Conceptual Design of the Vacuum System for the FCC-ee Main Rings

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photo: J. Wenninger, CERN
Big variation of nominal current vs beam energy, since all machine versions are limited to 50 MW of synchrotron radiation per beam:

\[
P(W) = 88.46 \cdot E^4(\text{GeV}) \cdot I(\text{mA}) / \rho(\text{m})
\]

\[
F(\text{ph/s}) = 8.08\cdot10^{17} \cdot E(\text{GeV}) \cdot I(\text{mA})
\]
Large use of montecarlo raytracing techniques

Two codes used: SYNRAD+ (SR) and Molflow+ (molecular flow)

**SYNRAD+ simulations: SR power and flux for the 5 beam energies and currents**

SR fans are projected on 14x6 cm² (HxV) screens, placed 50 m away from a 1 cm arc length i.e. +/- 1.4 mrad H and +/- 0.6 mrad V

SR power density (W/cm²) generated by 1m of dipole arc for the 5 beam energies; Total linear power is 744 W/m

SR flux density (ph/s/cm²) generated by 1m of dipole arc for the 5 beam energies; Total linear flux varies with each machine
**SYNRAD+: SR Flux Spectra**

Units: Vertical: photons/s/(0.1% bandwidth)/m; Range [10^6 - 2·10^{14}]
Horizontal: eV; Range [4 - 5·10^6]
**SuperKEKB e-e+ Collider**

Vacuum components and chamber cross-section good inspiration to us...

- Low-loss, water-cooled, “comb-type” contact fingers
- (KEK concept, to be adapted to our dimensions)
- Good for impedance reasons (few tapers)

Our two-in-one magnet design for the dipoles and the quadrupoles could profit from a vacuum chamber cross section like that of SuperKEKB:

- Winglets (to place SR absorbers)
- No need for tapers
- Low-loss components field-tested

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**FCC-ee**

Combined-yoke dipoles and quadrupoles – Magnetic models – and 1m-long prototypes

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Courtesy of A. Milanese, CERN
(see his contribution at Proc. FCC Week 2017, Berlin)
Material: OFC copper; Specific Cond.: $\sim47$ l∙m/s (CO, 20 ºC)

Schematics of SR absorbers and pumping slots (internal beam)

Pumping dome optimized via Molflow+ simulation: NEXTorr 1000

External Ring:
Pump.Port precedes ABS

Internal Ring:
Pump.Port face ABS

2x 1 m-long prototypes (3D printed)
1. The distribution of SR photons absorbed along the walls of the vacuum system are transformed into corresponding photon-induced desorption (PID) outgassing profiles.

2. The instantaneous SR flux density (ph/s/cm²) calculated on “textured” surfaces of the 3D model by SYNRAD+ are multiplied by the time since start of commissioning of the machine and then each photon dose (ph/cm²) is converted into a local outgassing yield $Q_{\text{PID}}$ (mbar·l/s), using experimental data for the material-dependent outgassing yield $\eta_{\text{PID}}$ (mol/ph). This is done within Molflow+.

3. The newly obtained Molflow+ file now has desorption surfaces which mimic the PID yield. Molflow+ is then used to simulate the random walk of the molecules. Pumping surfaces are defined, and relevant facets over which pressure, density, impingement rate, and other quantities of interest to the vacuum engineer are calculated.

4. Repeating the steps from 2 onward for different times during commissioning, we can obtain the pressure profiles at different moments.

5. In particular we can check whether the modelled pumping speeds are sufficient to meet the targeted pressure specifications: an accelerator like FCC-ee aims at having an average pressure along the beam path in the low $10^{-9}$ mbar range (e.g. $2.0 \cdot 10^{-9}$ mbar).
Molflow+: Molecular Flow Simulations

140 m-long typical section of one arc (5 dipoles and 5 quadrupoles/sextupoles, interleaved)

One example of Molflow+ calculation:

- Pressure distribution after 1 h of conditioning at nominal current, 45.6 GeV, 1390 mA;
- Chamber and absorber material is copper; No NEG-coating;
- 5x 110 l/s pumps on each beam;
- Simulated gas: CO (20 ºC);

Average Pressure: \(\sim 5.3 \cdot 10^{-8}\) mbar (\(~25x\) too high)
NEG-coating: yes or no?

Much faster machine commissioning with NEG-coating

➢ Pressure distribution after 1 h of conditioning at nominal current, 45.6 GeV, 1390 mA; Total PID gas load (2 beams): 8.93·10^{-6} mbar·l/s
➢ Chamber and absorber material is copper; NO NEG-coating
➢ 5x 110 l/s pumps on each beam;
➢ Simulated gas: CO (20 ºC);

Average Pressure: 5.2 x10^{-8} mbar (B1)
5.5 x10^{-8} mbar (B2)

➢ Pressure distribution after 1 h of conditioning at nominal current, 45.6 GeV, 1390 mA; Total PID gas load (2 beams): 1.02·10^{-7} mbar·l/s
➢ Chamber and absorber material is copper; NEG-coating
➢ 2x 110 l/s pumps on B2, 1x on B1;
➢ Simulated gas: CO (20 ºC);

Average Pressure: 9.7 x10^{-12} mbar (B1)
3.6 x10^{-9} mbar (B2)

NEG-coating on B1 has sticking coeff.= 0.001: HUGE effect!
• Modelling work has also been carried out for the MDI areas of FCC-ee, see relevant MDI meeting, study group, and workshop pages on indico

• A 3D model of the vacuum chamber geometry ~660 m upstream of the IP has been created; it implements the winglet cross-section with lumped absorbers and NEG pumps already described for the arc chambers

• SYNRAD+ and Molflow+ have been run, coupled for the high-current Z-pole machine and ttbar as well

• The figure on the right shows the model with the colour-coded pressure along the beam path and the absorbers in red

• Some absorbers need to be placed on the opposite side of the chamber due to the anti-bend configuration near the IP

See companion paper M. Boscolo et al., this conf.
Tunnel and Machine Component Irradiation Due to High-Energy SR Photons
(in combination with FLUKA team)

- We have also worked in conjunction with our FLUKA team (B. Humann, F. Cerutti) on the study of the effects of the proposed vacuum system design in terms of radiation deposition on different tunnel areas and components, for the ttbar 182.5 GeV version of the machine, which is characterized by extremely high SR critical energy (1.25 MeV).

- “VC”=Vacuum Chamber

Geometry – periodic cell

- Periodic cell of the arc
  - 140m
  - 5 dipoles (3 long, 2 short)
  - 5 quadrupoles
  - 4 sextupoles

- 25 SR absorbers per beam: Design and initial placement by R. Kersevan

- Cu vacuum chamber with winglets

- 182.5GeV (ttbar); electrons & positron
Conclusions and Future Work, R&D, Prototyping

➢ The conceptual design of the vacuum system of the FCC-ee collider rings has been obtained via extensive montecarlo modelling techniques

➢ As a starting point, we have taken and adapted some of the successful concepts applied on the SuperKEKB e-e+ collider

➢ We have determined that without NEG-coating, and it’s well documented low PID yields, the commissioning of the machine at low-energy and high-current would take a long time, making it difficult to integrate the required luminosity at the experiments

➢ We plan, during the second phase of the Horizon 2020 funding, the FCCIS program(*), to design, fabricate and test one full-scale prototype of one arc half-cell (25 m or so), and of all vacuum components, such as RF bellows with low-loss RF contact fingers, SR absorbers, long vacuum chambers with integrated absorbers (study also the welding/brazing/... techniques), pumping domes

➢ We also have a part in the design of the vacuum system for the Machine Detector Interface area (see companion paper by M. Boscolo et al., this conf.)

➢ We will contribute to the integration of the vacuum system and components into the tunnel layout, in particular towards the integration of the full-energy booster machine

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