Thermal and Deformation Analyses of the New 2.4 T Multipole Wiggler Vacuum Vessel at Siam Photon Source

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Abstract:

In order to meet the increasing user demands for hard x-ray synchrotron radiation, especially from those in the fields of macromolecular crystallography, x-ray imaging, and micro tomography, Siam Photon Source (SPS) plans to install a high-field multipole wiggler (MPW) in its 1.2 GeV electron storage ring. The MPW will be lent to SPS by ASTeC, Daresbury Laboratory, UK. The commissioning of the MPW is planned for 2013. In this report the thermal and deformation analyses of the new MPW beam vessel utilizing the Finite Element Method (FEM) is presented. Pressure distribution, thermal heating, and structural deformation induced by gravity are studied and discussed. Finally, design considerations for the physical aperture of the vessel are also explored and elaborated.

Keywords: Multipole wiggler, Siam Photon Source

1- Introduction

Recently an upgrade project funding for the installation of a new insertion device into the 1.2 GeV SPS storage ring for the production of hard x-rays was provided. The MPW, which will be lent by Daresbury Laboratory, UK, is expected to produce the required high flux.

The MPW was originally designed and manufactured by ASTeC and the Technology Department for the SRS in 2002 to produce the high magnetic field for a permanent magnet-based 2.4 T MPW with an operating gap of 20 mm [1].

The vacuum vessel design for the MPW needs to compromise between the requirements of the magnetic highest possible peak field (which demands a small gap) and the vertical aperture of the storage ring at its location [2-3]. The vertical aperture has been assessed for good injection efficiency. The vertical betatron value can be calculated by the equation of the betatron function in a straight section without focusing elements, while the vertical betatron value is ~3.2 m at the center of the long straight section (LSS). The minimum vertical aperture is determined by the physical aperture at the downstream-end of the vacuum vessel [4], which has a distance of 1.83 m from the center of the LSS (fig. 1). The corresponding vertical betatron value of 4.246 m at this location is the largest in the vacuum vessel for the MPW.

The acceptance of the SPS in the vertical direction is given by the maximum betatron function of ~19 m at the quadrupole magnet Q1 and the inner vertical size of the vacuum vessel (36 mm in full width), because it is constant around the storage ring [4]. The calculated value for vertical aperture, which is consistent with the vertical acceptance of the storage ring, is ~17 mm.

The internal vertical size of the vacuum vessel for the MPW is 18 mm, which is slightly larger than the vertical acceptance of the storage ring (17 mm). The inner horizontal dimension of the MPW is ± 53 mm, so that both vertical and horizontal acceptance of the storage ring are not reduced by the vacuum vessel for the MPW.

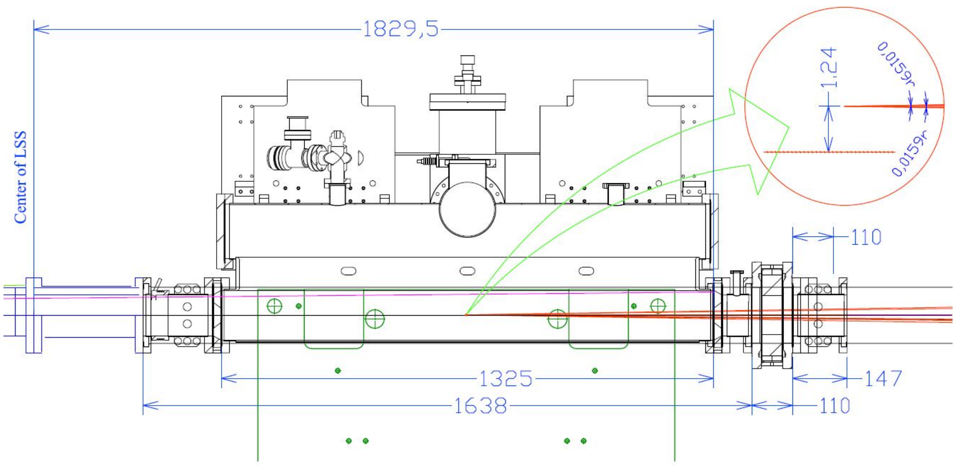

Figure 1: Detail drawing of the vacuum vessel for the MPW (Unit: mm)

2- Design

For the mechanical design of the MPW vacuum vessel a beam current of 150 mA was considered. The wiggler emits SR within a horizontal fan of ± 15.93 mrad and is used for the operating gap of 23 mm. The synchrotron light from the bending magnet, which is located in front of the vacuum vessel, will be blocked completely by the existing heat absorber (no internal heat load). However, the high temperatures during the baking process have to be considered. The system details are shown in figure 1.

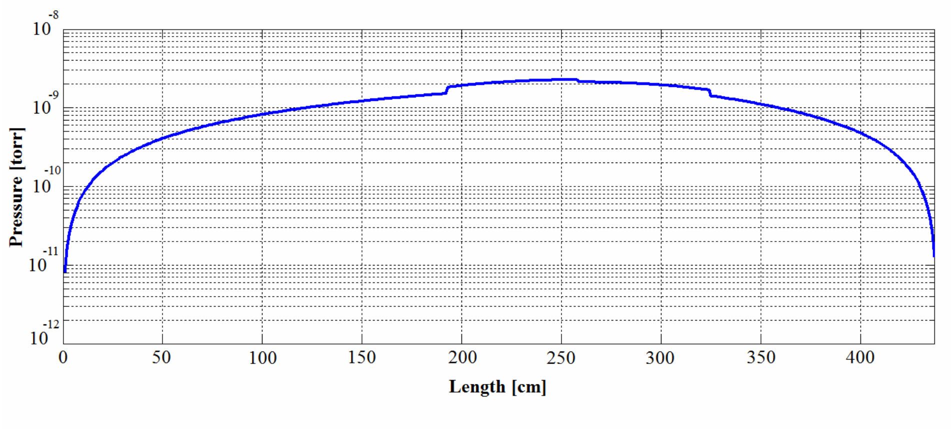

Figure 2: Pressure distribution along the LSS for the MPW

In order to assess UHV pressure in the storage ring after the installation of the MPW, the pressure distribution along the straight section has been performed by adopting the calculation of engineering formulae for the vacuum system [5]. Figure 2 shows that the maximum calculated pressure is ~1.5×10^{-9} Torr, which is slightly higher than the existing pressure in the storage ring. For an acceptable UHV pressure inside the storage ring, the vacuum design of the MPW vacuum vessel needs to provide an additional ion pump (500 l/s) on the lateral side of the vacuum vessel (fig. 3).

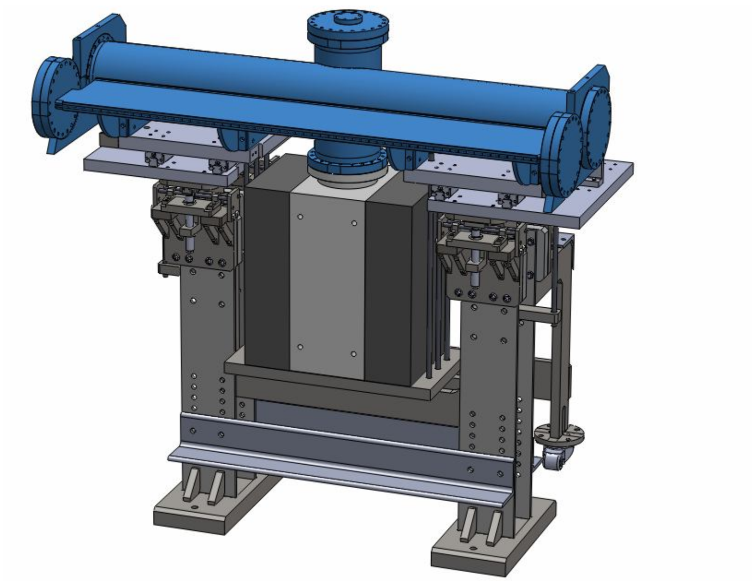

Figure 3: Vacuum vessel for the MPW and its support

For the vacuum vessel the material stainless steel 316L was selected, due to its high mechanical strength (as shown in Table 1) and low magnetic permeability (μ < 1.01 H/m) [6].

Table 1. Material properties of stainless steel 316L.

Density (kg/m^3)	7990
Ultimate tensile strength (MPa)	558
Yield strength (0.2% YS, MPa)	290
Modulus of elasticity (GPa)	193
Specific heat capacity(J/g-°C)	0.5
Thermal conductivity(W/m-K)	16.2
Thermal expansion coefficient (μm/m-°C)	16
Magnetic permeability (H/m)	<1.01

The vacuum vessel consists of a top and a bottom shell with the minimum wall thickness of 2 mm in the vertical direction. The exterior vertical size of the vacuum vessel is about 22 mm as shown in figure 4.

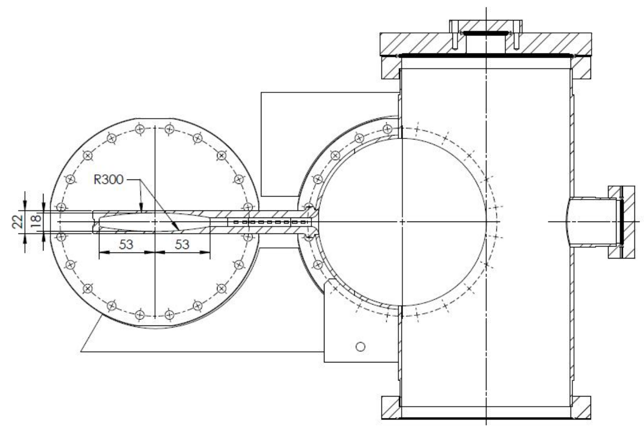

Figure 4: Cross section of the vacuum vessel for the MPW

3-The Finite Element Analysis

The Finite Element Analysis (FEA) was performed by the commercial program SolidWorks Simulation. The baking temperature was assumed to be constant of 120 °C on the external surface and 115 °C for the internal surface of the vacuum vessel. The atmospheric pressure was applied on the external surface of the vacuum vessel. The effect of gravity was also considered for this simulation. Due to the vessel has two planes of symmetry, a one quarter model could be used for the simulation.

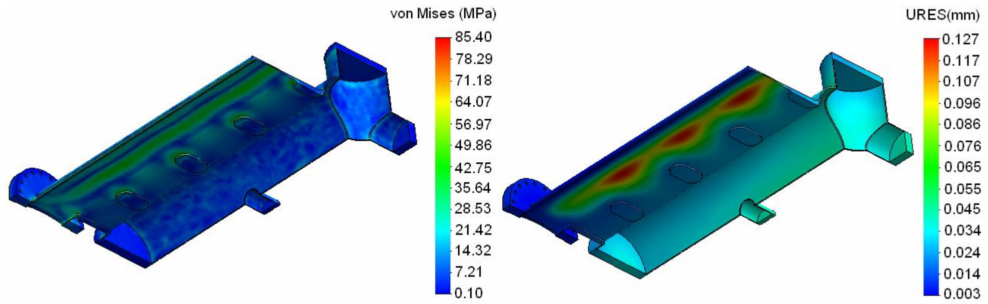

Figure 5: Stress and Deformation contour plot on a one quarter model

The maximum Von Mises stress due to the atmospheric pressure and the thermal load from the baking process and the effect of the gravity was simulated to be 85.4 MPa, while the maximum deformation on the model was simulated to be 0.127 mm as shown in figure 5.

The yield strength of SUS 316L is given with 290 MPa. For the simulated Von Mises stress of 85.4 MPa, which corresponds to a safety factor of ~ 3.4, no temperature damages are expected.

4-Conclusion

The vacuum vessel of the 2.4 T MPW of the Siam Photon Source has been designed for a minimum operating gap of 23 mm. The exterior vertical size of the vacuum vessel is 22 mm. For an acceptable UHV pressure in the storage ring, the vacuum design of the vacuum vessel has to provide an additional ion pump (500 l/s) on the lateral side. The influence of the thermal load from high temperatures during the baking process, the pressure difference, and the self weight of the vacuum vessel are numerically simulated. The vertical and horizontal acceptance of the storage ring will not be reduced by the vacuum vessel for the MPW.

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