PARTICLE FREE PUMP DOWN AND VENTING OF UHV VACUUM SYSTEMS

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Abstract

For particle free vacuum systems, as e.g. systems containing superconducting cavities to be operated at high gradients, 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.

A series of measurements to study the movement of particles in long tubes during pump down and venting using an in-situ vacuum particle counter has been performed. Based on these measurements a set-up using flow controllers, diffuser and pressure gauges has been developed to avoid introducing particles into the vacuum system as well as moving existing particles during pump down and venting. This set-up can be operated manually as well as via a control unit. The electronics unit is an in-house development at DESY. It is usually connected to an oil free pump station. This set-up allows automated pump-down and venting of critical vacuum systems in a reliable and reproducible way, being faster than the procedures used so far.

INTRODUCTION

The maximum achievable gradient for superconducting cavities has been improved substantially in the past years. 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. 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. Particles might be produced and/or moved during assembly, later operation of the cavities under vacuum and storage after venting to atmospheric pressure.

As a consequence vacuum components next to the superconducting cavities need to be treated with similar cleaning and installation procedures in clean rooms [1, 2]. 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. The same is true for storage of cavities after venting to atmospheric pressure, if the flanges are kept closed for some time when a pressure difference to the atmospheric pressure could build up,.

Even when using best clean room practises, it is not unlikely that some particles are produced within the vacuum system for example during assembly or by movable elements like valves or actuators.

For the superconducting linear accelerators of the SASE FEL FLASH at DESY and the European XFEL with more than 800 cavities to be used [3] the set-up and the procedures to pump down and vent UHV systems had to be improved substantially. Especially for the large scale production of the superconducting cavities for the European XFEL a set-up for particle free pump down and venting of vacuum systems with automated, reliable and reproducible procedures including the storage under atmospheric pressure is required.

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. Pump down and venting in such cases is mainly done using manually operated needle valves and performing especially the venting process much slower than usual (e.g. 3 h for venting a cavity string with a volume of 200 liter).

In order to develop an adequate set-up a series of measurements has been performed to study systematically the movement of particles in long tubes during pump down and venting. Based on the results several commercial elements have been tested and a compact set-up has been developed [4]. Following the first practical tests it became obvious, that improvements of the set-up and the procedures are necessary. Most of this has been realized meanwhile and will be described in this paper. In addition the procedures have been automated.

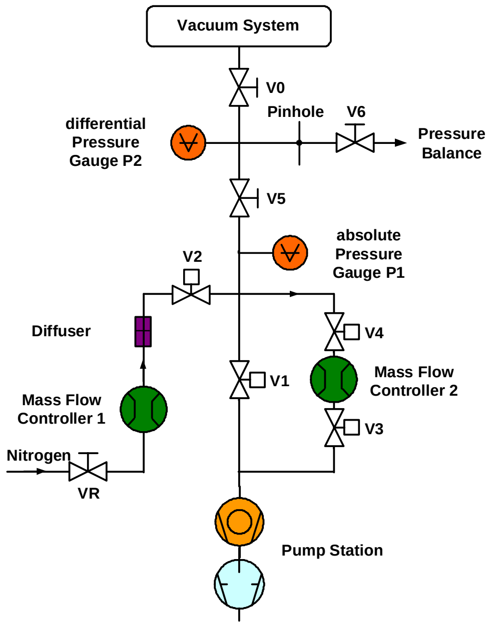
PARTICLE MOVEMENT IN UHV SYSTEMS

The movement of particles in UHV systems has been studied systematically [4] using an in-vacuum particle counter. Most measurements have been performed using a 10 m long tube of 63 mm diameter corresponding roughly to the length and volume of a cavity string of 8 TESLA cavities.

For these investigations neither have the tube and other components been made particle free by special cleaning procedures , nor has the assembly been done using a clean room. Instead particles had been introduced on purpose at different locations close to the ports for the in-vacuum particle counter.

The results of the measurements described in more detail in [4] can be summarized as follows:

- Movement of particles is mainly observed at the position next to the pumping and venting ports. The long tube homogenizes the gas flow and reduces turbulences.



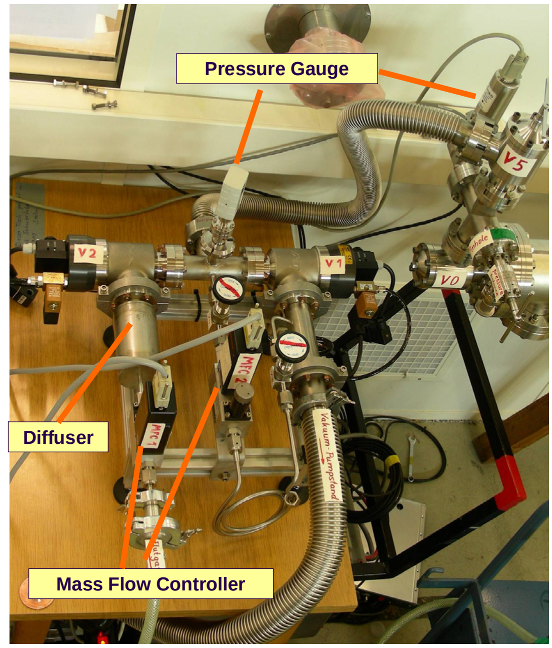


Figure 1: Improved set-up for particle free pump down and venting: schematics (left) and photograph (right).

- During pump down the number of particles decreases with decreasing pressure, indicating a reduction of turbulences. In the dirty system particles could be measured down to a pressure of about 100 mbar. If turbulences are again introduced by sudden changes of the throughput of e.g. changing the position of 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 even when moving valves.

As a consequence of these results the following points should be taken into account:

- The set-up for pump down and venting of critical systems should be connected as far as possible from components being sensitive to particles.
- Manual valves, even needle valves, are not well suited to adjust the gas flow for particle free pump down and venting.
- After venting a system the pressure difference between the vacuum vessel and atmosphere should be $\Delta p < 1$ mbar before opening the vacuum system.

SET-UP FOR PARTICLE FREE PUMP DOWN AND VENTING

Based on the results of the measurements described above, a compact set-up based on commercially available components has been developed. The key components are two mass flow controllers, a diffuser and pressure gauges. This set-up is put in-between an oil-free pump station and the vacuum system. Thus the set-up needs to allow a leak check down to leak rates of 10^{-10} mbar l/s after pump down before removing the pump station and the set-up for particle free pump down and venting.

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 turbulences by sudden changes of the open cross section are avoided. 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 measurement both the information of the absolute pressure, especially in the region around 1mbar, 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. This gauge type has been used for the initial set-up. However during the first applications to pump down a cavity string, it turned out, that both the loadlock transducer as well as the mass flow controller have leak rates in the order of 10^{-6} – 10^{-8} mbar l/s. This made the leak check of the string down to values < 10^{-10} mbar l/s with the present set-up impossible. Therefore the loadlock controller had been replaced by 2 separate gauges of type Baratron – one for absolute and one for differential pressure measurement – which are leak tight down to 10^{-10} mbar l/s. The mass flow controller in the pump line can be blocked by the two valves V3 and V4.

Automated as well as manual valves complete the mechanical set-up.

It turned out that separate components are necessary for pump down and venting as shown schematically in the left part of Fig. 1. In the vent line a nitrogen gas bottle or dewar is connected via a manual valve (VR) at the gas bottle/dewar 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 from hydrocarbons; eventually special filters (e.g. charcoal) should be added. The vent line continues with a diffuser and an automated valve (V2). Using the same set-up for pump down the diffuser would increase the pump out time from atmosphere to 1 mbar to an unacceptable long time. Thus for pump down a second mass flow controller (2) is installed. Once the inner opening is completely opened, further pump down is getting slower and slower. Therefore a bypass line with an automated valve (V1) is installed.

The pressure measurement is located next to the manual valve (V0) of a vacuum vessel. The other elements of the set-up will be described further down as they are the result of the first experience with the described set-up.

An electronics unit together with a programmable logic controller (PLC) completes the set-up.

PROCEDURES FOR PARTICLE FREE PUMP DOWN AND VENTING

For using the set-up it has to be connected to the manual valve of a vacuum vessel (V0 in Fig. 1), a gas bottle (e.g. nitrogen) to the vent line and a pump station to the pump line.

Pump Down Procedure

To start pumping, the valves to the vent and bypass line, V2 and V1, as well as the valve to the mass flow controller 2, V3, need to be closed. After starting the pump station the mass flow controller 2 is set to a mass flow of 3 l_N/min (50 mbar l/s). The flow controller in use increases the aperture to its initial value slowly and uniformly, so called soft start, thus avoiding turbulences. After opening valve V3 the pump down starts. 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 the valve V1 to the bypass line is safely opened without introducing further particle movement, once a pressure of 1 mbar is reached. The valves V3 and V4 are closed. If the pressure is low enough, a first leak check can be performed.

Venting Procedure

For the venting procedure nitrogen gas with 2-3 bar is filled into the line from the gas bottle up to 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, the other valves are closed. 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 V1. Venting of the vessel starts by setting mass flow controller (1) to a throughput of 3 l_N/min (50 mbar l/s), if using nitrogen. If using other gases, e.g. argon, the values have to be changed accordingly. This flow controller also uses a soft start. The venting is stopped by closing valve V2 if the differential pressure to atmosphere at the pressure gauge is $\Delta p = 0$ mbar. 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

If storage of the vacuum system under air pressure is planned before opening a flange, the system should be vented to some overpressure (1100 mbar). In addition some more elements are needed to allow pressure balance due to changes of the air pressure. We use two more valves, V5 and V6, together with a pinhole with 0.5 mm diameter made out of a 2 mm thick copper disk. For storage valve V5 is closed. Just before opening the vacuum system, valve V6 is opened till the differential pressure gauge reaches $\Delta p = 0$ mbar.

FIRST EXPERIENCE WITH TESLA CAVITY STRINGS

The improved set-up and procedures described above have been applied to complete strings of 8 TESLA cavities for pump down and venting. Initially the in-situ particle counter had been installed in between the set-up and the manual valve of the cavity string. As no particles had been detected the particle counter has not been used any more after the first applications. Meanwhile the system has been used for pump down more than 10 times and for venting more than 20 times with reproducible results.

For pump down the process time to reach a pressure of 1 mbar for a TESLA cavity string of about 200 l volume is now in the order 3 h as shown in the upper plot in Fig. 2. One should note that the data for the displayed pressure were taken from the Pirani Gauge while for the process control the loadlock transducer and later baratron gauges have been taken. Therefore the values displayed around 1000 mbar and 0.001 mbar are not very precise. The old procedure was either around 0.5 h with using the clean gas system in the clean room or around 24 h using a dewar after assembly of the complete module outside the clean room. As can be seen in the lower plot in Fig. 2 for the procedure at the clean room, the opening of the needle valve has been corrected manually several times, which could lead to the production and/or transport of particles. So the new, but longer procedure is safer with respect particle production and transport. On the other hand, the process time for pump down outside the clean room has substantially reduced. Still, further tests are needed to optimise the parameters for the pressure settings. This is indicated by the variation displayed in the initial data.

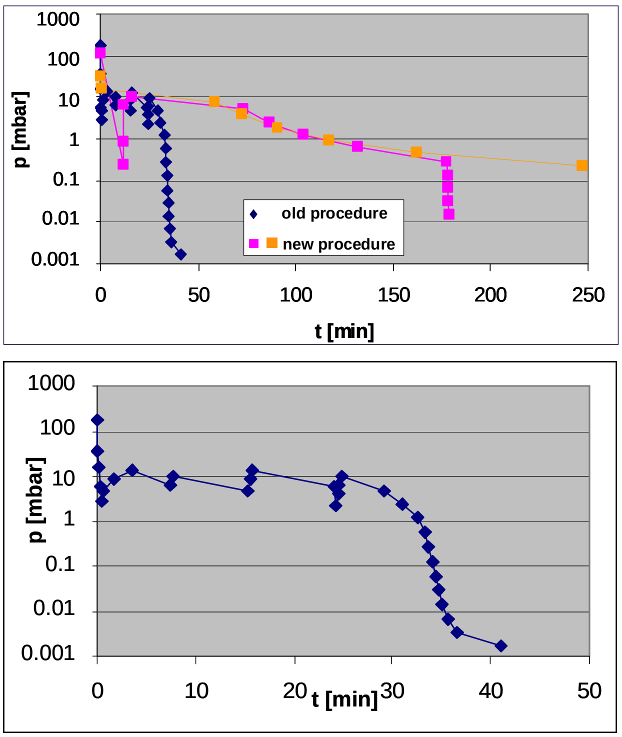


Figure 2: Pressure versus time during pump out of a cavity string using the old procedure (◆) and new procedure (■, ■). The lower graph shows the old procedure with an enlarged time scale.

For venting of a TESLA cavity string examples of the old and new procedures are shown in Fig. 3. The reduction in time is more than a factor of 5 from 9 h to 1.5 h. This is a substantial reduction of the process time.

Following the successful application of the improved set-up and procedures in the process of the recent module assemblies [4] and [5], a series of set-ups will be build in the near future to equip a larger number of oil free pump stations.

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 two pressure gauges has been developed.

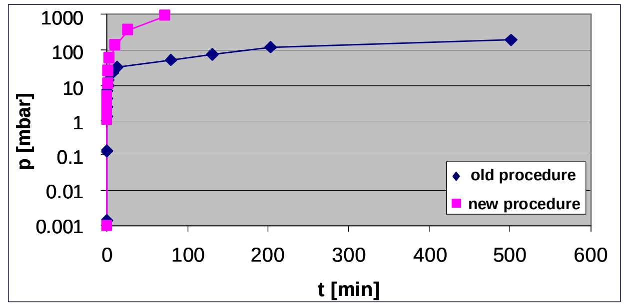


Figure 3: Pressure versus time during venting of a cavity string using the old procedure (◆) and new procedure (■).

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 in several cases. The initial indications of good results on accelerating modules are promising. The next steps include further optimisations of the parameters set in the PLC. The full automation of the procedures using a PLC needs to be well prepared for industrial production of the XFEL cryo modules.

Nevertheless, the duration 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.

ACKNOWLEDGEMENT

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