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# Developing the Particle Free Vacuum System at ESS

## Desenvolvimento de Sistema de Vácuo Livre de Partículas no ESS

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**ABSTRACT**

This paper discusses the acceptance criteria for particle free, the development of particle free pumping carts and the results of particle testing performed in the ESS accelerator.

**Keywords:** Accelerator, Vacuum, Particle free.

**RESUMO**

Este trabalho apresenta os critérios de aceitação, bombeamento livre de partículas e os resultados dos testes de partículas efetuados no acelerador ESS.

**Palavras-chave:** Acelerador, Vácuo, Ausência de partículas.

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## INTRODUCTION

The European Spallation Source (ESS) is a spallation neutron source based on a 2GeV-5MW proton linear accelerator (LINAC). The aim of ESS is to be the brightest neutron scattering facility enabling novel science in many fields such as biology, environmental research and fundamental physics. As of Q3-2018, the ESS Linear Accelerator is under installation with the ion source and the Low Energy Beam Transport (LEBT) sections undergoing qualification runs.

The protons receive most of their acceleration in the superconductive LINAC where their energy increases from 90 MeV, output of the normal conductive section, to 2 GeV delivered to the beam delivery systems. To achieve this energy, three designs of cavities are used: Spoke[1] (352.21 MHz – geometrical $\beta$ = 0.5), Medium $\beta$ (704.42 MHz – $\beta$ = 0.67) and High $\beta$ cavities (704.42 MHz – $\beta$ = 0.86). These cavities are hosted in groups of 2, 5 or 6 in cryo-modules (CM) and a total 13 Spokes, 9 Medium Beta and 21 High Beta CMs are employed. These superconducting accelerating structures provide a very high voltage gradient and, as such, are sensitive to particle contamination; hence they need to be protected to avoid performance loss due to enhanced field emission.

At ESS there are three main sources of particle contamination for the sensitive parts of the particle free accelerator:

1. The quantity of particles generated from active components such as pumping systems, gate valves, and instruments.
2. Particle contamination during LINAC installation and construction from the environment (dust in the tunnel or coactivity).
3. Particle contamination during assembly (human activities or non-adapted tools).

The particle free environment is controlled in 3 ways:

i. Avoid the transport of particles into the beam pipe;

ii. Work in a clean and classified environment; and

iii. Set up acceptance criteria and procedures to control them. Each part of the superconducting LINAC will be particle free checked before and during their installation.

In this paper we will discuss acceptance criteria for particle free in the ESS accelerator, development of particle free pumping carts, and the results of particle testing done for Nextorr® vacuum pumps and a study of fasteners.

## METHODS

### Particle Measurement

Particles are measured in a clean room ISO class 5 (Fig. 1), using a Solair 1100 (particle counter, Lighthouse) and an ionizing gas gun (TOPGUN, Simco) connected to a pure nitrogen gas bottle. Samples are prepared and measured in the ISO class 5 ESS cleanroom facility. The clean room was provided by STFC (Science & Technology Facilities Council) Daresbury laboratory and a mobile clean room for installation in the ESS tunnel is being developed together with STFC Daresbury.

**Figure 1:** ESS cleanroom supplied by our in-kind partner STFC where all measurements were made for these studies.

### ESS Acceptance Criteria[2]

There should be at most 10 particles in the 0.3 to < 5 µm range and no particles larger than 5 µm after 1 minute of ionized and filtered nitrogen gas throughput at 3 bars, 28l/min pumping capacity. These criteria were established for the assembly of superconducting accelerating structures (medium $\beta$ cryomodules) at CEA Saclay[3], the supplier of ESS cryomodules, and have been adopted at ESS. Figures 2 and 3 show examples of particle measurement.

### Development of the ESS Particle Free Pumping Cart

A particle free pumping cart (Fig. 4) is required on the beam line at ESS to ensure that no particles enter the system from both pumping down and venting the system. It is also important that particles already present in the system are not displaced into critical areas. For example, particles generated from gate valves opening and closing should not be moved in turbulent flow by pumping or venting. The pumping cart needs to be particle free and protocols must be followed during operation. We based our design (vacuum schematics shown in Fig. 5) on Böhnert *et al.*[4], however ours differs in the use of a control system and a diffuser instead of an inline ultra-high purity gas filter is installed on the venting line (Swagelok SS-SCF3-VR4-P-30). Its features are:

- Dry roughing pump – Kashiyama Neodry 15 E,
- Turbo pump – Pfeiffer Hi Pace 300,
- Full range gauge – Pfeiffer PKR 261,
- HV and UHV vacuum fittings,
- All Metal Mass flow controllers – MKS 5000 SCCM,
- Differential pressure switch to avoid overpressure during venting – Inficon VSD200 SP-2Torr,
- Ports for connecting RGA and/or leak detector,
- Automatic control system allows establishing vacuum in a safe and reliable way. For example, during pump down from atmospheric pressure, the pumping cart is in slow mode (see Fig. 6) and can't pass automatically to normal mode with the turbo pump if the vacuum pressure upstream to VVH (Fig. 5) is over 1 mbar and turbo pump doesn't reach its full speed.

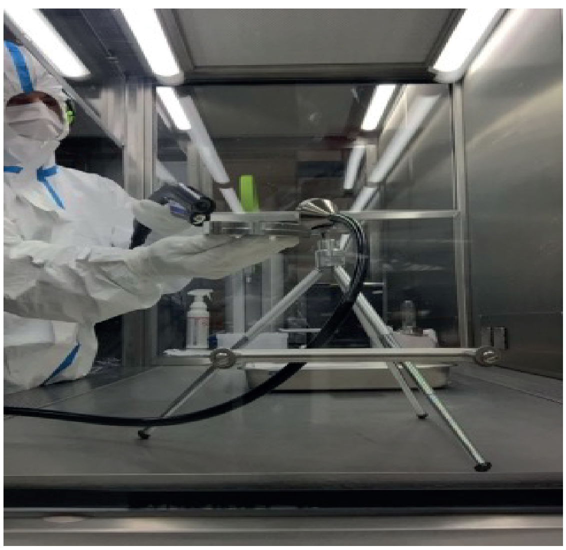

**Figure 2:** Measuring the quantity of particles of a blank flange DN63 CF after cleaning.


**Figure 3:** The control panel of Solair 1100 particle counter showing the number of particles registered after 1 minute of blowing ionized nitrogen gas at 3 bars.

**Figure 4:** ESS particle pumping cart.

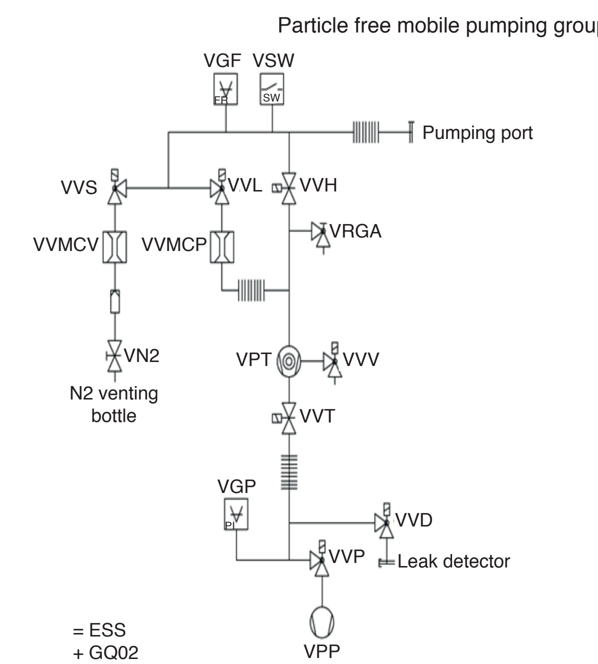


**Figure 5:** Schematics.

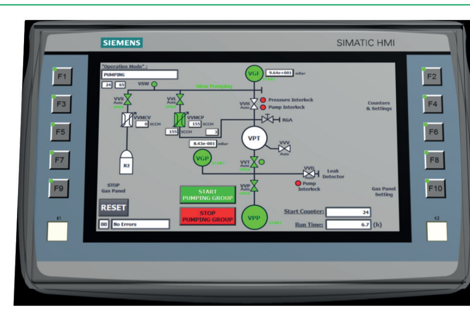


**Figure 6:** Control panel in slow pumping mode.

## EXPERIMENTS AND DISCUSSION

### Particle Testing Performed for Nextorr® Vacuum Pumps

As particles are generated by pump and assembly, the goal of this study is to assess particle performance of the pump and validate particle free procedures by using a particle free test model D1000-10 St 172 alloy and HV300 ZAO alloy as received on delivery.

At ESS we are using approximately 80 SAES NexTorr® pumps HV300 ZAO alloy on LWU's5 and D1000-10 (Fig. 7) on the LEDP (Low Energy Differential Pressure) module. Each one of them have to pass the particle free criteria before installing on the LWU. As these pumps have not previously been widely used in particle free accelerators, we performed particle tests on them to see if they were particle free on delivery and if they generate particles during activation (Figs. 8 and 9).

After 7 activations, particle test results (Figs. 10 and 11) demonstrate that pumps are qualified. Quantity of particles released is under ISO class 5; between tests, pump remains in ISO class 5 environment.

From the results of our study, we determined that blowing between 6 (HV300) and 13 (D1000-10) times prior to installation was sufficient. However, in other even more sensitive environments we recommend additional blowing after activation 2 times prior to installation.

### Fasteners for Vacuum and Cleanroom Applications

CF flanges will be used to connect beam instrumentation, valves and gauges and as all components need maintenance it is important to minimize the number of particles that may come from disassembly. On the LWU's we wanted to know which fastener combination would be optimal for use in the particle free environment. The objective of these measurements is to provide an indicative value of released particles during CF flange assembly and disassembly. The procedure is:

- The measurement consists of blowing the bolt with filtered and ionized nitrogen gas at 3 bars for 1 min. The collector of particles is positioned on the opposite side (Fig. 12).
- The measurement is done three times.
- Combination of screw and nut is measured before assembly.
- During assembly, a 4" silicon wafer (collector) is placed underneath DN63 flanges. The collector is then blown for particle measurement (Fig. 13).
- The screw and nut combination is measured after disassembly.

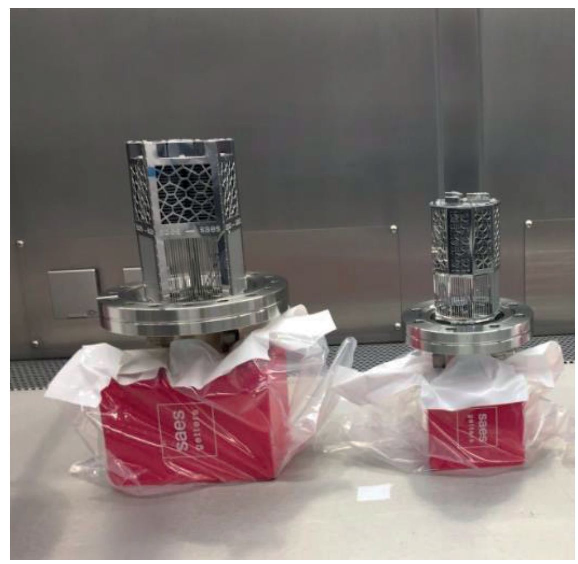


**Figure 7:** D1000-10 model (left) and HV 300 model (right).

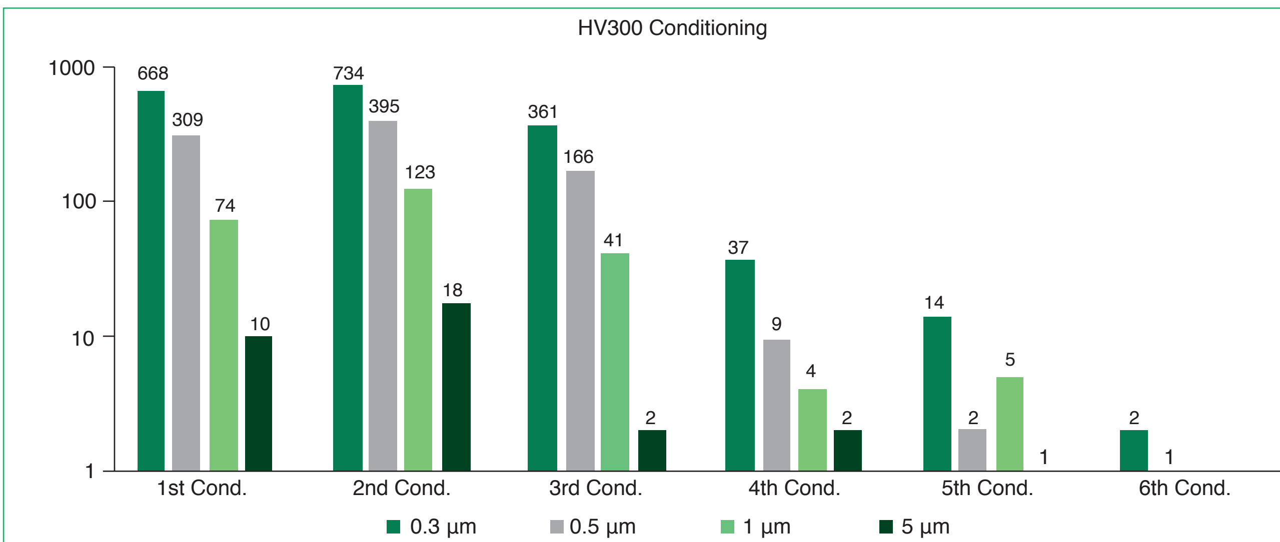


**Figure 8:** Particle count test made 6 times until ESS acceptance criteria are met (HV 300 ZAO alloy)

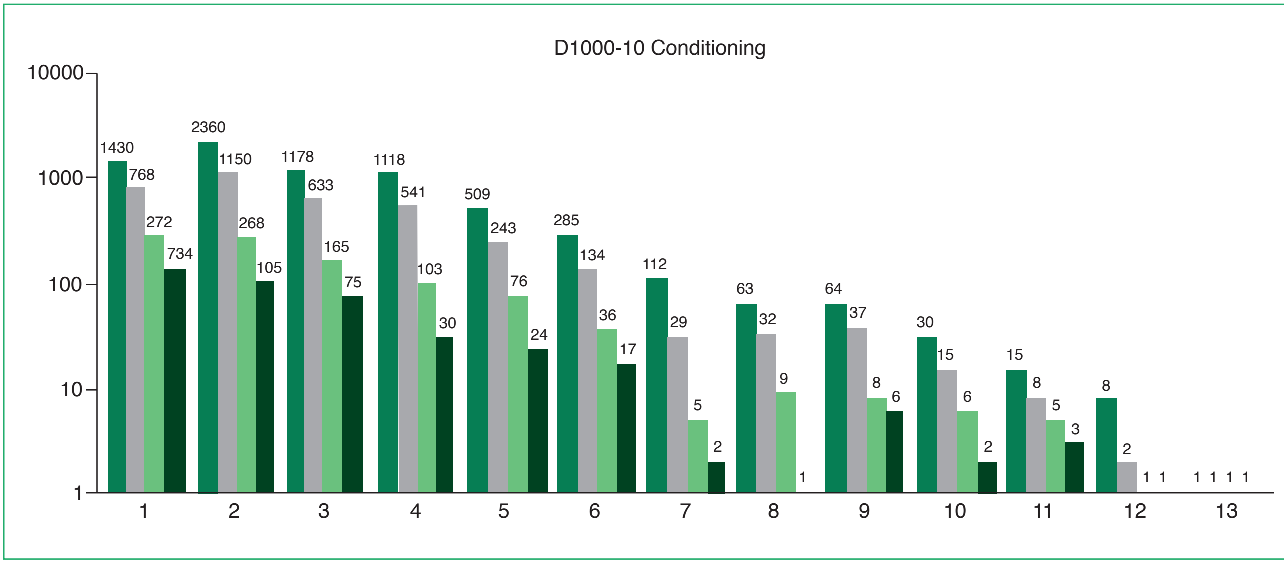


**Figure 9:** Particle count test made 13 times until ESS acceptance criteria are met (D1000-10 St172 alloy)

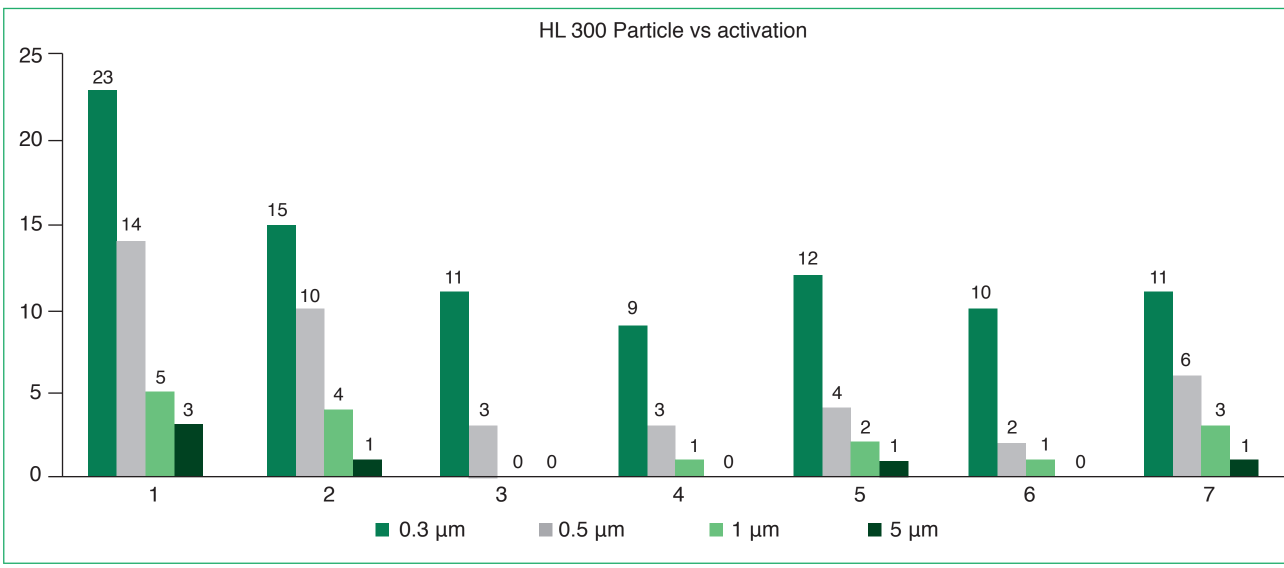


**Figure 10:** HV 300 ZAO alloy particle measurements.

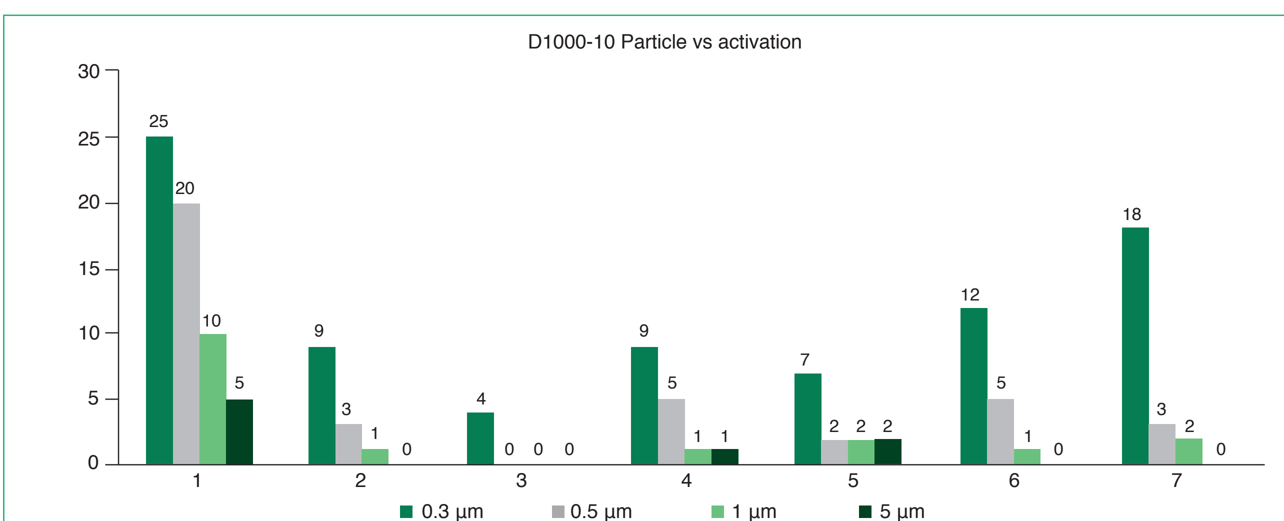


**Figure 11:** D1000-10 St 172 alloy particle measurements.

The Bolt combinations tested are shown in Table 1 and a summary of the results in Table 2. The complete results are not included here and can be provided on request. Of all the tested combinations these three are the best and yield similar results:

- Silver plated screw – standard nut.
- Silver plated screw – silver plated nut.
- Electro polished screw – Silver plated nut.

**Figure 12:** The operator is measuring the number of particles released by the bolt before assembly or after disassembly.

**Figure 13:** Particle measurment of the wafer after fastening.

**Table 1:** Bolt combinations tested.

| Material | Treatments on nut | Treatments on screw |
|---|---|---|
| M8 L45 hexagon head screw A4-316L 80 – Bumax-Fasterners | Standard | Standard |
| M8 hexagon nut A4-316L 80 | Silver plated | Silver plated |
| D 8.4 Plain washer A4-316L 300 | Kolsterized® | Electro polished |
| | Copper alloy | Kolsterized® |

**Table 2:** Summary table (gave a grade on three first for each test).

| | Combination standard screws and nuts | Standard screw + silver plated nuts | Standard screw + electropolished + kosterized nuts | Silver plated screw + standard nut | Silver plated screw + silver plated nut | Silver plated screw + electropolished + Kosterized nut | Electropolished screw + standard nut | Electropolished screw + silver plated nut | Electropolished screw + electropolished kolsterized nut | Electropolished kolsterized screw + standard nut | Electropolished kolsterized screw + silver plated nut | Electropolished kolsterized screw + electropolished + kolsterized nut | Standard screw + copper alloy nut | Electropolished screw + copper alloy nut |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serie 1 before assembly | | | | | | | | 5 | | | | | 3 | 1 |
| Serie 1 fastener | | | | 5 | | | | | 3 | | 1 | | | |
| Serie 1 after assembly | | | | | 1 | | 5 | 3 | | | | | | |
| Serie 2 before assembly | | | | 1 | 5 | | | | | | | | | 3 |
| Serie 2 fastener | | | | 3 | 1 | | | 5 | | | | | | |
| Serie 2 after assembly | 3 | | | 5 | | | 1 | | | | | | | |
| Serie 3 before assembly | | | 1 | | 3 | | | | | | | | | 5 |
| Serie 3 fastener | | | | 3 | 1 | | | 5 | | | | | | |
| Serie 3 after assembly | | | | 3 | 5 | | 1 | | | | | | | |
| Total point | 3 | 0 | 1 | 20 | 16 | 0 | 7 | 18 | 3 | 0 | 1 | 0 | 3 | 9 |

## CONCLUSIONS

In summary:

- ESS vacuum group designed and constructed particle free pumping carts, so transport of particles is minimized during venting and operation.
- SAES getter pump installed on the LWU's have been particle tested and fulfill ESS requirements. Testing indicates that the quantity of particles released fulfills ISO class 5 standard.
- Study of fasteners demonstrates 3 options of bolt combinations for different applications. Silver plated screw with either standard nut or a silver plated nut or an electro polished screw silver plated nut combination.

## ACKNOWLEDGEMENTS

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