Developments in the Diamond Storage Ring

N P Hammond, J Kay, G Rehm
Diamond Light Source Ltd, Harwell Science & Innovation Campus
Didcot, Oxfordshire OX11 0DE - UK

Abstract

The Diamond Synchrotron has been operational since January 2007. A review of the Storage Ring Electron Beam Position monitoring system and the design of the Visible Light Extraction Diagnostic are presented, together with development work associated with the Extraction of Infra Red Radiation.

1. Introduction

The 72 storage ring girders were assembled, tested, and installed from March 2005 to March 2006. The Diamond synchrotron has 24 achromat sections or cells, each cell comprising of 3 girders containing the magnetic elements and a corresponding straight section for insertion devices. The Electron Beam Position Monitors were all included in the storage ring girder build. The inclusion of a beamline which will utilise the infra-red portion of the synchrotron light will require a new design for the dipole and crotch vacuum vessels; this represents the first major modification to the storage ring girder assemblies since its installation.

2. Electron Beam Position Monitoring System

Each of the 24 identical achromat sections which make up the complete storage ring each contain five secondary Electron Beam Position Monitors (EBPM's) and 2 Primary Electron Beam Position Monitors (PEBPM's). The 5 EBPM's are incorporated into the main vacuum vessels, adjacent to anchor points of the vacuum vessels and generally feed back to the beam orbit correction system. The PEBPM's are located at the beginning and end of the achromat sections, and are supported separately from the magnet support girders; they are isolated mechanically from adjacent components by metal bellows. Linear transducers monitor any movement of the EBPM's with respect to the adjacent magnet. Linear transducers also monitor the movement of the PEBPM's with respect to the tunnel floor, which is achieved by mounting the transducers on top of carbon composite stands which have a near zero expansion coefficient. The PEBPM themselves are mounted on steel stands. This system allows any physical movement of the monitoring buttons to be discounted as electron beam movement. An example of the EBPM system is illustrated in figure 1left, the PEBPM system is illustrated in figure 1 right.

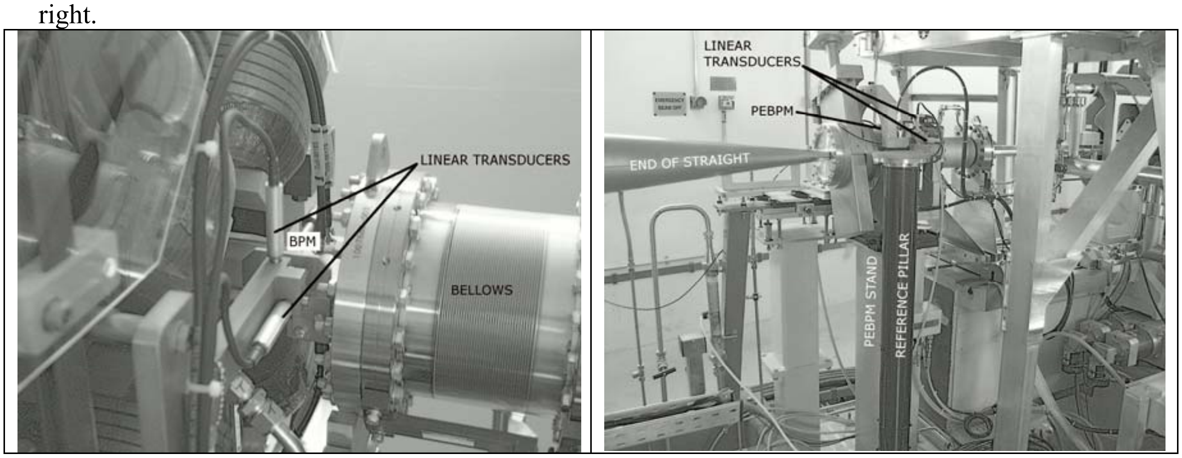

Figure 1 left, typical BPM; right, typical PBPM

From these two arrangements it would be reasonable to conclude that EBPM's would physically move with variations in beam current, whereas PEBPM's would only move with variations in the tunnel air temperature. A surprising result was therefore the observation that the PEBPM's were moving with varying beam current to a greater extent that the EBPM's as illustrated in figure 2 below, and horizontally more so than vertically.

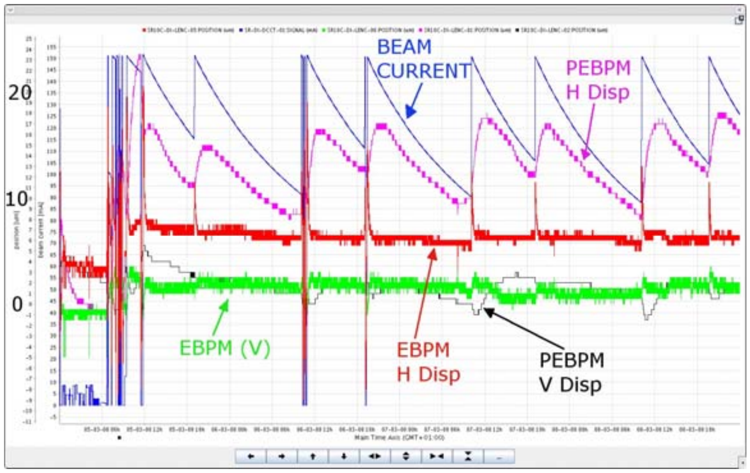

Figure 2 Beam Position Monitor displacements compared with beam current. Displacement in microns indicated in larger font on y axis. Without cooling

Temperature sensors indicated that the displacements (6-7μm horizontally) were due to temperature increases of up to 50 degrees centigrade (the beam trip value) of the BPM blocks. The likely cause of this is due to RF heating of the BPM buttons. The mechanical isolation of the BPM blocks by bellows also provides a poor heat conduction path, which further promotes the temperature rises. From the temporal evolution of the button block temperature, the total heating power has been estimated to be around 13W (for a set of four buttons) at the nominal operating current of 300mA. So this effect is not a displacement of the block, but a measurement of its thermal expansion. In order to mitigate this effect a series of air amplifiers [1] were positioned adjacent to the PEBPM buttons with their flow directed towards the buttons as shown in figure 3 below. With a flow of 10l/sec from the 6 bar line these devices generate about 100l/s by dragging in large amounts of ambient air, which is enough to significantly reduce the heating.

Figure 3 Position of an air amplifier adjacent to PBPM buttons

After fitting these devices the horizontal displacements of the PBPM buttons reduces to 3μm. It is worth noting that the intermediate EBPM's which are in good contact with water cooled vessels experience an initial displacement during each beam injection, where an initial displacement of 10μm during storage ring injection soon reduces back to the nominal position.

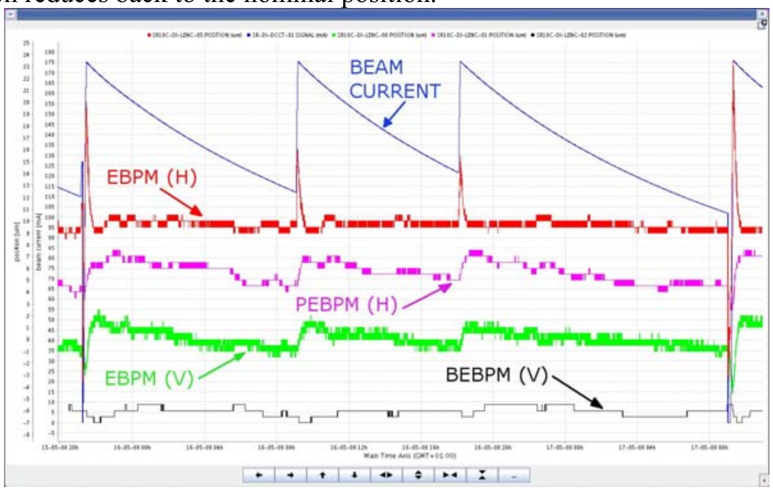

Figure 4 Beam Position Monitor displacements compared with beam current. Displacement in microns indicated in larger font on y axis, after the addition of cooling.

The effects will not be present after Diamond switches to top up operation mode.

3. Visible Light Extraction Mechanism

The system is located in cell 1 of the storage ring, immediately downstream from the injection straight. The light is reflected towards the outside of the storage ring through a high quality fused silica window via an in-vacuum mirror. Once outside the vacuum the beam of light is further reflected downwards, then at low level the beam exits the storage ring via a conveniently located cable labyrinth, usually used for conveying cables between the beamline and front end. This is illustrated in figure 5 below.

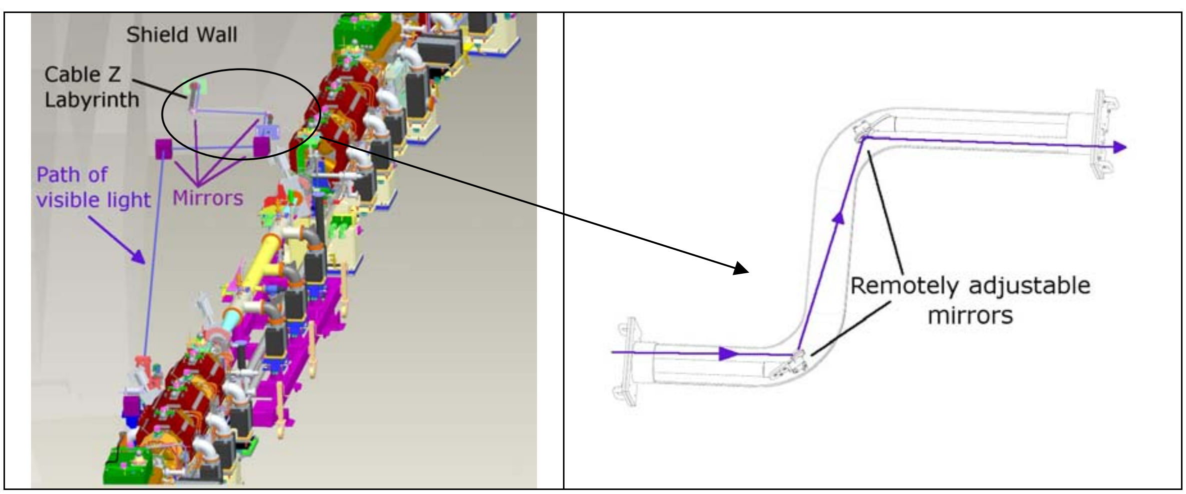

Figure 5 Beam path of visible light extraction diagnostic (left), path through cable labyrinth (right)

The overall aim of this design was to keep the design of the in-vacuum mirror as simple as possible. No active cooling was employed, and the adjustment method of mirror was to have the bare minimum degrees of freedom.

The first mirror is located at the end of the beam extraction leg of the crotch vessel just in front of the beam port absorber, which in this position has been modified to include an X-ray window for a different

diagnostic system. Figure 6 below shows the assembly in isolation from adjacent equipment. Internally there is a plane mirror which turns the visible light through 90 degrees. 'A' is the visible light extraction window, 'B' is the vacuum isolating valve, and 'C' is the actuating mechanism. By retracting the mirror and closing the valve the mirror system may be removed if necessary. 'E' is the beam port absorber, which is present on all crotch legs not yet fitted with a Front End. 'D' is a thin air-cooled aluminium window for X-ray extraction for use by another system. 'F' is the supporting structure mounted on the adjacent storage ring girder.
The principles of function are the same as many similar systems with a nickel coated mirror on an OFHC copper substrate. This mirror is lowered into the beam, manually but remotely, until a significant temperature increase is registered. It is then retracted slightly and remains at that position, above the highest powered portion of the synchrotron light and reflects only the relatively low power portion of the emerging visible light. The temperature is interlocked so that a beam trip will occur if the mirror lower edge exceeds 50°C. This light is reflected through a right angle and emerges from the vacuum via a fused silica window as shown in figure 6 below. The light is then conveyed out through the storage ring shield wall, via further mirrors to various experiments such as a streak camera and a time resolved photon counting system for fill pattern measurement located in the Experimental Hall.

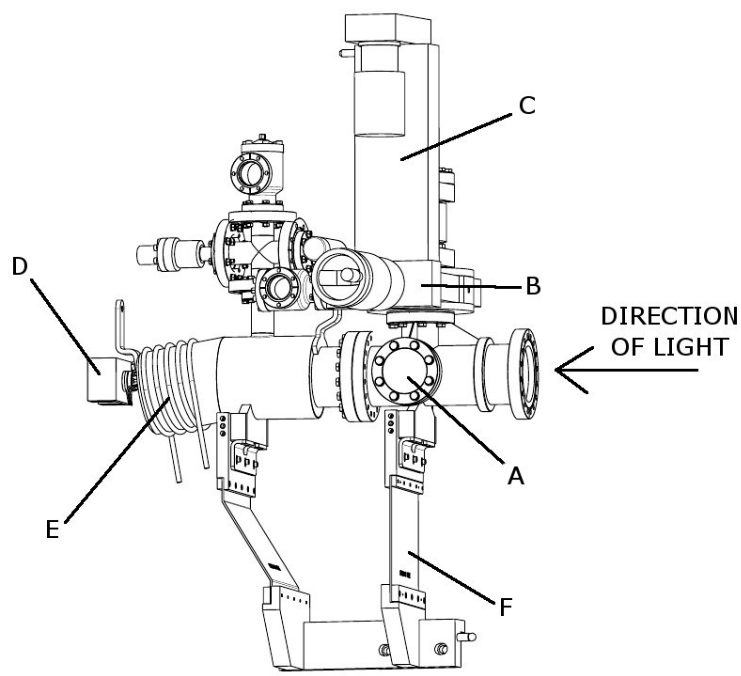

Figure 6 The arrangement of the first mirror assembly at the end of the x-ray leg of the crotch vessel.

Figure 7 overleaf shows details of the internal mirror. 'A' is the mirror, 'B' is the mirror mounting plate, 'C' is the support arm from the actuator, 'D' are the two mirror adjusting screws, 'E' are copper strips, and 'F' are the two thermocouples.

The right angle through which the extracted light is turned only needs to be approximate, therefore no adjustment was necessary, and the only adjustment required was the tilt in the vertical plane. This was achieved via two screws, 'D' in figure 7, in the back of the mirror mount, the fulcrum being located at E. This adjustment was carried out on a bench prior to installation using a representative mounting flange and reflecting laser light onto a target.

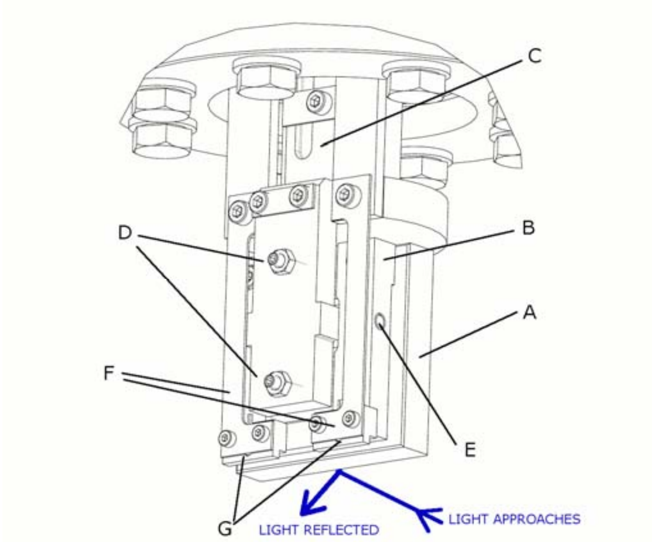

Figure .7 Details of the in vacuum mirror of the Visible Light Extraction Diagnostic

The temperature measurement at the lower 'leading' edge of the mirror is obtained from two thermocouples 'G', this measurement is used by the actuating mechanism to prevent the mirror dipping into the high energy portion of the light. Two copper strips 'F' are used to conduct heat away from the thermocouples, so that sufficient temperature differential may occur to enable the system to detect that sufficient mirror withdrawal has occurred.

4. Infra Red Light Extraction

Normally at dipole 2 the exit aperture is restricted to 21.6mrad (h) and 10mrad (v). In order to extract the infra red part of the synchrotron light, a much bigger aperture of 50mrad (h) and 30mrad (v) is required, the portion of horizontal beam required is -10mrad to +40mrad (h) and ±15mrad (v), which therefore includes both edge light and bending light. Two options to be considered early on in the design were whether to extract the light immediately at the crotch absorber, or whether to allow an increased beam port leg of the crotch vessel to extend through the downstream magnetic elements into the front end region.

The advantages of upstream extraction are that the overall aperture is smaller, and the light can be directed upwards and over the top of the downstream storage ring components towards the shield wall. The advantages of downstream extraction are that the heat load on the mirror is less critical therefore the mirror will not need active cooling, any vibration of the optical components will be less significant, and the surface tolerances of the mirror are less stringent.

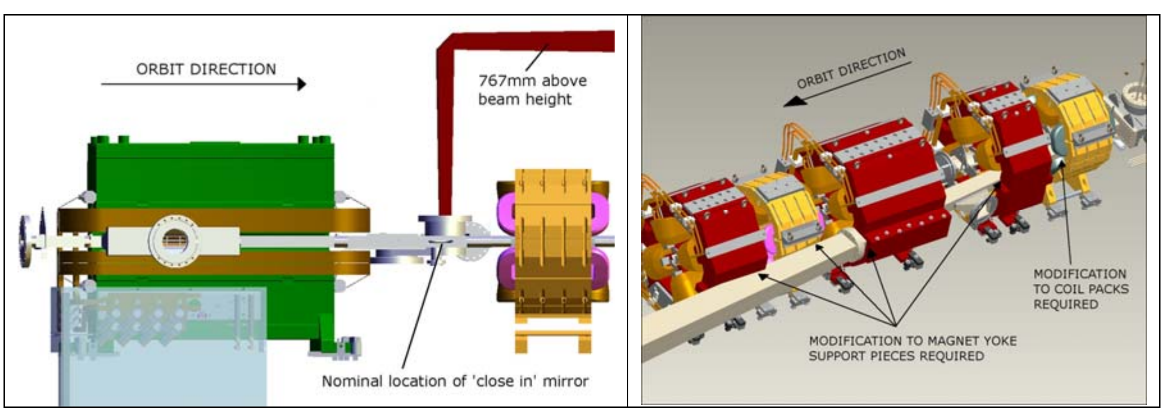

Figure 8 The two optional methods of IR light extraction 'close in', and 'far out'

The first optical element that faces the direct SR has to withstand the heat load coming from white beam irradiation. In order to avoid vibration issues from fluid pumps, it is desirable to have no cooling for the 1st IR mirror. In practice by removing the central fan containing more intense light, excessive mirror heating can be avoided whilst still guaranteeing collection of the wider IR light. The UHV and radiation resistance requirements for the front end favour a metal substrate for the 1st mirror; copper or aluminium alloy have good thermal and mechanical properties, but aluminium alloy is preferred for its lightness. Two possible solutions were considered to avoid mirror heating by x-rays, namely a water-cooled horizontal pipe masking the front of the first mirror (the "cold-finger" solution) or providing a horizontally slot at the centre of the mirror to allow the more intense portion of the fan to pass through and be absorbed behind the mirror. The drawbacks of having a 'cold finger' in front of the mirror are vibrations arising from the active cooling, and that the absorber itself (estimated temperature of 110°C) could re-radiate onto the mirror, therefore the slotted mirror option was chosen. Experience at other light sources has indicated that an un-cooled centrally slotted mirror can be used successfully [3]. The extracted IR beam can be focussed to a waist size sufficiently small to exit the storage ring through the conveniently located survey port.

The beamline will be dedicated to Micro-Spectroscopy in the mid-IR domain (λ = 2 to 25μm), but will deliver useful photon flux also in the far-IR region thanks to a uniquely wide Front End. In fact the 30mrad vertical opening guarantees a spectral extension up to the THz region (1 THz/300μm) from day one, while the 50mrad horizontal aperture allows using both bending and edge radiation from the same bending magnet source to feed two independent end stations on the same beamline.

Modifications of the storage ring dipole and crotch vessels and the magnets downstream of the second dipole were necessary in order to extract the necessary fan from the IR source. New dipole and crotch vessels are being manufactured, which includes a specific absorber for the beamline in the X-ray leg of the crotch vessel, a component usually incorporated into the Front End. The slit absorbers present in the existing dipole vessels, which limit the vertical aperture to 10mrad, have been completely removed from the new vessel. The interference between the exit beam and the slit absorbers is illustrated in figure 9 below.

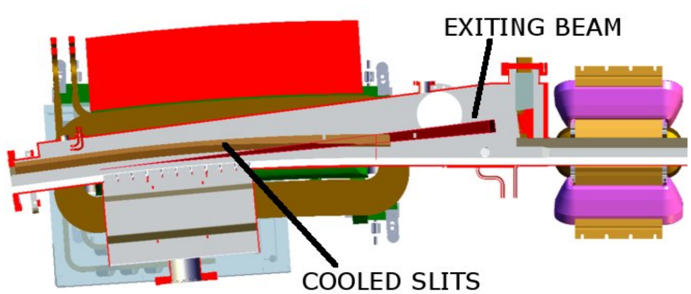

Figure 9 Beam exit fan shown in relation to the dipole vessel slit absorbers

The magnet modifications are underway using spare magnets from the original deliveries. Briefly, two sextupole and three quadrupole magnets require modification to allow the larger vacuum vessel aperture to pass through or next to them. Only one magnet requires new reconfigured coils, the others require modified (non-magnetic) yoke support pieces, but no magnetic yokes or performances are compromised.

5. References

[1] KAVAC, Vacuum Pumps for Air Amplification. Parker Hannifin Ltd, Milton Keynes, UK

[2] B22 IR micro-spectroscopy beamline; Conceptual Design, DLS internal report BLS-B22-REP-0005.