Reflectivity and Photo Yield measurements of technical surfaces

Eliana La Francesca$^{1,2}$, G. Gwalt$^3$, F. Schäfers$^3$, F. Siewert$^3$, A. Sokolov$^3$, M. Angelucci$^1$ and R. Cimino$^1$

$^1$ Laboratori Nazionali di Frascati- INFN

$^2$ Università “Sapienza” di Roma

$^3$ Helmholtz Zentrum Berlin

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Outline

- Synchrotron radiation in FCC-hh
- Reflectivity
- Carbon Reflectivity
- Bressy II measurements
- Conclusions
Synchrotron Radiation detrimental effects

- Heat load on the accelerator walls
- Photon stimulated desorption
- Production of secondary electrons
- Beam instability

LHC has a non negligible SR production.

In the Highest Energy Proton Circular Collider ever designed, FCC-hh, large production of Synchrotron Radiation is expected
## FCC Parameters

http://tlep.web.cern.ch/content/fcc-hh

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LHC</th>
<th>H-L LHC</th>
<th>FCC-hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>c.m. Energy [TeV]</td>
<td>14</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Circumference C [km]</td>
<td>26.7</td>
<td></td>
<td>100 (83)</td>
</tr>
<tr>
<td>Dipole field [T]</td>
<td>8.33</td>
<td></td>
<td>16 (20)</td>
</tr>
<tr>
<td>Injection energy [TeV]</td>
<td>0.45</td>
<td></td>
<td>3.3</td>
</tr>
<tr>
<td>Peak luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$]</td>
<td>1.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Stored beam energy [GJ]</td>
<td>0.392</td>
<td>0.694</td>
<td>8.4 (7.0)</td>
</tr>
<tr>
<td>SR power per ring [MW]</td>
<td>0.0036</td>
<td>0.0073</td>
<td>2.4 (2.9)</td>
</tr>
<tr>
<td>Arc SR heat load [W/m/aperture]</td>
<td>0.17</td>
<td>0.33</td>
<td>28.4 (44.3)</td>
</tr>
<tr>
<td>Critical photon energy [keV]</td>
<td>0.044</td>
<td></td>
<td>4.3 (5.5)</td>
</tr>
</tbody>
</table>

### Dipoles at cryogenic temperature of 1.9 K

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Heat Load Dissipation VS Temperature

\[ P_{TOT} \sim 3 \, GW \]

\[ P_{TOT} \sim 80 \, MW \]

Credits: R. Kersevan -- Beam Dynamics meets Vacuum, Collimations, and Surfaces

FCC needs a Beam Screen at the highest possible temperature compatible with vacuum stability, impedance...

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FCC Week 2017, 1 June Berlin
Synchrotron Radiation interaction with Matter

FCC-hh SR incidence angle: 0.035 deg (0.62 mrad) 
~ 21 m from source 
Photon fan strip ~ 2mm

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Synchrotron Radiation interaction with Matter

Arc SR Heat Load = 28.4 (44.3) W/m/aperture

Reflected + Absorbed + Transmitted

Specular reflected

Scattered

To be increased in cold parts (Superconductor Magnets)

To be increased in high temperature parts (BS)

R. Cimino, V. Baglin and F. Schäfers, PRL. 115 (2015) 264804

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Reflectivity

X-Ray Reflectivity depends on a limited number of parameters:

- Photon energy and light polarization
- Angle of incidence
- Surface roughness
- Material
Specular Reflectivity VS Incidence angle

http://henke.lbl.gov/optical_constants/

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Reflectivity

X-Ray Reflectivity depends on a limited number of parameters:

- Photon energy and light polarization
- Angle of incidence
- **Surface roughness**
- Material
Specular Reflectivity VS Roughness

REFLEC simulations

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Reflectivity

X-Ray Reflectivity depends on a limited number of parameters:

- Photon energy and light polarization
- Angle of incidence
- Surface roughness
- Material
Specular Reflectivity VS Material

\[ \theta_i = 0.035 \text{ deg} \]

\[ R_a = 50 \text{ nm} \]

REFLEC simulations

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Specular Reflectivity: the case of Carbon

\[ \lambda(C) \sim 3.5 \text{ nm (X-ray range)} \]

20 nm of C can reflect all photons

\[ \text{Attenuation depth (} \lambda \text{):} \]
\[ P(x) = \exp(-x/\lambda) \]

For \( x = \lambda \) the intensity of X-rays falls to 1/e of its value at the surface.

R. Cimino, V. Baglin and F. Schäfers, PRL. 115 (2015) 264804
BESSY-II Optic Beamline and Reflectometer


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BESSY-II Optic Beamline and Reflectometer

- Incidence angle $\theta$: $-90^\circ$ – $90^\circ$
- Detector in-plane $2\theta$: $-180^\circ$ – $180^\circ$
- Detector off-plane $\chi$: $-4^\circ$ – $4^\circ$
- Sample – detector: 310 mm
- Six axes sample positioning
- Sample current measurement
- GaAsP-Photodiodes
- Detector slits, pinholes


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Bessy II Measurements

- Photon Energy range $35 \div 1800$ eV
- Beam height $h=0.3$ mm
- Incident Beam measurement
- GaAsP Photodiodes (4x4mm) (1.2*4mm)
- Incidence angle $0.25, 0.5$ deg
- Reflectivity measurement

Photo Yield:
$$PY = \frac{N_e}{N_\gamma}$$

Specular Reflectivity
Scattered Light
Copper samples

AFM (20x20μm²)

Cu 1A

Sample | RMS Roughness (Rₐ)
-------|------------------
Cu 1A   | 10 nm
Cu 2A   | 30 nm
Polished |
Copper sample Cu1A and REFLEC simulations

At grazing incidence angle contaminants are influencing Cu Reflectivity

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Specular Reflectivity VS Photon energy (Preliminary Results)

Carbon coating reduces reflectivity at low energy

At high energy reflectivity is significantly enhanced
Total Reflectivity VS Specular Reflectivity

\[ \theta_i = 5 \text{ deg} \]

Specular reflection

- \( R_a = 0.5 \text{ nm} \)
- \( \theta_r = 2\theta_i \)

Wide angle scatter

Small angle scatter

<table>
<thead>
<tr>
<th>Sample</th>
<th>Specular Reflectivity</th>
<th>Total Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu 1A</td>
<td>0.61</td>
<td>0.73</td>
</tr>
<tr>
<td>Cu 1A + CC</td>
<td>0.78</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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Photo Yield VS Incidence angle

Preliminary Results:
- little dependence on roughness
- Carbon coating seems to reduce PY

\[ \theta_r = 2\theta \]

\[ \text{PY} = \frac{N_e}{N_\gamma} \]

\[ h\nu = 1800 \text{ eV} \]

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cu 1A ((R_a=10 \text{ nm})) Max value</th>
<th>Cu 2A ((R_a=30 \text{ nm})) Max value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>0.47</td>
<td>0.46</td>
</tr>
<tr>
<td>Cu + CC</td>
<td>0.23</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Conclusions

- At FCC-hh SR incidence angle contaminants will influence Reflectivity.
- Carbon coating seems to increase Total Reflectivity and reduce absorption and related Heat Load.
- For technical surfaces scattered light cannot be neglected.
- Photo Yield does not seem to significantly depend on roughness and decrease with CC.
- Our preliminary results suggest that further work is needed in order to qualify the use of Carbon Coating to increase Reflectivity.
- Experimental data are important to characterize SR behaviour and HL for all materials to be used in FCC-hh dipoles and Interaction points.
Thank you for your attention.