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STATUS OF THE ALL SUPERCONDUCTING GUN CAVITY AT DESY

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Abstract

At DESY, the development of a 1.6-cell, 1.3 GHz all superconducting gun cavity with a lead cathode attached to its back wall is ongoing. The special features of the structure like the back wall of the half-cell and cathode hole require adaptations of the procedures used for the treatment of nine-cell TESLA cavities. Unsatisfactory test results of two prototype cavities motivated us to re-consider the back-wall design and production steps. In this contribution we present the status of the modified cavity design including accessories causing accelerating field asymmetries, like a pick up antenna located at the back wall and fundamental power- and HOM couplers. Additionally, we discuss preliminary considerations for the compensation of kicks caused by these components.

INTRODUCTION

The photo injector of the European x-ray free electron laser (E-XFEL) consists of a normal conducting radio frequency (RF) gun operating with pulsed RF resulting in high accelerating fields. Bunches with moderate charge (20 pC to 1 nC), small transverse emittances (0.1 to 1 µm) and a high beam energy (6.1 MeV) are provided to the subsequent accelerator [1].

Superconducting radio frequency (SRF) guns have the potential to provide bunches with similar parameters (20 to 250 pC at 3 MeV) without additional accelerating stages to the subsequent accelerator. Hence, it is the preferred choice for a future additional CW operation mode of the E-XFEL [2–5]. Although substantial R&D has been performed in recent years resulting in SRF guns in operation [6–12], the potential of the technology is still not exploited sufficiently [13] for the use at the E-XFEL.

The classic approach of a photo injector uses a RF gun cavity in combination with a cathode insertion system. In the case of SRF cavities this setup still faces challenges w.r.t. multipacting, field emission, cathode heating and lifetime [14, 15]. SRF gun cavities with cathodes at a closed cavity back-wall should not suffer from such problems. But, only metallic and superconducting cathode materials can be used which have relatively small quantum efficiency (QE). Due to the moderate bunch charges required for the photon generation in the E-XFEL this is acceptable with the power available at lasers from industry [16]. At DESY we perform R&D in collaboration with TJNAF (Thomas Jefferson National Accelerator Facility, US), NCBJ (National Center for Nuclear Research, Poland), BNL (Brookhaven National Laboratory, US), HZB (Helmholtz-Zentrum Berlin, Germany) and HZDR (Helmholtz-Zentrum Dresden-Rossendorf, Germany) to develop such an all superconducting RF gun [17].

The obvious choice is the use of niobium as the cathode material. Unfortunately, the QE turned out being too low for existing laser systems [18]. But, the QE of lead is sufficiently high [19], it is also a superconductor and it does not degrade over periods examined so far [20]. First tests, coating the halve-cell back-wall of an SRF gun cavity (prototype called '16G1') with lead, were performed in 2008 [21, 22]. These cavities suffered from cathode surface quality problems [23]. A cathode plug which can be coated separately [24, 25] or even produced from bulk material, screwed into a hole at the cavity back wall, was the next attempt [26, 27]. The first prototype cavity (16G2) of this kind achieved the required gradients in vertical tests in 2012. Vertical tests were repeated in 2014 [28] and 2016. Unfortunately, cavity 16G2 soon suffered from mechanical problems and deformations at the back-wall giving rise to the prototype cavities 16G3 and 16G4 [17].

STATUS OF GUN CAVITIES

In spring 2017 we built together with industry the two SRF gun cavities 16G3 and 16G4 with mechanically reinforced backside and improved cathode plug design, Fig. 1. The work included new auxiliaries like the cavity handling frames; work at the high pressure rinsing (HPR) nozzle and the electro polishing (EP) cathode. After the fabrication of the cavities by industry we performed the chemical surface treatment at the DESY facilities starting with a main EP at 16G3. Optical inspection revealed flat and shiny dents following the geometry of the nozzle arrangement of the EP cathode give rise to change the nozzle inclination, which turned out being not optimal either. In both cases some granular surface areas at the backsides remained after the fine EP. Applying otherwise the recipe used for the XFEL 9-cell cavity production [29] we verified in late 2017 the cathode plug sealing is leak tight at 2 K and the backside mechanically stable. Performing vertical RF tests, both cavities did not perform as expected, Fig. 2. They showed a massive increase of thermal losses at accelerating gradients above 10 MV/m under all of the following test conditions: at temperatures of 1.8 K and 2 K, with lead coated and uncoated niobium cathode plugs and applying fast and slow cooldown [30]. We used the second sound method [31, 32]

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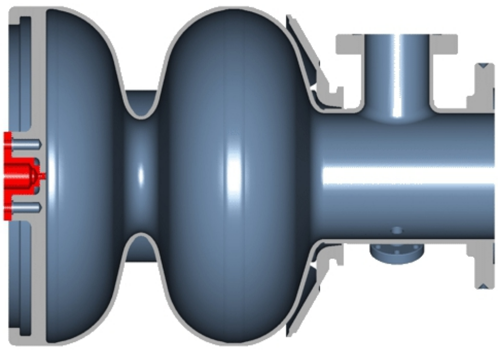
Figure 1: All superconducting gun with a plug (red) with lead cathode screwed into a hole on the cavity backside

for examining the quench location. The cavities quenched in the equator region of the full cell at gradients between 11 MV/m and 14 MV/m without showing field emission (FE).

In general, the surface removal by buffered chemical polishing (BCP) depends much less on the cavity geometry than the removal by EP. Hence, we decided performing BCP at 16G3 and 16G4 together with industry. This required the development of special connections to run in and out the acid, tightening the cathode hole reliably preventing acid flowing through, and a special cavity handling frame. Late autumn 2018 BCP was applied (removal of about 100 µm at 16G3 and 16G4 smoothing out the cavity back wall surfaces as expected. Unfortunately, the performance of both cavities measured end 2018, beginning 2019 did not improve; they still showed a massive decrease of the quality factor at accelerating gradients above 10 MV/m under all test conditions: 1.8 K and 2 K, plugs with and without lead coating, fast and slow cooldown. The quench spots remained nearly unchanged; likewise the maximum gradients and we did not observe FE. These results led us to three main hypotheses as possible causes: issues during fabrication, back wall material problems and the back wall geometry causing insufficient cooling.

Reviewing the cavity fabrication together with the manufacturer didn't reveal deviations from procedures or any suspicious action. The back walls of the cavities where cut out of a thick ingot disk of large grain niobium and mill-cut to the final geometry. We performed RRR measurements and asked a company for a gas analysis of two niobium probes cut out of the ingot disk adjacent to the area used for the back-walls. The measured RRR of 294 is well within specification, likewise the contents of oxygen (2.53 ppm), nitrogen (4.24 ppm) and hydrogen (0.23 ppm). All these values are in agreement with the values provided by the niobium supplier. Further in the future we consider material examinations cutting off parts from the cavities to verify nothing happened to the niobium after providing it to the cavity manufacturer.

Simulations of the cooling at different back wall areas confirmed less cooling of the inner RF surface at areas of thicker niobium for stiffening and for the threads used for fixing the cathode plug. At 16G4 we performed vertical

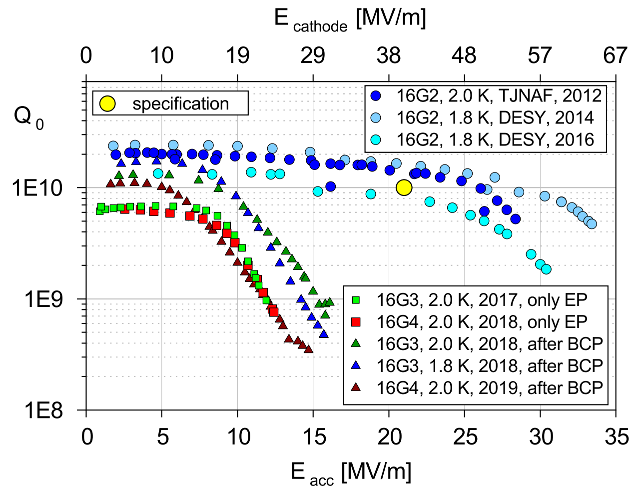

Figure 2: Vertical test results of the prototypes 16G2, 16G3 and 16G4 of an all superconducting gun.

tests with temperature sensors at the back-wall close to areas of thicker niobium and areas with the usual thickness of SRF cavities of about 2.7 mm (Fig. 3). The measurements showed also higher temperatures near the areas of thicker niobium and near the cathode where the RF field distribution should cause less heating as compared to the equator region. Tests with rotated temperature sensor arrangement showed the same results making local defects at the inner cavity surface unlikely. At 16G3 we drilled holes in the areas of thicker niobium to mount temperature sensors inside and study the temperature behavior inside these areas. The plug temperature is measured with a temperature sensor inserted in the small backside hole of the plugs.

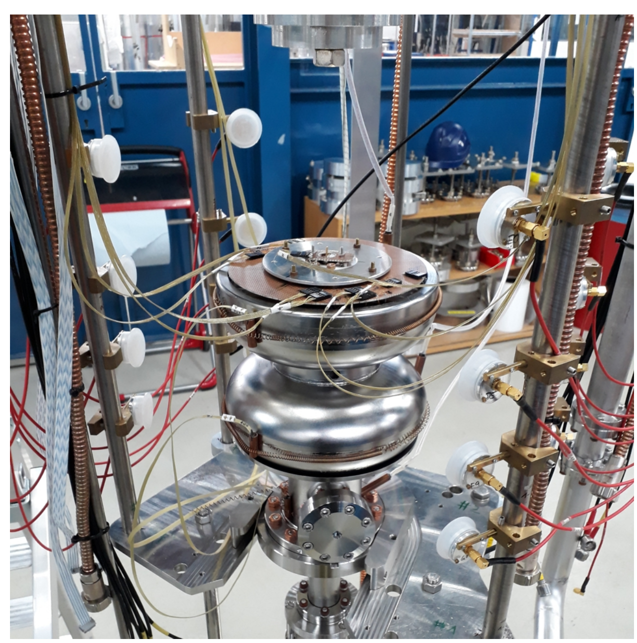
Figure 3: Cavity 16G4 equipped with temperature sensors.

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To study the potential influence of the cathode plug and the cathode plug cooling, we prepare further tests with special cathode plugs: out of pure niobium, out of Copper and also out of pure niobium but with cathode surface area retracted almost to the plug sealing area.

As preventive action we reviewed RF surface quality checks before back wall welding: The eddy current examination will not cover the equator region due to the back wall rim. X-ray imaging may be an option; the spatial resolution of X-ray tomography is too low.

BACK WALL OF SHEET MATERIAL

A well performing SRF gun cavity with an ideal cooled back wall will be a major experimental indication for the hypothesis that poor cooling at the thick back wall areas plays a role for the poor performance of 16G3/4. Therefore we ordered the two new cavities 16G5 and 16G6. They are copies of 16G3/4 but with a back wall made of 3 mm niobium sheet material stiffened by a niobium u-profile welded onto the backside and the rim produced by spinning. These cavities will also be used to examine surface treatment techniques. Leaving out the cathode hole simplifies the handling. We expect a better understanding of the surface removal by BCP performing ultra-sonic measurements of the back wall thickness. These cavities may also serve for studies on fine EP treatments.

FUTURE DESIGN CONSIDERATIONS

We expect the three cavities 16G7 to 16G9 to be the first cavities usable for beam generation. Hence, before deciding on the back wall design optimized for both cooling and mechanical stiffness, we will wait for test results from the cavities 16G5/6. Nevertheless, we are already purchasing the niobium needed for these three cavities.

Investigations on whether HOM couplers for HOM damping are required are still ongoing. In contrasts to applications asking for high beam current, we are satisfied with moderate beam current but the beam quality is of particular importance.

Transverse kicks caused by the power coupler also spoil the beam quality. The beam can be shielded by an additional inner beam tube. For being efficient enough we found the length of the usual beam tube of our SRF cavities is much too short. Presently we are investigating two other measures: A can-like structure opposite the power coupler port cause a kick itself which can compensate the coupler kick. The longitudinal position of the power coupler port can be optimized to reduce the coupler kick action significantly.

The focusing of electrons just leaving the cathode area will be better with a slightly longer half-cell. In addition, retracting the cathode plane somewhat from the back wall plane improves the beam focusing, too. Both will be implemented at the cavities 16G7 to 16G9.

We foresee ports for pick up antennas in the back wall of the new SRF gun cavities for better RF control. The radial position is optimized to minimize the disturbance of the RF field by the pick-up antenna.

SUMMARY AND OUTLOOK

Initial 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 does not degrade over periods examined so far. The design of a mechanically stable SRF gun cavity with a leak tight cathode plug directly screwed to the back wall turned out being more challenging than expected. The special design feature of the half cell with closed back wall requires the adaptation of many techniques used for the fabrication and treatment of single and 9-cell accelerating cavities. Furthermore, the design of the back wall seems requiring special attention w.r.t. cooling and heat transfer. The time needed for the fabrication of superconducting cavities and also the time needed for the development of new and the adaptation of existing infrastructure to the special needs of SRF gun cavities determines the progress. Nevertheless, we are confident overcoming these challenges. It is time to address additional design issues like the need for power coupler kick compensation, the possibility for HOM suppression, and the pick-up antenna in the back wall for improved RF control.

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