UV AND VISIBLE LIGHT DIAGNOSTICS FOR THE ESRF STORAGE RING

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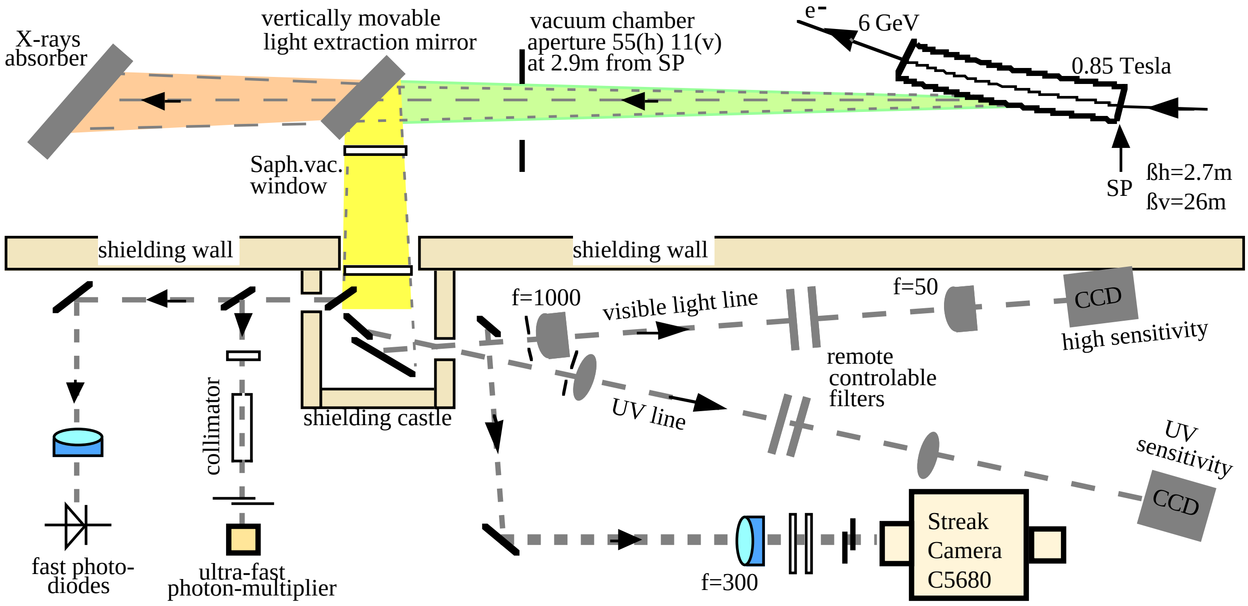

Figure: 1 overview of light source and diagnostics

ABSTRACT

A 0.85T Dipole is the light source for a number of UV & Visible light diagnostics that measure very different characteristics and parameters of the 6GeV Storage Ring. A light extraction system using a vertically movable mirror with a thermal probe in a feedback loop in order to avoid mirror surface deformation by the thermal load of the 1.5KW X-ray source is described.

A two-lens telescope is used to form an image of the transverse electron beam. Two independent and inexpensive telescopes are in permanent operation as 'beamspot' monitors to cover requirements of maximum sensitivity and maximum resolution, one operating in the visible spectrum and a second at 250nm UV light.

Bunch length measurements are performed with a 2ps resolution Streak Camera that uses synchroscan streaking at 1/4 RF and a dual time base enabling measurements on one or several bunches on a turn-by-turn basis.

A photon multiplier coupled with a photon counter system measures single bunch purity with a dynamic range $>10^6$. Position sensitive detectors detect and analyse transverse position fluctuations of the electron beam.

1 THE LIGHT SOURCE

The 6GeV electron beam emitting synchrotron light in a 0.85T dipole constitutes the light source with a critical energy of 20KeV. The UV and Visible Light spectrum that is used, 200-700nm, has a vertical opening angle of 2.3-3.5mrad (for 80% of peak flux). Horizontally the vacuum chamber aperture lets through a fan of ≈10mrad. The polarisation characteristics are typically dipolar.

The total photon flux in the 200-700nm spectral band is $\approx 4\cdot 10^{16}$ per second for a nominal ESRF Machine current of 200mA. This represents less than 30mW compared to a total emitted X-ray power of ≈1.5KW. In the so-called 1/3 filling mode the yielded photon flux is $\approx 4\cdot 10^{8}$ per bunch while in a Single Bunch filling mode there is $\approx 6\cdot 10^{9}$ per bunch.

The transverse electron beam dimensions (σ) of the source point are 102µm(hor.) and 32µm(vert.). This is for local Beta values of 2.6m (hor.) and 26m (vert.) and Machine emittances of 4nm (hor.) and 0.04nm (vert.) achieved with ≈1% coupling [1].

2 THE LIGHT EXTRACTION

2.1 The Extraction Mirror Concept

The main difficulty in extracting the UV & Visible Light from a powerful X-ray synchrotron light source is avoiding surface deformation to the extraction mirror caused by the energetic heart of the light beam. In the past an extraction mirror of Beryllium with a limited thickness (for minimum heatload absorption) was unsuccesful. Any design aiming at total light extraction with a mirror fully inserted in the X-ray beam would make the mirror surface suffer from expansion in the vertical centre so that only a small fraction of the light flux can be extracted with a reasonably small wavefront distortion.

The position of the extraction mirror being ≈3.2 m from the source point means that the vertical dimensions of the light fan are ≈10mm. The new concept of the extraction mirror is illustrated in figure 2. It aims at extracting the 'top part' of this light fan with a mirror piece, the edge of which would remain just above the energetic X-ray heart of the beam. A thermal probe with three thermocouples is positioned behind and ≈300µm lower than this mirror and senses the heart of the beam.

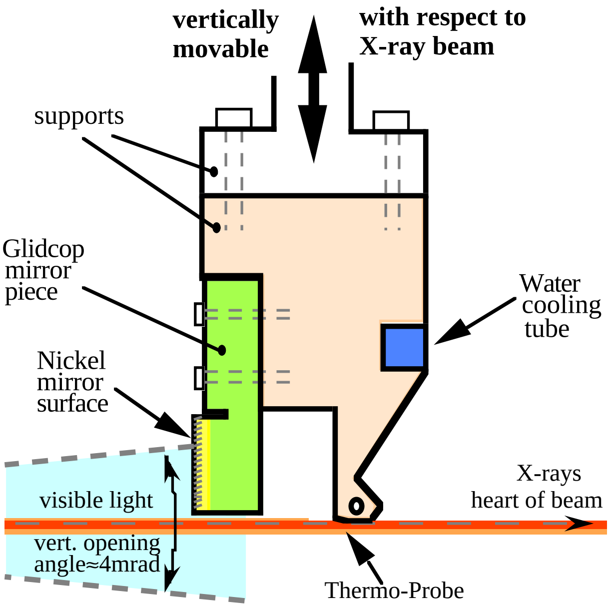

Figure: 2 Concept of the 'partial' Light Extraction Mirror

The whole assembly is movable in vacuum by the application of a vacuum chamber with bellows and vertical motorisation. A simple software loop provides the feed-back which controls the vertical position of the mirror in order to keep the temperature of the thermal probe at ≈55°C. In this way the mirror piece itself is kept as close as possible to the heart of the beam without absorbing more than ≈1W of beam power. It is ≈0.5mm above the heart of the beam which means that ≈45% of the available light flux is extracted.

The time response of the loop is ≈100ms which is sufficient to react to slow, vertical, electron beam orbit drifts or to beam injection. A hardwired Machine Interlock ensures that at temperatures ≥70°C the electron beam is instantly cut in order to guarantee a fail-safe protection of the mirror in the exceptional case of very unstable beam.

2.2 The Mirror Piece

The mirror piece itself is made of Glidcop with a Nickel surface deposit. The above explained concept can only work satisfactorily if the flatness characteristics of the mirror surface are respected right up to the edge of the mirror. An adapted but relatively simple polishing technique allows to attain flatness specifications within 100nm up to less than 100µm from the edge.

2.3 Transmission into the Optics Lab

The light is deflected at 90° and leaves the vacuum environment through a 1mm thick Sapphire window. It enters into a 3.5m long tube under atmospheric conditions but with a UV quartz glass window at the end in order to avoid air turbulence in the tube. The tube goes through a 1m thick concrete SR tunnel shielding wall. A shielding castle contains three different mirrors which deflect the light to the various systems on two optical tables (2.2m^2 and 1.5m^2), on either side as shown in figure 1. Permanent access and work is possible in this air conditioned optics lab. Its dark room alone covers ≈30m^2 with an additional 90m^2 of working space. In this lab the closest point from the source is about 8m.

The optical materials chosen are compatible with the high radiation dose from the SR tunnel whilst stable mechanical supports for the above components avoid any vibrations.

3 THE BEAM SPOT MONITORS

3.1 General Description

The purpose of this diagnostic is to yield a permanent 'life' image with high contrast and quality of the transverse beam to the operation crew and to estimate the beam dimensions in both planes with maximum precision. The beam dimensions at ≈100µm or less, the closest distance of access of ≈8m and the light emission angles between 1-10mrad, have determined the choice for a two lens telescope to form an image on a CCD camera.

A first lens of f=1m (de-magnification ≈7) is followed by a second lens of f=50mm (magnification ≈10) and provides an image of convenient size on a standard size CCD matrix of 6.4 X 4.8mm. The total length of such a telescope is less than 2 meters. It also contains neutral density and bandpass filters which can be remotely controlled so that the operation crew can easily adjust to changing SR beam currents.

The CCIR video output is fed to two different image treatment systems. One of these systems performs precise calculations with optional image manipulations and data storage, and the other provides a 25Hz 'life' high contrast image to a 22" RGB screen in the control room.

The calibration of the transverse magnification of this imaging system is needed to obtain measurements of absolute dimensions. This is done in a very efficient, simple and inexpensive way by using individual tranverse µ-metric slides for each of the three components (2 lenses + CCD camera). Displacing each of these components a precise value in one plane represents a transverse source point displacement of the same value (but of the opposite sign) and a displacement of the beam spot on the CCD matrix of that value multiplied by the total-magnification.

The above description is common to two independent beam spot monitors that are operational. A visible light beam spot monitor can work at different wavelengths (400-700nm) and bandwidths (10-200nm) and uses two achromats and a CCD camera with a good sensitivity (not cooled or intensified). This covers usage with SR beam currents as low as 100µA during specific Machine Physics studies.

A UV beam spot monitor uses two UV-graded fused Silica lenses and an inexpensive CCD camera with the glass protection window removed from its chip. The sensitivity at the used wavelength of 250nm (15nm bandwidth) is sufficient to function at all nominal SR beam currents. The UV spot monitor provides a better resolution in the measurement of the transverse dimensions as is described below.

3.2 Diffraction Limited Resolution

The resolution is quasi-entirely limited by the diffraction effect. All other effects like wavefront distortion by the imperfect optical components, depth of field and curvature effects of the dipole source, mechanical vibrations or air turbulences have been analysed, been resolved or found to be negligible.

The vertical beam dimensions of the source point have been significantly reduced from 130 to 32µm (σ) by the Machine lattice evolution (from 7 to 4nm emittance) and reduction in hor.-vert. coupling from 10% to ≈1%. Consequently, even with the UV system at 250nm this value is no longer approachable as diffraction accounts already for nearly 100µm (σ). An X-ray pinhole camera performs the routine emittance measurements of the ESRF Machine with sufficient precision [2].

Despite these limitations the beamspot monitors constitute a primary diagnostic for operation with the advantage of permanent availability and high reliability.

4 THE STREAK CAMERA

Part of the extracted light is fed to a Streak Camera which has performed a large number of bunch length measurements and is used with great flexibility in the observation and analysis of longitudinal instabilities. [3] This Hamamatsu C5680 device is fully integrated into the ESRF's computer network and a dedicated application program provides complete remote control and powerful image treatment from the control room.

The vertical (fast) streak deflection is synchronised to the RF of the machine by the use of a synchroscan module at 88MHz. An additional horizontal time base permits to stock many streaks of one or several bunches on a turn-by-turn basis in one single image. An internal MCP intensifier permits pure single shot measurements at Machine currents below 100µA. This MCP is gateable (70ns) with a few MHz repetition frequency and a specially developped programmable gating pulse generator enhances the scope and flexibilty of its use. This generator, the dual time base, CCD read-out camera and video digitizer are all synchronised to the orbit frequency so that stable 'life' video images are produced at 8Hz.

The ESRF bunch length is measured with very reproducible results between 45 and 150ps for bunch intensities from 0 to 10mA. In special Machine physics studies with 1 or 2GeV beam energy, low (+&-) alpha lattices or beam injection conditions, the streak camera yields precise information on the longitudinal characteristics and behaviour of the electron beam. [4]

5 BUNCH PURITY MEASUREMENT AND FUTURE DEVELOPMENTS

The Single Bunch purity measurement uses a photon counting method with an ultra-fast photo-multiplier (PM) coupled to a multi-channel analyser (MCA). Its output result is the ratio of bunch population between two neighbouring bunches (2.8ns distance). [5]

A collimator and filters reduce the light flux to a single photon (per ≈10turns ≈30µs) that is detected by the PM with the MCA measuring the time-interval between detection and an RF reference clock. After a few minutes measurement time a dynamic range of 10^6 is attained. This diagnostic is in permanent operation with full remote control and read-out.

Rapid transverse beam displacements cannot be analysed with the slow beam spot monitors. Fast position sensitive detectors have been employed to measure these position fluctuations on a few 100Hz frequency scale with amplitudes as small as 10% of transverse beam dimensions. Faster movements can be detected and, by adapted optics and ultra-fast photo-diodes, such systems are under development for future operational use.

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