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CONCEPTUAL DESIGN OF THE DIAMOND-II VACUUM SYSTEM

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Abstract

The conceptual design of the vacuum system for the Diamond-II storage ring upgrade is described. Due to the small vessel cross section, typically 20 mm inside diameter (ID), and the consequent conductance limitation, distributed pumping is provided by non-evaporable getter (NEG) coating supplemented by ion pumps at high gas load locations. *In-situ* bakeout is incorporated to allow rapid recovery from both planned vacuum interventions and unplanned vacuum events. The vacuum vessels are constructed mainly from copper alloy while stainless steel is used in regions of AC magnets requiring low electrical conductivity. The proposed layout, engineering and build sequence of the vacuum system are described along with gas flow simulations confirming the vacuum performance advantages of NEG-coated vessels compared with uncoated vessels.

INTRODUCTION

Diamond-II is a proposed in-place upgrade to the 562 m circumference Diamond Light Source storage ring [1] aimed at increasing both the photon beam brightness and the number of insertion device beamlines which can be accommodated. A modified 6BA 24-cell lattice is foreseen with 18 standards straights, 6 long straights and 24 new mid-achromat straights. The general layout of one cell is shown in Fig. 1.

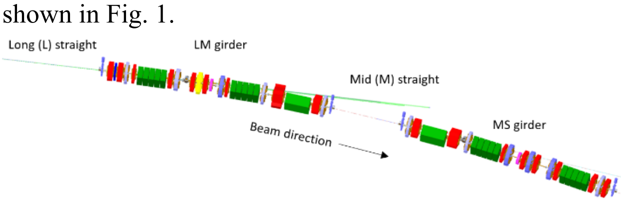

Figure 1: General layout of one cell showing the 2 straights and 2 girders.

The vacuum performance target is to achieve a pressure of 10^{-9} mbar or lower with 300 mA stored beam after 100 A.h of beam conditioning, which is expected to produce a gas lifetime in excess 10 h.

The vacuum system also has to be compatible with machine impedance, beam stay clear and applied magnetic fields and must allow for extraction of useful photon beams while handling the synchrotron radiation (SR) heat loads. It must be reliable in operation, with a comprehensive control and monitoring system and interlock protection.

KEY FEATURES

For simplicity, a circular vacuum vessel with 20 mm internal diameter and 1 mm wall thickness is preferred where possible. This allows a nominal 1 mm clearance all the way round for an *in-situ* bakeout system within the typical magnet inscribed diameter of 24 mm. In some areas the vessel has to be widened out to a "keyhole" or "ante-chamber" section for photon beam extraction and/or to handle the SR heat load.

A 20 mm ID vessel is strongly conductance limited, and there is little space between the lattice magnets for discrete pumps, hence distributed pumping is needed to avoid large pressure "bumps". The distributed pumping is provided by a non-evaporable getter (NEG) coating inside the vessels, an established technology for accelerators, e.g. [2, 3, 4]. Discrete sputter ion pumps are fitted in areas of high gas load (near high intensity photon absorbers) to boost the local pumping speed, to reduce NEG coating saturation effects and to pump inert gases and methane.

VACUUM SIMULATIONS

Vacuum simulations were carried out using geometric ray tracing followed by the Diamond in-house 1-dimensional "Pressure Profile" code [5] for three different wall materials: Uncoated stainless-steel/copper, Fully-activated NEG coating and Saturated NEG coating (taken to have the same outgassing properties as fully activated NEG coating but zero pumping speed). Four different gases were used (H_2, CH_4, CO and CO_2) and the Z^2-weighted sum of the partial pressures was calculated to produce the CO-equivalent pressure which is relevant to beam lifetime [6].

As the vacuum vessel layout has not yet been finalised, the simplest geometry with a 20 mm ID circular cross-section vessel centred on the electron beam axis with no photon extraction was used. Only dipole radiation was included with no insertion devices. Material properties were taken from published sources [7, 8] and from practical operating experience at Diamond.

Figure 2 shows the photon flux emitted from the 6 dipole magnets in one cell (cell 5) and the received flux at the vacuum vessel wall downstream of each magnet.

Figure 3 shows the calculated CO-equivalent pressure with and without stored beam.

Figure 4 shows the calculated mean CO-equivalent pressure along the whole cell with 300 mA stored beam for a range of beam conditioning doses.

For the uncoated vessel, the target pressure of 10^{-9} mbar is still not achieved even after a beam conditioning dose of 10,000 A.h which corresponds to more than 7 years' operation with 5000 h operation per year at 300 mA. Clearly this falls far short of the target vacuum performance to achieve this pressure after only 100 A.h or less.

For the fully-activated NEG coating the target pressure is achieved after only 6 A.h beam conditioning and even for the saturated NEG coating the target pressure is

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achieved after only 50 A.h beam conditioning. These both meet the target vacuum performance.

These predictions are likely to be rather optimistic as the assumption is 100% coverage of NEG coating and both scattering and re-emission of synchrotron radiation from the walls are neglected. Nevertheless, the vastly superior performance of the NEG coated vessels compared with the non-NEG-coated vessels is clearly shown.

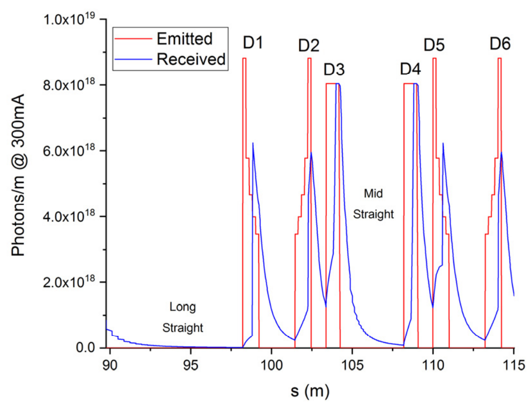

Figure 2: Photon flux emitted from dipole magnets and incident on vessel wall *vs* distance along cell 5.

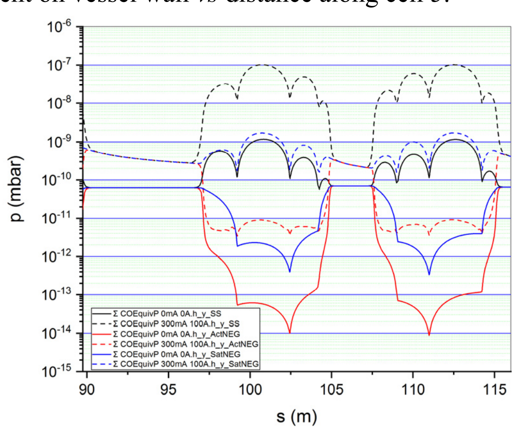

Figure 3: CO-equivalent pressure *vs* distance in cell 5 for 3 different wall materials with and without stored beam. SS=uncoated stainless-steel/copper, ActNEG = activated NEG coating, SatNEG = saturated NEG coating.

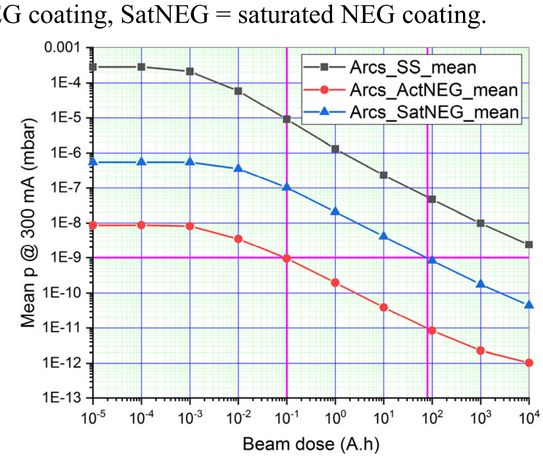

Figure 4: Mean CO-equivalent pressure in cell 5 *vs* beam conditioning dose for 3 different wall materials.

ENGINEERING

The proposed geometry of the Diamond-II vessels is very similar to the Double-Double-Bend Achromat (DDBA) upgrade which was installed in one cell at Diamond in 2016 [9].

The main differences are the slightly smaller cross-section of 20 mm ID for Diamond-II compared with 27 × 18 mm internal size elliptical tube for DDBA. The vessels in DDBA were not NEG coated which was deemed an acceptable compromise on vacuum performance for a single cell but not for a whole machine as in Diamond-II. In addition the beam energy is being increased from 3 GeV on Diamond/DDBA to 3.5 GeV on Diamond-II which provides somewhat higher heat loads. Hence many of the construction methods, materials and components for DDBA are expected to be applicable to Diamond-II.

As in DDBA, a mixture of vessel materials is proposed for Diamond-II. Copper alloy is the default material due to its favourable combination of mechanical and thermal properties and ease of fabrication. Stainless-steel is used in areas of AC magnets where low electrical conductivity is needed. Aluminium is also of interest in some areas due to its ease of fabrication but it does have the disadvantage of a higher thermal expansion coefficient, and thus more expansion during bakeout, and like copper it is incompatible with AC magnets. CuCrZr alloy is proposed for discrete photon absorbers as it can have a CF flange knife edge machined directly into the material thus avoiding a brazed joint. Additive manufacturing is a rapidly developing technology and could also be of interest in some areas.

Figure 5 shows a concept, based on DDBA, for the crotch region where the photon beams are extracted.

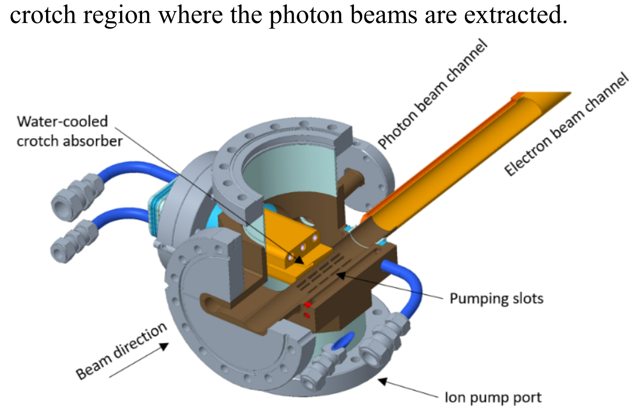

Figure 5: Concept for crotch area where photon beams are extracted to the front ends and beamlines.

Designs for other components such as RF-shielded bellows, flanges and beam position monitors are currently being reviewed and evaluated. Figure 6 shows one candidate design for the Diamond-II RF shielded bellows and BPM station based on the DDBA design.

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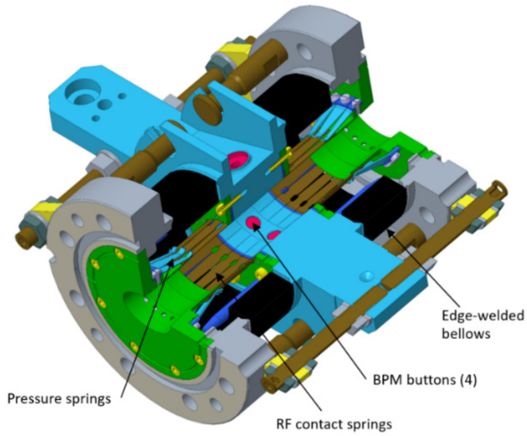

Figure 6: Candidate RF bellows and BPM station design for Diamond-II based on the DDBA design.

An *in-situ* bakeout system based on thin film polyimide heaters and a PLC-controller was developed for DDBA (see Fig. 7) and it is planned to further develop this for Diamond-II. Particular attention will need to be paid to radiation tolerance of the heaters as this will be a permanently installed system.

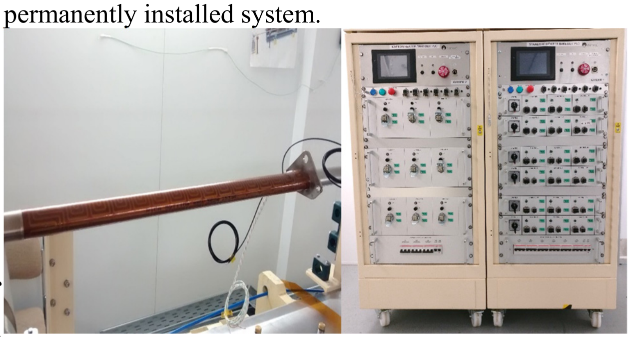
Figure 7: Composite picture showing (left) DDBA vessel wrapped with polyimide bakeout heater and (right) PLC-based bakeout controller developed for DDBA.

CONTROLS AND INTERLOCKS

Each storage ring cell is divided into 4 vacuum sections using commercially-available pneumatically-actuated RF-shielded gate valves. Each vacuum section contains at least 2 total pressure gauge sets (cold cathode and Pirani gauge pair) and at least one residual gas analyser (RGA) or at least a port where a diagnostic RGA can be connected without venting the vacuum section. Temperature sensors are fitted to the vacuum system at key points to check for excessive RF or SR heating.

All the instrumentation is connected to the standard EPICS control, monitoring and archive system. A separate PLC-based machine protection system monitors for excessive temperatures or deterioration of vacuum and takes appropriate action to protect the machine hardware.

BUILD SEQUENCE

In the current mechanical design, each cell is built on 2 girders and each girder is conveniently isolated by 3 gate valves (connecting to the previous and next straights and to a front end). Therefore it is possible to mount and interconnect all the vacuum vessels on a girder and bake and activate the NEG coating in a separate location in advance of the installation. The entire girder and vacuum string can be installed in its final location without venting and without needing a further bakeout or NEG activation. *In-situ* bakeout is installed on each girder and could be used if required to recover from an unplanned vacuum event. In case of a planned intervention, high purity neon venting could remove the need to reactivate the NEG coating [10].

NEXT STEPS

The next step is to finalise the lattice and vacuum system layout including pumping, heat load management and photon beam extraction and to carry out more detailed 3-dimensional vacuum simulations to verify the vacuum and thermal performance of the design.

Studies to confirm the NEG coating effect on the machine impedance plus trials of the NEG coating process are needed to verify that all the different vessel geometries can be coated consistently and reliably.

Future work will also cover detailed design and prototyping of vessels, RF-flanges, RF-shielded bellows, BPM stations and bakeout system.

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