

VACUUM SYSTEM DESIGN FOR THE MAX IV 3 GeV RING

E. Al-Dmour, D. Einfeld, J. Pasquaud, M. Quispe,
CELLS, ALBA Synchrotron, Cerdanyola del Vallès, Spain.
J. Ahlbäck, P. Fernandes Tavares, M. Grabski, MAX-lab, Lund, Sweden.

Abstract

We describe the conceptual design of the vacuum system of the 3 GeV electron storage ring in the MAX IV facility currently under construction in Lund, Sweden. The standard vacuum chambers are for the most part a cylindrical copper tube with 11 mm inner radius whereas stainless steel will be used at selected locations for beam position monitors, bellows and corrector vacuum chambers. In order to cope with the low vacuum conductance, distributed pumping will be provided through NEG coating of all chambers, including those in dipole magnets making MAX IV the first storage ring to be fully NEG coated. We present the mechanical and thermal design of these chambers and discuss the challenges involved in extracting insertion device radiation as well as coping with the heat load from both IDs and bending magnets in a machine with large bending radius, narrow chambers and tight mechanical tolerance requirements.

INTRODUCTION

The MAX IV synchrotron radiation (SR) facility is currently being constructed in Lund, Sweden. It consists of a 3 GeV Linac injector and 2 storage rings operating at 1.5 and 3 GeV respectively [1].

The lattice of the 3 GeV ring is based on compact multi-bend achromat (MBA) lattice and has a nominal horizontal emittance below 0.3 nm.rad. [2].

The storage ring has a circumference of 528 m and consists of 20 achromats, each achromat consists of 5 unit cells (with 3° bending magnet) and 2 matching cells (with 1.5° bending magnet) and each of the unit and the matching cells will be manufactured from one iron block. Additionally, the achromat contains two (total 40) short straight sections (Shortstr) which will be devoted for RF cavities, diagnostics, absorbers (to pass SR to the front ends), injection...etc; the total length of each achromat is 26.4 m. Moreover, long straight sections (Longstr) of 5 m are located between each achromat (see Figure 1).

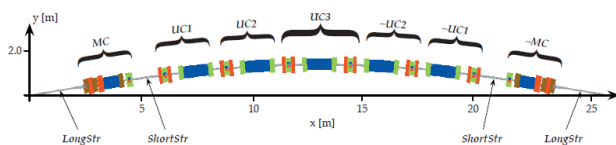


Figure 1: Schematic of one achromat of Max IV 3 GeV storage ring, magnets: dipoles (blue), quadrupoles (red), sextupoles (green) and octupole (brown).

THE STORAGE RING VACUUM SYSTEM

Collaboration has been established in the summer of 2010 between Maxlab and CELLS to design the vacuum system of the MAX IV machine. This includes: the mechanical design, finite element analysis (FEA), call for tender drawings and documents...etc.

Main Design Considerations

The storage ring vacuum is following the achromat sections, in the sense that it is divided into 20 vacuum sections. The vacuum chambers layout will follow the definition of the matching cells and the unit cells within the achromat; therefore, each achromat consists of 9 vacuum chambers followed by the long straight vacuum chamber.

The design of the vacuum system of MAX IV has constrains which have been imposed by the lattice design and the machine requirements.

One of the main challenges of the vacuum system design of MAX IV is that the magnets have small apertures (25 mm), as a result, the vacuum chamber within the magnets is of circular profile with an inside diameter of 22 mm, the thickness of the tubes is 1 mm.

The combination of the dense lattice and the small aperture of the vacuum chambers, impose that it is not possible to go into conventional lumped pumping, as a result, NEG coating is going to be used all over the storage ring, not only for the straight parts of the chambers but also for the bent parts. The NEG coating has been implemented in other SR facilities, but not to the same extent as in the case of the 3 GeV ring of MAX IV. The complication of coating of bent tubes and having chambers which are made of different materials is adding more challenges, not only for the vacuum system design but also the manufacturing.

The other issue which has an impact on the vacuum system design is the handling of the SR; the vacuum chambers will be made of OFHC copper tube and cooling circuits will be welded to the chamber to remove the heat load from the radiation generated by the bending magnets.

For the purpose of fast correction; some parts of the chambers (where the corrector magnets are located) need to be made of stainless steel.

Welded bellows are installed on each side of the majority of the vacuum chambers, those bellows will reduce the stresses due to the thermal power, reduce the vacuum chambers deformation and also the deformation of the BPM which are located between each vacuum chamber.

The vacuum chambers will be connected to each other using modified Conflat® (CF) flanges, wherein the gap

facing the e-beam is small; this will give a small contribution to the impedance budget of the machine.

The Design of the Vacuum Chambers.

Within the achromat, the chambers start and finish at the location of the BPM. Due to this, there are 9 vacuum chambers in the achromat and one dummy vacuum chamber between each achromat. The chambers (from design point of view), can be divided into three main types, which are presented as follow:

VC-1: this is the first chamber in the achromat, and needs to handle the SR coming from the insertion devices (ID) and pass it to the following chamber. The chamber begins with a welded bellows with RF fingers and a stainless steel tube which is inside the corrector magnets, and then a copper tube of 22 mm with a bend of 1.5° for the dipole. The main part of the chamber is the copper absorber which has an antechamber to allow the SR to pass. The chamber ends with a stainless steel part welded to the BPM block (see Figure 2).

The OFHC copper absorber needs to handle up to 6 kW of power coming from the ID installed in the straight. In order to handle this power, 3 cooling circuits are implemented in the design. The antechamber shape changes gradually allowing the radiation to be absorbed in stages and by the end shadow the following parts of the chamber.

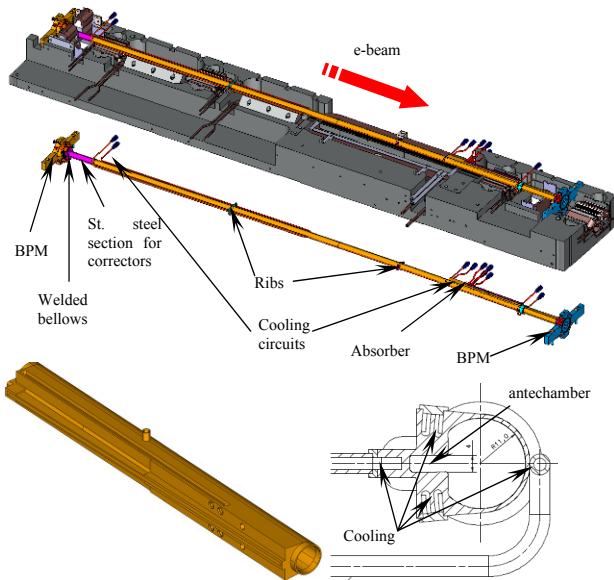


Figure 2 the layout of VC-1 inside and outside the magnet block, the absorber and a cross section in the absorber.

VC-2: this is the second chamber in the achromat, and it needs to pass the SR coming from VC-1 to the front end. The chamber starts with a copper tube with an antechamber, followed by the pumping port which will also host the crotch absorber, this section is made of stainless steel, following the crotch absorber, the chamber splits into two branches: the first is a copper tube of circular shape which will accommodate the circulated beam and the other branch is a circular stainless steel tube which marks the start of the front end.

The absorber will take the SR from the bending magnet upstream. The crotch absorber has a similar design of that of SLS/ANKA absorbers [3]; it will be made of OFHC copper with cooling circuits inside the copper block to remove the heat (see Figure 3).

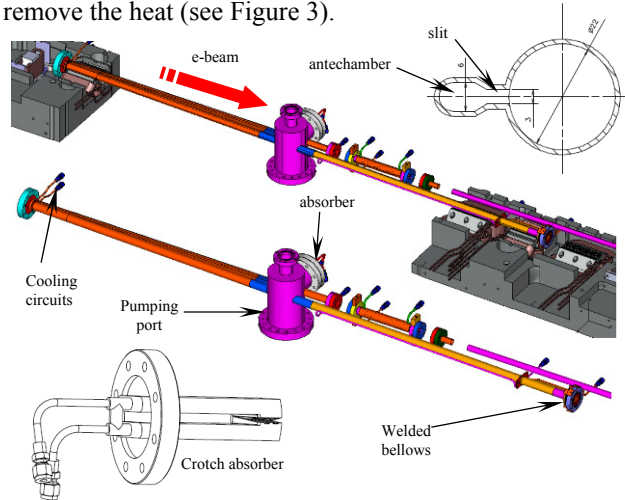


Figure 3: the layout of VC-2 inside and outside the magnet block, cross section at the start of the vacuum chamber and the layout of the crotch absorber.

VC-3: this is the third vacuum chamber in the achromat, and the design of this chamber is similar to the remaining vacuum chambers in the achromat (the unit cells (UC) and matching cell 2 (MC-2)). The chamber starts and ends with welded bellows and it is made of copper (apart from the corrector section which is made of stainless steel), see Figure 4.

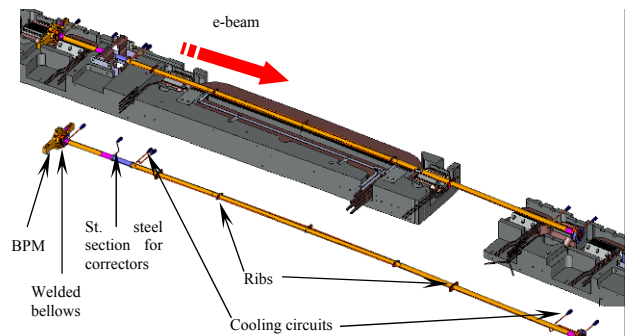


Figure 4: the layout of VC-3 inside and outside the magnet block.

As there are some sections of the vacuum chamber which do not have cooling, it has been decided to implement a small absorber to shadow these parts and protect them from SR; this includes the BPM, bellows, pumping ports and the corrector stainless steel sections.

Finite Element Analysis (FEA)

189 kW of power from the bending magnets SR needs to be removed, and as all the vacuum chambers of the storage ring are exposed to this power and working as absorbers, it was necessary to perform FEA which will guarantee the mechanical stabilities of the chambers.

The FEA were performed to estimate the stress, deformation and temperature distribution due to SR. The results must be within the design criterion, which consists of max. limit for stress in copper is less than 50 MPa and the max. temperature difference is less 150 °C and finally the max. water temperature should not exceed the boiling temperature (at the water pressure in use).

The power densities estimated were high, which implies that the cooling system must be efficient to handle this.

As an example, Figure 5 shows the thermal and the structural results of the FEA for VC-3, respectively. The max. temperature is 104 °C which is located close to the absorber which is protecting the bellows, on the other hand the max. stress is 72 MPa, which is on the stainless steel bellows.

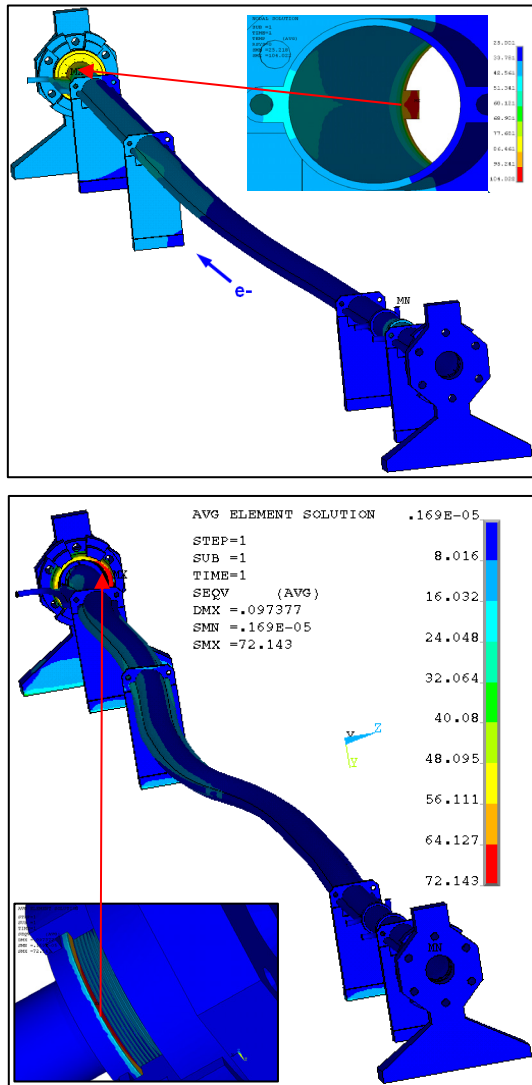


Figure 5: the thermal and structural FEA results for VC-3.

The Pressure Profile

The pressure profile is calculated using the desorption yields measured at CERN [4] scaled with the beam power. Conductance is for nitrogen in circular tube and pumping speed of the coating 0.5 l/s.cm². Peaks for gas

loads from the photon beam pipe and a non-coated RF cavity are shown in Figure 6, together with the pressure profile with and without beam.

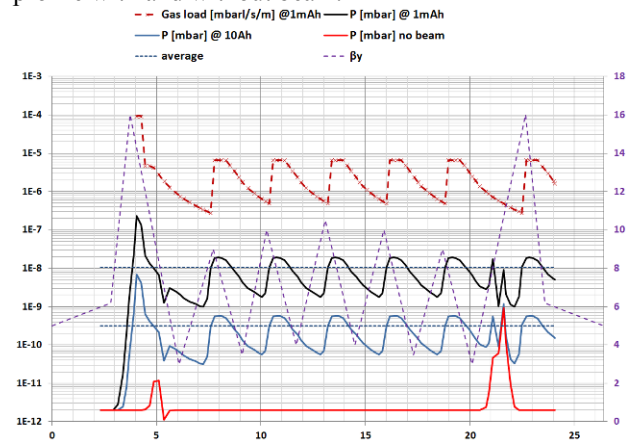


Figure 6: gas load, thermal and dynamic pressure and the beta function for one achromat.

Assembly Procedure

In the small apertures of the magnets there is no room for the thermal expansion of the chambers during activation of the NEG coated chambers. The 9 chambers in the achromat (about 22 m long) will be assembled on a bench beside the magnets in the tunnel. They will be sealed off by gate valves, pumped down, and baked in a movable oven before installed on the lower magnet halves.

CONCLUSIONS AND PERSPECTIVES

A design for the MAX IV 3 GeV ring vacuum system has been described, which incorporates several novel features, in particular the extensive use of NEG coating in a copper tube of small radius. Further work is foreseen as part of an on-going review of this design, with the aim of simplifying the construction and NEG coating procedures as well as reducing costs. In particular, this review includes the elimination of stainless steel chambers for correctors, which minimizes the need for joining of dissimilar materials in NEG coated chambers. Weak fast correctors will be added around other stainless steel parts such as bellows and transitions.

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