DRY-ICE CLEANING OF RF-STRUCTURES AT DESY

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Abstract

Dry-Ice cleaning is today a well-established cleaning method in matters of reducing harmful dark current and field emission in copper RF-structures like RF-Guns such as for the European XFEL, FLASH and REGAE. This led to the idea to clean longer RF-structures, in particular 3GHz transverse deflecting structures for the European XFEL. We developed a cleaning device with the capability to clean up to 2 m long structures in horizontal position with an inner diameter of not more than 40 mm. Furthermore this device allows cleaning 9-cell TESLA-type Nb-cavities as well. A report of the technical layout and results of RF-tests will be given.

INTRODUCTION

For the past ten years cleaning of copper RF-structures such as RF-photo Guns at FLASH and PITZ with carbon dioxide dry-ice snow cleaning became a well-established method to reduce harmful dark currents emitted from particles raised from the inner surface of the copper structure [1]. It could be shown that dry ice cleaning reduces dark currents by an order of magnitude. The present dark current of the Gun 3.1 at FLASH is about 5µA while running with operating parameters, whereat the limiting value is 20uA. Former cleaning methods, like High Pressure Water (HPWR) or alcohol rinsing led to dark currents in a range of hundreds µA. The very good achievements resulted in cleaning RF-Photo Guns for REGAE and the EXFEL as well. Since the 3 GHz Copper REGAE-Gun was never cleaned with liquids like water or alcohol, we do not have a direct comparison here. But the subsequent RF-conditioning was done very fast. It took no longer than 2 weeks to reach a gradient of 100MV/m [2]. Measurements at the EXFEL Gun, while running under operating parameters, led to dark currents in the range of 20µA.This altogether brought us to the idea, to clean more challenging structures from a cleaning point of view, such as Transverse Deflecting Structures (TDS) [3] for the EXFEL.

Originally the dry ice snow cleaning project was started to show if full equipped superconducting Niobium cavities could be cleaned in that way in addition and as a final step after a HPWR. With the original cavity cleaning device, it was only possible to clean 1-cell test cavities, whereas the new setup allows us to clean 9-cell 1.3 GHz Niobium cavities in horizontal position.

CARBON DIOXIDE DRY-ICE SNOW CLEANING

The functional principle and a detailed description of the cleaning mechanism are described in [4]. Liquid carbon dioxide flows at high pressure (50 bar) through a special formed nozzle, expands at the outlet and forms a dry-ice/gas mixture with a ratio of 45 % snow. This mixture is surrounded by a Nitrogen-gas stream, with 15 bar pressure, to ensure a proper acceleration of the jet. The cleaning takes place by thermal-mechanical and chemical forces: Breaking up the contaminations by shock-freezing, applying high shearing forces due to high momentum of the snow crystals and increasing of the volume by a factor of 500 after sublimation of the snow and acting as good chemical solvent for hydrocarbons and silicones.

CLEANING OF RF-PHOTO GUNS

The vertical cleaning device used for RF-photo Guns installed at FLASH, EXFEL and REGAE is shown in Fig.1.

Figure 1: Set-up for RF-Photo Guns.

Here the Gun moves up and down while it rotates. The cleaning lance stays in a fixed position while the nozzle can be moved continuously from horizontal to vertical orientation to ensure that the overall inner surface of the Gun will be cleaned. A more detailed set of cleaning parameters can be found in [5].

CLEANING OF TRANSVERSE DEFLECTING STRUCTURES FOR EXFEL

The requirements for operating RF – structures under ultra-high vacuum conditions are i.a. particle free vacuum and a short conditioning time. Cleaning such components with fluids, implicates the difficulty to get rid of fluid residues after the cleaning process. In certain cases complex geometries inside the structures, like trapped volumes, prevent the draining of fluids. Anyway the draining can only be done in vertical orientation and moreover in a

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clean-room which often do not have the required headroom.
The positive experiences we made while cleaning RF-Photo Guns brought us to the idea to use dry-ice-cleaning for the TDS as shown in Fig.2. For this task we developed together with the Fraunhofer Institute (IPA) in Stuttgart, Germany, a device to clean longer structures in horizontal direction. The challenge was to construct a cleaning lance with a sufficient overall length without bending. Since the long version of the TDS is more than 1700 mm long, the lance should have a length of about 2000mm.

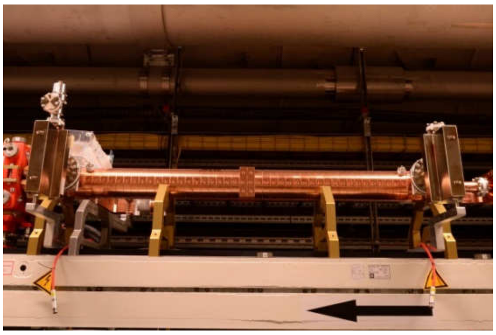

Figure 2: Transverse Deflecting Structure installed in EXFEL.

Technical lay-out of the new device

Using only one lance with such length bear the risk that the lance starts to resonate and due to oscillation amplitudes of several millimetres, it eventually will damage the inner surface. Since the inner diameter of the TDS is not more than 40mm and the lance according to the construction cannot be smaller than 32mm in diameter, the distance between lance and surface is very small. To avoid these problems, we build a system using two lances coupled in the middle with a bayonet coupling to ensure stability regarding to the oscillations. The lances are built as a tube to contain the gas media supplies and bearing a head with the nozzles and the coupling (Fig.3).

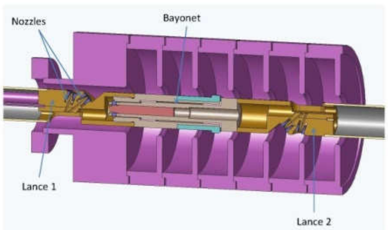

Figure 3: Drawing of coupled lances inside the TDS.

We decided to keep the lances in a fix position and move the TDS on a linear guide unit back and forth while it rotates. This implicates that we have to move the TDS over one lance before coupling. Since the lances (tubes) are almost 2.4 m long and carries the head with nozzles and coupling, the bending at the end is several millimetres. Here we ensured a pretension of the tubes using an adjustable wire inside of the tubes, fastened at the head, so that the lances stay in perfect horizontal position. The lances have two nozzles each with different jet angles to guarantee a cleaning of the overall inner surface (Fig. 4).

Figure 4: Two coupled lances with 4 nozzles.

The entire installation as shown in Fig. 5 is constructed with commercially available aluminium construction profiles. The dimensions of the set-up are app. 6m x 1.0m x 0.7m. The essential part is an over 4m long motor driven linear guide unit which moves the TDS back and forth. The TDS rotates via a motor driven roller drive which also acts as support for the TDS. Altogether the set-up includes 3 supports. These supports are made of 2 rolls each which can be adjusted in the height. Thereby we can guarantee that the beam axis of the TDS is in the height position of the cleaning lances. One lance is in a fix position mounted on the set-up, the other one can be moved sideways and in the longitudinal position for putting the TDS on the device and for coupling/decoupling the lances. Each lance has its own gas media supply which are connected to our CO_2 and N_2 supplies.
Furthermore we mounted our 6 kW infra-red heater in a position near the nozzles to avoid a too strong cooling of the TDS. Moreover we have to mention that an adequate electrical grounding is necessary to avoid electric charge. During pre-tests we observed sparks between lance and the set-up from time to time.

Figure 5: Entire new Installation with mounted dummy pipe.

Cleaning process of the TDS

During several pre-tests done with a simple pipe used as a dummy with a corresponding inner diameter, we preset the feed rate of the linear guide and the rotation of the

TDS to ensure that the entire surface would be hit by the jets. In total we cleaned three TDS, one short (700 mm) and two long versions (1700 mm). Each structure was cleaned in 2 runs, i.e. the dry-ice jet cleaned the surface in total 4 times. Each run lasted 0.5 h (short) respectively 1.5 h (long). During cleaning the structures will cool down very fast close to the sublimation point of the carbon dioxide. Since a distinct temperature gradient is a major property of the cleaning effect, we had to heat the structures from outside with the 6 kW infrared heater. Nevertheless a frosted outer surface appeared in a while, but the fast vacuum pumping-speed first time after cleaning and the fast commissioning of the short TDS in the EXFEL-tunnel pointed to an adequate cleaning process, even if the thermal effect is not fully present.

CLEANING OF 9-CELL NB CAVITIES

As we built our new cleaning set-up as a multi-purpose device with regards to clean rotation-symmetric structures with different dimensions and beam pipe diameters we decided to clean an EXFEL-type 9-cell Niobium Cavity as well.

Dry-Ice cleaning tests with 1-cell Niobium Test cavities years ago showed that we in principle can reach results compared to HPWR at least [5]. However there were some major differences in the cleaning process compared to the process back then. First of all the overall cleaning time per cell was reduced limited by the immense consumption of nitrogen. Cleaning one 9-cell cavity needs about 800 m^3 of nitrogen gas. By doubling the number of nozzles to four and a 9-time longer duration we just could perform two runs with one tank filling. To compare we cleaned a 1-cell cavity with 4 runs.

Usually a cavity assembly takes place in a cleanroom with vertical air flow combined with air recirculating, but due to technical and safety reasons we installed all dry-ice cleaning equipment in a cleanroom with horizontal airflow. In terms of particle-free assembling of a cavity a vertical flow is more or less necessary, but in terms of personal safety reasons a horizontal flow without air recirculation is not negligible. In that way we transport the hazardous carbon dioxide out of the cleanroom without reaching the maximum permissible value.

Cleaning process of a 9-cell Niobium Cavity

For this cleaning experiment we used an EXFEL-type cavity from the actual production. We cleaned the cavity with two runs. Although we also used the infra-red heater while cleaning, we purged the cavity with N_2 for 0.5 h after each run to avoid a condensation of humidity from the ambient air on the inner surface. During the following assembly of the mounting-parts, like blind flanges and feed troughs, we kept one lance inside the cavity blowing with N_2. In that way we produced a slightly overpressure avoiding an intrusion of particles into the cavity. The entire assembly was done with the cavity on the device.

Unfortunately our positive expectations after this first attempt could not be confirmed. The former maximum field-gradient of 31MV/m was reduced to 14MV/m limited by field emission already starting at 9MV/m. A trend of the Q (E)-curves from the last two tests of the cavity is shown in Fig. 6.

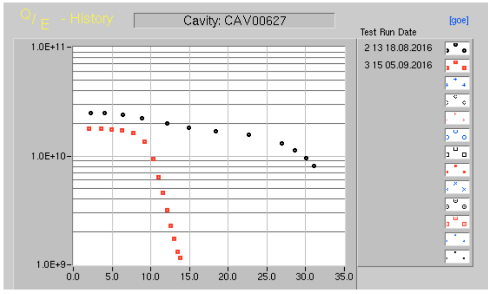

Figure 6: Q (E)-curves of the cavity
Before cleaning (black curve)
After dry-ice cleaning (red curve).

In spite of the bad test result of the cavity test, we assume that the dry-ice-cleaning method is applicable also, since 1-cell tests could prove that. There is clearly a need for optimizing in matters of assembling mounting parts directly on the device. Maybe the horizontal airflow of the cleanroom is a disadvantage at this point. Also inappropriate flow conditions in the area of the beam-tube flanges when cleaning here, makes a transport of particles towards the inside of the cavity eventually possible. This has to be investigated in future.

CONCLUSION

For cleaning RF-structures made of Copper the dry-ice-cleaning method is the proven and well established procedure. Reducing the number of removable particles results in a successfully reduction of undesired dark-currents. The absence of humidity or residues of fluids, compared to wet cleaning methods, leads to an obvious shortened commissioning time related to the vacuum. For longer RF-structures such as the TDS, cleaning in horizontal position is the most appropriate method.

Concerning the cleaning of the 9-cell Niobium Cavity we could show that the new cleaning device is usable for cavities as well. We could show that the cleaning process itself is working. In our opinion the bad RF-test result of the 9-cell Niobium Cavity was not caused by a non-proper cleaning but was rather related to a non-optimal handling and assembly of the cavity after the cleaning. For future tests we surely have to adopt the well-established assembly procedures for 9-cell Cavities [6].

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REFERENCES

[1] S. Schreiber, S. Lederer, ”Lifetime of Cs_2Te cathodes operated at the FLASH facility”, in Proceedings of FEL2015, Daejeon, Korea, August 2015, paper TUP042, pp 464 – 467.

[2] K. Floettmann, private communication, DESY, 2016.

[3] H. Huck et al, ”First results of commissioning of the PITZ Transverse Deflecting Structure”, in Proceedings of FEL2015, Daejeon, Korea, August 2015, paper MOP039.

[4] A. Brinkmann, J. Iversen, D. Reschke, J. Ziegler, ”Dry-Ice Cleaning on SRF-Cavities”, in Proceedings of EPAC 2006, Edinburgh, Scotland, June 2006, paper MOPCH154, pp 418 – 420.

[5] D. Reschke et al,” DRY-ICE CLEANING: The most effective cleaning process for SRF Cavities?” in Proceedings of SRF2007, Peking, China, October 2007, paper TUP48, pp 239 – 242.

[6] A. Matheisen, private communication, DESY, 2016.