

ESS VACUUM HANDBOOK PART 2 – VACUUM EQUIPMENT STANDARDIZATION



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1. INTRODUCTION

The European Spallation Source (ESS) is an accelerator-driven neutron spallation source. The linear accelerator (LINAC) of which is a critical component. The role of the accelerator is to create protons at the ion source, accelerates them to an appropriate energy, and steer them onto the target to create neutrons via the spallation process for use by a suite of research instruments.

2. SCOPE

The ESS Vacuum Handbook comprises four (4) parts:

ESS Vacuum Handbook Part 1 – General Requirements for the ESS Technical Vacuum Systems,

ESS Vacuum Handbook Part 2 – Vacuum Equipment Standardization Manual,

ESS Vacuum Handbook Part 3 – Vacuum Design & Fabrication Manual,

ESS Vacuum Handbook Part 4 – Vacuum Test Manual

Part 2 of this Handbook provides requirements and guidelines, for vacuum equipment for use on the accelerator, target neutron instruments, choppers, neutron guides and other supporting equipment e.g. mobile pump carts. It is only applicable to technical vacuum systems and equipment. The implementation of the Vacuum Equipment Standardization policy is to ensure that consistent standards are employed throughout all these systems.

The Vacuum Handbook will be updated periodically throughout the life of the project.

All queries or the request for additional information concerning the contents of this Handbook should be addressed to the ESS Vacuum Group Section Leader (VGL).

3. PROCUREMENT POLICY

Please refer to tender documents for information regarding procurement.

4. PRESSURE SAFETY STATEMENT

Vacuum equipment is designed and rated for a 1 bar differential service pressure unless specifically designed for a higher-pressure value.

If the vacuum device or equipment has the potential to be pressurised to a pressure exceeding 1 bar differential service pressure then relieve devices of sufficient flow capacity must be installed to protect the equipment. Refer to the ESS Vacuum Handbook Part 1, Pressure Rating of Vacuum Vessels and Components, for further information.

For designs that must exceed a 1 bar differential service pressure contact the VG to develop a strategy and equipment specifications where higher differential service pressure can be achieved.

5. STANDARD VACUUM EQUIPMENT

5.1. Pumps

5.1.1. Roughing Pumps

Dry pumps

Dry roughing pumps will be used on the accelerator, target, and neutron instruments including choppers, neutron guides and supporting equipment, e.g. mobile pump carts.

ONLY dry pumps shall be used on the accelerator including associated supporting equipment and mobile pump carts.

Due to cleanliness requirements of the superconducting section of the accelerator ONLY specific pumps will be used. These pumps will be suitably marked for this application.

These pumps shall be dry and free of oils, lubricants, hydrocarbons or other fluids in the pumping chamber and shall not generate particulate or particles during operation.

These pumps shall comply with the "Vacuum Equipment Specification for ESS Dry Roughing Pumps"

Oil Sealed Pumps

Where capacity limitations prevent the use of dry pumps, conforming to the above specification, e.g. for the pumping of larger vessels used for neutron instrument applications, oil sealed pumps, including pump sets incorporating blowers (mechanical booster pumps) may be considered. In this case these pumps are to be suitably trapped to avoid the potential for the contamination of equipment due to the back streaming of oil. In general, the pump/ pump set shall be isolated from the chamber/ equipment by an automatic valve that closes on pump shut down while the housing of the pump shall be vented to prevent the possibility of oil being shucked into the equipment.

Oil sealed pumps and pump sets shall be procured against specific equipment specifications developed by the VG to meet specific pumping requirements.

Other Roughing Pumps

The selection and use of other types of roughing pump, e.g. liquid ring pumps, pumps with special requirements, e.g. chemical series pumps, explosion proof pumps, oil sealed pumps charged with perfluoro-polyether oils etc. are not precluded, but the application and their selection will be subject to approval of the VG.

In all case the requirements for these pumps will be established by the VG in conjunction with the end user of the equipment to allow a technical specification for this equipment to be developed by the VG.

General Requirements for Roughing Pump Installations

Any specific requirement affecting the procurement of a pumping unit shall be identified during the development of the technical specification. If these are additional requirements for which a standard specification exists then this shall form an Appendix to the standard specification.

Additional requirements may include but not limited to:

- Specific vacuum connections,
- Electrical supplies,
- Radiation levels, etc.

5.1.2. Cryochillers

The use of cryochillers, having a closed loop cryogenic refrigeration system, should be considered for the efficient pumping of water vapor, which can constitute up to 65% to 95% of the residual gas load leading to extended pump down times for systems vented directly to air. This is especially true

for larger vessels that will be used for neutron instrument applications where the surface area is large.

The cryochiller together with their associated closed loop cryogenic refrigeration system shall be procured against specific equipment technical specifications developed for the procurement by the VG.

5.1.3. Turbo-molecular and Compound Drag Pumps

Turbo-Molecular Pump (TMP) and compound drag pumps will have potential applications in the accelerator, target, neutron instrument including choppers, neutron guides, supporting equipment and mobile pump carts.

TMP's are suitable for generating a clean vacuum in the pressure range of 10^{-1} to 10^{-8} Pa (10^{-3} mbar to 10^{-10} mbar) due to their high compression ratio. They will also find application on large instrument tanks that may be cryogenically pumped to provide a leak test capability.

It is desirable that these pumps are suitable for mounting in any orientation, have a high compression ratio for light gasses, have flanges compatible with the equipment on which they are mounted and able to run using detached drive controller's (remote) with a long radiation resistant cable if needed.

Where possible the pump should be mounted directly to the volume to be evacuated, to maximize conductance, together with an isolation valve to allow in-situ maintenance. The control logic implemented for pump control shall reflect the valve option used.

The drive electronics shall include suitable communication links to interface with the ESS Integrated Control System (ICS) and shall be specified in the equipment specification.

These pumps shall comply with the "Vacuum Equipment Specification for ESS Turbo-molecular".

5.1.4. Sputter Ion Pumps

Ion Pumps

The use of Ion Pumps (IP) will primarily be limited to applications on the accelerator. These pumps shall be of either noble diode or triode configuration to ensure a high pumping speed for noble gases and providing argon stability during long-term operation.

Due to the high voltage used only "finger safe" connectors shall be used on the pump.

In general, these pumps will be mounted directly to the volume to be pumped with no intermediate gate valve.

The orientation of the IP when installed shall be preferable down, i.e. the pump inlet shall facing in an upward direction to prevent the potential for particulates from the pump entering the vacuum system, unless approved by the VG. This pump orientation is essential for those used in the superconducting sections of the accelerator.

Ion pumps shall comply with the "Vacuum Equipment Specification for ESS Sputter Ion Pumps".

Ion Pump Controllers

Ion pump controllers (IPC) shall be compatible with all IP's procured against "Vacuum Equipment Specification for ESS Sputter Ion Pumps".

IPC's shall include suitable communication links to interface with the ESS Integrated Control System (ICS) and these shall be specified in the equipment specification.

IPC's shall comply with the "Vacuum Equipment Specification for ESS Sputter Ion Pumps Controllers"

5.1.5. Non-Evaporable Getter Pumps

The Non Evaporable Getter (NEG) pumps are based on high porosity sintered materials to maximize performance (speed and capacity) and mechanical characteristics. The getter material can be in the form of a thin film on a surface with limited capacity or cartridge style consisting of multiple surfaces to increase both capacity and pumping speed.

It is essential that only NEG pumps having non-particulate generating getter material surfaces be used on the accelerator.

NEG pumps will require a secondary pump for regeneration. The preferred choice being a TMP with a suitable backing pump.

For initial activation and subsequent regeneration the NEG pump getter will need to be ramped to ~ 623 K (~ 400°C) and held at this temperature for several hours before ramping down to room temperature.

The pump must be maintained under vacuum or in an inert atmosphere when not in use.

Non-Evaporable Getter Pumps and controllers shall be procured against specific equipment technical specifications developed for the procurement by the VG.

Non-Evaporable Getter Pumps and controllers shall be procured against specific equipment technical specifications developed for the procurement by the VG.

5.1.6. Combination NEG and Ion Pumps

Combination NEG and ion pumps combine the technologies of both the NEG and IP into a single pumping unit.

The comments made above for these individual types of pump apply equally to NEG and IP combination pump.

NEG and IP combination pump and their controllers shall be procured against specific equipment technical specifications developed for the procurement by the VG.

5.1.7. Cryopumps

Cryopumps shall not be used in applications where there is the potential for the pumping and accumulation of explosive gas mixtures unless specifically designed for that purposes and approved by the VGL.

The selection and use of cryopumps, will, in general, be limited to the pumping of large instrument detector tanks where a high pumping speed will be required. Only cryopumps with stand alone closed cycle refrigeration compressors shall be used.

The system is to be designed with a vacuum gate valve located between the volume being pumped and the cryopump since this will allow the cryopump to be cooled down while the chamber is being roughed to the crossover pressure.

It is essential to ensure that, as a minimum the crossover pressure is reached before bringing the cryopump online to prevent heating of the cryopump (gas load swamps the cooling capacity of the pump).

With the use of this type of pump consideration must be given to the strategy to be adopted for leak detection since with standard cryopumps the helium pumping speed will over power the leak detection system. Leak testing can be accomplished by either backing a TMP mounted directly on the chamber or connecting a pump cart to the chamber with either options backed by a leak detector with the cryopump isolated from the chamber (gate valve closed) for testing.

Cryopumps and compressors shall be procured against specific equipment technical specifications developed for the procurement by the VG.

5.2. Valves

A variety of valves will be used on the accelerator, target and neutron instrument including choppers, neutron guides, supporting equipment and on mobile pump carts. The specific requirement and features of each will depend on the specific application. The range of valve types and configurations that will be used will include:

- Valve types:
 - Gate valves
 - Angle valves
 - Solenoid valves
 - Fast valves
 - Soft-start valves
- Valve mounting arrangements:
 - CF or KF mounting flanges,
 - Insertable style where space is limited, and
 - Screw fittings, basically limited to solenoid valves used for rough vacuum applications, e.g. venting roughing pumps.
- Internal gate seals:
 - Metal, and
 - Elastomer
- Bonnet seals:
 - All valves used for UHV or high vacuum applications shall have metal bonnet seals unless specific approved by the VG.
- RF shields:
 - RF closures across valve apertures to provide a continuous RF path and/ or to protect elastomer seals.
- Actuation:
 - Pneumatic,
 - Solenoid,
 - Manual, screw or toggle.
- Position indicators:
 - All pneumatically actuated vales will have open and closed limit switches,
 - Manual valves, if specified, will have manual position indicators and/ or limit switches.

Other features that are required for a particular application will be defined in the appropriate technical specification of that equipment which may include e.g. operating temperature, radiation levels, operating cycles, gate differential pressure during opening.

Special attention needs to be given to the cleanliness requirements of the superconducting section of the accelerator where valves in this location must limit particulate generation to an absolute minimum and specific inspection/ QA requirements must be implemented to ensure this.

All valves providing remote operation shall use 24V DC solenoids.

5.2.1. Gate Valves

Gate valves shall comply with the following specifications:

- "Vacuum Equipment Specification for ESS Metal Sealed Gate Valves used in the Superconducting Section of the Accelerator"
- "Vacuum Equipment Specification for ESS Metal Sealed Gate Valves for General Applications"
- "Vacuum Equipment Specification for ESS Elastomer Sealed Gate Valves for General Applications"

5.2.2. Angle Valves

Angle valves shall comply with the following specifications:

- "Vacuum Equipment Specification for ESS Metal Sealed Angle Valves Used in the Superconducting Section of the Accelerator"
- "Vacuum Equipment Specification for ESS Metal Sealed Angle Valves for General Applications"
- "Vacuum Equipment Specification for ESS Elastomer Sealed Angle Valves for General Applications"

5.2.3. Fast Valves

Fast valves will be installed in the accelerator to provide protection against the occurrence of a sudden loss of vacuum event.

The first set of fast valves will be located directly upstream and downstream of the superconducting section of the accelerator, providing protection for the superconducting cryomodules as a result of a loss of vacuum event occurring in the warm sections of the LINAC.

The second set of fast valves will be located in close proximity to the tuning beam dump line and in the beam to target line to protect the LINAC and superconducting section of the accelerator from a sudden loss of vacuum event occurring in these areas, e.g. failure of the tuning dump window.

These valve(s) will remain in the closed position if tripped and will need to be reset following resolution of the triggering event.

The fast valve system shall be reliable with a response time as fast as possible. The gate seal shall be metal where possible and particulate generation must be an absolute minimum, which specific inspection/ QA requirements implemented to ensure this.

The fast valve system shall include fast valve, fast valve controller and sensor.

Fast valves system shall comply with the following specification:

"Vacuum Equipment Specification for ESS Fast Valve Systems for the Accelerator"

5.2.4. *Soft-start Valves*

Soft-start valves are passive devices that consist of a throttle flap(s) supported on a common axis and maintained in the open position by a spring. When initially roughing the system the high flow rate in the line immediately closes the valve and reduces the pipe conductance by about 99%. As the flow rate decreases the flap(s) gradually opens, opening fully at a differential pressure of about 1.5 Pa (150 mbar) leaving the pumping path unobstructed.

These devices shall be used where high flow rates (velocity) can damage or generate turbulence that could cause the transportation of particulate that could damage or impact installed equipment e.g. transportation of particulate into the superconducting section of the accelerator impacting cavity performance.

Soft-start valves shall comply with the following specification:

"Vacuum Equipment Specification for ESS Soft-start Valves"

5.3. **Pressure Relieve Devices**

Pressure relieve devices will be used on an as required basis to ensure compliance with Section 4 of this manual.

The pressure relieve devices, when used, can either be active or passive devices (burst discs). All devices shall be qualified by regular inspection or code qualified in the case of burst discs.

Pressure relieve devices permanently installed on the accelerator shall be limited to the use of passive devices (burst discs).

Pressure relieve devices shall comply with the following specifications:

"Vacuum Equipment Specification for Pressure Relieve Devices for ESS Accelerator Applications"

"Vacuum Equipment Specification for Pressure Relieve Devices for ESS General Applications"

5.4. **Vent Filters**

Vent filters shall be used on all vacuum systems that may suffer performance degradation as the result of the ingress of particulate during venting. On critical systems and all accelerator systems only metal filters shall be used. The material used for the filter shall conform to the list of approved materials in the Part 2 of the ESS Vacuum Handbook.

Vent filters used in the superconducting section of the accelerator shall have an element pore size not exceeding 0.5 micron.

Vent filters used in the warm sections of the accelerator shall have an element pore size not exceeding 2 micron.

Vent filters that are permanently installed on the accelerator shall be isolated from accelerator vacuum during operational periods by a manual valve.

Vent filters shall comply with the following specifications:

"Vacuum Equipment Specification for Vent Filters for ESS Accelerator Applications"

"Vacuum Equipment Specification for Vent Filters for ESS General Applications"

5.5. Mass Flow Control System

Mass flow control system will be used on the accelerator to control the flow of ionizing gas into the proton source and will have the following major features:

- Able to control up to three individual gas sources in a ratio control mode from:
 - 100% for a single gas source:
 - 99:1 to 50:50 for two gases, and
 - 98:1:1 to 33:33:33 when operating with three gases
- Each gas shall have a separate flow measurement device, metering valve and shut of valve.
- The flow measurement device shall be temperature compensated.
- All component parts of the system exposed to the gas stream shall be constructed of DIN 1.4404 (AISI 316L) stainless steel. The use of any elastomers shall be pre-approved by the VG.
- The mass flow controller system shall have a rack mountable display with manual override to provide flow control of each individual gas.
- Input/ output signals shall be provided to allow remote operation up to 100m.

The Mass Flow Control System shall comply with the detailed technical requirements specified in the following equipment specification:

"Vacuum Equipment Specification for Mass Flow Control System for ESS Accelerator and other Applications"

5.6. Vacuum Gauges and Gauge Controllers

5.6.1. General Requirements

Vacuum gauges will be used for all technical vacuum systems making total pressure measurements in the rough, high and UHV pressure regimes and will comprise the following major types:

- Thermal Conductivity (Pirani) Gauges used for measurement in the range atmosphere to 10^2 Pa (10^{-4} mbar).
- Cold Cathode Gauges (Pennnig and Inverted Magnetron) used for measurement in the range 10^{-1} Pa to 10^{-8} Pa (10^{-3} mbar to 10^{-10} mbar).
- Capacitance Manometers used for measurement in the range atmosphere to 10^{-3} Pa (10^{-5} mbar).

Other measurement devices may also be considered dependant on the application, e.g. diaphragm vacuum gauges, piezo vacuum gauge, capsule dial gauges etc.

In addition, the ion current of ion pumps can be used to provide other measurement options for pressure.

Some of the considerations that need to be given when selecting and installing the measurement devices include:

- Appropriate selection of the installation location due to the potential for pressure gradients,
- Potential pumping effect of the sensors,
- Sputter effect of cold cathode gauges,
- The impact of strong magnetic and electrical fields,
- The bake-out requirements for equipment and gauges when operating in the UHV regime,
- Selection of switching points for ionization gauges to avoid contamination,

- Redundancy for critical pressure measurements,
- Redundant gauges to allow switching to a second gauge head without the need to break vacuum to improve maintainability.

All gauges shall be non-particulate generating.

Gauges will be used to measure the vacuum levels within the vacuum system and provide outputs to allow the control and the operation of valves and pumps and other vacuum devices and provide interlocks.

The drive electronics, especially on the accelerator, will need to be separated from the gauge head due to the potential of a radiation environment.

Gauge Construction and Materials

- All gauge heads shall, where possible, be mounted on 300-series stainless steel CF 40 DN flange.
- The gauge head vacuum seals shall be all metal.
- For application on the accelerator, the gauge head, including feedthrough and connectors shall be designed to be compatible for operation in a high ionizing radiation environment. The use of Teflon® or PTFE type materials for any component is prohibited.
- The gauge head must be suitable for remote operation at distances up to 100m from the controller when the recommended type of gauge cable is used.

Gauge Bakeout Temperature

TCGs and CCGs requiring a bakeout capability shall have a minimum bakeout temperature of 423 K (150°C) with cables disconnected.

Gauge Leak Rate

The gauge heads shall be leak tight when checked with a mass spectrometer leak detector with a minimum sensitivity of $2 \times 10^{-9} \text{ Pa m}^3 \text{ s}^{-1}$ ($2 \times 10^{-10} \text{ mbar l s}^{-1}$).

5.6.2. Thermal Conductivity (Pirani) Gauges

The Thermal Conductivity (Pirani) Gauge shall comply with the detailed technical requirements specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Thermal Conductivity Gauge (TCG) for Accelerator and other Applications"

5.6.3. Cold Cathode Gauges (Penning and Inverted Magnetron)

The Cold Cathode Gauges (CCG) shall comply with the detailed technical requirements specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Cold Cathode Gauges for Accelerator and other Applications,"

5.6.4. Thermal Conductivity and Cold Cathode Gauge Controllers

Controller Configuration

The controller shall control as a minimum two (2) CCGs and two (2) TCGs simultaneously. The controllers shall operate gauge heads at up to 100m distances when appropriate cables are used.

Due to the expected high ionizing radiation fields in some locations, especially the accelerator, gauge controls shall not be mounted directly on the gauge. Consult the VG for other applications.

TCG Control Module

The TCG control modules shall operate two (2) TCGs in the range atmosphere to 5×10^{-2} Pa (5×10^{-4} mbar). The gauge calibration and total pressure measurement shall be in N_2 and shall indicate within $\pm 35\%$ of the absolute N_2 pressure at room temperature. The controller shall allow adjustment of the maximum scale reading when the sensor is at atmospheric pressure. Similarly, a zero adjustment shall be provided for use when the sensor is at or below 5×10^{-3} Pa (5×10^{-5} mbar).

CCG Control Module

The CCG control modules shall operate the CCG's between 1×10^{-1} Pa (1×10^{-3} mbar) and 1×10^{-8} Pa (1×10^{-10} mbar). The gauge calibration and total pressure measurement shall be in N_2 and shall be $\pm 50\%$ the absolute N_2 pressure between 1×10^{-1} Pa (1×10^{-3} mbar) and 1×10^{-8} Pa (1×10^{-10} mbar).

The controller shall have provisions to turn the CCG on and off automatically through a TCG. The CCG shall be turned on when the TCG is at or below a set pressure level, and turned off when the pressure exceeds the set point level. The pressure at which the CCG is turned off and on shall be user-programmable.

Front Panel Display and Controls

Each controller shall have a digital front panel display that is capable of displaying the programmable or selectable gauge parameters and pressure reading of any gauge powered by the controller.

Analogue Outputs

The controller shall have a 0-to-10 volt analogue output for each gauge, allowing determination of the gauge pressure.

Set Points

The controller shall have a minimum of one (1) set point per gauge.

Set Point Response Time

The set point relay response time, the delay between the analogue voltage reaching the set point and the relay contact opening, shall be less than 100 ms.

Communication

The controllers shall have a remote serial communication ports. The communication protocol shall provide access to all gauge readings and programmable parameters that are accessible through the front panel controls. Recovery of remote communication upon power-up shall not require local intervention.

The Thermal Conductivity and Cold Cathode Gauge Controllers shall comply with the detailed technical requirements specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Thermal Conductivity and Cold Cathode Gauge Controllers for Accelerator and other Applications"

5.6.5. *Capacitance Manometers*

The capacitance manometer uses a sensor capsule from which the pressure is determined by measuring the change in capacitance between the metal diaphragm and an adjacent, fixed dual electrode and provides extremely precise measurements of total pressure. No gauge calibration is required for a particular gas since a total pressure reading is provided.

The use of these devices will be limited to applications where accurate pressure measurements need to be made in the range from atmosphere to 10^{-3} Pa (10^{-5} mbar) is required and where the accuracy requirements cannot be provided by a thermal conductivity (Pirani) type gauge.

The Capacitance Manometers shall comply with the detailed technical requirements specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Capacitance Manometers for Accelerator and other Applications"

5.7. **Leak Detectors**

5.7.1. *General Requirements*

Helium mass spectrometer leak detectors (MSLD) will be used to qualify and confirm the integrity of vacuum boundaries and check the leak tightness of components, vacuum equipment and vessels, etc.

All MSLD's procured and used at ESS will be of modular design and incorporate robust components to provide a high degree of reliability when operated in an industrial type environment. The units used are required to incorporate protective features that will withstand accidental events that may occur during normal use, e.g. sudden vents to air, power failures and mechanical shocks during routine transportation.

The MSLD shall be mounted on a mobile cart with space provided for storage of accessory equipment and be capable of being operated when installed on the mobile cart or located independently on a suitable flat surface.

The design shall provide a simple operator interface and allow single operator operation via a hand held remote controller. Comprehensive interface capability shall be provided to allow interfacing with an external computer.

A high pumping speed for helium shall be available at the inlet port to provide a fast response time.

The MSLD shall incorporate an internal calibrated leak that can be checked by means of an external calibrated leak.

The MSLD will be used to conduct leak testing in accordance with the requirements of SS-EN-1779.

The MSLD will use a quadrupole mass filter/measurement element.

ONLY dry roughing pumps shall be used for the MSLD (see section 5.1 of this manual).

Due to cleanliness requirements of the superconducting section of the accelerator ONLY MSLD units suitably marked for this application will be used in this area.

5.7.2. Performance

The MSLD shall satisfy the following minimum performance parameters:

Leak rate range	5×10^{-11} to 1	$\text{Pa m}^3 \text{s}^{-1}$
Maximum Test Pressure, large leak mode	> 600	Pa
Maximum Test Pressure, normal mode	2	Pa
Helium pumping speed, inlet port	> 4	L s^{-1}
High vacuum pumping capacity, air	100	L s^{-1}
Rough pumping capacity, air	22	$\text{m}^3 \text{h}^{-1}$
Helium response time, at test port	< 0.5	s
Start-up time including self calibration	< 360	s
Test gas	Helium 3 and 4 with option for hydrogen	u
Measurement range, Sniffer mode	1×10^{-6} to 10	$\text{Pa m}^3 \text{s}^{-1}$
Helium response time, 15 feet probe, Sniffer Mode	< 0.5	s

5.7.3. Maintainability

The MSLD shall be serviceable with standard hand tools and test equipment and no special tools or test equipment shall be necessary to replace or repair any printed circuit board.

5.7.4. Technical Requirements Specification

The detailed technical requirements for this equipment is specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Helium Mass Spectrometer Leak Detector (MSLD) for the Accelerator and General Applications"

5.8. Residual Gas Analysers

5.8.1. General Requirements

Residual Gas Analysers (RGA) will be used for the measurement of partial pressure (ISO/TS 20175) within a system to characterize the residual gas composition during pump down or any other mode of operation, and in some cases this device will support leak testing.

The RGA will consist of the measurement head and combined controller/ display unit that shall be rack mountable. The controller shall be suitable for being located remotely from the head at distances of up to 100 m.

The RGA controller shall be able to communicate, via an Ethernet communication link, with the facilities central control system.

5.8.2. Performance

Mass Range

The RGA shall provide a mass range from 1 to 100 amu.

Minimum Detectable Partial Pressure

The RGA shall have a minimum detectable partial pressure of 1×10^{-12} Pa (1×10^{-14} mbar).

Resolution

The RGA shall provide a resolution of < 0.5 amu @ 10% peak height.

Stability

Mass stability shall not be less than ± 0.1 amu during an eight (8) hour period, after a 30 minute warm-up, when the temperature change is < 5 K (5°C). During this period the variation in peak height shall not exceed 2%.

Ion Source Materials and Construction

The ion source shall have two independent filaments made of thoria-coated iridium.

Analyzer (Gauge) Head Construction

The analyzer head shall be mounted on a 300 series stainless steel CF 40 DN flange or equivalent. No part of the ionizer head or mass filter shall protrude past the mounting flange.

Analyzer Head Orientation

The analyzer head shall be suitable for installation and operational in any orientation.

5.8.3. Technical Requirements Specification

The detailed technical requirement for this equipment is specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Residual Gas Analysers (RGA) for the Accelerator and General Applications"

5.9. Mobile Pumping Carts

Mobile pumping carts will be used for a variety of purposes on the accelerator, target and neutron instrument including choppers, neutron guides, etc.

Mobile Pumping Carts (MPC) will be connected via an isolation valve to the main vacuum system when needed.

Some MPC's will be connected via a manual valve without interlocks while other units will be interlocked through an isolation valve via an electrical connector where the system and pump cart pressures will be used as a valve interlock.

MPC shall be procured against specific equipment technical specifications developed for the procurement by the VG.

The detailed technical requirement for this equipment is specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Mobile Pumping Cart for the Accelerator and General Applications"

"Vacuum Equipment Specification for ESS Mobile Pumping Cart for the superconducting section of the accelerator"

6. STANDARD VACUUM EQUIPMENT

6.1. Flange Sealing Systems

The sealing systems used will generally be dictated by the operating pressure regime, with metal sealing for high vacuum and UHV applications and elastomer sealing for rough and some high vacuum applications. In addition, environmental considerations that could have an influence on the sealing system selected, e.g. radiation levels, operating temperature, etc. may influence the choice made.

Material used for flanges are generally stainless steel: DIN 1.4301 (AISI 304), DIN 1.4306 (AISI 304L) DIN 1.4401 (AISI 316), DIN 1.4404 (AISI 316L) or DIN 1.4429-ESR (AISI 316LN) where low magnetic permeability < 1.005 is required. For some rough vacuum applications other materials are available and may be suitable. Please consult the VG for recommendations regarding the use of alternate materials.

6.1.1. Flange Types

ISO clamped-type Flanges

These flanges use a wedge design to apply the seal force through a clamping ring or chain clamp to a seal that is incorporated into a centring ring (ISO 2861:2020 and ISO 1609:2020). The seal is typically an elastomer although metal seals of indium are available but require the use of a chain clamp to apply the additional seal pressure needed. Only indium seals shall be used for high vacuum and UHV applications.

ISO bakeable knife-edge flanges (Conflat style - CF)

These flanges shall conform to standard dimensions (ISO 3669:2020) and are available in sizes up to 400mm tube diameter. These flanges are the preferred type for high vacuum and UHV applications.

The bolt tighten sequence shall be in a star pattern to ensure even compression of the sealing gasket. Bolts shall be tightened to finger tight and progressively tightened one turn at a time until the design torque values are reached.

For trial assemblies and initial leak testing the copper seal gasket may be substituted with an elastomer seal.

ISO-K and ISO-F flanges (63 mm up to typically 630mm)

These flanges use either parallel sealing surfaces for sealing with a centring ring (ISO 2861:2020) or metal gasket (diamond type aluminium seal) or contain a seal groove for either metal (Helicoflex type seals) or elastomer O-ring sealing where the clamping of the sealing surfaces is applied by claw clamps (ISO-K) or bolts (ISO-F). Only metal seals shall be used for high vacuum and UHV applications.

The sealing principle of the Helicoflex type seal is based upon the plastic deformation of a jacket of greater ductility than the flange materials. This occurs between the sealing face of a flange and an elastic core composed of a close-wound helical spring. The spring is selected to have a specific compression resistance. During compression, the resulting specific pressure forces the jacket to yield and fill the flange imperfections while ensuring positive contact with the flange sealing faces. Each coil of the helical spring acts independently and allows the seal to conform to surface

irregularities on the flange surface. Surface tolerances and surface finish are important for obtaining a good sealing.

Other Flanges

Metal gasket face seals are suitable for both high vacuum and UHV applications. These sealing systems are typically available up to 18mm and are used primarily for pipe connections. Swagelok being the most common type of fitting used.

Wire sealed flanges: An OFHC copper wire shall be used to affect the seal. They are available for tube sizes up to 630mm but are not commonly used.

Flanges form EVAC (ISO-CeFiX®) or MKT use a similar sealing arrangement as CF flanges but the sealing pressure is applied through a wedge design with a chain clamp used to apply the pressure to the seal. These sealing systems are available up to 250mm tube size. The use of the chain clamp makes them suitable for applications in radiation areas where the time required to make the vacuum connection can be significantly reduced compared to CF. Further the connection can be made remotely using long handled tools.

6.1.2. Sealing

Metal Seals

Metal seals shall be OHFC copper where possible and shall only be used one time before being discarded.

For Helicoflex type seal consult the manufactures catalog for material selection and confirm the suitability of this selection with the VG.

Elastomer Seals

Under normal circumstances Fluoroelastomer (FKM - Viton) O-rings should be selected and these are suitable for use up to a temperature of 423 K (150 °C).

If a higher temperature is required select Perfluoroelastomer (FFKM - Kalrez or Chemraz) which is suitable up to 473 K to 523 K (200 °C to 250 °C)

If additional radiation resistance is required, select EDPM (ethylene propylene diene monomer), which is suitable for radiation levels up to 1 MGy compared to Viton, which is suitable up to 0.5 MGy.

6.1.3. Fasteners

Fasteners shall be made of DIN 1.4301 (AISI 304) or equivalent or DIN 1.4429_ESR (AISI 316LN-ESR) when magnetic permeability is an issue.

The bolts used shall be silver plated to prevent the potential for galling (cold welding), with a washer under the head of the bolt or nut. Greases and oil shall not be used as a thread lubricant.

6.2. Bellows

6.2.1. Hydroformed

A specialized type of die forming that uses a high-pressure hydraulic fluid to press room temperature working sheet material into a die. Hydro formed bellows made up of thin stainless-steel DIN 1.4XXX (AISI series 300) without attached flanges or with internally welded flanges is

cleanable and is permitted. Note, however, that they are limited in axial movement and lateral offset in comparison to edge welded bellows. They have a relatively high spring rate and therefore dedicated compression tools are required during installation. Special attention must be taken to the end-pieces of such bellows due to inclusion contents and possible leaks as well as corrosion after welding. Therefore, it is recommended to use only multidirectional forged stainless-steel DIN 1.4429-ESR (AISI 316LN-ESR) for the end-pieces.

The use of weld collars is recommended where a third party undertakes the welding to an adjacent component.

Please consult the VG for recommendations regarding the selection and use of hydroformed bellows.

The detailed technical requirement for this equipment is specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Hydroformed Bellows for the Accelerator and General Applications"

6.2.2. Edge-welded

Edge welded bellows are made up of thin stainless-steel DIN 1.4XX (AISI series 300) diaphragms welded on the inside and outside diameters by means of laser or micro-plasma to form a series of convolutions. The bellows can be delivered very clean and ready for UHV usage. However, if they get contaminated (e.g. during installation), it is difficult to re-clean them. "Off-the-shelf" bellows may also be used but they need to be qualified before use. Welded bellows must be capable of maintaining continuous leak-free operation and withstand a minimum of 50 thermal cycles from room temperature to 473 K (200 °C) while under vacuum, for the stroke and offset positions specified. Before being put into operation, each bellows needs to be leak tested by using a mass spectrometer helium leak detector. Beside large axial strokes, these bellows also allow for non-negligible lateral and angular displacements. Further they have a comparable low spring rate and therefore no compression tools are required during installation. It is recommended to specify stainless steel DIN 1.4404 (AISI 316L) for the bellow material and multidirectional forged DIN 1.4429-ESR (AISI 316L-ESR) for the end-pieces.

The detailed technical requirements for this equipment is specified in the following equipment specification for this system:

"Vacuum Equipment Specification for ESS Edge-welded Bellows for the Accelerator and General Applications"

6.2.3. Electroformed

These bellows are produced by electro-deposition: building thin layers of metal onto a precision-machined mandrel and chemically removing the mandrel afterwards.

Electrodeposited nickel alloy is the standard material (ferromagnetic!) and therefore not suitable for use on the accelerator. Copper, silver and gold are also available either as a surface finish or base metal.

Electroformed Bellows shall be procured against specific equipment technical specifications developed for the procurement by the VG.

7. OPERATIONAL LIFE AND MAINTENANCE FOR VACUUM EQUIPMENTS

The operational life and maintenance of ESS vacuum equipment will depend on the duty cycles and environmental conditions to which the equipment is exposed.

The maintenance strategy for ESS vacuum systems will be primarily based on corrective maintenance, addressing field object failures. In general, field object failures will not result in the removal of the beam permit, allowing the vacuum system to continue operating in a degraded mode. Replacement of failing components will be scheduled for the next shutdown period as part of corrective maintenance. Spare parts for the most critical components will be kept in stock to ensure timely replacements.

When applicable, maintenance of equipment will follow the manufacturer's recommendations.

7.1. Vacuum Pumps

The time between maintenance periods for vacuum pumps will depend on their in-service duty. Typically, pumps are expected to provide 60,000 to 100,000 hours of operation between service intervals. Maintenance or replacement becomes necessary when a loss in ultimate vacuum performance is observed. This can be checked during operation and non-operational periods. In some specific locations, the radiation environment may accelerate pump failure. To mitigate this, radiation-hard pumps or redundancy strategies will be employed, minimizing the impact on beam availability in the event of failure. Preventive replacement of pumps may also be considered on a case-by-case basis.

7.2. Vacuum Valves

The time between maintenance periods for vacuum valves is generally not limited by the number of operational cycles—typically in the range of hundreds of thousands of cycles—but rather by the environmental conditions to which the valves are exposed. Most valves in the accelerator are of the all-metal type, which require very little maintenance. These valves are monitored and inspected practically during every operation.

Most laboratory units, however, are elastomer-sealed and may be subject to long-term deterioration due to aging and radiation, necessitating seal replacement. Operational behavior and leak testing can be conducted as part of the maintenance strategy to determine whether seal replacement is required.

Solenoid valves, in particular, may experience failure due to aging and radiation exposure. Spare solenoid valves will be kept in stock to allow for quick replacement in case of failure. Preventive replacement of solenoid valves may also be considered on a case-by-case basis. Again, behavior in the field is the primary reference and is monitored continuously.

Key hardware in the accelerator area does not require local inspection (as it is a radiation-controlled area) due to remote performance monitoring, in line with the ALARA principle (As Low As Reasonably Achievable).

7.3. Vacuum Gauges and pressure Switches

Vacuum gauges and pressure switches generally do not require regular maintenance. Functional checks of gauge operation is conducted during operation and substitution is possible on shutdown periods. Calibrations are only possible before installation when necessary.

7.4. Vacuum controllers

The electrical components of vacuum equipment is subject to specific maintenance procedures from an electrical perspective. These procedures ensure that the controllers continue to perform reliably under operational and environmental conditions.

During shutdown periods, detailed inspections and tests can be conducted to verify the integrity and performance of the controllers. However, during operation periods, vacuum controllers are under constant monitoring, which can often substitute for local inspections in certain cases. Continuous monitoring allows the detection of early warning signs, such as deviations in operational parameters, and enables proactive maintenance to minimize downtime.

8. APPENDIX

8.1. Standards

Document	Description
ISO 15614-1	Arc welding
ISO 3669-2:2020	Bakable flanges Part 2: Dimensions of knife-edge flanges
ISO 9803-1:2020	Mounting dimensions of pipeline fittings Part 1: Knife-edge flange type
ISO 9803-2:2020	Mounting dimensions of pipeline fittings Part 2: Knife-edge flange type
ISO 2861:2020	Dimensions of clamped-type quick-release couplings
ISO 20175	Vacuum technology - Characterization of quadrupole mass spectrometers for partial pressure measurement
SS-EN -1779	Non-destructive testing - Leak testing - Criteria for method and technique selection
DIN 1.4301/AISI 304	Standard Cr-Ni stainless Steel alloy (ISO X5CrNi18-10)
DIN 1.4306 (AISI 304L)	Standard Cr-Ni low carbon version of AISI 304 (ISO X2CrNi19-11)
DIN 1.4401 (AISI 316),	Standard Cr-Ni-Mo stainless Steel alloy (ISO X5CrNiMo17-12-2)

DIN 1.4404 (AISI 316L)	Standard Cr-Ni-Mo low carbon version of AISI 316L (ISO X2CrNiMo17-12-2)
DIN 1.4429 (AISI 316LN)	Standard Cr-Ni-Mo-N low carbon and nitrogen-strengthened (ISO X2CrNiMoN17-13-3)
DIN 1.4429-ESR (AISI 316LN-ESR)	Electro-Slag Remelted (ESR) variant of 316LN for high purity (ISO X2CrNiMoN17-13-3 ESR)

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Karl Jousten (editor), Handbook of Vacuum Technology, Wiley-VCH, 2008.

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Felix Sharipov, Rarefied Gas Dynamics: Fundamentals for Research and Practice, Wiley-VCH (2016).

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8.2. Units

This document uses the SI system to express units, however other deviations are mentioned accordingly.

Symbol	Unit
m	metre
g	gram
s	second
A	ampere (electric current) [C s ⁻¹]
K	kelvin (temperature)
mol	Mole
J	joule (energy) [N m]
W	watt (power) [J s ⁻¹]

N	newton (force) [m g s^{-2}]
Pa	pascal (pressure) [N m^{-2}]
V	volt (electrical potential) [W A^{-1}]
°C	degree Celsius (temperature) [K] *no-SI unit
bar	bar (pressure) [Pa] *no-SI unit (defined by IUPAC)
l	litre (volume) [m^3] *no-SI unit
C	conductance [$\text{m}^3 \text{s}^{-1}$; $\text{l}^3 \text{s}^{-1}$]
u	unified atomic mass *no-SI unit

8.3. Abbreviations

ASTM	American Society for Testing and Materials
AISI	American Iron and Steel Institute
AMU	Atomic Mass Unit
CCG	Cold Cathode Gauge
DC	Direct Current
DIN	Deutsches Institut für Normung
DN	Nominal Diameter
ESHR	Essential Health and Safety Requirements
ESR	Electro Slag Remelted
ESS	European Spallation Source
EU	European Union
HC	Hydrocarbon
ICS	Integrated Control System
IKC	In-Kind Contributor
IP	Ion Pump
IPC	Ion Pump Controller
ISO	International Organization for Standardization
LINAC	Linear Accelerator
MPC	Mobile Pumping Cart
MSLD	Mass Spectrometer Leak Detector
NCR	Non-Conformity Report
NDT	Non-Destructive Testing

NE	Nitrogen Equivalent
NEG	Non-Evaporable Getter
QA	Quality Assurance
QC	Quality Control
RF	Radio-Frequency
RGA	Residual Gas Analyzer
SI	International System of Units
SOW	Statement Of Work
SRF	Superconducting Radio-Frequency
TCG	Thermal Conductivity Gauge
TMP	Turbo-Molecular Pump
US	Ultra-Sound
VESM	Vacuum Equipment Standardization Manual
VG	Vacuum Group
VGL	Vacuum Group Section Leader
VHB	Vacuum Handbook
VTM	Vacuum Test Manual

8.4. Nomenclatures

CF	Conflat TM by Varian Corp.
EDPM	Ethylene Propylene Diene Monomer
FFKM	Perfluoroelastomer (Kalrez or Chemraz)
FKM	Fluoroelastomer (Viton)
HV	High Vacuum
LV	Low (rough Vacuum)
MV	Medium Vacuum
OFHC	Oxygen-Free High Conductivity TM
UHV	Ultra-High Vacuum

9. GLOSSARY

Term	Definition
ESS	European Spallation Source
HV	High Vacuum
IKC	In Kind Contributor
LINAC	Linear Accelerator
RV	Rough Vacuum
NE	Nitrogen Equivalent
UHV	Ultra-High Vacuum
VG	Vacuum Group
VH	Vacuum Handbook
VGL	Vacuum Group Section Leader

DOCUMENT REVISION HISTORY

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1	First issue	Marcelo Juni Ferreira	2016-04-14
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3	Updated review for operation	Laurence Page	2025-01-28
4	Transferred to template (no change of content)	Laurence Page/Gunilla Jacobsson	2025-04-09