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VACUUM SYSTEM OF THE FCC-ee*

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Abstract

The analysis and design of the vacuum system for the FCC-ee e- and e+ rings is outlined. The main vacuum-relevant parameters are recalled, with particular emphasis on the copious emission of synchrotron radiation (SR) along the rings, and its direct and indirect effects on vacuum, namely surface heating, SR-induced molecular desorption, generation of photoelectrons. A status report of the present design, analysis, and prototyping phase of several key vacuum components is also given.

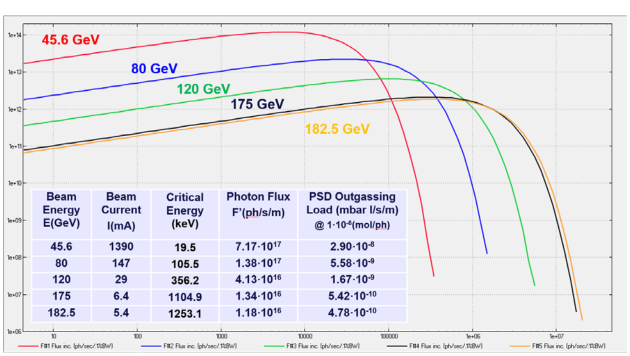
VACUUM-RELEVANT MACHINE PARAMETERS

This paper refers to the version of the machine described in the Conceptual Design Report [1], i.e. the 97.756 km circumference rings. Out of the 5 beam energies foreseen for the experimental runs, see table on inset of Fig 1, we have analysed only the lowest-energy, highest beam current Z and the highest-energy, lowest beam current ttbar, as they represent all cases vacuum-wise.

All machines are bound to generate 50 MW of SR, therefore their beam currents scale as $1/E^4$, with E being the beam energy. There is therefore a large change of stored current, which makes the design challenging for vacuum, especially for the 45.6 GeV, 1390 mA, Z energy.

Synchrotron Radiation Spectra

The SR spectrum for e^-/e^+ circular accelerators is strongly dependent on beam energy. Its characteristic parameter is the critical energy ε_c of its spectrum, which varies as the third power of the beam energy E. Figure 1 shows the spectra of the five machines. The table on the figure also shows some vacuum-relevant parameter, such as the linear photon-stimulated desorption (PSD) yield, in units of mbar·l/s/m, computed assuming a molecular yield of



Beam Energy E(GeV)	Beam Current I(mA)	Critical Energy (keV)	Photon Flux F'(ph/s/m)	PSD Outgassing Load (mbar l/s/m) @ $1\cdot10^{-6}$(mol/ph)
45.6	1390	19.5	$7.17\cdot10^{17}$	$2.90\cdot10^{-8}$
80	147	105.5	$1.38\cdot10^{17}$	$5.58\cdot10^{-9}$
120	29	356.2	$4.13\cdot10^{16}$	$1.67\cdot10^{-9}$
175	6.4	1104.9	$1.34\cdot10^{16}$	$5.42\cdot10^{-10}$
182.5	5.4	1253.1	$1.18\cdot10^{16}$	$4.78\cdot10^{-10}$

Figure 1: SR spectra: Units: Vertical: ph/s/m/(0.1% Bandwidth); Horizontal: eV; Intervals: Vertical: [106; 2·1014]; Horizontal : [4; 5·106]; Inset table: linear photon flux, and linear PSD rate at each energy.

$1\cdot10^{-6}$ molecule/photon (mol/ph). The "per meter" unit refers to length along the arc dipole orbits, with bending radius ρ = 10.760 km.

It can be seen on Fig. 1 that the spectrum for the Z machine is almost entirely generated below the Compton threshold for aluminium or copper (~100 and 200 keV, respectively), while for all other higher energy machines there is going to be a substantial fraction of the total photon flux generated above the Compton threshold. Operation with LEP-2 at high energies has shown that this Compton-generated photons interact with the vacuum chamber material and can created a rather isotropic background of X and gamma rays, which can then re-enter the vacuum system and generate additional outgassing [2, 3]. We have therefore devised a way to contain locally this high-energy isotropic source of radiation which could otherwise activate and damage machine and tunnel components [4].

VACUUM HARDWARE

Synchrotron Radiation Absorbers

The operation timeline adopted for the FCC-ee physics program, see Fig. 3 of Ref. [1], calls for an initial 4-year time span during which the machine starts at the Z energy and then in a matter of 2 years it gets to nominal luminosity. This is a very challenging specification, as the Z machine corresponds to a very high beam current, B-factory-level, at unprecedented high energy: we need to design a very performing vacuum system, with high linear pumping speed, low dynamic desorption, and quick conditioning. To cope with this requirement and reduce the Compton-scattered background (see previous section), we have explored via numerical simulations the possibility to implement a number of short, lumped SR ures which collect and concentrate the SR that would otherwise impinge along the external wall of the vacuum chamber, like done at most modern light sources. For all machines, the linear SR power density, if the SR fan hits the external wall, is around 620 W/m (including a dipole packing factor of 0.85). Using 150 mm-long lumped absorbers we can collect the SR fan which would otherwise on average hit 5.6 m of external wall, therefore speeding up the conditioning time by a factor between 4 and 7, depending on the exponent of the power-law conditioning curve [5]. Some details and calculations are shown in Fig. 2. Correspondingly, the SR power density on the SR absorbers' surface goes up from 1.4 W/mm² to 32 W/mm² (flat wall vs inclined surface of the SR absorber) for the Z machine, and from 4 W/mm² to 115 W/mm² for the ttbar at 182.5 GeV. The material chosen for the SR absorbers is CuCrZr, and the manufacturing technology is additive manufacturing, 3D printing. The absorbers will be connected to the chamber either via brazing or using other techniques. First prototypes will be available at the beginning of 2023.

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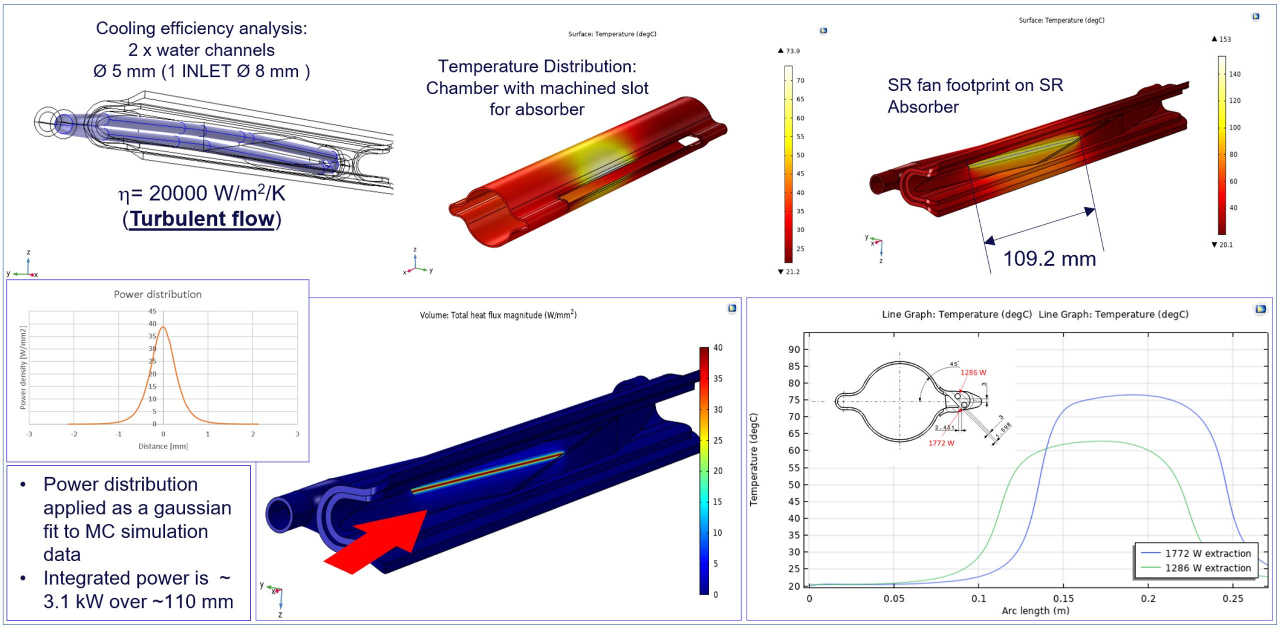

Figure 2: Composite figure showing results of calculations carried out for the SR absorbers; clockwise, from upper left: optimisation of turbulence vs pressure drop; temperature distribution near one SR absorber; temperature distribution along one absorber; wall temperature at the cooling channels vs length; SR power density along one absorber; vertical distribution of SR fan (from ray-tracing montecarlo simulation, SYNRAD+ code).

Vacuum Chamber, Surface Treatment, and Flanges

Taking advantage of the R&D program carried out for the FCC-hh study, we are adopting the shape-memory alloy (SMA) technology for sealing the flanges of the FCC-ee [6]. The maximum length of the chambers as been determined to be around 12 m, which should fit into the requirements for the fabrication of the long dipoles (up to ~ 24 m) in two segments. Based on technology developed for the HL-LHC program, we are confident that 12 m-long chambers could be NEG-coated in a horizontal position, which would greatly simplify the coating process and related costs [7]. Fig. 3 shows the tests carried out to join the oval flanges to a short vacuum chamber sample (made by wire-erosion) using the friction stir welding (FSW) technology, following the contour of the chamber placed inside a matching groove machined on the flange. The first results are very encouraging. An *ad hoc* study group has been set up to build a representative test section of the FCC-ee arcs, including short dipole, quadrupole and sextupole magnets or mock-up models of them. We are also testing additive manufacturing technology, cold plasma spray, to add thick layers of copper to the vacuum chamber extrusion and machine directly on these layers the body of the beam-position monitors (BPM). Prototyping is underway. Concerning the BPM electrodes, we are also testing the possibility to mount each of them on a small flange, again using the SMA technology to reduce the machining of holes for the screws.

NEG-coating has been proposed to keep the PSD contribution low, reduce the number of photoelectrons and their contribution to the electron-cloud effect, and provide distributed pumping to the system [8]. NEG-coating requires thermal activation to a minimum temperature of 180 °C, with the possibility to raise the temperature later should many activation cycles be needed.

We are testing a new technology based on the deposition by cold-spray of an insulating ceramic layer on top of which a thin titanium strip is also sprayed and used as ohmic heating element by running through it an appropriate current. This system is radiation resistant, an important feature for a machine like the FCC-ee which will generate copious amounts of high-energy particles and radiation. Figure 4 shows a CAD-made view of the set-up and one of the many calculations which have been carried out about this. Prototypes are already under study in our laboratories.

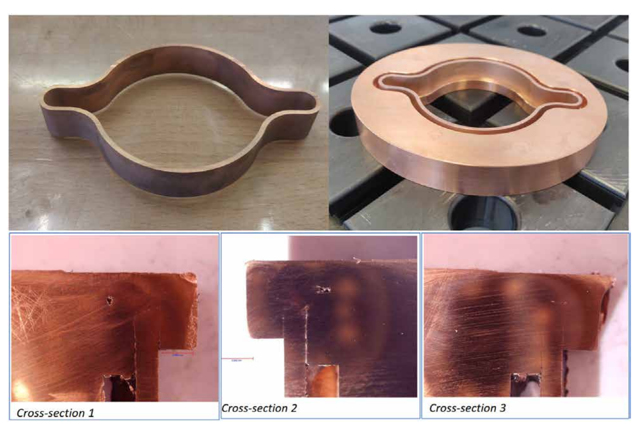

Figure 3: Short chamber extrusion, oval flange, and cross-section of the FSW tests, showing correct joining of the two parts.

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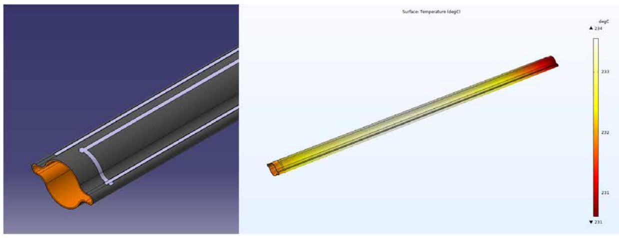

Figure 4: Left: CAD view of the chamber extrusion covered with insulating ceramic layer and sprayed Ti tracks; Right: Temperature distribution computed for a 5m-long chamber.

RF Bellows

We are designing two different bellow assembly types with RF contact fingers. One implements a modified version of the SUPERKEKB comb-type RF contacts, the second one a modified version of a contact-less type developed at CERN for the triplet area of the HL-LHC. Given the importance of minimising the impedance budget of the rings, at the same time numerical simulations of the impedance contributions of such RF contact finger geometries is underway [9].

CONCLUSIONS

The analysis and design of the vacuum system for the FCC-ee arc rings have advanced considerably. We have designed and are prepared to test soon many components of the system, utilizing novel technologies which, if validated, will allow us to simplify the design, fabrication, and installation of many components, while cutting on the cost of the vacuum system. Future refinements of the vacuum system design will include a detailed analysis of the new machine lattices, the exact position of each SR absorber, and the need to optimize the installation of the chambers on the girders, in view of quick replacement in the tunnel should it be needed in case of accidents during scheduled operation time.

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REFERENCES

[1] A. Abada *et al.*, "FCC-ee: the lepton collider", *Eur. Phys. J. Spec. Top.,* vol. 228, pp. 261-262, 2019. doi:10.1140/epjst/e2019-900045-4

[2] R. Kersevan, "FCC-ee beam vacuum concept: the beam pipe of FCC-ee", in *Proc. FCC Week 2018,* Amsterdam, NL, April 9-13, 2018, https://indico.cern.ch/event/656491/contributions/2947258/

[3] M. Jimenez *et al.*, "The pressure and gas composition evolution during the operation of the LEP accelerator at 100 GeV", *Vacuum,* vol. 60, pp. 193-189, 2001. doi:10.1016/S0042-207X(00)00383-3

[4] B. Humann, "Synchrotron Radiation studies for the FCC-ee arc with FLUKA", in *Proc. FCC Week 2021,* 28 June-2 July, 2021, https://indico.cern.ch/event/995850/contributions/4405383/.

[5] O. Malyshev, "Beam Induced Desorption", in *Proc. CERN Accelerator School Vacuum For Particle Accelerators*, June 6-16, 2017, Glumslov, Sweden, https://cas.web.cern.ch/schools/glumslov-201

[6] F. Niccoli *et al.*, "NiTi shape memory alloy pipe couplers for ultrahigh vacuum systems: development and implementation", *Smart Mater. Struct.*, vol. 31, no. 6, pp. 065014, 2022. doi:10.1088/1361-665X/ac6999

[7] P. Costa Pinto, "In-situ amorphous carbon coating of the beam screen of LHC's standalone magnets", in *Proc. IPAC'20,* Caen, France, May 2020, paper THVIR02. doi:10.18429/JACoW-IPAC2020-THVIR02

[8] R. Kersevan, "FCC-ee beam vacuum challenges, concepts and future R&D plans", in *Proc. FCC Week 2019,* 24-28 June, 2019, Brussels, Belgium, https://indico.cern.ch/event/727555/contributions/3449896/.

[9] P. Krkotic, CERN, personal communication.