9 Vacuum system

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The vacuum system design of SEE-LS will employ state-of-the-art techniques used by the newly built synchrotron radiation facilities. The magnet openings are small, and accordingly the vacuum chambers will have small apertures; therefore they will be conductance-limited vacuum chambers. Consequently, lumped pumps are not an efficient approach to achieving the necessary target vacuum pressure levels. To overcome this issue, a non-evaporable getter (NEG) coating will be used, which will allow a high pumping speed for active gases along with reduced photon-induced desorption; as a result, a few ion pumps will be used, mainly to remove noble gases at the areas of high outgassing.

9.1 The vacuum layout

The storage ring of the SEE-LS is divided into 16 achromats, and the vacuum system layout will follow this sectioning; ultra-high vacuum (UHV) valves with RF fingers will be placed on each side of the achromat, allowing a space of 5.4 m for the insertion devices (IDs). Figures 9.1 and 9.2 show the layout of one vacuum section.

The vacuum chamber will be made of oxygen-free silver bearing copper. The chamber profile on the extremities of the achromats will be circular with an inside diameter of 24 mm, while in the middle of the achromat the chamber will be elliptical (with internal dimensions of 18 mm × 22 mm). The chamber will have a thickness of 1 mm, and distributed cooling will be included along its length to remove the power from the synchrotron radiation striking the chamber wall. A cross-section of the vacuum chambers, together with the magnet profiles, is shown in Fig. 9.3; the clearance to the magnets is 0.5 mm. The cross-section is slightly larger than that of the MAX IV storage ring (22 mm inside diameter); thus, one can have even smaller apertures and use the additional clearance to the magnets for heaters and insulation, which allows in situ bake-out for the vacuum chambers.

The photon extraction occurs after the first dipole of the achromats, and the chamber at this location must have an antechamber through which the photon beam will pass to the front ends. The chamber will pass through the sextupole after the first dipole, and then a crotch absorber is placed where the photon beam and the electron beam become separated. A similar layout for the MAX IV storage ring is shown in Fig. 9.4. Figure 9.5 shows the area of extraction of the photon beam and Fig. 9.6 a cross-section of the chamber at the exit of the sextupole.

Bellows with RF fingers will be welded onto each side of the vacuum chamber body; this will allow the chamber to expand due to thermal expansion when the beam hits the walls. In case an in situ bake-out is implemented, bellows with a larger stroke should be considered. Beam position monitors (BPMs) will be connected on each side of the chambers; standalone BPMs will be used, similar to the design at MAX IV (see Fig. 9.7). The BPMs will be supported by the magnet structure with a mechanical design which aims to minimize the mechanical motion of the BPM bodies as a result of heating of the vacuum chambers by the incident synchrotron radiation.

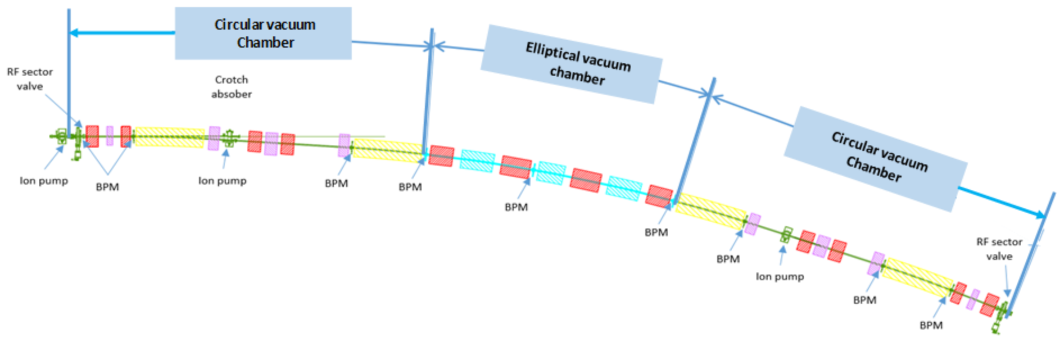

Fig. 9.1: The layout of the vacuum system of one achromat

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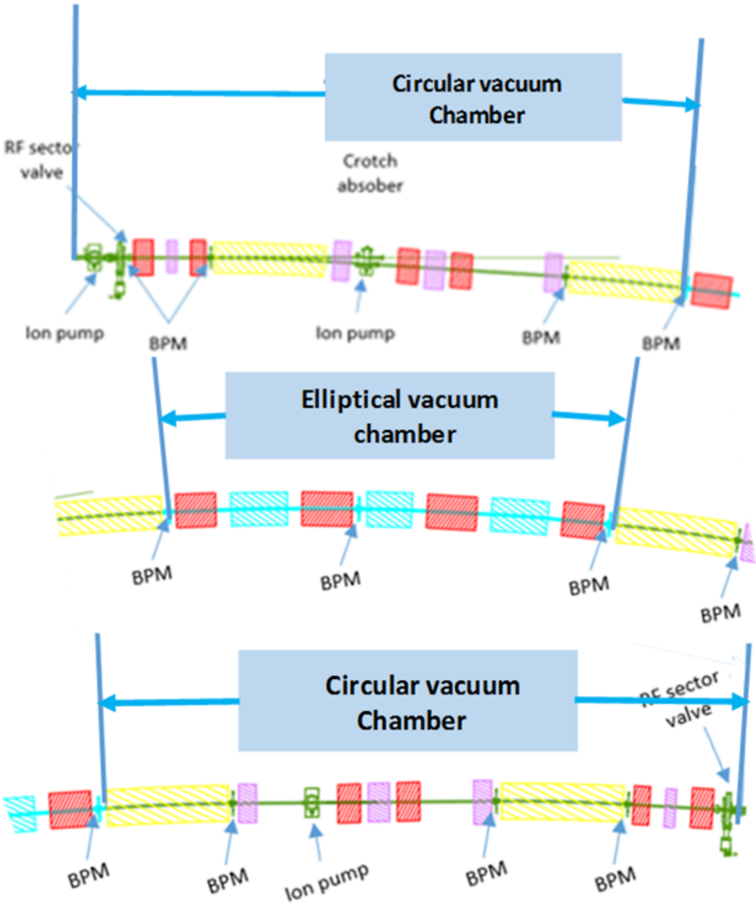

Fig. 9.2: The layout of the vacuum system at the beginning, middle, and end of one achromat

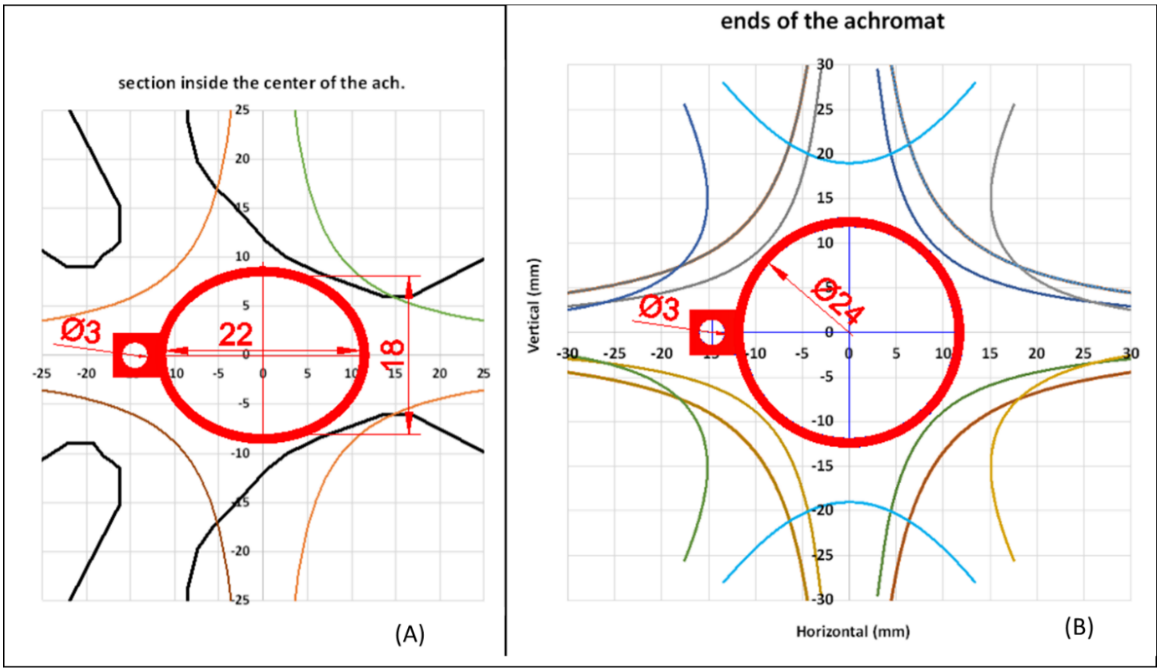

Fig. 9.3: The cross-section of the vacuum chambers inside the magnets: (A) at the centre of the achromat; (B) on the edges of the achromat.

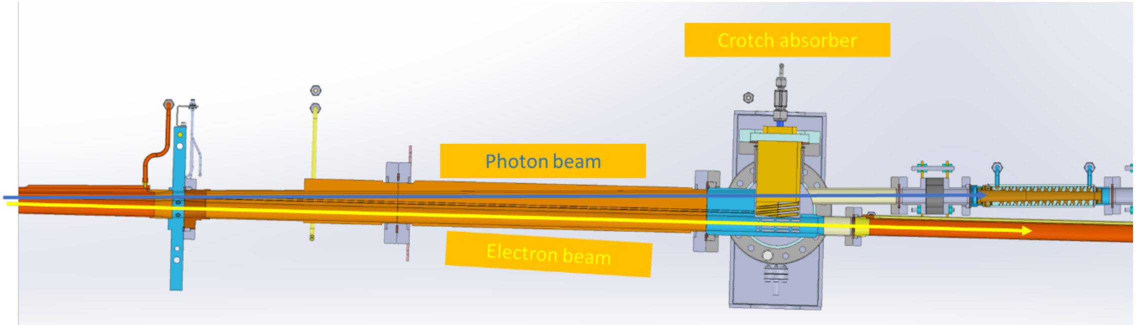

Fig. 9.4: The area of the photon beam extraction of MAX IV

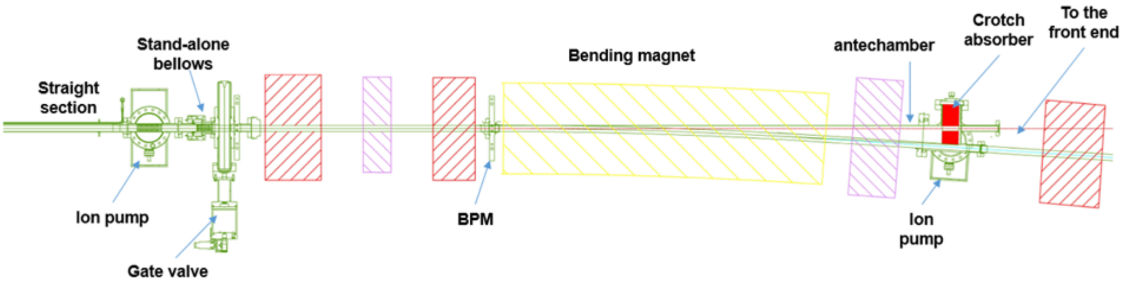

Fig. 9.5: The area of the photon beam extraction for SEE-LS

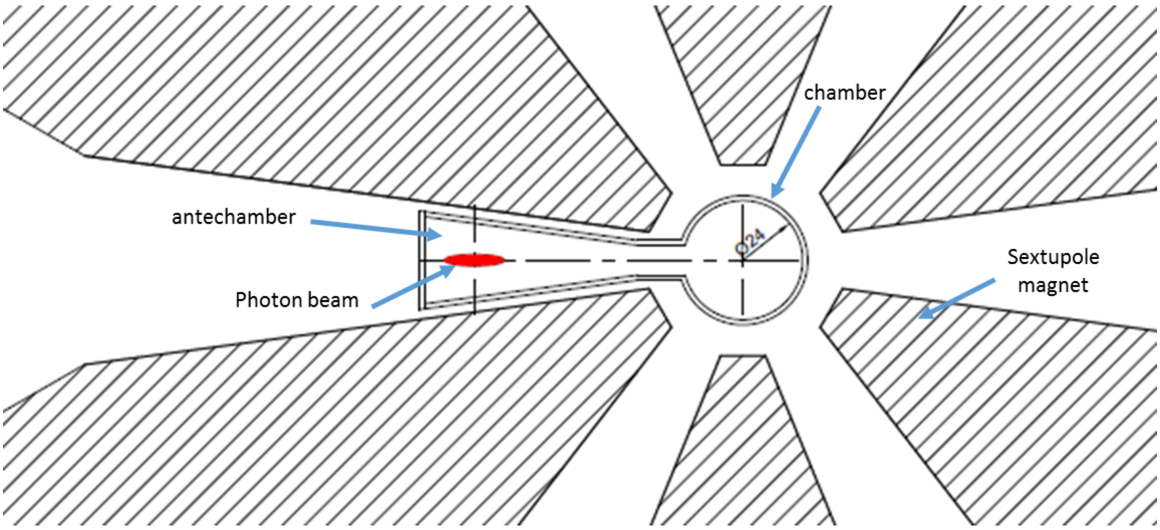

Fig. 9.6: Section inside the sextupole before the crotch absorber, the chamber with an antechamber

The overall mechanical design of the vacuum chambers needs to carefully take into account the beam coupling impedance, in terms of both the limitations it could impose on the maximum attainable beam current and the potential chamber heating due to beam-induced fields. In general, a chamber that is as smooth as possible is desired from an impedance point of view, and the choice of copper as the chamber material also minimizes resistive wall impedance effects.

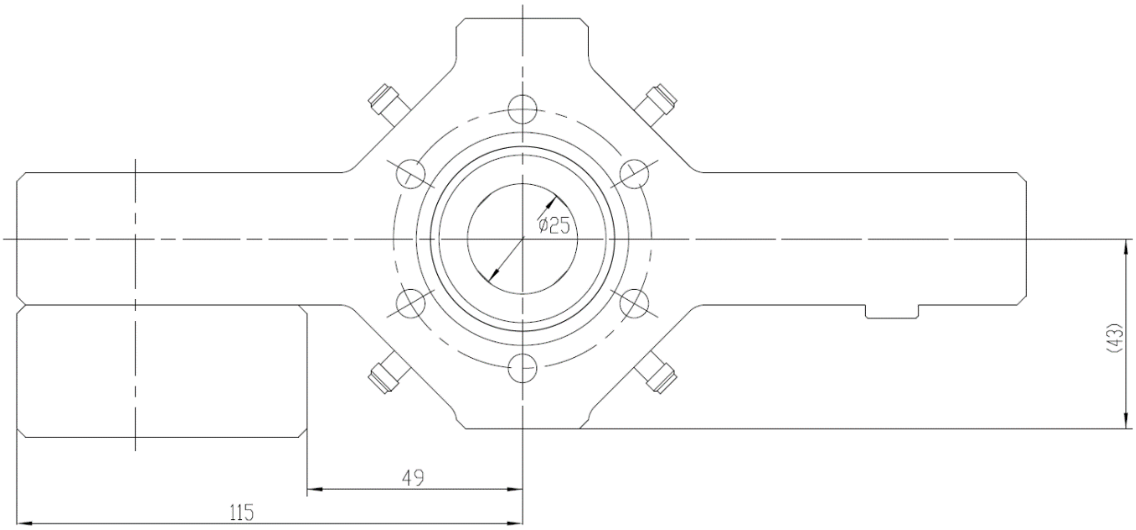

Fig. 9.7: The standalone BPM of MAX IV

The conceptual design of the chambers follows that used at the MAX IV 3 GeV storage ring, and technologies developed at MAX IV will be adapted to the small apertures that the SEE-LS storage ring will have. Figure 9.8 shows a cross-section of the unit cell vacuum chamber of MAX IV, including the distributed cooling in the side of the chamber and the welded bellows on the extremities. Figure 9.9 shows a 3D view of the unit cell of the MAX IV chamber, and Fig. 9.10 shows some parts and the chambers of the MAX IV storage ring [9.1].

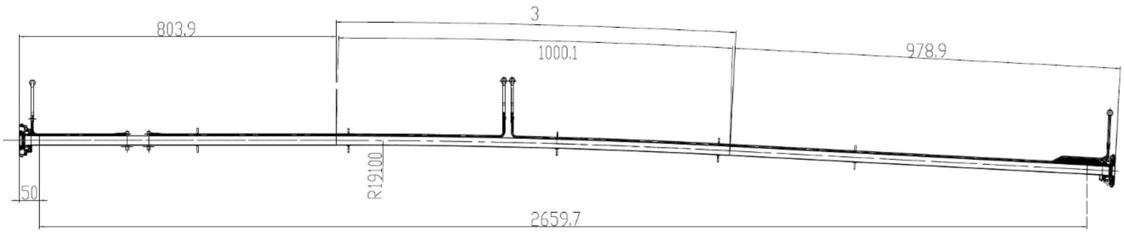

Fig. 9.8: A cross-section of the unit cells of the MAX IV vacuum chamber

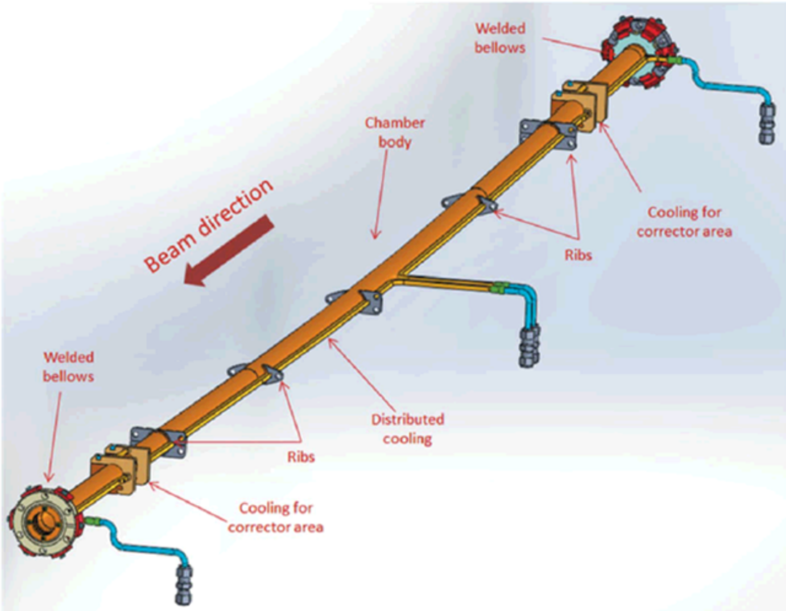

Fig. 9.9: Three-dimensional view of the unit cells of the MAX IV vacuum chamber

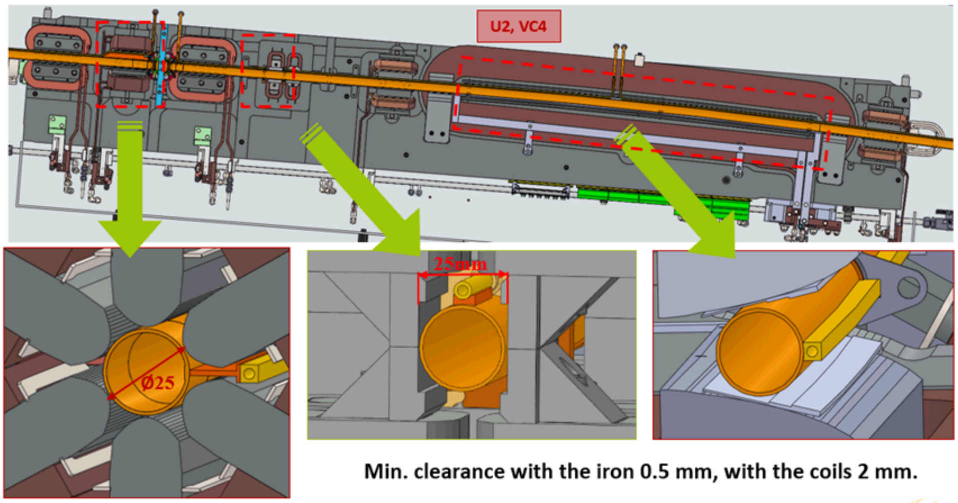

Fig. 9.10: MAX IV vacuum chamber layout, showing the cross-section of the beam pipe with the cooling tubes in the different magnets.

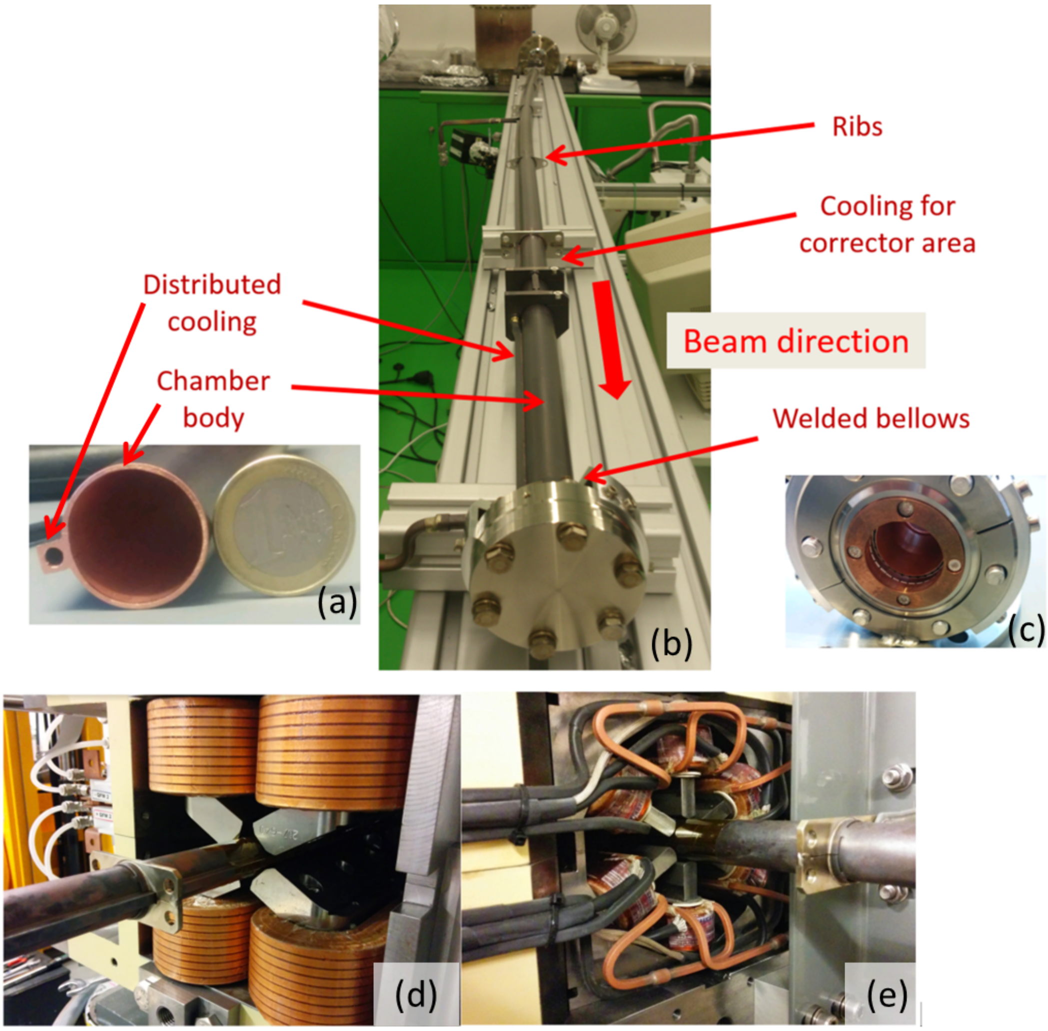

Fig. 9.11: MAX IV vacuum chamber layout: (a) cross-section of the vacuum tube with cooling pipe; (b) one assembly of MAX IV vacuum chamber; (c) welded bellows; (d) the chamber inside the quadrupole magnet; (e) the chamber inside the sextupole magnet.

9.2 The synchrotron radiation power from bending magnets

The total power from the bending magnets is around 93 kW, which must be absorbed by the walls of the vacuum chambers; the crotch absorber will receive around 600 W of power from the M11 bending magnet. The synchrotron radiation from the bending magnet has a small vertical opening of 0.2 mrad. Each type of dipole will contribute differently to the total power budget and has a different power density; Table 9.1 shows a summary of the angular and linear power densities, as well as the total power from each type of dipole of the achromats.

9.3 The pumping speed needed

The simulations for estimating the pumping speed needed for vacuum systems or the pressure profile for systems having NEG coating are not straightforward, mainly because the sticking coefficients of the various gases could vary depending on the NEG saturation.

The following paragraph gives a rough estimation of the pumping speed needed; more detailed calculations (considering the different gases, beam doses, etc.) must be performed.

Table 9.1: Power densities from the dipole magnets on the vacuum chamber walls

Element	Field	Angular power density	Linear power density on the chamber wall	Power density on the chamber wall	Total power per achromat
	(T)	(W/mrad)	(W/mm)	(W/mm^2)	(kW)
M11	0.47	12.36	0.73	5.68	1.60
M12	0.46	12.20	0.69	5.38	1.55
MQ1	0.69	18.16	1.50	13.60	1.65
MQ2	0.86	22.70	2.05	20.62	1.03
				Total power per achromat (kW) =	5.83
				Overall ring power (kW) =	93.27

The main source of gas inside the vacuum chambers during operation is photon-stimulated desorption (PSD); the outgassing due to PSD is estimated to be 3.3×10^{-5} mbar l/s. In order to achieve the target pressure of 10^{-9} mbar (which would allow a good beam lifetime, in excess of 10 hours), the total pumping speed should be at least 33 000 l/s for mass 28. The main source of pumping down will be from the NEG coating. CERN has reported that the pumping speed from activated NEG coating for hydrogen is around 0.5 l/(s cm^2), and that for CO or N_2 is around 5 l/(s cm^2) [9.2]. Assuming that the NEG coating is almost saturated all along the ring circumference and that its pumping capacity for mass 28 is reduced to 0.2 l/(s cm^2), we would have a pumping speed of around 43 000 l/s from the NEG coating. In addition, each achromat will have four small ion pumps, which are needed for pumping noble gases that are not pumped by the NEG coating and are also needed in areas of high outgassing to limit the NEG saturation in those areas. The total pumping speed from all the ion pumps in the ring will be around 3000 l/s. The overall estimated pumping speed installed will be around 47 000 l/s, which is higher than what is needed; however, this would allow a better pressure to be achieved sooner. A summary of the calculations for the total pumping speed is shown in Table 9.2.

Table 9.2: Estimation of the total pumping speed needed for the storage ring

Parameter	Value	Unit
Target dynamic pressure	1.00E-09	mbar
PSD yield after conditioning	1.00E-06	Molecules/ph
Total photon flux	8.08E+20	photons/s
PSD outgassing	3.26E-05	mbar.l/s
Total pumping speed needed	32643.20	l/s
Pumping speed for nitrogen from NEG coating (assuming semi-saturated coating): 0.2 l/(s cm^2)	43730.97	l/s
Pumping speed for nitrogen from ion pumps (effective pumping speed around 50 l/s, four ion pumps per achromat)	3200	l/s
Total pumping speed installed	46930.97	l/s

A fully NEG-coated vacuum system will provide faster conditioning than that of traditional vacuum systems, which are based on the use of lumped pumps. Figure 9.10 shows the MAX IV normalized average pressure rise versus the accumulated beam dose [9.3]. The conditioning slope is 0.82, a value slightly higher than that reported during the commissioning of other facilities [9.4, 9.5].

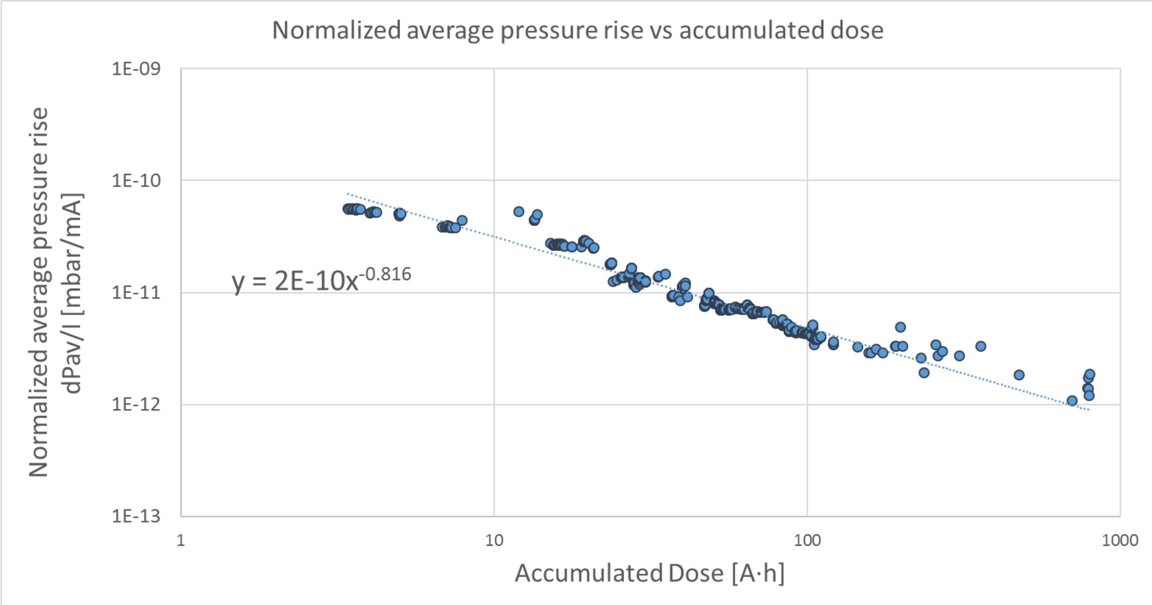

Fig. 9.12: The normalized average pressure rise (mbar/mA) versus the accumulated beam dose (A h) for the MAX IV 3 GeV storage ring.

With a value of 10^{-12} mbar/mA, according to Fig. 9.12 a pressure of 1.9 nTorr could be reached with a current of 250 mA. This meets the requirements of the SEE-LS.

The general layout of the vacuum system for accelerators is described in Ref. [9.6].

References

[9.1] E. Al-Dmour *et al*., *J. Synchrotron Rad.* **21** (2014) 878, https://doi.org/10.1107/S1600577514010480

[9.2] P. Chiggiato, Beyond Ti-Zr-V: present development on thin film coating for beam pipes, CERN-TS-NOTE-2008-006 (CERN, Geneva, 2008), https://cds.cern.ch/record/1119298

[9.3] P.F. Tavares *et al*., *J. Synchrotron Rad.* **25** (2018) 1291, https://doi.org/10.1107/S1600577518008111

[9.4] M.P. Cox *et al*., *J Phys. Conf. Ser*. **100** (2008) 092011, https://doi.org/10.1088/1742-6596/100/9/092011

[9.5] C. Herbeaux *et al*., Vacuum conditioning of the Soleil storage ring with extensive use of NEG coating, Proc. EPAC2008, Genoa, Italy, 23–27 June 2008, p. 3696. https://inspirehep.net/record/795489

[9.6] CAS-CERN Accelerator School: Vacuum for Particle Accelerators, Glumslöv, Sweden, 6–16 June 2017, https://cas.web.cern.ch/schools/glumslov-2017