29th Linear Accelerator Conf. LINAC2018, Beijing, China JACoW Publishing
ISBN: 978-3-95450-194-6 doi:10.18429/JACoW-LINAC2018-MOPO037

SRF GUN DEVELOPMENT AT DESY

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Abstract

A future upgrade of the European XFEL (E-XFEL) foresees an additional CW operation mode, which will increase the flexibility in the photon beam time structure [1–3]. One of the challenges of this operational mode is the need for a CW operating photo injector. We believe that using an SRF gun is the preferred approach as the beam parameters of normal conducting pulsed guns can be potentially met by SRF guns operating CW. For more than a decade DESY, in collaboration with TJNAF, NCBJ, BNL, HZB and HZDR, has performed R&D to develop an all superconducting RF gun with a lead cathode. In the frame of E-XFEL CW upgrade feasibility studies, the SRF-gun R&D program gained more attention and support. Within the next few years we would like to demonstrate the performance of the all superconducting injector required for the E-XFEL upgrade. The selected approach offers advantages w.r.t. the cleanliness of the superconducting surface, but requires a complete disassembly of a cryostat and stripping the gun cavity in a clean room to exchange the cathode. Thus it is practical only when the life time of the cathode is at least several months. In this paper we present the actual status of the R&D program, next steps and the longer term plans.

INTRODUCTION

At present, the high brightness beams required for the E-XFEL are reliably generated by normal conducting (NC) pulsed RF gun technology [4]. The NC CW gun technology developed by LBNL has been chosen as baseline for LCLS-II, operating CW, because SRF guns have not yet demonstrated reliable operation [5]. In contrast to LCLS-II the schedule of the future upgrade of the E-XFEL permits some development time to demonstrate reliable operation of SRF guns. Table 1 contains a comparison of the basic parameters of the three technologies.

ALL SUPERCONDUCTING GUN

RF guns are commonly first installed and aligned to the subsequent accelerator components before inserting cathodes via cathode insertion systems. This approach permits a quick exchange of cathodes but faces challenges at ultra-clean superconducting (SC) cavities w.r.t. cathode heating, cathode lifetime, field emission and multipacting. R&D is still required and ongoing, e.g. performed at HZDR [6–8] and HZB [9–11]. Work on SRF guns performed elsewhere can be found in [12].

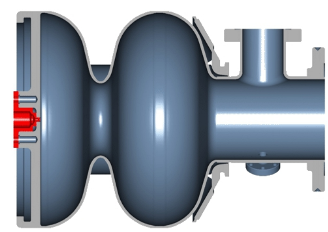

Figure 1: All superconducting gun with a plug (red) with lead cathode screwed into a hole on the cavity backside.

Since more than a decade DESY in collaboration with TJNAF, NCBJ, BNL, HZB and HZDR performs R&D to develop an all superconducting RF gun, e.g. see [13–17]. The recent design foresees a plug with a lead cathode screwed in a clean room into a hole on the cavity backside and sealed with indium, Fig. 1. Doing so, the cavity can be cleaned after the cathode insertion, and possibly lost cathode particles should not heat and quench the cavity, as they are all superconducting. In contrast to setups with cathode insertion systems, exchanging cathodes requires a complete disassembly of the cryostat and bringing the gun cavity back into the clean room. Consequently, this approach requires reasonable long cathode lifetimes above 100 days.

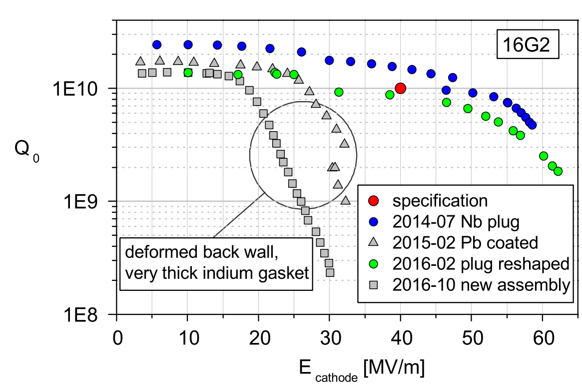

Figure 2: Promising vertical test results of the first prototypes of an all superconducting gun.

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Table 1: Photocathode Gun Technology Providing High Brightness Beams

Design beam parameters	Unit	CW SRF Gun for European XFEL	APEX CW Gun (NC) for LCLS-II	Pulsed NC Gun at European XFEL
bunch train duty cycle	[%]	100	100	0.6
beam current	[μA]	up to 25	up to 60	up to 27
bunch repetition rate	[kHz]	1000 to 100	620 to 100	up to 4500
bunch charge	[pC]	20 to 250	10 to 300	20 to 1000
transverse emittance	[μm]	0.4 to 0.8	0.2 to 0.6	0.2 to 1.0
beam energy at gun exit	[MeV]	3	0.75	5.1
RF parameters				
operation frequency		3 GHz	186 MHz	1.3 GHz
accelerating gradient	[MV/m]	21	19.5	31
electric peak (cathode) field	[MV/m]	40	19.5	60
RF inout power		750 W	about 100 kW	about 42 kW

Vertical tests of the first prototype SRF Gun cavities with cathode plugs called 16G1 and 16G2 performed at DESY [18] showed promising results with world record gradients of up to 60 MV/m at the cathode, Fig. 2. This was achieved with buffered chemical polishing (BCP) surface treatment of 16G2 performed at JLAB. The mechanical instability of the back wall required very thick indium gaskets and degraded the performance of this prototype.

At BNL we measured the quantum efficiency (QE) of lead cathodes, Fig. 3 and [15, 19], and at HZDR we examined the lifetime by irradiating a lead cathode over 550 hours [20]: The QE is sufficient for the specified bunch charge using an industry built laser. So far, we didn't observe a degradation of the QE over time.

TEST WITH BEAM

The tests performed so far indicate this type of SRF gun may work as needed. Nevertheless, the next required step is the demonstration of a sufficiently long lifetime of the cathode irradiated with a laser in a cavity operating at the design gradient and generating electron bunches with charge up to 250 pC. We choose this as our goal for the next years, after finalizing the construction and commissioning of the E-XFEL.

This system test will be performed in one of tests stands used for series module testing during the E-XFEL construction phase. New SRF gun cavities with improved design where built. In addition, some other components need to be developed, constructed and purchased. These are a cryomodule, housing the SRF cavity and a cold beamline with solenoid magnet together with the cryogenic supply of such a module. Power couplers and a power rf source for CW operation need to be adapted. A cathode laser, a laser beam line and a mirror chamber for bringing the laser beam into the beam line is required, plus some beam diagnostics and a small beam dump.

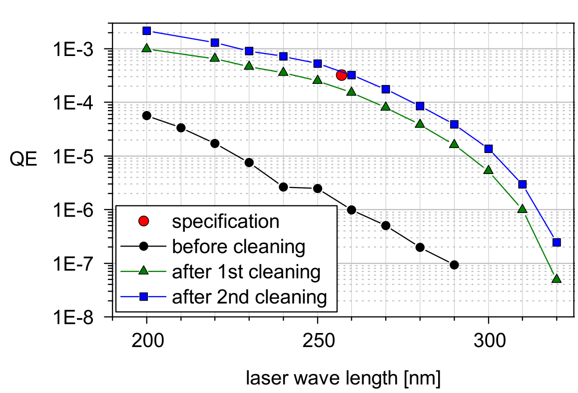

Figure 3: At BNL measured QE of DESY lead cathodes: before laser cleaning at 248 nm, after 1st cleaning applying 1000 shots with 0.06 mJ/mm^2 each, after and 2nd cleaning applying 10000 shots the QE specification of 3.2 10^{-4} at 257 nm was met.

COMPONENTS AND DEVELOPMENTS

In spring 2017 we built together with industry two **new SRF gun cavities** (16G3 and 16G4) with improved mechanical design of the back wall and cathode plugs. It was first validated by a mechanical model and includes stiffening ribs and titanium thread inserts. New auxiliaries like handling frames for the clean room and the chemical surface treatments were designed and built.

At DESY we have well-established procedures for the **surface treatment** of single- and nine-cell SRF cavities where acid and water flows through two big holes of the beam pipes at both ends. In contrast, the SRF gun cavities have one beam pipe and opposite the tiny hole for the cathode plug which in addition needs to be protected from the acid for keeping the design value of the diameter. R&D for the SRF gun recipe and treatment has been performed and is still ongoing. This includes the adaptation of the electropolishing (EP) apparatus and the design of new EP cathodes. A new high pressure rinse (HPR) nozzle for optimal cleaning

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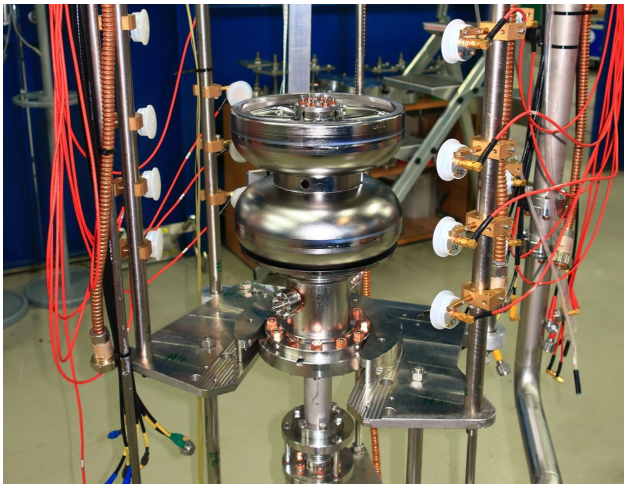

Figure 4: The new SRF gun cavity 16G3 in the insert ready for a first vertical test.

of the half-cell and avoiding impacting the cathode area is under construction. Acrylic glass models are ordered to study the HPR. In autumn 2017 EP and HPR was applied to the new SRF gun cavities and lead coated niobium cathode plugs were installed.

End 2017 and beginning 2018 we performed vertical tests of 16G3 and 16G4 at temperatures of 2 K, 1.8 K and 1.6 K applying normal cool down and slow cool down (from 13 K with ap. −0.1 K/min) for flux expulsion. In all cases the maximum gradients were below specification. There was no field emission. Second sound data was taken and first analysis performed. Obviously the surface treatment was not optimal. There are rough areas at the cavity surfaces visible.

Surface removal by buffered chemical polishing (BCP) may be less sensitive on the cavity geometry and was successful applied at the first two cavities, see above. Therefore, BCP (removal of 110 to 140 µm) at industry followed by a so-called flash EP (removal of 10 to 40 µm) at DESY will be applied next. The subsequent vertical tests are panned before End 2018.

We investigate different types of **cathodes and cathode plugs**. These are lead coated niobium plugs, bulk lead disks on niobium plugs and bulk lead plugs. The focus of the R&D is on the preparation of the niobium plugs before the coating, the lead coating performed at NCBJ and the clean room compatibility. First bulk lead plugs have been assembled to the mechanical model of the cavity back wall and leak tests performed at 2 K.

A **cryo-module** surrounding the SRF gun cavity and a cold beamline with solenoid magnet and other cold components is under development and construction. For future flexibility we decided HZDR and HZB cavities with their cathode exchange systems should also fit in. Special features are the ability to align the gun cavity and beam line when the module is cold, likewise the (cold) solenoid. There is a common interest on such a flexible platform for testing different SRF gun designs from HZDR, HZB and DESY. We coordinate design items at regular meetings with the relevant colleagues of all three laboratories.

We purchased an industry built laser similar to the ones already used at DESY as **cathode laser**, e.g. [21]. It consists of an infrared laser (1030 nm) whose light (average 20 W) is converted by a exchangeable conversion unit to the ultraviolet at 257 nm with a tunable pulse length from 300 fs to 15 ps and 2 W average power. One conversion unit is optimized for beam operation at a repetition rate up to 1.13 MHz, the other one for 100 kHz for laser cleaning of the cathode. The laser will next be installed in the laser laboratory adding a mirror chamber, a dummy beamline and a model of the SRF gun cavity back wall. We foresee QE measurements of the lead cathodes and studies for scanning the cavity backside to locate the cathode.

Other components required for the system test with beam are either already available and may need to be integrated into the setup and test stand, like the RF power source, or still need to be developed, constructed and purchased. Just started beam dynamic examinations are needed for the design, e.g. before deciding on a solenoid magnet.

SUMMARY AND OUTLOOK

First component tests of an all superconducting RF gun showed promising results. SRF gun cavities surpassed the required gradients in vertical tests, the QE is sufficient for the specified bunch charge and did not degrade within 550 hours of irradiation. The next step is the demonstration of a sufficiently long lifetime of the cathode irradiated with a laser in a cavity operating at the design gradient and generating electron bunches. We stated working on this goal which we plan to achieve within the next few years. In the successful case the setup of an injector operating CW in the second injector tunnel of the E-XFEL will follow. It will consist of the gun, L-band and third harmonic SRF modules and all the other beam line components and used for testing accelerator components operating CW.

ACKNOWLEDGEMENTS

The authors acknowledge the significant contributions from numerous colleagues at all institutes joining the effort for an all superconducting RF gun. Many people from industry contribute to this effort as well.

REFERENCES

[1] J. Sekutowicz *et al.*, *PRST AB* 8, 010701 (2005)

[2] J. Sekutowicz *et al.*, in *Proc. FEL2013*, paper TUOCNO04

[3] R. Brinkmann *et al.*, in *Proc. FEL2014*, paper MOP067

[4] F. Stephan *et al.*, *PRST AB* 13, 020704 (2010)

[5] J. F. Schmerge *et al.*, in *Proc. FEL2014*, paper THP042

[6] A. Arnold *et al.*, *NIM* A 577 (2007) 440–454

[7] A. Arnold and J. Teichert, *PRST AB* 14, 024801 (2011)

[8] J. Teichert *et al.*, *NIM* A 743 (2014) pp.114–120

ISBN: 978-3-95450-194-6 doi:10.18429/JACoW-LINAC2018-MOPO037

[9] A. Burrill *et al.*, in *Proc. IPAC2014*, paper WEPRI005

[10] A. Burrill *et al.*, in *Proc. IPAC2015*, paper WEPMA011

[11] A. Neumann *et al.*, in *Proc. SRF2015*, paper THPB026

[12] J. Sekutowicz, SRF2015, paper THAA02

[13] A. Neumann *et al.*, in *Proc. IPAC2011*, paper MOODA03

[14] M. Schmeißer *et al.*, in *Proc. IPAC2013*, paper MOPFI002

[15] R. Barday *et al.*, *PRST AB* 16, 123402 (2013)

[16] J. Lorkiewicz *et al.*, *Proc. SPIE*[0] Vol. 9662 (2015) 966233

[17] R. Nietubyc *et al.*, *NIM* A 891 (2018) 78–86

[18] D. Kostin *et al.*, in *Proc. SRF2015*, paper THPB056

[19] J. Smedley, T. Rao, and J. Sekutowicz, *PRST AB* vol. 11, pp. 013502, 2008

[20] J. Teichert *et al.*, EuCARD-2 report 12.9, 2016

[21] B. Marchetti *et al.*, in *Proc. IPAC2017*, paper TUPAB040