DETAILLED EXPERIENCE OF SYNCHROTRON LIGHT EXTRACTION SYSTEM WITH SLOTTED MIRROR AT THE ESRF

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Abstract

A slotted, non-cooled, mirror was implemented for the extraction of synchrotron light to feed an Infra-Red spectrometer and microscope in a new laboratory. The slot lets the energetic part of the synchrotron light go through and is kept vertically centred on the heart of the X-ray beam in a slow feed-back loop. This paper reports the experience obtained on : 1) The quality and stability of an imaged light spot that demonstrates the entire system being free of wave-front distortion and vibrations. 2) Elastic deformation study on the Aluminium mirror. 3) Mapping of edge radiation, produced by the interference of light emitted by the edges of up- and down-stream dipoles. 4) UV induced mirror blackening with dependence on the choice of the mirror material.

PRINCIPLE & OPERATION MODES

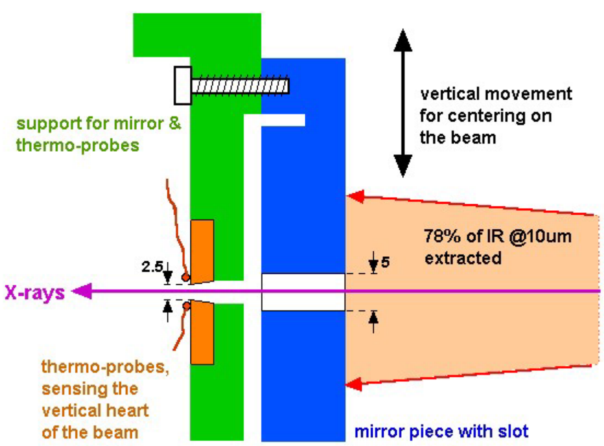

Figure 1: Slotted mirror vertically centred on photon-beam.

The concept of a slotted mirror was adopted for the extraction of InfraRed light from the cell-23 down-stream dipole for reasons of maximum flux extraction and minimum wavefront distortion to preserve the high brightness quality of the source. Although 22% of the lightflux (λ=10um) is lost through the 5mm high slot of the mirror, at 3.2m from dipole entrance, the extracted light is free of any distortion if the upper and lower parts of the mirror surface can be manufactured to good flatness (1um peak-valley) upto a negligible distance (0.1mm) from the slot-edge. The diamond milling technique employed allowed meeting these requirements on the 10mm thick single block aluminium mirror [1].

The 2nd requirement is to keep this slot centred on the photon beam heart under all circumstances and in a highly reliable way so to avoid the occurrence of the high energetic (155W/mrad hor.) X-ray beam hitting any part of the mirror surface and inflicting permanent deformation. This is achieved by thermoprobes (each made up of 3 individual thermocouples) above and below the heart of the beam. At a 1.25mm distance from the beam (at 200mA ESRF current) each probe absorbs at total of ~0.8W which results in a steady-state temperature of 70C. A slight off-centre results in a differential temperature between the upper and lower side, which is then corrected for in a software control loop that keeps the 2 readings equal within a hysteresis value of a few degrees.

Although the control loop is slow it is to be noted that the ESRF electron beam is surveyed by 2 different types of vertical beam machine interlocks. In case of either a sudden large vertical step (>0.7mm), or a fast vertically oscillating beam (amplitude >0.4mm) around a normal average position, these interlocks would cut the stored beam quickly. Therefore the control loop for the mirror does not have to provide itself for a total protection against all sorts of abnormal electron beam behaviour. Nevertheless, for an ultimate protection, a hardwired interlock is triggered directly and independently by the device if any temperature reading exceeds 100C.

The mirror assembly is also equipped with a thermoprobe at the extreme lower end so that it can be operated in a so-called 'half-mirror mode'. Furthermore the mirror can be also be totally extracted, or fully inserted so the deflect all the impinging dipole light (see fig.2). In the latter case, used only for specific studies reported here below, the thermal deformation is avoided by operation under low (<1mA) electron beam current.

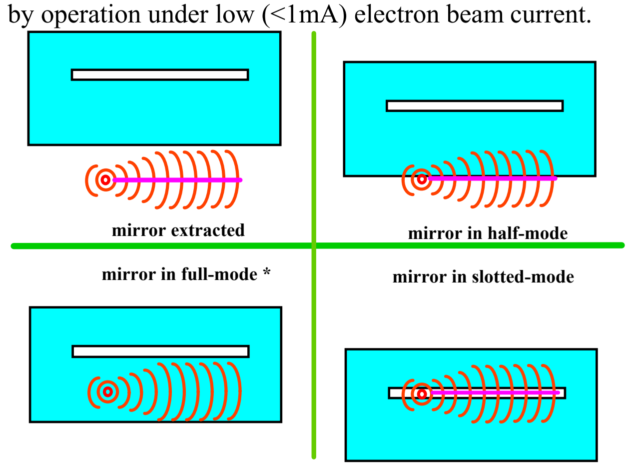

Figure 2: Mirror in 4 vertical positions & operation modes.

Note the absence of cooling to the mirror assembly so to avoid the introduction of any vibrations by a (water) cooling circuit, while allowing keeping the system light, compact and simple. The X-rays going through the slot are absorbed 2.5m downstream by a standard beamport absorber, with a 400litres Ion vacuum pump adjacent to it. There is no specific pump for the mirror assembly.

THERMAL DEFORMATION STUDIES

The complete transferline of the Infra-Red light is shown in fig.3. It shows that the light is first deflected horizontally at 90deg. (M1) after which it is directed upwards (M2) to leave the Storage Ring tunnel through the roof slabs. The emitted light cone (~10mrad, limited by 35mm optical aperture of the CVD window) is divergent up to 6.4m where it meets the first focussing element M3. It is to be noted that at the first commissioning stage (Jan.2004) of this transferline only the M1 & M2 were installed and the light, at this 6.4m distance from the source point, was simply projected (for mapping measurements reported further below) or imaged (for here reported deformation studies) with a 1.5m achromat and 400nm bandpass filter onto a CCD camera. Also a quartz window replaced the CVD window at that time.

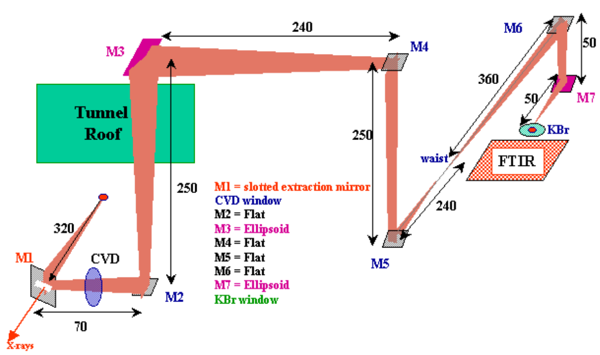

Figure 3: Schematic overview of the full transferline.

In the imaging system an aperture selected the light from the 0.4T flatfield only (P=0.37W/mrad·mA). The beam current was first limited to only 0.1mA, and images were recorded and analysed to verify that their measured dimensions in both planes agreed to the theoretical values from the electron beam and the diffraction at 400nm. Then the current was gradually increased to 5mA and the first signs of vertical beam splitting were apparent at 2mA. These disappeared completely after reducing the current to 1mA. A 2nd cycle was carried out with the beam current ramped up to 20mA : The fig.4 shows the initial image at 1mA (A), the images at 10 and 20mA (B & C), and the subsequent image after reducing again to 1mA. With this last current of 1mA the image fully retrieved its initial shape and dimensions.

The conclusion from this is that, for our 10mm thick aluminium at 45deg. incidence to the beam, the mirror surface deformation is negligible upto 86mW per mm horizontal mirror, and symmetric after that, and reversible upto at least 1.7W per mm horizontal mirror. Knowing the vertical power profile of the X-ray beam these values can also be expressed at 0.25W/mm2 and 4.9W/mm2 respectively.

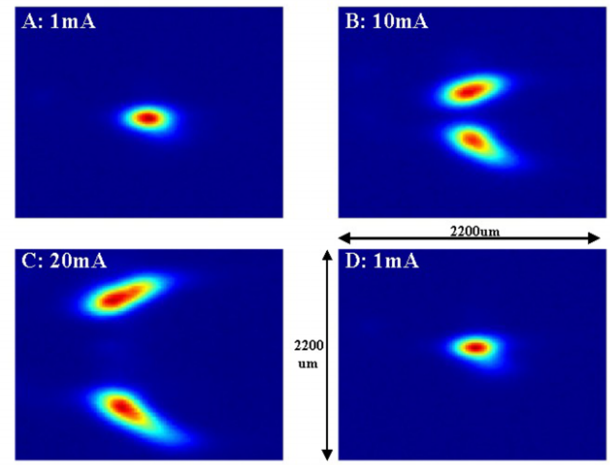

Figure 4: beam images under subsequent beam currents .

MAPPING OF EDGE RADIATION

The possibility to insert the mirror fully at low current and to directly project the undistorted light at low beam current now also allowed to 'map' precisely in both planes the angular intensity distribution. It is known that this intensity distribution around the axis of the electron beam dipole entrance is substantially different from the classical synchrotron inside the flat-field part [2]. This is because of the existence of fringe (or edge) fields at this point and the interference between the light emitted from the up- and down-stream dipoles.

The left image in fig.5 shows the measured intensity distribution as projected directly, after a 500nm bandpass filter, onto a CCD camera at 6.2m distance. The right image shows the result of the distribution calculated with the SRW code, both images have a ~13x9mm scale (HxV).

The large consistency between the measured and calculated values is also true for the full (10mrad) horizontal extracted light that shows the strong peak intensity of the edge region with respect to the flat-field region. The images in fig.6 show this projected light for 2 different colour-scales. The total image (60mm wide) was formed by assembling numerous individual CCD images recorded from the camera on a scanning translation stage.

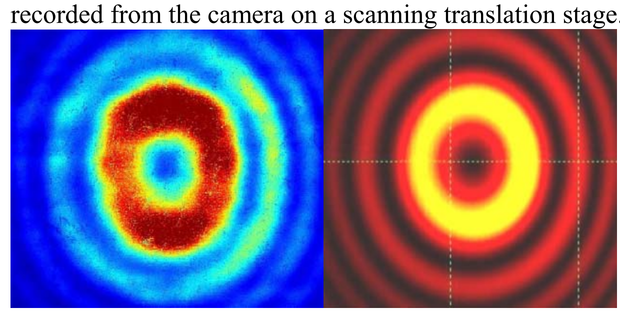

Figure 5: Images of edge radiation at 500nm wavelength : measured (left), calculated with SRW (right) .

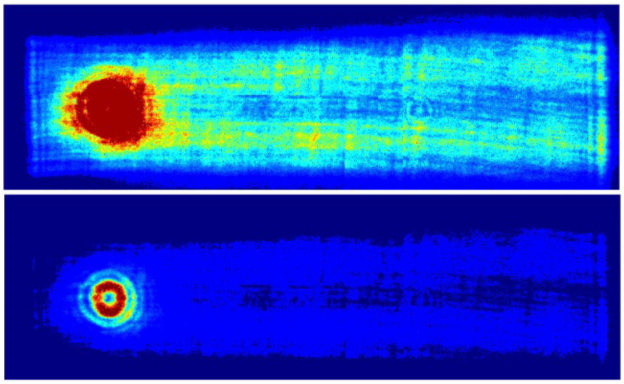

Figure 6: images of full horizontal light extraction.

BLACKENING OF MIRROR & WINDOWS

During the first months in 2004 the mirror was operated in its foreseen slotted mode. During the May shut-down, when the transferline construction was continued with the installation of M3-M6 mirrors and the installation of the CVD window, a severe blackening was observed at both the slotted mirror and on the vacuum-side of the quartz UHV window (30cm downstream the mirror) that had been utilised until then.

Both the mirror and the window have a similar pattern of this blackening with varying intensity depending on horizontal and vertical position (fig.7). The analysis of this particular pattern reveals that a certain spectral range of UV light (i.e. λ=20-200nm) is causing this phenomenon (referred to as 'Carbon-cracking') that is notably known to exist on certain type of soft X-ray synchrotron beamlines. [3]

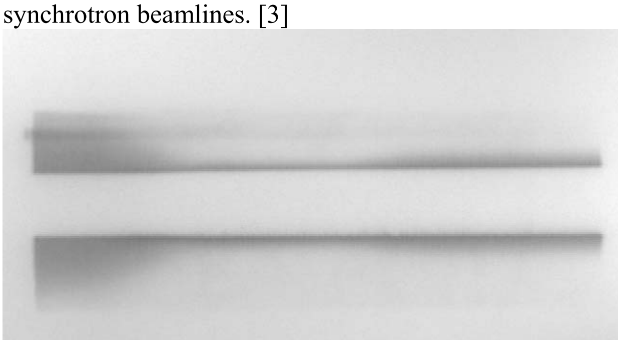

Figure 7: Blackening pattern on a quartz window.

While initially the quality of the vacuum (~4E-9mbar) was suspected it was found that another mirror (a 'half-mirror' for light extraction in cell-5 dipole for diagnostic purposes) in very similar conditions (light exposition, temperature, vacuum quality) did not show such blackening, even after many years of use. The mirror is made out of a Cu-Al alloy (Glidcop) with a nickel coating. Also the sapphire UHV window just down-stream did not show any blackening signs either.

The relative easy access to these components in the system at cell-5 have made it possible to undertake a few practical experiments here to verify if indeed the choice of material for both the mirror and the window are determinant. These experiments will be concluded in summer 2005 after having exposed a single mirror with 3 distinct zones of different coatings (aluminium, gold and nickel) to the synchrotron light. Preliminary results clearly suggest that aluminium is very prone to the blackening phenomenon while gold and nickel are not. Presently it is unknown if the CVD window is affected or not by this blackening.

CONCLUSION

The slotted mirror is now in continuous operation service since January 2004, and has not given rise to any interference with the machine operation or with the local machine vacuum quality. The concept of the slotted mirror not only avoids the mirror surface deformation from X-ray heatload, but also allows to realise a simple, compact and straightforward design that functions reliably without additional water-cooling or vacuum pumps.

The flexible way of vertical mirror positioning also allowed in the commissioning stages to measure the dipole light characteristics, to assess thermal heatload deformation to the aluminium mirror, and to verify the quality of stability and optical wavefront transmission.

The phenomenon of surface blackening on the aluminium mirror is being investigated in more depth, for determining an appropriate coating treatment.

The author expresses thanks to the many colleagues in the ESRF design office, vacuum group, computer services, diagnostic group, alignment group and operation group that have participated in the concept, design, realisation, installation and commissioning of this mirror device. Special thanks are expressed to P.Dumas, O.Chubar and F.Polack of Soleil, and J.Susini of the ID21 beamline for participation in the design elaboration of the light extraction system.

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