PARTICLE FREE PUMP DOWN AND VENTING OF UHV VACUUM SYSTEMS

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Abstract

Vacuum systems containing superconducting cavities which have to be operated at high gradients need to preserve the cleanliness of the superconducting cavity surfaces. In addition to an adequate preparation of the cavities and the neighbouring vacuum components special care needs to be taken during pump down and venting. Neither should be particles introduced into the vacuum system, nor should particles already present within the system be moved towards critical areas.

For the superconducting linear accelerators of FLASH and the European XFEL at DESY a series of measurements have been performed to study the movement of particles in long tubes during pump down and venting. For this purpose an in-situ vacuum particle counter has been used. By reducing and varying the gas flow during these processes, it is possible to perform these actions without moving particles present inside such systems. Based on these measurements a set-up using various filters, flow controllers and a pressure gauge has been developed to avoid introducing particles into the vacuum system as well as moving existing particles. This set-up allows automated pump-down and venting of critical vacuum systems in a reliable and reproducible way, being much faster than the procedures used so far.

INTRODUCTION

During the past decade the maximum achievable gradient for superconducting cavities has been improved substantially. One major contribution to this improvement is the consequent treatment and preparation of the cavities in clean rooms with procedures similar to standards in semiconductor industry [1]. Dust particles can act as field emitters, degrade the quality factor and thus limit the performance of the superconducting cavities. Therefore particles on the inner surface of the cavities need to be absolutely avoided. As a consequence vacuum components next to the superconducting cavities need to be treated with similar cleaning procedures [2] and [3]. In addition special care needs to be taken during pump down and venting of the vacuum systems. Neither should be particles introduced into the vacuum system, nor should particles already present within the system be moved towards critical areas.

For the superconducting linear accelerator of the SASE FEL FLASH at DESY [4] and the just started project of the European XFEL with more than 1000 cavities to be used [5] it is necessary to substantially improve the procedures used so far. While particle filters effectively prevent the introduction of particles into vacuum systems, it is much less known how to avoid the movement of particles within the system, which for example have been produced by movable elements like valves or actuators. So far pump down and venting in such cases is mainly done using manually operated needle valves and performing the processes much slower than usual. Typical process times are several hours, e.g. 20 h for venting a cavity string with a volume of 200 liters.

Especially for the large scale production of superconducting cavities for the European XFEL it is important to develop a set-up for particle free pump down and venting of vacuum systems with automated, reliable and reproducible procedures.

For this purpose a series of measurements have been performed to study systematically the movement of particles in long tubes during pump down and venting. Several commercial elements have been tested to automate the procedures resulting in a compact set-up and well defined procedures which will be described in this paper.

PARTICLE MOVEMENT IN LONG TUBES

For systematic studies of the movement of particles within long vacuum tubes and how it could be minimized or even prevented during pump down and venting an in-vacuum particle counter has been applied.

Experimental Set-up

The set-up consists of a 10 m long tube of 63 mm diameter as shown in Fig. 1. The tube corresponds roughly to the length and volume of a cavity string. On the right side of the tube both a pump station for pump down as well as a nitrogen bottle for venting are connected. Both connections have initially been equipped with manual needle valves in order to vary the gas flow over a wide range. In addition a diffuser has been added in the vent line at some stage of the measurements to prevent particles to enter the system as well as to homogenize the gas flow as described in more detail in the following section.

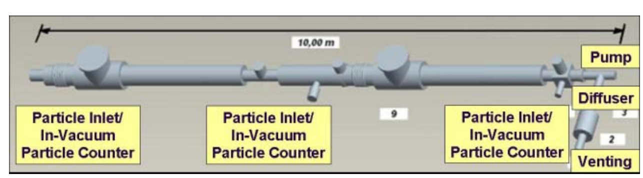

Figure 1: Experimental set up for measuring particle movement in long tubes.

For particle measurements an in-situ vacuum particle counter equipped with KF-flanges was used. For these measurements metal seals have be used for all UHV connections including the particle counter. The in-vacuum counter could be installed at three different locations at both ends and in the middle of the vacuum tube as indicated in Fig. 1. As the sensitive volume of the particle counter is quite small and thus does not cover the complete cross section of the vacuum tube, the measured particle numbers are no absolute values but rather indicate a tendency.

For these investigations neither have the tube and other components been made particle free by special cleaning procedures as e.g. described in [3] and [4] nor has the assembly been done within a clean room. Instead particles had been introduced on purpose at three locations close to the ports for the in-vacuum particle counter as indicated in Fig. 1. All operations on the needle valves have been done manually. Therefore each tested procedure has been repeated at least five times to get some statistics of the results.

Results

The outcome of the investigations can be summarized as follows:

Movement of particles is mainly observed at the position next to the pumping and venting ports. Sometimes moving particles could be observed at the middle position, but very rarely at the opposite position from the pump or vent port. Thus the long tube homogenizes the gas flow and reduces turbulences. As a consequence the set-up for pump down and venting of critical systems should be connected as far as possible from components being sensitive to particles.

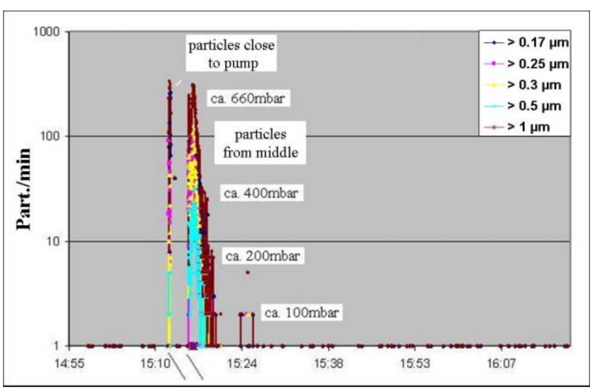

Figure 2: Particle counts per min during fast pump down without any measures to avoid particle movement.

During pump down the number of particles decreased with decreasing pressure, indicating a reduction of turbulences. As seen in the measurement in Fig. 2, where no special measure where taken during pump down, particles could be measured down to a pressure of about 100 mbar, with the initial peak originating from particles introduced at the port next to the pump and the second one due to particles introduced at the middle port. However, if turbulences are again introduced by sudden changes of the throughput of e.g. a needle valve, particles had been detected down to pressures of about 1 mbar. Only for pressures < 1 mbar no more particle movement has been observed. As a consequence manual valves are not well suited to adjust the gas flow for particle free pump down and venting. For venting a system this means that the pressure difference between the vacuum vessel and atmosphere should be below 1 mbar before opening the system.

In vented systems movement of particles has been observed after some hours. This has not been studied in further detail, most likely the movement is due to thermal changes and/or mechanical vibrations. As a consequence the time the vacuum system is kept vented should be minimized.

The results described above have been confirmed for a tube with smaller diameter of 16 mm.

SET-UP FOR PARTICLE FREE PUMP DOWN AND VENTING

Based on the measurements described above, a compact set-up based on commercially available components has been developed. The key components are mass flow controllers and diffusers.

A mass flow controller keeps a given gas flow constant using a variable diaphragm. For the applications described in this paper, flow controllers applying a soft start, i.e. increasing the aperture to its initial value slowly and uniformly, have been chosen, thus avoiding turbulences by sudden changes of the open cross section. The mass flow controllers have an intrinsic particle filter on the side of the incoming flux.

Diffusers are widely used in semi-conductor industries for fast and particle free venting of large vacuum systems. The diffuser combines a stainless steel filter to prevent particles larger than 3 nm entering the system and a diffuser membrane that allows gas flow in 360°. Thus turbulences in the gas flow are largely reduced and large amounts of gas can flow through in a uniform manner, limiting the disturbance of particles in the system. For the described application a commercially available diffuser has been adopted to our needs. The KF flange has been cut and the remaining body has been welded into a tube with sufficiently large diameter with a Conflat™ flange on the other side.

Concerning pressure both the information of the absolute pressure, especially in the region around 1 mbar, as well as the differential pressure against air is required. Both functionalities are provided by a single sensor, a Loadlock Transducer. It combines a Piezo for gas independent differential pressure measurement against air pressure and MicroPirani™ sensor technologies for absolute pressure measurement between 1000 mbar down to 10^{-5} mbar. Automated as well as manual valves complete the set-up.

It turned out that separate components are necessary for pump down and venting as shown schematically in the left part of Fig. 3. In the vent line a nitrogen gas bottle or dewar is connected via a manual valve (V3) to a mass flow controller (1) at an inlet pressure of 2-3 bars. In case of using a gas bottle special attention must be given to the cleanliness of the fittings, eventually special filters (e.g. charcoal) should be added. The vent line continues with a diffuser and an automated valve (V1). Using the same set-

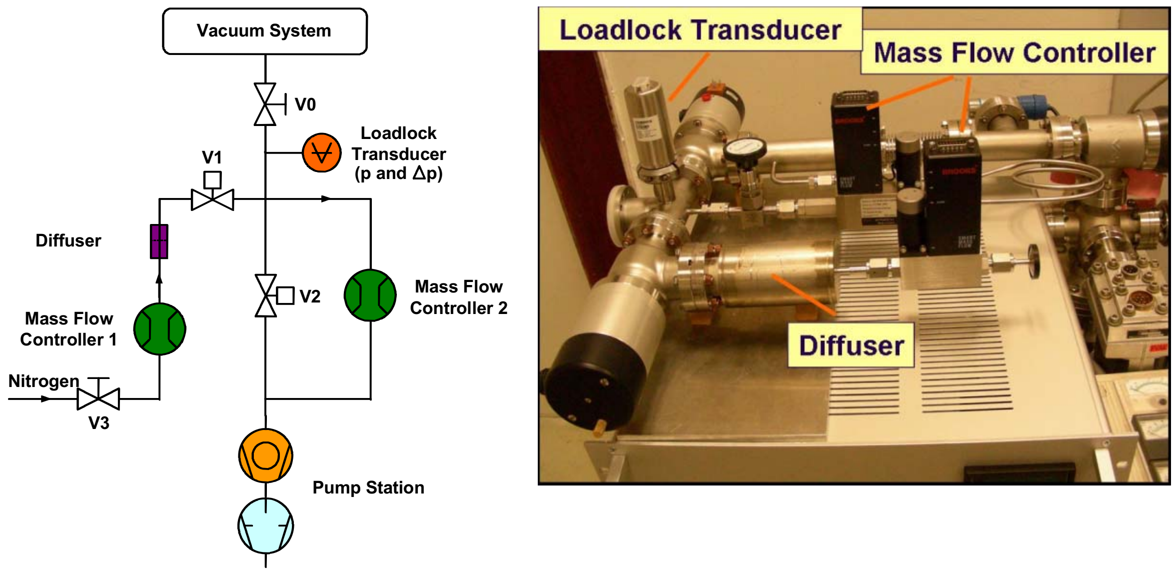

Figure 3. Set-up for particle free pump down and venting: schematics (left) and photograph (right).

up for pump down the diffuser would increase the pump out time from atmosphere to 1 mbar by a factor of 4 from 30 min to 120 min. Thus for pump down a second mass flow controller (2) and a bypass line with an automated valve (V2) are installed. The Loadlock Transducer is located next to the flange which is connected to the manual valve (V0) of a vacuum vessel. This compact set-up shown in the photograph of Fig. 4 (right) could be easily connected to a pump station.

Although the set-up is currently not yet completely run by computer control, the goal is to have the complete automation of the whole procedure in the near future using a programmable logic controller (PLC).

PROCEDURES FOR PARTICLE FREE PUMP DOWN AND VENTING

For practical applications the set-up has to be connected to the manual valve of a vacuum vessel (V0 in Fig. 3), a gas bottle (e.g. nitrogen) in the vent line and a pump station in the pump line.

In case of venting, it is advisable to remove particles in the vent line between the diffuser, valve V2, the mass flow controller 2 and the manual valve V0. Performing pump and purge, e.g. fast pump down followed by fast flushing with nitrogen several times, most particles will be moved out towards the pumps. For pump down this procedure is not needed as particles will be moved towards the pumps.

Pump down procedure

To start pumping, the valves to the vent and bypass line V1 and V2, need to be closed. The pumping will start through the mass flow controller 2, which is set to a mass flow of 50 mbar l/s. The controller in use increases the aperture to its initial value slowly and uniformly, so called soft start, thus avoiding turbulences. With decreasing pressure, the aperture is further increased to keep the flow constant. However once the maximum opening is reached, the achievable gas flow will decrease. The flow controller with its intrinsic particle filter will always limit the pump speed to much smaller values than without it and thus increase the further pump down time to unacceptable values. Therefore a bypass line is foreseen. The valve V2 is safely opened without introducing further particle movement, once the Loadlock Transducer indicates a pressure of 1 mbar.

Using this procedure no particles are registered by the in-vacuum counter in the upper graph in Fig. 4 during the pump down

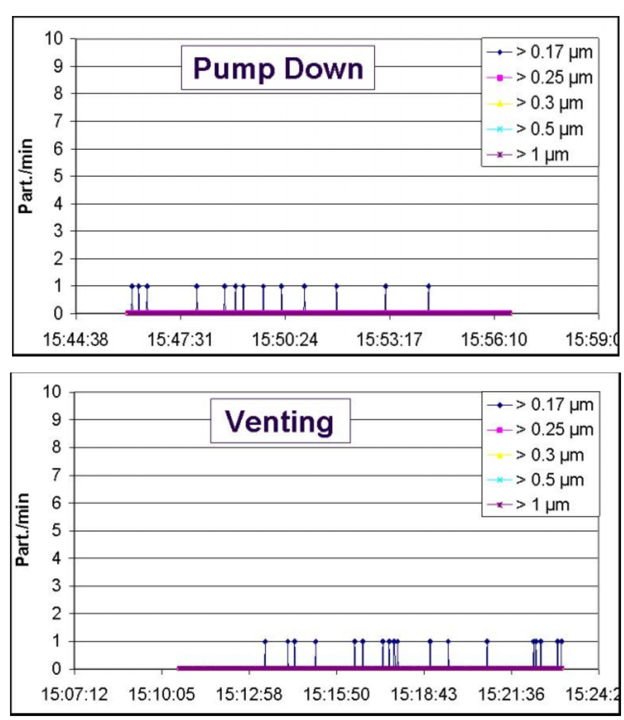

Figure 4: Particle counts per min during pump down (top) and venting (bottom).

Venting procedure

For venting nitrogen with 2-3 bar is filled into the line from the gas bottle through the manual valve V3 up the mass flow controller 1, which is closed. The remaining vent line is initially pumped out using the pump station with the valves V1 and V2 open. Once a pressure of at least 0.1 mbar is reached the manual valve to the vacuum vessel V0 is opened and the pump line is shut off by closing V2 and mass flow controller 2. Venting of the vessel starts by setting mass flow controller 1 to a throughput of 50 mbar l/s, which slowly and uniformly adjusts its aperture. The venting is stopped by closing valve V1 if the differential pressure to atmosphere at the Loadlock Transducer is 0. Only then the vacuum vessel should be opened. As the air pressure usually varies, there should be not much time difference between venting and opening of the system. Otherwise one should make sure, that there is no pressure difference between the vented and still closed system and the ambient air.

The lower graph in Fig. 4 shows an example without any particle detection for venting a long tube.

Practical Applications

The new set-up and procedures described above have been applied for pump down and venting of a full string of 8 TESLA cavities. For quality control the in-situ particle counter had been installed in between the set-up and the manual valve of the cavity string. No particles had been detected during the complete pump and vent cycle.

So far these procedures have been performed according to best knowledge, but without systematic studies as described in this paper using particle filters and manual needle valves as well as doing the process very slowly.

For pump down the process time to reach a pressure of 10^{-6} mbar has been reduced by a factor of 3 from 10 h to 3.5 h. The reduction in time for venting is more than a factor of 10 from 24 h to 1.5 h as shown in Fig. 5. This is a substantial reduction of the process time.

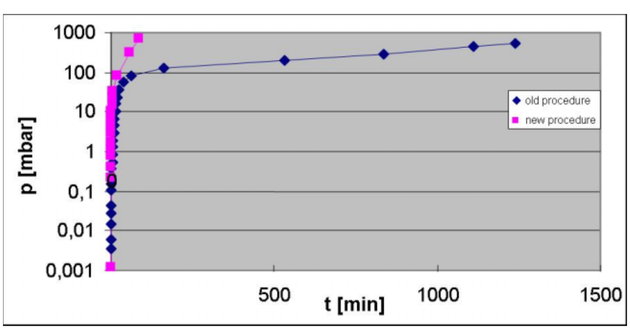

Figure 5: Pressure versus time during venting of a cavity string using the old procedure (◆) and much faster new procedure (■).

SUMMARY

Systematic studies in a long vacuum tube have shown that pump down and venting of UHV vacuum systems is possible without introduction and/or movement of particles within the system. Based on these measurements a set-up using various commercially available filters, flow controllers and a pressure gauge has been developed. This set-up allows automated pump-down and venting of critical vacuum systems like superconducting cavities in a reliable and reproducible way. The process times have been significantly reduced. The next step is the full automation of the procedures using a PLC to be well prepared for industrial production of the XFEL cryo modules.

Nevertheless, the time where such sensitive systems are kept at air pressure should be minimized as particles might start to migrate due to thermal changes or mechanical vibrations.

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