ACDIV-2018-12
April 2018

Results of the FCC-hh Beam Screen at the KIT Electron Storage Ring KARA

L. A. Gonzalez, M. Gil-Costa, F. Perez, I. Bellafont, V. Baglin, P. Chiggiato, C. Garion, R. Kersevan, S. Casalbuoni, E. Huttel

Abstract

In the framework of the EuroCirCol collaboration (work package 4 "Cryogenic Beam Vacuum System"), the fabrication of three FCC-hh beam screen (BS) prototypes has been carried out with the aim of testing them at room temperature on the Karlsruhe Institute of Technology (KIT) 2.5 GeV electron storage ring KARA (Karlsruhe Research Accelerator) light source. The three BS prototypes will be tested on a beamline installed by the collaboration, named as BEam Screen TEstbench EXperiment (BESTEX). KARA has been chosen because its synchrotron radiation (SR) spectrum, photon flux and power, match quite well the one foreseen for the 50+50 TeV FCC-hh proton collider. Each of the three BS prototypes, 2 m in length, implement a different design feature: 1) baseline design (BD), with electro-deposited copper and no electron-cloud (EC) mitigation features; 2) BD with set of distributed cold-sprayed anti-EC clearing electrodes; 3) BD with laser-ablated anti-EC surface texturing. We present here the results obtained so far at BESTEX and the comparison with extensive Monte Carlo simulations of the expected outgassing behavior under synchrotron radiation.

Accelerator Division
Alba Synchrotron Light Source
c/ de la Llum, 2-26
08290 Cerdanyola del Valles, Spain

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBE5

RESULTS ON THE FCC-hh BEAM SCREEN AT THE KIT ELECTRON STORAGE RING KARA*

L. A. Gonzalez [1], LNF-INFN, 00044 Frascati (Rome), Italy
M. Gil-Costa[1], Ciemat, 28040 Madrid, Spain
F. Perez, I. Bellafont[1], ALBA, 08290 Barcelona, Spain
V. Baglin, P. Chiggiato, C. Garion, R. Kersevan, CERN, 1211 Geneva, Switzerland
S. Casalbuoni, E. Huttel, IBPT-KIT, 76131 Karlsruhe, Germany
[1]also at CERN, 1211 Geneva, Switzerland

Abstract

In the framework of the EuroCirCol collaboration [1] (work package 4 "Cryogenic Beam Vacuum System"), the fabrication of three FCC-hh beam screen (BS) prototypes has been carried out with the aim of testing them at room temperature on the Karlsruhe Institute of Technology (KIT) 2.5 GeV electron storage ring KARA (KArlsruhe Research Accelerator) light source. The three BS prototypes will be tested on a beamline installed by the collaboration, named as BEam Screen TEstbench EXperiment (BESTEX). KARA has been chosen because its synchrotron radiation (SR) spectrum, photon flux and power, match quite well the one foreseen for the 50+50 TeV FCC-hh proton collider. Each of the three BS prototypes, 2 m in length, implement a different design feature: 1) baseline design (BD), with electro-deposited copper and no electron-cloud (EC) mitigation features; 2) BD with set of distributed cold-sprayed anti-EC clearing electrodes; 3) BD with laser-ablated anti-EC surface texturing. We present here the results obtained so far at BESTEX and the comparison with extensive Monte Carlo simulations of the expected outgassing behavior under synchrotron radiation.

INTRODUCTION

The Future Circular hadron Collider (FCC-hh) is a proposed successor of the Large Hadron Collider (LHC) which aims to provide hadron collision at a center of mass of 100 TeV [2]. Proton beams travelling through FCC-hh´s arcs would originate unprecedented levels of Synchrotron Radiation (SR). A comparison between the main SR related parameters of LHC and FCC-hh is shown in Table 1. As SR is known to be at the origin of many beam detrimental effects [3], a novel shaped beam screen [4] (BS) is being designed to minimize the SR related photo desorption, photoelectron generation and heat load effects at FCC-hh. Three FCC-hh BS prototypes have been manufactured according to the current BS baseline designs (BD) and are being tested at the BEam Screen Testbench EXperiment (BESTEX) installed in the 2.5 GeV electron storage ring KARA (KArlsruhe Research Accelerator) light source at the Karlsruhe Institute of
Technology (KIT). KARA has been chosen due to its similarities with FCC-hh in terms of SR spectrum, photon flux and power. The photon spectrum of KARA would be exactly the same as that of FCC-hh at 50 TeV provided KARA runs at 2.2 GeV instead of the standard 2.5 GeV.

Table 1: Comparison Between LHC and FCC-hh SR Parameters

	LHC	FCC-hh	BESTEX
SR Power [W/m]	0.2	32	32
SR Flux* [ph/m/s]	$4.2\cdot10^{16}$	$1.5\cdot10^{17}$	$4.85\cdot10^{16}$
Critical E [eV]	44.2	$4.3\cdot10^{3}$	$6.2\cdot10^{3}$
Glancing Angle [mrad]	5.06	1.34	18

*Photon Energy above 4eV at nominal operation

The experimental results obtained at BESTEX have been compared to intensive Monte Carlo calculations in order to benchmark the validity of the simulations and improve the considerations taken into account.

EXPERIMENTAL DETAILS

Experimental Setup

BESTEX is an experimental instrument that allows to study SR induced effects on non-leak tight tubular samples under ultra-high vacuum (UHV).

A schematic layout of BESTEX is presented in Fig. 1. SR can be collimated both vertically and horizontally before impinging on the 2 m long test sample which can be pivoted about a vertical axis so as to be able to irradiate at any required glancing angle. To perform the experiments presented in this paper, the collimation aperture was chosen so that the sample is irradiated along 1.8 m of its inner wall, depositing a total power density of 32W/m as it is foreseen at FCC-hh arc dipole sections [3-4]. Under this constraints SR impinges onto the sample at a mean glancing angle of 18 mrad. Table 1 shows a comparison between the SR parameters at BESTEX and FCC-hh. Calibrated vacuum Bayard Alpert Gauges (BAG) are strategically placed along the system upstream

*The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBE5

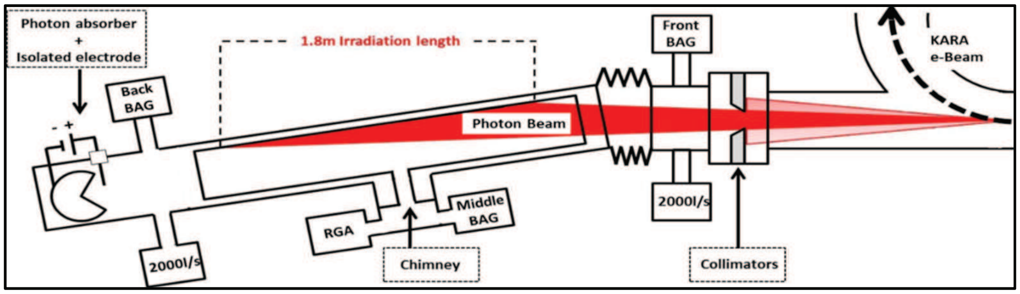

Figure 1: Schematic description of BESTEX.

(*Back BAG*), downstream (*front BAG*) and in the middle point (*Middle BAG*) of the test bench. The latter, together with a calibrated residual gas analyzer (RGA), allow to measure photo desorption yields from the inner part of the sample under study by using a chimney connection as depicted in Fig. 1. A water-cooled photon absorber is placed at the back end of the setup. The absorber is equipped with an insulated electrode on which a positive bias voltage can be applied so as to measure the photo electrons generated during photon irradiation, and from it derive the fraction of reflected photons.

Samples

Two main baseline designs (BD1 and BD2) have been developed for the FCC-hh BS. Both designs implement a main chamber (MC) and an antechamber (AC) separated by a slot aperture at the BS's equatorial plane, through which SR travels before impinging on either a reflector tip (in BD1) or a saw-tooth profile (in BD2). More detailed description of these two designs can be found elsewhere [4].

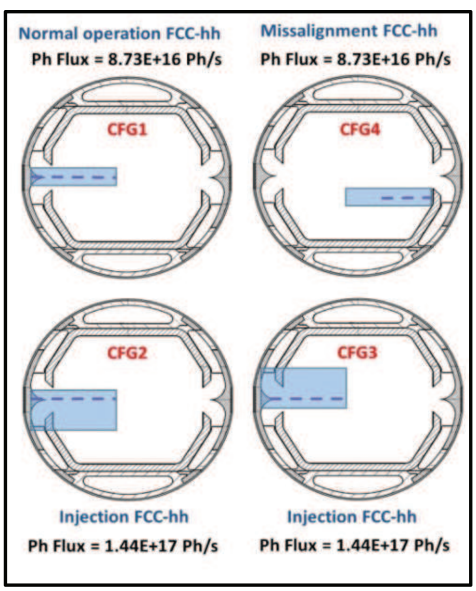

Figure 2: Graphical descriptions of the different geometrical configurations in which the samples were irradiated.

The results presented in this paper correspond to 2 FCC-hh beam screen prototypes labeled as BS1 and BS2 and manufactured according to BD1. BS2 is also equipped with a longitudinal clearing electrode deposited via cold-spray techniques. A ceramic layer was deposited between the BS inner wall and the clearing electrode in order to provide electrical insulation. Before insertion into BESTEX, the samples were cleaned following standard UHV procedures. Then, after installation, bake out cycles of 24h at 150ºC were performed in order to remain within vacuum pressure limits required to operate the storage ring KARA.

The samples were irradiated in four geometrical configurations as shown in Fig 2. Each configuration resembles a different scenario of FCC-hh operation i.e. normal operation (CFG1 in Fig. 2), ramp up during beam injection (CFG2 and CFG3 in Fig. 2) and misalignment (CFG4 in Fig 2). The samples were aligned with respect the KARA's e^- beam plane so as to irradiate the intended area with an accuracy of 200µm.

RESULTS

The log-log plots presented in Fig. 3 show the evolution of the pressure normalized to the KARA´s e^-beam current as a function of the accumulated dose during irradiation of BS1 and BS2.

For the sake of clarity, only the results corresponding to *Middle BAG* are presented. At low photon doses, the normalized pressure during irradiation of BS2 is about 2 orders of magnitude higher than for BS1. This effect is ascribed to the presence of the clearing electrode isolating ceramics in BS2, having photo desorption yields higher than electrodeposited Cu. This indicates that a large amount of photons are reflected back to the primary chamber after direct irradiation on the reflectors tip. As the photon dose increases, the normalized pressure decreases linearly with a slope of -0.5 and -0.9 for BS1 and BS2 respectively. In the transition from CFG1 to CFG2, the photon flux is incremented by 75%, distributed over irradiated areas which had not received direct photons before, and therefore limited photon conditioning. As a result, a pressure rise up to ~6×10^{-10} mbar/mA can be observed for both BS1 and BS2. As the photon dose increases at CFG2 the vacuum rapidly recovers to values in the range of 10^{-11} mbar/mA for BS1, while in the case of BS2 it remains above 10^{-10} mbar/mA. After irradiation in

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOZGBE5

CFG3 the changes in the dynamic pressure are negligible for both samples indicating that a pre-conditioning of the newly irradiated region took place during previous configurations.

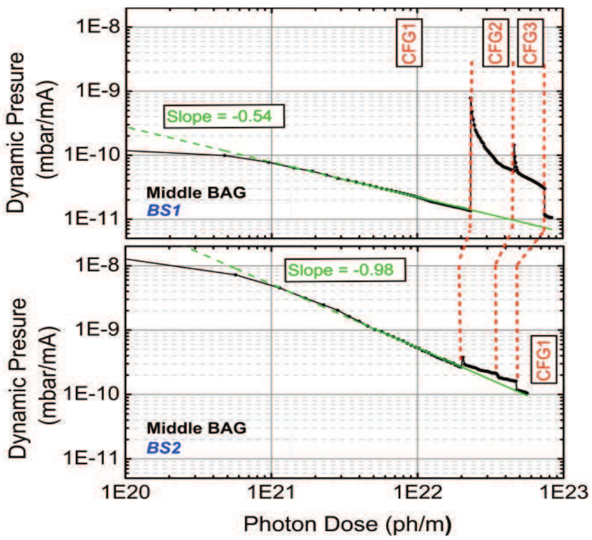

Figure 3: Evolution of the dynamic pressures normalized to the beam current for BS1 (Up) and BS2 (Down).

The SYNRAD+ and Molflow+ Monte Carlo codes [5] have been used to simulate the pressure evolution of BESTEX during irradiation of BS1 at two different photon doses, namely 3Ah and 9.5Ah.

Table. 2: Pressure Evolution During Irradiation of BS1. Comparison Between Experimental Results and Calculations

	3Ah		9.5 Ah	
	Exp	Calc	Exp	Calc
Middle (mbar)	5.7E-9	6.3E-9	3.0E-9	3.3E-9
Front (mbar)	2.9E-9	2.9E-9	2.0E-9	1.6E-9
Back (mbar)	2.0E-9	2.8E-9	1.0E-9	1.4E-9

The calculation of the dynamic pressure was an iterative process whereby the geometrical details and physical parameters of the 3D models used by the two codes were refined.

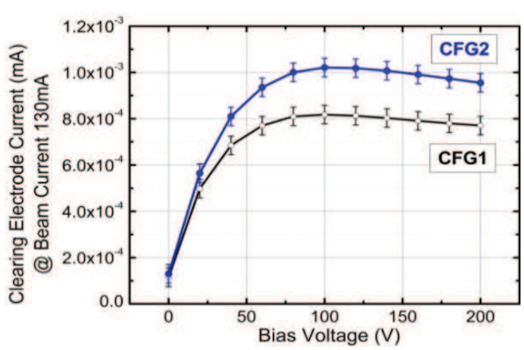

Figure 4: Results obtained on the clearing electrode at CFG1 and CFG2.

A comparison between experimental results and calculations is presented in Table 2. It can be observed that the relative discrepancy between experiments remains below 30% in all cases. The plot of Fig. 4 shows the photo electron currents measured on the clearing electrode of BS2, as a function of the applied bias voltage, for CFG1 and CFG2. The photo electron current was normalized to a KARA's electron beam current of 130mA. It can be observed how the amount of photo electrons generated is considerably larger as the photon flux increases from CFG1 to CFG2.

CONCLUSIONS

Two FCC-hh beam screen prototypes were irradiated under similar SR conditions to those of FCC-hh. The BS design tested so far show a satisfactory behavior under SR in terms of vacuum pressure. However the experimental results indicate a large amount of photons reflected towards the inner part of the BS after direct irradiation on the BS walls, which would potentially result into beam detrimental effects. The third prototype, equipped with a saw-tooth profile in place of the photon deflector tip, will be tested in the second half of 2018. It has also been confirmed that Monte Carlo simulations reasonably predict the evolution of the dynamic pressure with the photon dose, and this gives us confidence when using such simulations as a guide for the design of the whole FCC-hh [6]. Measurements on the photoelectron generation have been carried out providing an important input for e-cloud predictions [7].

ACKNOWLEDGEMENTS

This work was carried out within the framework of the EuroCirCol project WP4.6 Measurements on cryogenic beam system prototype. The authors wish to acknowledge the work of the CERN and KARA technician teams.

REFERENCES

[1] https://fcc.web.cern.ch/eurocircol/Pages/default.aspx

[2] M. Benedikt, "FCC-hh Hadron Collider – Parameter Scenarios and Staging Options", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, paper TUPTY062.

[3] Oswald Gröbner, "Dynamic outgassing", CERN-OPEN-2000-275, 1999, https://cds.cern.ch/record/455559

[4] F. Perez, "FCC-hh beam vacuum concept (I): BS design, tests and feasibility", FCCweek'18, Amsterdam, The Netherlands.

[5] Roberto Kersevan, Marton Ady, Molflow+ and Synrad+ website, url: cern.ch/molflow, CERN (April 2018), https://indico.cern.ch/event/656491/contributions/2947257

[6] I. Bellafont et al., "Photon tracing and gas-density profiles in the FCC-hh", *in Proc. FCC Week 2018 Conf.*, Amsterdam, 2018, https://indico.cern.ch/event/656491/contributions/2938813/

[7] L. Mether, "Electron cloud", *in Proc. FCC Week 2018 Conf., Amsterdam*, 2018, https://indico.cern.ch/event/656491/contributions/2923529/