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EXPERIMENTAL METHODS FOR THE ASSESSMENT OF NEG PUMPS WORKING IN DUST-SENSITIVE ENVIRONMENTS

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Abstract

Non-evaporable getter (NEG) pumps have been widely adopted by many accelerator facilities since decades. However, their use in dust-sensitive areas—such as superconductive radio frequency (SRF) cavities—has always been limited by concerns about accidental dust emission, which could induce detrimental field emission. As future machines will necessarily rely on highly-efficient SRF cavities, able to supply very high accelerating gradients, requirements in terms of particle release from vacuum components (e.g., pumps and valves) are becoming more and more stringent. At the same time, achieving stable ultra-high vacuum (UHV) conditions is crucial, as condensed residual gas might also be a potential source of field emission. At present, a unified standard procedure to assess dust generation and propagation along a machine is still missing and discussions are ongoing in the vacuum community. Recent experimental measurements demonstrated the compatibility of sintered NEG pumps with ultra-clean environments, due to their intrinsic very low dust release. In parallel, in-situ tests performed at different accelerator facilities showed absence of dust contamination from NEGs and no impact on cavities efficiency.

INTRODUCTION

The performance of SRF cavities has substantially improved over the past years, to meet the high accelerating gradients required by future high-energy physics machines. At the same time, the production and preparation of SRF cavities has become extremely challenging, due to the strict requirements in terms of surface polishing and cleaning that are necessary to ensure a correct functioning of such devices [1, 2].

As a matter of fact, particulates can trigger field emission, resulting in lower accelerating gradients and higher cryogenic heat loads. Strict cleaning procedures are therefore necessary for every component, including gate valves, bellows, and vacuum pumps [3, 4]. Special care should be paid also during pump-down and venting, to prevent particulate migration from neighbouring vacuum components towards the SRF cavities [5, 6]. In parallel, field emission can be triggered also by residual-gas condensation on cold-cavity surfaces and, for this reason, stable UHV conditions are strictly necessary not only inside the cryomodules but also all along the neighbouring warm sections.

NEG pumps become thus crucial, thanks to their high pumping speed and capacity for all getterable gases (*i.e.*, H_2, H_2O, N_2, CO, O_2, and CO_2), combined with their compact size and ease of operation [7]. However, their employment in dust-sensitive environments has been so far limited by concerns about accidental particulate emission during NEG activation and machine operation, which would likely trigger field emission. These concerns are fully justified when considering traditional NEG elements (disks, pills, strips) made of compressed St707® powders, which are intrinsically subject to dust release and whose use in dust-sensitive applications should be thus avoided.

Starting from the 1990s, SAES has put on the market new NEG alloys, such as St172™, which come in the form of disks made by high-temperature sintering instead of compression; in this case, getter powders are tightly bound together in a single body, showing a dramatic decrease of dust emission while still keeping a very large surface area and internal porosity. The latest-released ZAO® alloy, in particular, allows the production of sintered NEG disks characterised by strong mechanical properties and extremely-low particulate shedding, paving the way to the use of these new NEG pumps in dust-sensitive vacuum systems.

NEG pumps made of sintered disks have been already successfully tested at different accelerator facilities, focusing in particular on the absence of particle contamination during in-situ activation and operation [8, 9]. In parallel, the experiments described in the following have been recently made at SAES to clearly underline the difference between compressed and sintered NEG elements in terms of particle release, as well as to confirm the full usability of sintered NEGs in proximity of SRF cavities.

PARTICLE RELEASE UNDER N_2 FLOW

Experimental Setup

These tests have been carried out in a dedicated ISO-6 clean room (24 m^2) at SAES R&D laboratories. The pump under test was installed horizontally in a DN35CF four-ways cross (with an extension to accommodate the whole NEG cartridge). The pump was coupled to a rotatable flange, so that it could be freely oriented around its axis. This particular and "closed" setup was adopted in order to avoid any possible perturbation from the surrounding environment during the measurements. Pure N_2 flowed into the system from the upper side, passing through a zero-particle filter (<30 nm); N_2 pressure was set at 1 bar on an upstream manometer, connected to the system's inlet through an antistatic hose.

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On the lower side, the DN35CF cross matched with the isokinetic probe connected to the inlet of the counting instrument (TSI AeroTrak portable particle counter 9510). The results are given in terms of particles/ft^3 in a cumulative way (for instance, 100 particles/ft^3 of 0.7 µm indicates the overall number of particles ≥0.7 µm).

Experimental Procedure and Results

The measure of particle release induced by N_2 flowing onto NEG pumps aimed at a better understanding of how compressed and sintered NEG disks would behave during venting operations in a real machine.

Two NEG pumps have been tested on this setup: first, a CapaciTorr® Z400 with sintered ZAO disks and, afterwards, an equivalent cartridge with compressed St707 disks. Each pump underwent the following experimental procedure:

- Background measurement: 10 cycles with N_2 flowing through the empty system (*i.e.*, with a blank DN35CF flange in place of the pump's base flange) into the particle counter.
- NEG measurement: 20 cycles with N_2 flowing through the getter cartridge into the particle counter; the pump was rotated 90° clockwise around its axis every 5 cycles. The N_2 inlet valve was closed while rotating the pump and reopened just few seconds before starting the new series of 5 cycles, in order to fully monitor any possible particle release from the cartridge induced by the gas flow.

The background measured in the empty system before testing each pump is shown in Fig. 1. The values recorded before testing sintered disks (left) were initially quite high and, cycle after cycle, a cleaning effect given by N_2 flowing into the system was noticeable; compressed disks (right) were tested in the following days, hence the observed lower background values were a direct consequence of the cleaning level achieved during the previous tests.

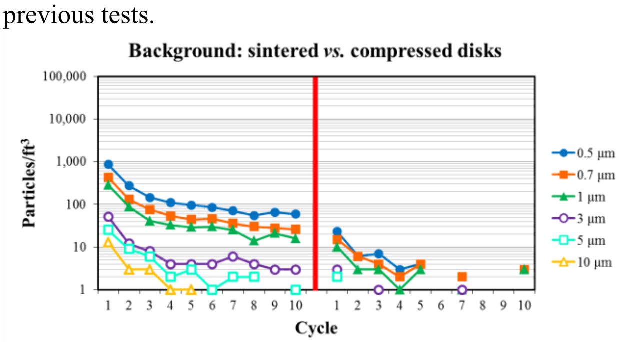

Figure 1: Background measured prior to testing ZAO (left) and St707 (right) disks.

However, a reverse situation appeared after the insertion of each NEG pump: Fig. 2 and Fig. 3 show the results of 20 cycles with N_2 flowing onto ZAO sintered disks and St707 compressed ones, respectively (vertical dashed lines indicate 90° rotations of the NEG cartridges every 5 cycles).

With sintered disks, little if any difference was noticeable compared to the background and, overall, there was a steady decrease towards lower values of released particles/ft^3 (cf. Fig. 2). The partial recoveries observed during the 1st cycle and immediately after each 90° rotation were likely caused by N_2 flow directly impinging on different portions of the NEG disks, as well as by inevitable mechanical perturbations induced in the system by the rotation itself. The last cycles (19th and 20th) evidenced a drop of all the monitored particle sizes below the threshold of 10 particles/ft^3. Few weakly-bound particles were thus initially removed from sintered disks by the gas flow and particle release quickly tended to zero, thanks to the strong bonds created by sintering.

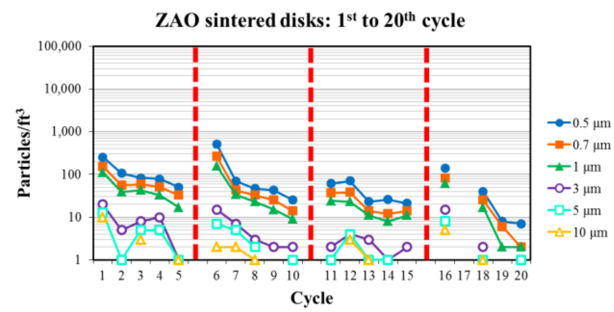

Figure 2: Particles released by ZAO sintered disks during 20 consecutive cycles (90° rotation every 5 cycles).

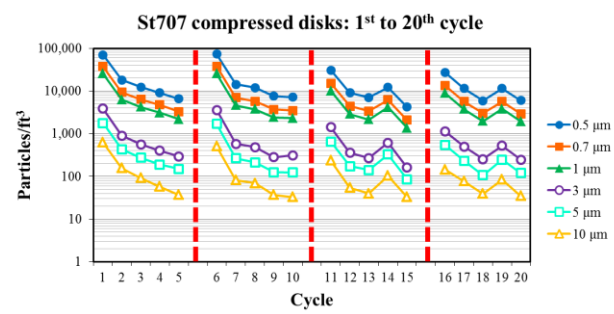

Figure 3: Particles released by St707 compressed disks during 20 consecutive cycles (90° rotation every 5 cycles).

On the other side, the number of particles/ft^3 released by compressed disks was about three orders of magnitude higher than the corresponding background and more than two orders of magnitude higher compared to sintered disks (cf. Fig. 3). Moreover, no significant variation was noticeable throughout the entire series of measurements, indicating the inability to achieve a stable and permanent cleaning of a NEG pump made of compressed disks. Indeed, unexpected rises (e.g., 14th and 19th cycles) seem to suggest that, from time to time, compressed disks are inevitably affected by the sudden release of weakly-bound particles. At the end of the 20th cycle, the number of particles emitted by compressed disks was a factor 1000 larger compared to sintered disks.

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DIPPING TESTS IN ULTRASONIC BATH

In parallel, other tests have been made at SAES to ascertain the difference in terms of particle release by sintered and compressed NEG pumps under tough stress conditions. Each NEG cartridge was dipped in a solvent inside a beaker and underwent 10 sonication cycles (5 min each) in an ultrasonic bath. At the end of each cycle, the solvent was filtered and particles were collected on a paper filter and weighted.

The results are resumed in Table 1. The amount of particles released by sintered disks fell below scale sensitivity (*i.e.*, 0.01 mg) after 2 cycles only, while the amount of particles lost by compressed disks was much higher and it did not decrease cycle after cycle: the 10th cycle was still comparable to the first ones.

Table 1: Particles Released during Dipping Tests

Cycle	ZAO disks [mg]	St707 disks [mg]
1	0.85	7.9
2	0.41	4.4
3	<0.01	1.4
4	<0.01	1.3
5	<0.01	2.0
6	<0.01	1.2
7	<0.01	1.2
8	<0.01	1.3
9	<0.01	0.9
10	<0.01	2.2
Total	1.26	23.3

Even by visual inspection, the filters used to collect particles released cycle after cycle by sintered (Fig. 4) and compressed disks (Fig. 5) clearly demonstrated the much higher robustness of the first ones. The larger amount of particles released by compressed disks is consistent with results shown in Fig. 2 and Fig. 3.

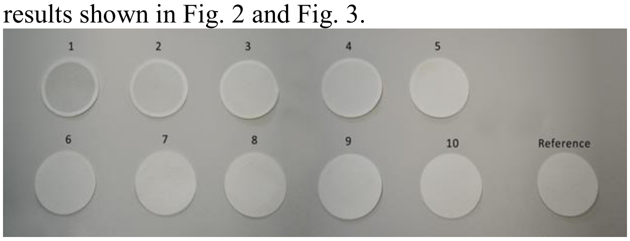

Figure 4: Overview of filters used to collect particles lost by ZAO sintered disks during 10 dipping tests.

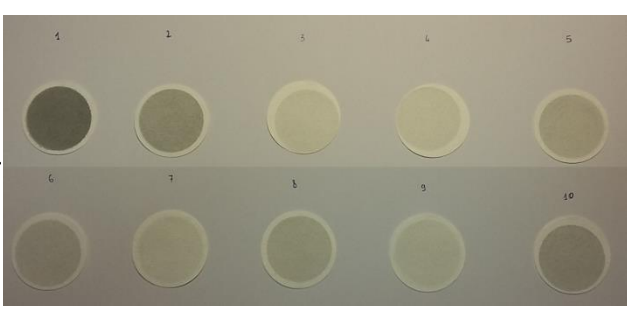

Figure 5: Overview of filters used to collect particles lost by St707 compressed disks during 10 dipping tests.

Although the scale sensitivity was rather limited, these tests likely provide an upper limit in terms of particle release by NEG pumps, due to the chosen experimental conditions which are more stressing than the expected UHV working conditions.

CONCLUSIONS

The clear superiority of sintered NEG elements over compressed ones, in terms of particulate release, has been proven both by particle counting under N_2 flow and by dipping tests in ultrasonic bath.

These findings are in agreement with experimental evidence collected at several accelerator facilities and showing that NEG pumps with ZAO elements can be used next to cryomodules, without performance degradation of the cavities or field-emission onset.

NEG pumps with sintered disks are currently employed also in other dust-sensitive applications, such as electron microscopes, vacuum suitcases for photocathode transportation [10].

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