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THE DESIGN OF A 2 m LONG COPPER LIGHT EXTRACTION VESSEL AT DIAMOND LIGHT SOURCE FOR THE DIAMOND-II UPGRADE

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Abstract

The design of a 2 m long light extraction copper vacuum vessel for Diamond-II (D-II) storage ring upgrade in Diamond Light Source (DLS) is described. Initially, an aluminium vessel with two discrete copper absorbers was considered, further studies have shown the concept was not capable of handling high heat loads making the aluminium vessel arrangement an unworkable solution. Therefore, it was decided to change the design concept from an aluminium vessel to a copper vessel. The main difference between two concepts is that the copper vessel has integrated absorbing surfaces instead of discrete absorbers. Due to the change, it was possible not only to reduce the power densities of the absorbing surfaces, but also it allows placing active cooling directly on the high heat loaded areas. These two factors contributed to a significant reduction of the peak temperatures. Synchrotron light raytracing, thermal analysis, vacuum performance, beam impedance, prototyping and next steps of the new copper vessel are also covered in this paper.

INTRODUCTION

The D-II Storage ring vacuum system comprises 48 arcs and 48 straights [1]. There are 4 main types of arc girder vessel strings: MS, SM, ML and LM girder vessel strings. The above-mentioned copper vessel is located on the upstream end of the LM girder vessel string, vessel 2 shown in Fig. 1. There are 6 LM Girders in the whole storage ring, which means 6 LM vessel 2 are required for various light extractions. The vessel is designed in a way that it covers all 6 cases, hence no special vessels are required. The most challenging case is the LM girder vessel 2 for I05 light extraction.

Figure 1: Diamond II LM girder vessel string.

The main challenges associated with the design of this vessel at that particular location are, firstly, the heat loads of I05 beamline upgrade involving the installation of a powerful and highly divergent APPLE-knot quasi-periodic (QP) insertion device (ID) [2]. Second aspect is the requirement of a homogeneous NEG (non-evaporable getter) coating on the complex internal geometry of the vessel. Detailed FEA analysis shows the peak temperature is reduced from 446°C to 71°C for the copper vessel as compared to the aluminium vessel discrete absorbers. The change from an aluminium vessel to a copper vessel will not only reduce the peak temperatures, thereby making it a workable solution according to DLS FEA criteria [3], but has the added benefits of improved vacuum performance, reduced beam impedance, reduced capital and operating cost, as well as reduced manufacturing risks due to splitting of vessels into three separate sub-vessels.

DESIGN AND PROTOTYPING

Figure 2 shows the design of both aluminium (a) and copper (b) versions of LM girder vessel 2. Many features of the original aluminium vessel design have been reused on the copper vessel, particularly regions of multipole magnets, downstream pumping, and crotch absorber section etc. Key differences between two vessel designs are listed in the Table 1. The copper vessel is comprised of 3 separate sub-vessels: vessel 2_a, _b, and _c, where vessel 2_b is the highest heat loaded section.

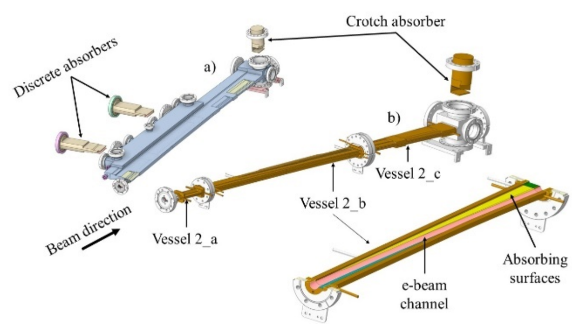

Figure 2: LM girder vessel 2 design versions: a) aluminium and b) copper.

Table 1: Design Differences Between Al. and Cu Vessels

Features	Al. Vessel	Cu Vessel
Antechamber	yes	no
Discrete absorbers	yes	no
Bimetallic flanges	yes	no
Int. Absorbing surfaces	no	yes
Water cooled	no	yes
NEG coated	no	yes
Manufacturing method	welded	brazed

There are two sets of beam position monitor (BPM) buttons at the entry and exit flanges. Vessel 2_a upstream flexible flange allows movements of +2 mm extension, -5 mm compression, and ±0.25 mm of lateral offsets. The design constraints are different for each sub-vessel (e.g. available space, power load etc.), and these factors are dictating the design of both internal and external geometries. Figure 3

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highlights cross-sectional views and the aperture dimensions in several critical locations of the vessel. The minimum height of the vessel was limited to 6 mm due to the NEG coating limitations. The prototype NEG coating experiments will prove whether the 6 mm aperture can be reduced up to 5 mm or not. Minimum wall thickness of the copper vessels is 1 mm, in a very localised areas, around multipole magnets regions. This approach has already been taken in other light sources [4].

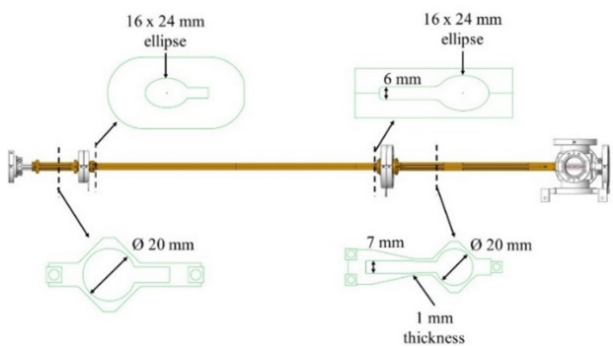

Figure 3: LM girder vessel 2 internal apertures.

The prototyping phase is divided into two directions: NEG trials and full prototype vessel manufacturing (NEG coated). It was decided to test the NEG coating on the trial assembly, firstly to ensure that the coating requirements on such a complex geometry is achievable, and secondly to define the minimum height of the vessel. NEG coating trials and full prototype vessel manufacturing is currently in progress.

RAYTRACING AND FEA

The long and wide shape of the copper vacuum vessel offers a much larger surface area for photon absorption than discrete absorbers and gives the possibility of placing cooling channels closer to the region of highest heat load. Figure 4 illustrates the simulation method.

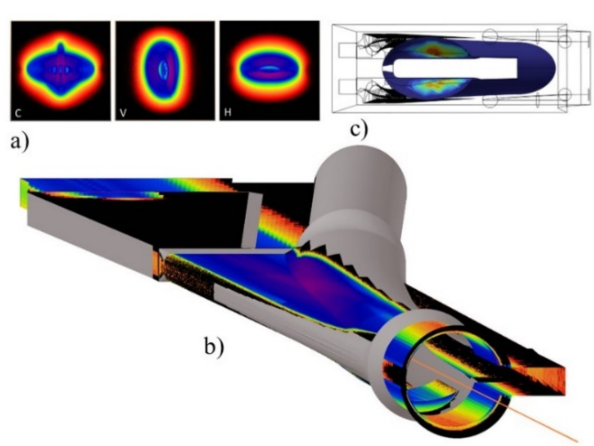

Figure 4: Simulation procedure: a) I05 APPLE-knot QP normal incident power density, polarisation in 3 modes (Synrad), b) Ray tracing onto the walls of the vacuum vessel, circular mode (Synrad), c) Projected wall power density in ANSYS.

First, Synrad is used to illuminate the vessel walls for each of the three modes (horizontal, vertical, and circular) of the APPLE-knot Quasi-periodic ID with a period of 140 mm and 10 eV minimum electron energy. The heat load is then mapped onto a FEA model and a conjugate heat transfer analysis is performed in COMSOL using turbulent flow in the cooling channels on the upper and lower sides of the vessel shown in Fig. 5. Several design iterations have been performed and the maximum vessel wall temperature for the circular mode is 71° for a total heat load of 7 kW and peak (absorbed) wall power density of 4 W/mm^2. Figure 6 shows maximum displacements and stresses due to atmospheric pressure loading of copper vessel around the thin-walled regions. Maximum 21 µm deflection and 16 MPa Von Mises stress was predicted in static structural FEA analysis.

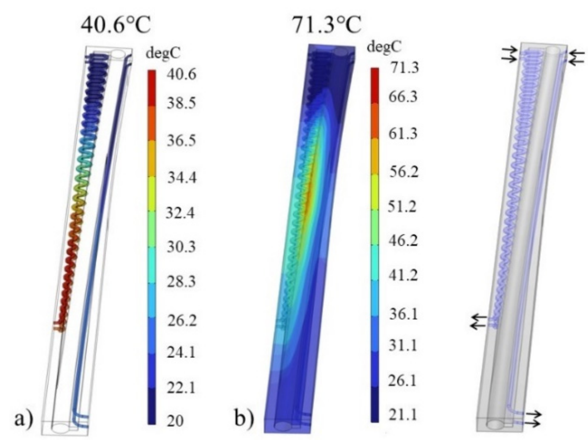

Figure 5: COMSOL simulations a) coolant temperature and b) vessel body temperature.

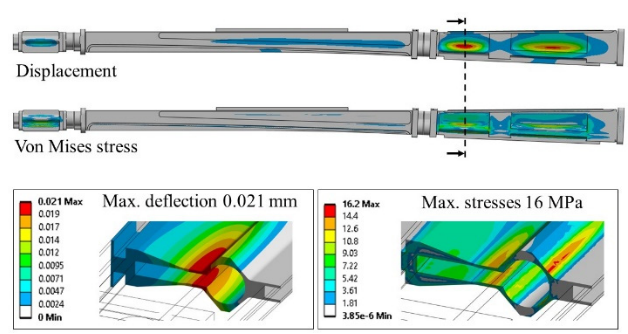

Figure 6: Maximum displacements and stresses of the copper vessel due to atmospheric pressure loading.

VACUUM SIMULATIONS

Monte-Carlo dynamic simulations were carried out for the two vessel designs using Synrad and Molflow [5]. Firstly, Synrad was used to model the synchrotron radiation photons incident on the vessel wall including reflections. Molflow was then used to calculate the pressure distribution along the electron beam path, taking into account photon stimulated desorption. This was carried out for the 4 main residual gases (CO, H_2, CO_2 and CH_4) and for a range of beam conditioning doses in Ampere.hours. Figure 7 shows the calculated pressure *vs.* distance curve along the

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entire machine cell. The pressure in LM vessel 2, between z = 400 and z = 600 cm along the electron beam path, is reduced from 10^{-8} mbar to 10^{-10} mbar after 100 A.h with an electron beam current of 300 mA. This compares with the design target of average pressure 10^{-9} mbar or lower under these conditions. This illustrates the beneficial reduction in pressure for the NEG-coated copper vessel compared with the uncoated Aluminium vessel.

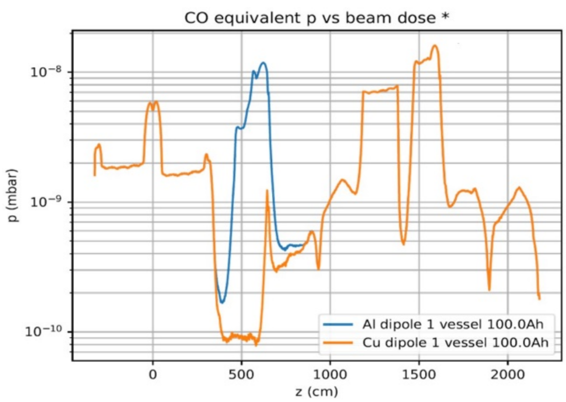

Figure 7: Calculated pressure vs. distance curve along the entire machine cell.

BEAM IMPEDANCE SIMULATIONS

Wakefields and impedance were calculated for the two vessel designs using CST Studio [6]. A bunch length of 1 mm and wake length of 300 mm were used for the simulations. A comparison of the real transverse and longitudinal impedances are shown in Fig. 8. The copper vessel has significantly reduced impedance, especially at low frequencies in both transverse planes. This is especially important in the horizontal, where the aluminium design for this vessel was one of the most significant contributors to the total storage ring impedance. A summary of loss and kick factors for the two designs is shown in Table 2. The horizontal kick factor is reduced by nearly a factor of 60 for the copper design. Reduction in the other planes is smaller, but still significant.

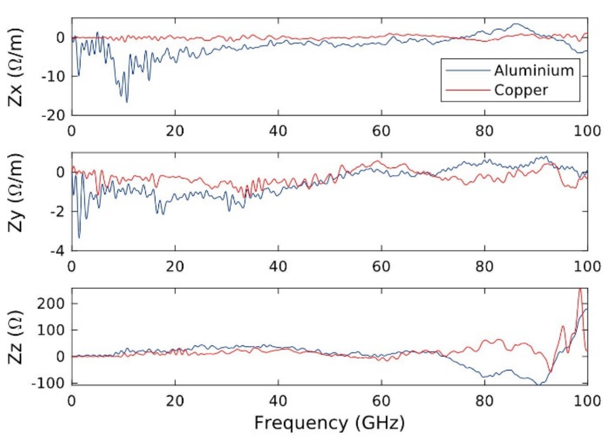

Figure 8: Comparison of real impedance for aluminium and copper vessel designs.

Table 2: Transverse Kick and Longitudinal Loss Factors Comparison for Two Designs

	kx V/pC/mm	ky V/pC/mm	kz V/pC
Aluminium	-0.1206	-0.0284	0.2378
Copper	-0.0021	-0.0063	0.0778

CONCLUSION

A workable solution of LM girder vessel 2 was developed for Diamond II storage ring, which is capable of handling the heat load of a new APPLE-knot insertion device. Peak temperatures of the copper vessel have been reduced from 446°C to 71°C compared to the previous concept. The beam impedance and average vacuum pressure around vessel 2 was significantly improved. NEG coating trails and the full prototyping vessel manufacturing has already been commenced. The intention is to implement the light extraction copper vacuum vessel of the LM girder onto the remaining MS, SM and ML girder designs. The intention is to implement the same concept of the copper vessel onto the MS, SM and ML girder designs.

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