

DRY-ICE CLEANING: THE MOST EFFECTIVE CLEANING PROCESS FOR SRF CAVITIES?

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Abstract

The dry-ice sublimation-impulse cleaning (DIC) technique using a two component ring jet has been proven as a highly efficient cleaning process for niobium and copper surfaces. The liquid carbon dioxide flows through a ring-type nozzle assembled in a purpose-built cleaning head, expands to form a dry-ice / gas mixture and is accelerated by the surrounding nitrogen. A set-up for the HORIZONTAL cleaning of single-cell niobium cavities has been successfully commissioned during the last years. A preliminary parameter set for effective final cleaning is established. Several cavities have been cleaned and tested without any detectable field emission up to 36 MV/m. As application of the DIC technique might result in additional cleaning potential for accelerator structures, an extension of the set-up and testing of nine-cell cavities is planned until mid of 2008. Furthermore, DIC was applied to the copper injector "gun" cavity for TTF/FLASH [1] recently. In order to reduce the dark current of the gun cavity, a vertical cleaning setup was developed and tested.

MOTIVATION

Despite substantial improvement of the surface preparation techniques during the last years, enhanced field emission imposes one major high gradient limitation on superconducting niobium accelerator structures. Also in normal conducting copper rf gun cavities used in FLASH and the future European XFEL [2] dark currents due to particle contamination are a severe limitation. Therefore, advanced final cleaning and handling procedures must be applied to avoid surface contaminations like particles, hydrocarbons, etc. and mechanical damages like scratches. In addition to the well-established final cleaning techniques, dry-ice cleaning offers additional potential. As proven by many measurements on flat niobium and copper samples dry-ice cleaning is effective for the removal of particles and field emission sites [3, 4, 5]. As a dry cleaning process, it allows the final treatment of horizontally assembled cavities with their power coupler as well as the treatment of water sensitive components, e.g. copper rf gun cavities.

EXPERIMENTAL

A detailed description of the cleaning mechanism and the experimental set-up for Nb cavities has been given in [5, 6, 7].

DIC acts on the contamination by a combination of thermo-mechanical and chemical forces. The former are created by three effects: embrittlement of the

contamination as a result of rapid cooling (shock-freezing), the tough pressure and shearing forces due to the high momentum of the snow crystals hitting the surface and the powerful rinsing due to the 500 times increased volume after sublimation. Particles down to 100 nm can be removed. Chemo mechanical forces occur, when high momentum snow particles hitting the surface partially are melting at the point of impact. In its liquid phase carbon dioxide is a good solvent for non-polar chemicals, especially for hydrocarbons and silicones. The cleaning process acts locally, dryly and without residues.

The cleaning effect can be monitored easily using surface and conventional air particle counters

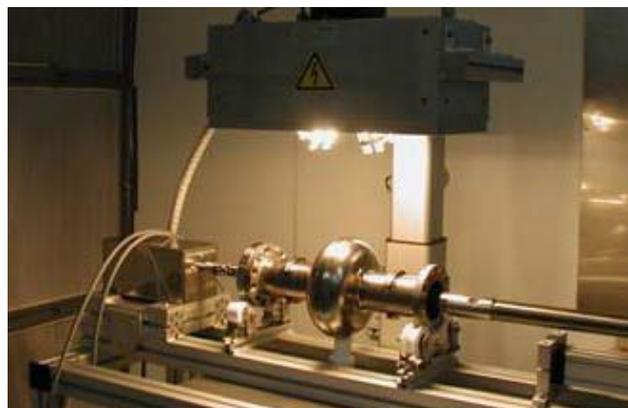


Figure 1: Set-up for Nb cavity cleaning with IR heater in upper rest position and horizontal nozzle system. The exhaust system (not visible) acts from the bottom close to the open cavity flange.

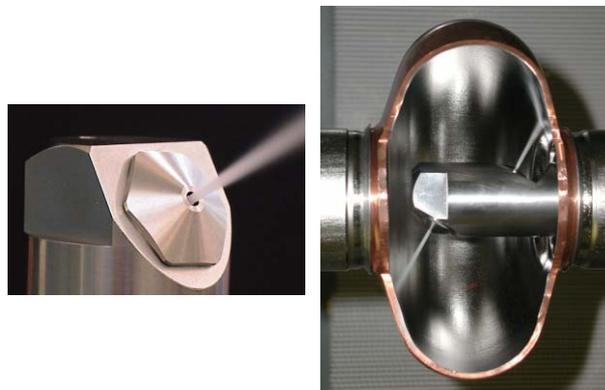


Figure 2: Nozzle system for Nb cavity cleaning

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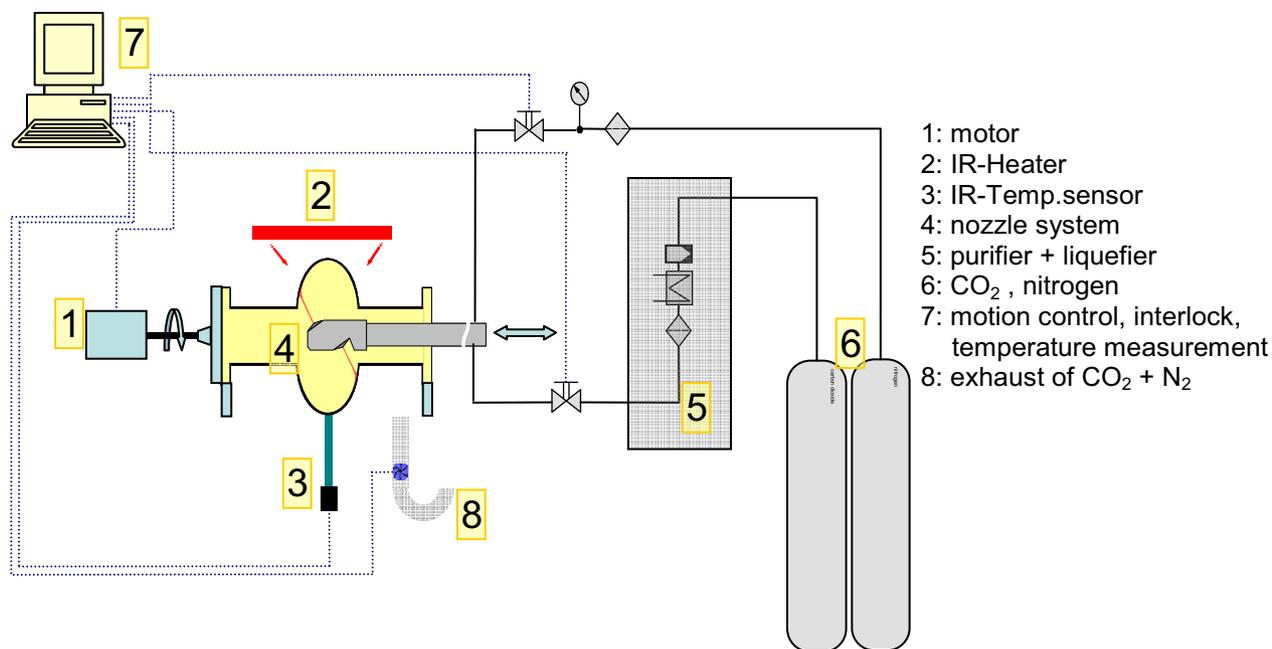


Figure 3: Schematic sketch of the dry ice cleaning system

The set-up allows horizontal cleaning of (1 – 3)-cell cavities (Figure 1). The key component of the system is a dedicated nozzle system (Figure 2). The CO₂ jet is surrounded by a supersonic nitrogen stream, which provides additional acceleration and focussing of the jet as well as a partial prevention of moisture condensation at the cleaned surface. A cooler/purifier unit liquefies the gaseous CO₂ and maintains a temperature of app. -15 °C at the extraction in order to keep the fraction of snow in the jet at app. 45 %. In order to ensure a high thermal gradient between cavity surface and snow jet as well as to avoid condensation, a dedicated IR heater system is used. A schematic sketch of the system is given in Figure 3.

During the last years the operational and cleaning parameters have been improved successively. In order to monitor the particle removal depending on the cleaning position, a commercial air particle counter is used systematically. The Nb cavity is cleaned with assembled top flange. Typically, three runs with a duration of app. 30 min. (single-cell cavity) each are applied followed by a final double-speed run with nitrogen only. Though previously thoroughly cleaned and not directly hit by the snow jet, the pick-up feedthrough could be identified as a significant source of particles, even after several DIC runs. Therefore, during the last DIC run the motion range of the snow jet is reduced. Finally, the cavity is mounted vertically to its support frame, the pumping port with rf antenna is assembled and the cavity with its flanges is leak checked.

The extension of the set-up in order to clean TTF nine-cell cavities without Helium tank is under preparation.

RESULTS ON NB CAVITIES

Recent encouraging results on single cell Nb cavities show no field emission in 3 of 4 tests up to 35 MV/m (Figure 4). In one test moderate field emission is present. The tested cavities are limited by quench at 33 – 35 MV/m. In a test series on one cavity (1DE11), between the tests the cavity outside is pre-cleaned before entering the cleanroom, vented with pure nitrogen under defined conditions, disassembled, dry-ice cleaned and assembled for the next rf test. DIC and assembly are performed as described above.

Confirming the excellent results on flat samples in one test series on a single-cell cavity the best performance is achieved after using DIC instead of the standard high pressure rinse (HPR) with ultrapure water as final treatment. As presented in figure 5 in the first test after HPR the cavity showed moderate field emission. A first attempt applying DIC with the previously used operation

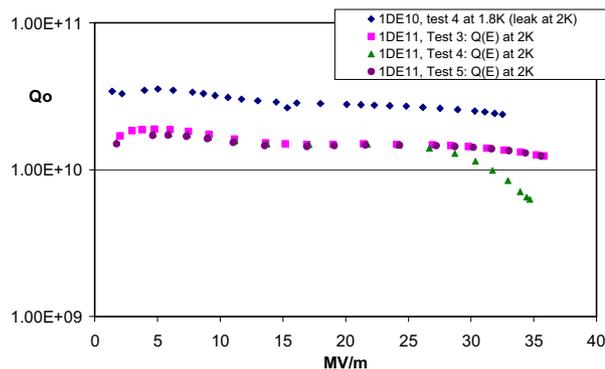


Figure 4: Q(E)-performance of the latest 4 DIC cleaned cavity tests

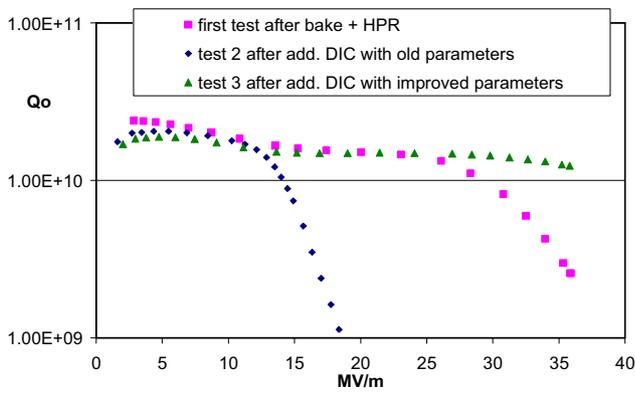


Figure 5: Q(E)-performance of one single cell cavity after HPR (test 1, pink), DIC with old parameters (test 2, blue) and DIC with improved parameters (test 3, green)

parameters in order to improve the cavity performance failed. The cavity was limited by strong field emission. After an additional DIC sequence using improved operation parameters, the cavity was free of field emission and limited by quench at > 35 MV/m.

Many rf tests of dry-ice cleaned cavities show processable multipacting in the typical field range between 15 – 21 MV/m. If this is significantly enhanced compared to HPR cleaned resonators needs to be clarified with more tests.

Within the very limited statistics on cavities no final judgement about the superiority of DIC or HPR can be given. Though more data on the efficiency of both cleaning techniques are necessary and helpful, it needs to be emphasized that DIC gives additional cleaning options instead of replacing HPR.



Figure 6: Vertical cleaning set-up for copper rf gun cavities

COPPER RF GUN CLEANING

In order to provide low dark currents in the gun cavity of the photo injector of FLASH and for the future European XFEL, a dedicated vertical cleaning set-up (Figure 6) was constructed, commissioned and recently started up. Compared to the previously applied cleaning using HPR, the risk of an objectionable oxidation of the sensitive rf surface is minimized. Remarkable is the new nozzle system with a 110° degree rotatable nozzle (Figure 7). This design is necessary in order to assure a complete and effective cleaning of the rf gun geometry, i.e. the surface close to the cathode and the first cell of reduced length. In order to avoid any particulate recontamination created by the motion of the nozzle, the nozzle system is exhausted.

The first gun cavity has been cleaned recently, and the cavity test is under preparation.

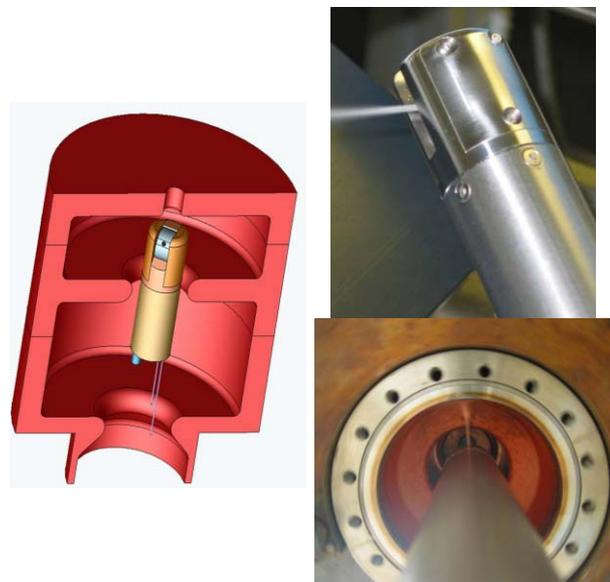


Figure 7: 3D-model of gun cavity with rotatable nozzle (left); rotatable nozzle (upper right); bottom-up view of the cleaning of the gun cavity (lower right)

OPEN TOPICS

Basically, DIC as a powerful and effective cleaning technique can be applied to a wide range of accelerator components in addition to rf cavities. Nevertheless, as comparatively new technique in our field, it requires more development and optimisation. A list of open topics with respect to cavity cleaning is given and briefly discussed below:

- What is the preferable design of the nozzle head? With the recently developed movable nozzle the jet can be always adjusted perpendicular to the surface ensuring the best possible cleaning effect. Two or more fixed nozzles may allow a faster cleaning, but increase the problem of humidity condensation (see below).

- The combination of cleaning parameters needs further investigation, in order to exploit the full potential of DIC. The most prominent parameters are
 - i) angle dependence of cleaning efficiency,
 - ii) cleaning efficiency depending on cleaning speed,
 - iii) cleaning efficiency depending on distance between nozzle and cavity surface,
 - iv) influence of nitrogen pressure on jet properties and cleaning.

A study of these parameters on intentionally and defined contaminated samples is under preparation, but funding is critical in the moment.

- In order to reduce consumption of CO₂ and moisture condensation, a smaller CO₂ capillary size in the nozzle combined with a high cleaning speed requires evaluation.
- The drive system of Nb cavity rotation has to be modified and improved in order to reduce the danger of particle contamination and allow cleaning of nine-cell cavities without and with Helium tank.
- Depending on the cavity type and the necessity of heating the cavity, the possible application of warm inert gas needs to be evaluated, especially for Nb nine-cell cavities with their He-tank.
- Based on the commissioning and first operational experiences, the mechanics and control of the gun cleaning installation are under improvement. The goal is an easy and reliable routine cleaning procedure of the gun cavities for FLASH and the European XFEL.

If the above mentioned extension of the existing set-up with respect to Nb nine-cell cavities can be realized successfully in the near future, the goal is an effective and simple cleaning facility for fully equipped nine-cell accelerator cavities with He-tank.

SUMMARY AND OUTLOOK

A set-up for the horizontal cleaning of single- to three-cell cavities is in successful operation. The present parameter set of DIC gives reproducible gradients of 35 MV/m in single-cell cavities with no or low field emission loading. The next step is the extension of the existing set-up to nine-cell cavities as soon as funding is available. The goal is a cleaning facility for fully equipped nine-cell accelerator cavities with He-tank.

An additional cleaning set-up for copper rf gun cavities has been commissioned successfully. A new nozzle system with 110° degree rotatable nozzle has been developed for effective surface cleaning of the complex surface geometry. The results of the first cleaning will be available in the near future.

Further optimisation and better knowledge of the process are necessary for cavity cleaning as well as for further applications. Several relevant topics for optimisation and improvement are identified, e.g. nozzle design, cleaning speed and angle, heating options.

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