A VACUUM SYSTEM FOR THE ESS ACCELERATOR

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Abstract

A description is given of the design of a vacuum system for the linac (including the ion sources and front end), rings and proton beam lines for the 1.3 GeV proton accelerator of the European Spallation Source (ESS) [1].

1 THE LINAC

1.1 Pressure Requirements

The vacuum pressure required in the machine is based on the desire to keep beam losses to a minimum and to allow "hands on" maintenance (~10 μSv/hr). At full power, 10 MW and 1.3 GeV, this is equivalent to a fractional particle loss of 10^{-7} per metre length or 1 W/m. The largest loss when the beam interacts with the residual gas is due to charge exchange of the H^- ions. In the normal conducting linac (NCL) the majority of the residual gas will be water vapour. The charge exchange cross sections in oxygen [2] are used due to lack of measurements with water.

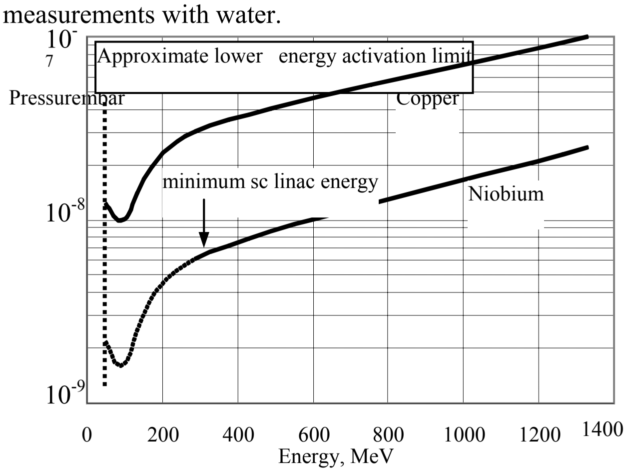

Figure 1: Maximum vacuum pressure (water vapour) versus energy of a 10 MW H^- beam, to allow hands-on maintenance.

Barbier [3] has characterised the induced activity in materials by a *danger parameter*. Barbier lists the calculated gamma danger parameter for a number of different cases. Multiplying the cross section by the danger parameter, a vacuum pressure may be found that allows hands on maintenance. Figure 1 shows this maximum pressure as a function of the beam energy for copper and niobium, the main materials in the NCL and superconducting linacs (SCL) (both options are being considered for the ESS). An infinite irradiation time and 1 hour cooling time has been chosen as a typical worst scenario. It also assumes that the charge exchanged beam hits the vacuum chamber wall adjacent to the point at which the charge change took place.

These calculations show that a pressure of $\leq 10^{-8}$ mbar is needed at the front end of the linac, rising to $\leq 10^{-7}$ mbar at the maximum energy. The SCL will achieve pressures well below 10^{-10} mbar and the losses due to the residual gas can be ignored. (The SCL does not require pumping, other than initially.) However, the SCL has a normal conducting linac below 300 MeV. Thus, the most difficult region requiring the lowest pressure, between 100 and 300 MeV, is a normal conducting section common to both the NCL and the SCL. The pressure requirements are not particularly onerous in the higher energy sections of the NCL. However, the pressure in the room temperature sections between the cryostats of the SCL is demanding (10^{-10} mbar). Below 100 MeV the activation falls off sharply, and the design pressure is $\leq 10^{-6}$ mbar.

1.2 General Design Philosophy and Outgassing Rates

Since the accelerator and beam lines are areas of high radiation, the design philosophy is to install only essential components of high integrity, reliability, long life and requiring minimum maintenance. The components should be rapidly removable. Band clamps, rather than bolts, will be used on flange connections wherever possible. The whole vacuum system will be built to uhv standards using metals and ceramics, including metal seals and all metal valves, to eliminate hydrocarbon contamination, reduce outgassing rates and to be radiation hard.

The pumping speed requirements depend on the specific outgassing rate. The outgassing rate for clean, un-baked copper at 10 hours is taken as 2×10^{-10} mbar l/s cm^{-2} [4]. There is a distinct advantage in vacuum baking the copper to reduce the rate by 2-4 orders of magnitude. However, the time taken to bake is several days following every let up to atmosphere, and this is a severe penalty. Hence, the linac will not be vacuum baked.

1.3 Vacuum System for the Ion Source, RFQ and Chopper

It is assumed that there will be two ion sources in each arm of the funnel [1]. The hydrogen gas load is taken as ~1 mbar l s^{-1}. Three large turbomolecular pumps, each of 2000 l/s are required to remove this heavy gas load at the exit of each of the ion sources. Even then, the pressure at the exit of the source is high, 10^{-4} mbar, and a series of baffles and differential pumping is required to reduce the pressure to ~10^{-6} mbar at the entrance of the RFQ. Figure 2 shows the system schematically. The vacuum system will be designed to uhv standards with all metal and ceramic components. The only exceptions, due to cost considerations, are the Viton sealed gate valves on the turbomolecular pumps.

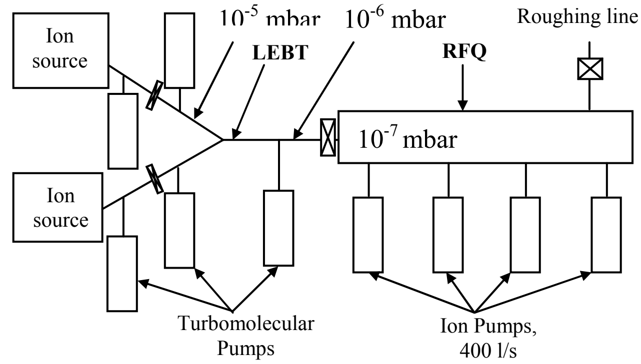

Figure 2: Schematic diagram of the vacuum system for the ion source, LEBT and RFQ. Approximate pressures are shown. The speeds of the turbomolecular pumps are 1000 l/s and 6000 l/s at the ion sources. Gate valves (not shown) are provided above each turbomolecular pump.

Each of the four sections of the rfq will have one ion pump of 400 l/s speed to give a pressure of $<10^{-7}$ mbar. Three 50 l/s ion pumps will pump the chopper.

1.4 The Vacuum System for the Drift Tube Linac

The drift tube linacs connected to each arm of the funnel are 1200 cm long and 120 cm in diameter. Each linac will be initially pumped by the mobile roughing units (MRU) – see section 1.5.3 - through DN200 all metal valves and then pumped by two 400 l/s ion pumps and 10000 l/s Polycold* cryo-pump units to a pressure of $<10^{-7}$ mbar. DN40 gate valves will isolate the vacuum systems at each end of the tanks.

1.5 The Vacuum System for the ESS Cavity Coupled Linac and Funnel

The normal conducting cavity-coupled linac (CCL) consists a large number of rf accelerating cells. The cells are arranged in groups (tanks) with bore diameters of 1.5 to 2 cm. Bridge couplers link the rf in the tanks. The total length of the structure is ~700 m and the final energy is 1.3 GeV. Figure 3 shows a group of cells and the rf coupling cavities at the side of the accelerating structures.

1.5.1 Conductance to the Cavities

It is assumed that the pumping will be through the couplers and that the pumping holes in the cavities and accelerating cells do not significantly perturb the rf fields. The apertures in the walls of the accelerating cells and the coupling cavities are assumed to have an area of 40 cm^2. Assuming the wall thickness is very small at these holes, the conductance is ~460 l/s for air. The conductance of the coupling cavity itself is more difficult to calculate accurately because of the complex geometry, but may be approximated by taking a rectangular duct of 20x6 cm^2 cross section and 25 cm length. The conductance is ~700 l/s.

* Polycold® Systems International, San Rafael, California, USA.

A short length of flexible bellows will be required between the coupling cell and the pumping system. The bellows will be about 10 cm diameter and 5 cm long, having a conductance of ~600 l/s. RF liners will probably be required in the bellows. The resultant conductance through the coupling cell to the accelerating cavity is ~130 l/s. In practice the apertures may not be able to be this large and the conductance will be smaller, perhaps by up to a factor of 2.

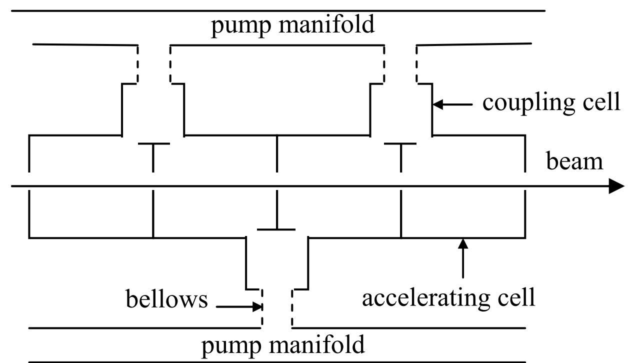

Figure 3: Schematic diagram of a group of cells and couplers. Pumping is through short flexible bellows from the coupling cells to the manifolds.

1.5.2 Pumping Speed

At the front end of the linac the cells are 12 cm long, and the surface area of a cell is ~3.7x10^3 cm^2. The surface area of the coupling cells is ~1.8x10^3 cm^2. The pressure drop from the accelerating cavity to the pumping port on the coupling cell is ~4x10^{-9} mbar. With a pump of 200 l/s speed (i.e. speed approximately matched to conductance) the pressure in the accelerating cavity will be ~1x10^{-8} mbar. This just reaches the "specification". Note that every accelerating cell is pumped through the coupling cells on both sides of the linac, to reach this pressure. Pumping these cells is conductance limited so little is gained by increasing the pump size.

The high-energy end of the linac has an accelerating cell length of 24 cm and area of 5.2x10^3 cm^2. Because the pressure required is only 10^{-7} mbar, a pumping speed of 50 l/s at every other coupling cell is adequate to reach 7x10^{-8} mbar. The central section of the linac will require 100 l/s pumping at every other coupling cell.

Thus, the pumping for every accelerating cell will consist of: 200 l/s for the first section of the linac up to 250 MeV; 100 l/s for the next section up to 445 MeV; and the last section will have 50 l/s for the first half of its length and 25 l/s for the second. The total pumping speed, including the bridge couplers and inter-tank beam lines is ~2x10^5 l/s.

1.5.3 Pumping Scheme

For economy, a manifold pipe will be used to pump the linac because it allows larger but fewer pumps. The manifold will be ~25 cm in diameter. Two manifolds will be required for the first length of the linac attached to the coupling cells at the top and bottom of the linac. The rest of the linac will require only one manifold. The bridge couplers will also be connected to the manifold.

Ion pumps are preferred over turbomolecular pumps because of their radiation resistance, low maintenance, long life and reliability. About 200 pumps will be required each with a speed of 1000 l/s. Two mobile 1000 l/s turbomolecular pump units (MRU) will be attached to a 100 m length of linac to initially evacuate the system. These MRUs will be removed after pump down and can be used to evacuate other parts of the accelerator. Dry pumps, to avoid oil contamination, will accomplish roughing. This will produce a hydrocarbon free system so necessary for good operation of the ion pumps. After roughing, most of the gas load will be water vapour, thus Polycold cryo-pumps will be used in conjunction with the ion pumps. The cryo-tube will run along the length of the vacuum manifold and have a total speed of ~2500000 l/s.

The linac will be divided up into 100 m sections for operational convenience by all metal beam gate valves. These valves will have an rf liner in the open position.

The funnel is similar to the linac having several cavities, quadrupole and septum magnets in the 7 m long arms with 2.5 cm diameter apertures. Again the system is conductance limited and must be pumped at frequent intervals. Hence the two manifolds from the front section of the linac will extend along the two arms of the funnel.

2 THE ESS RINGS AND BEAM LINES

2.1 Introduction

It is assumed that the general radiation levels in the area of the rings and proton beam lines will be similar to the corresponding areas in ISIS [5] allowing hands on maintenance except in a few regions such as the collectors.

The vacuum system will be built to uhv standards as in the linac. Aluminium vessels will be used in the rings to give the required electrical conductivity for the pulsed proton beam image currents. Aluminium or stainless steel will be used for the vessels in the beam lines. The components in the beam lines will be carefully cleaned, but not vacuum baked, to achieve a specific outgassing rate of $\leq 5 \times 10^{-10}$ mbar l/s/cm^2 at 10 hours [4].

The average design pressures in the achromatic bend is 4×10^{-8} mbar and 10^{-7} mbar in the proton beam lines up to the rings. The pressure in the rings is 10^{-7} mbar and 10^{-6} mbar in the beam lines to the targets.

However, to avoid the possible e-p instability [6] produced through beam interaction with the residual gas and subsequent secondary electron emission from the chamber walls, it may be necessary to significantly reduce the vacuum pressure. Alternatively, or in addition, coated vacuum chambers may be needed to reduce the secondary emission coefficient. The SNS project has decided on a vacuum pressure of 10^{-9} mbar [7]. To reduce the pressure to these low levels will require an increase in the pumping speed or a reduction of the specific outgassing rate. It is impractical to increase the pumping speed by more than a factor of 10 before the pumps touch each other. A more practical solution is to give the system a modest vacuum bake at ~100°C for one day. This would reduce the outgassing rate of the aluminium vessels to $\sim 10^{-12}$ mbar l/s/cm^2 [8] and would correspondingly reduce the pumping speed requirement. Whilst this is attractive, there is a practical disadvantage. Until the e-p instability has been studied, it is not proposed to alter the existing design pressure of 10^{-7} mbar.

The minimum number of valves will be installed; there are no valves in the rings and no fast acting valves in the system. Valves are used to attach the turbomolecular pumps for initial evacuation.

2.2 Pumps

Ion pumps varying in speed from 20 l/s to 400 l/s will be used, as appropriate. It is proposed to use the same mobile turbomolecular pump units (MRU) from the linac to evacuate the system. All metal valves will be used to attach the roughing pumps to the system.

3 CONTROL SYSTEM

Control of the entire vacuum system will be local with both local and remote (via the computer system) monitoring with computer links to the central control system. The systems will be fail safe, shutting down in the appropriate manner through the hardwired local control systems. The controls and supplies will be located close to the appropriate pumps and gauges but sufficiently far away from the accelerator to be shielded from radiation.

Monitoring of the system pressures will be by inverted magnetron and wide range Pirani gauges strategically located around the system. Quadrupole mass analysers will be installed for diagnostic and leak detection purposes. Small all-metal right angle valves will be distributed around the system for attachment of additional diagnostics.

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