5 shows the remaining beam with the core blocked and no clear structure can be observed in the tails (See also the middle and bottom trace of Fig. 7 and 8).

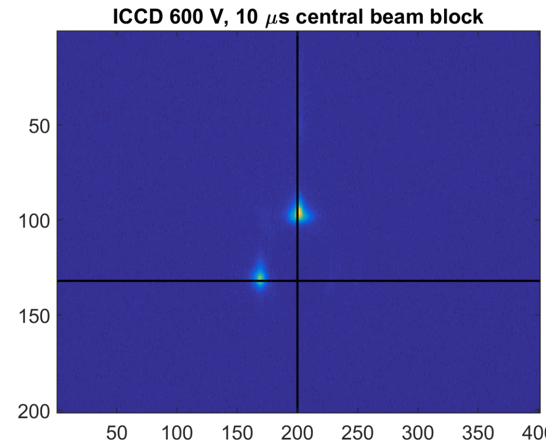

Figure 5: Image of the beam with the opaque disk blocking the core and a longer ICCD exposure time.

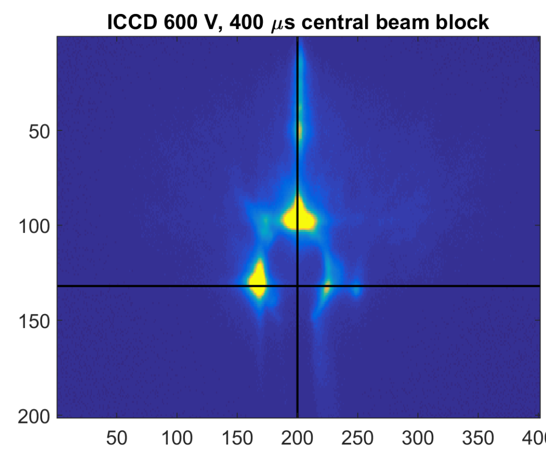

Figure 6: ICCD images taken with the coronagraph.

Description of scanning beam block position and and exposure time. Avoiding saturation and looking deeper into the beam halo by collecting more photon counting statistics.

For longer exposures the tails started to saturate before sufficient photon counting statistics could be collected, as can be seen in the bottom trace in Fig. 7 and 8. To overcome this limitation – so the sensitivity of the apparatus could be explored – the beam block was moved horizontally in steps to cover more and more of the tail and at each point a long exposure was collected. Figure 9 shows a typical image from a high gain and long exposure time.

A composite plot of the horizontal profiles made by scanning the beam block position horizontally can be seen in Fig. 10. After blocking the beam core and tails – shown by the colour traces in Fig. 10 – it is possible to set the ICCD to high gain and long exposure times without saturating the image. The black traces are an overlay of profiles as the

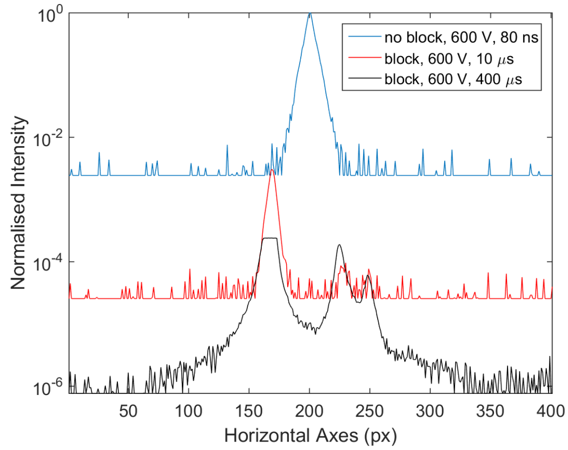

Figure 7: Composite of horizontal beam profiles from on the black lines in Figures 4–2.

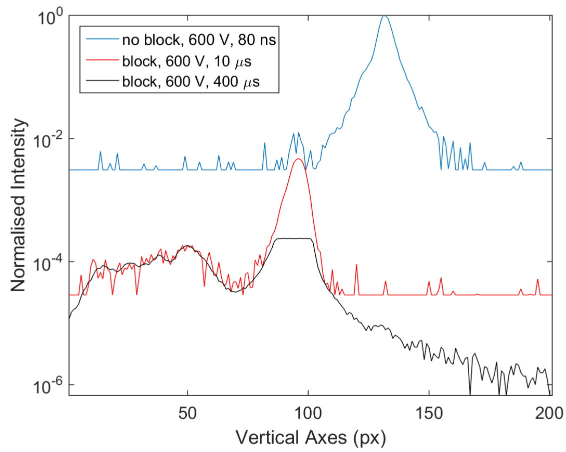

Figure 8: Composite of vertical beam profiles from on the black lines in Figures 4–2.

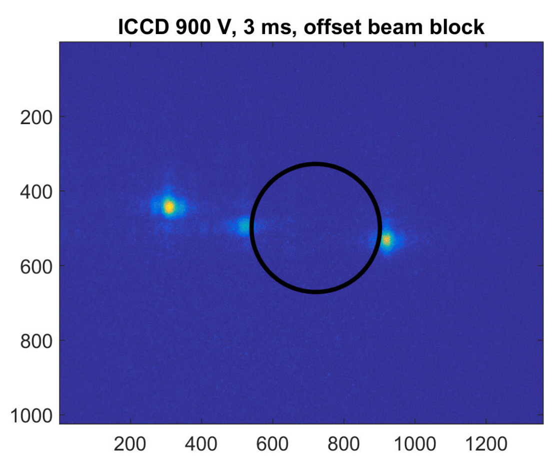

Figure 9: ICCD image for a high gain and long exposure time with a black circle indicating the offset position of the beam block.

beam block was moved and the sensitivity is seen to plateau at 10^{-4}. The lens in the coronagraph have been used on another beamline and shown to have a sensitivity of 10^{-7}, so the data was interpreted to be scatter from the SR extraction system. Most likely the extraction mirror is not smooth enough or has been damaged from long term exposure to SR beams. Since it is know to be difficult to polish the edge of mirrors, the extraction technique used on this beamline to only take the top half of the SR beam with the bottom part of a mirror is a likely cause of a high amount of scattered beam observed in the coronagraph.

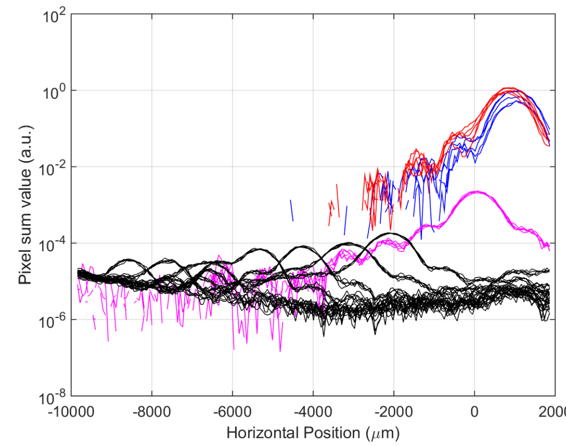

Figure 10: Composite of horizontal beam profiles while scanning the beam block position.

CONCLUSIONS AND FURTHER WORK

The coronagraph works well in principle and has been successfully used to make measurements with a sensitivity down to 10^{-4}. The existing extraction mirror is not smooth enough and introduces too much scatter to observe phenomena at the fundamental limit of the coronagraph at a sensitivity of 10^{-8}. A new mirror will be installed which consists of a solid block of Beryllium which has been polished to $\lambda/10$ quality. The new mirror will also extract the visible light over the full vertical acceptance of the beam allowing more light to be extracted and improving the quality of the beam. The beam transport pipe – which was designed for a focussed beam not a diverging beam – will also be enlarged and fitted with baffles to reduce the unwanted reflections and scattering of the light in beamline.

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