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VACUUM MODELS FOR MINERVA LINAC DESIGN*

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Abstract

The goal of MYRRHA project is to demonstrate the technical feasibility of transmutation in a 100 MW Accelerator Driven System (ADS) by building a new flexible irradiation complex at Mol (Belgium). The MYRRHA facility requires a 600 MeV accelerator delivering a maximum proton current of 4 mA in continuous wave operation, with an additional requirement for exceptional reliability. Supported by SCKCEN and the Belgian federal government the project has entered in its phase I: this includes the development and the construction of the linac first part, up to 100 MeV. We here review the MINERVA linac vacuum system modelling studies that enabled to validate the choice of materials and vacuum equipment. The strengths and weakness of the vacuum design, highlighted by the models, will be discussed as well as the required improvements.

INTRODUCTION

The MYRRHA [1, 2] (Multi-Purpose Hybrid Reactor for High Tech Applications) project aims at building an ADS (Accelerator Driven System) demonstrator to study the technical feasibility of nuclear wastes incineration. It consists of a high power proton accelerator (4 mA – 600 MeV) which has to maintain a very high level of reliability to guaranty the robustness and the availability of the driven reactor [3, 4].

The MINERVA (MYRRHA Isotopes productioN coupling the linEar acceleRator to the Versatile proton target fAcility) project is the first phase of MYRRHA project. It consists of the construction of the linear accelerator up to 100 MeV. MINERVA accelerator (Fig. 1) is composed of): the LEBT (Low Energy Beam Transport), the RFQ (Radio Frequency Quadrupole), the CH cavity Booster, the MEBT-3 (Medium Energy Beam Transport), single spoke superconducting linac and HEBT beam transfer lines.

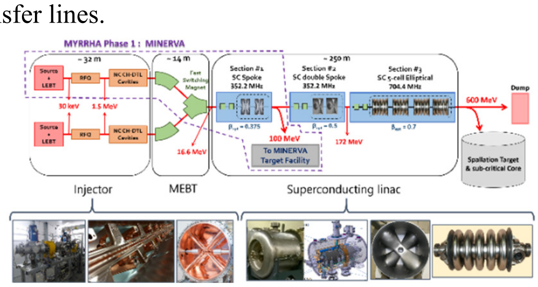

Figure 1: Conceptual scheme of MYRRHA [5].

The vacuum layouts of the different sections have been defined [6]. The vacuum level requirements are similar to other high power proton linacs. It depends on the section and the used accelerating technology: normal conducting (NC) or superconducting (SC). It can go from 10^{-6} to 10^{-10} mbar. In general, dry vacuum pumps will be used and, if necessary, a bake out will be performed. Vacuum system modelling was realized according to the mechanical designs or constructed elements (such as the LEBT and RFQ [7]). For other parts the vacuum model is based on the architecture defined with the beam dynamics model. And we used a conservative assumptions to highlight points of attention.

VACUUM DESIGN

The LEBT, the RFQ and the first half of the CH-Booster mechanical designs are already defined. Thus, for those sections, the model is realistic. The second half of the CH-Booster is similar to the first half, so it can be considered as defined. The MEBT-3 mechanical design is under definition. For this section, vacuum system modelling is considered "disadvantageous" (with a minimum of pumping ports) to be pessimistic and to orientate the final design. As for the single spoke linac section, the single spoke cavities are defined and the warm sections between each cryomodules are almost defined, so the model is realistic.

To improve the space charge compensation (SCC) [8], and in particular the beam neutralization transient time, it has been envisaged to keep a pressure level of 10^{-5} to $5{\times}10^{-5}$ mbar, with possible injection of Argon or Krypton gas into the LEBT. The collimator cone at the end of the LEBT reduces the conductance and the gas flux from the LEBT to the RFQ.

The end of MEBT-3 and the main superconducting linac are using spoke cavities cryomodules, operating at 2 Kelvin. All the guiding and focusing magnetic elements operate at ambient temperature. To limit the pollution, a bake out has to be performed on the whole MEBT-3 and single spoke linac. Required vacuum levels in mbar of the different sections are shown in Table 1.

Table 1: Required Vacuum Levels

LEBT	RFQ	CH-Booster	MEBT-3	Spoke linac
10^{-6} to $2{\times}10^{-5}$	10^{-7} to $5{\times}10^{-7}$	$8{\times}10^{-8}$ to $3{\times}10^{-7}$	10^{-10} to 10^{-9}	10^{-10} to 10^{-9}

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SIMULATIONS

Conductance Calculation

The main used formulas to calculate pipes conductance are:

- Cylindrical pipe:

$$C = 122 \times \left(\frac{D^3}{L}\right) \tag{1}$$

where D is the diameter and L is the length of the pipe.

- Rectangular section pipe, by converting the rectangular section to a circular section, the formula for cylindrical pipe can then be used. To convert rectangular section to cylindrical section, we use:

$$D = 2 \times \sqrt{\frac{h \times w}{\pi}} \tag{2}$$

where h is the height and w is the width of the section pipe.

- Thin wall orifice, diameter reducer or collimator:

$$C = 116 \times \pi \times \frac{D_1^2}{4 \times \left(1 - \left(\frac{D_1}{D_2}\right)^2\right)} \tag{3}$$

with $D_1 < D_2$

- For complex conductance, as spoke cavities conductance, Molflow+ [9-11] software is used. Simulation with Molflow+ (Fig. 2) provide the entrance conductance and the transmission probability and then, the spoke cavity conductance by using:

$$C = entrance\ conductance \times transmission\ probability$$
$$C = 0.289\ \mathrm{m^3/s} \times 17.8\% \tag{4}$$
$$C = 0.052\ \mathrm{m^3/s}$$

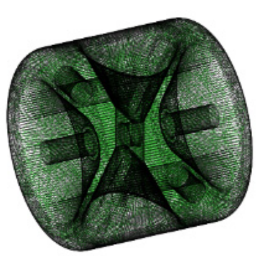

Figure 2: Spoke cavity modelled with Molflow+ software.

Outgassing Flux Calculation

Each materiel is characterized by a specific outgassing rate (see Table 2). The outgassing flux of each material is calculated by multiplying the outgassing rate by the surface of the element.

Each equipment has its own outgassing flux use in the calculation (see Table 3).

VITON gaskets have an outgassing rate and also a permeation flux. The permeation flux (2.5×10^{-6} Pa.m^3/s) is the total flux for 1 m² of VITON in contact with the vacuum. When used, VITON gaskets are the main source of outgassing in the vacuum vessel.

Table 2: Outgassing Rate

Description	**Outgassing rate (Pa.m/s)**
Stainless Steel after 50 hours pumping	4×10^{-8}
Stainless Steel baked out at 200°C during 24 hours	2×10^{-10}
Niobium after 10 hours pumping	8.06×10^{-7}
Niobium baked out	8.06×10^{-8}
Niobium @T=2K	4.03×10^{-8}
Copper after 50 hours pumping	10^{-6}
Copper baked out	10^{-8}
VITON after 50 hours pumping	2×10^{-4}
VITON baked out	10^{-6}

Table 3: Outgassing Flux

Description	**Outgassing flux (Pa.m/s)**	**Baked out (Pa.m³/s)**
Gate valve VAT Series 10.8 CF100	10^{-9}	5×10^{-10}
Gate valve VAT Series 10.8 CF150	2×10^{-9}	10^{-9}
Gate valve VAT Series 11 CF150	2×10^{-8}	10^{-8}
Pirani gauge + cold cathode gauge + RGA	2×10^{-9}	5×10^{-10}
Faraday cup	4×10^{-7}	
Slots	5×10^{-8}	
Emittance meter	2×10^{-6}	
Wire scanner	4×10^{-7}	6×10^{-8}
BPM	5×10^{-8}	10^{-9}
Chopper	6.2×10^{-8}	
VITON permeation	2.5×10^{-6}	
Spoke cavities (1,2 m² niobium)	10^{-6}	10^{-7}

Simulations

The beam line is modeled using PSpice [12] software (electronic computer aided design software), by using the analogy between vacuum and electronic (see Fig. 3).

C in m^3/s ⇔ 1/R in Ω^{-1}
Q in Pa.m^3/s ⇔ I in A
P in Pa ⇔ U in V

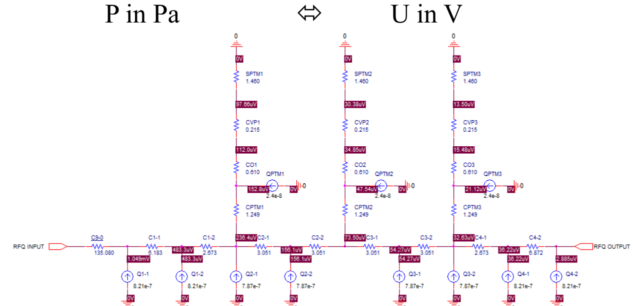

Figure 3: RFQ modelling with PSpice software.

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The simulated results from PSpice software provide the pressure along the beam line.

RESULTS

The main results are shown on Figs. 4-8. Simulations were performed in different configurations and status of evacuation. The initial configuration is the beam line before baking out the MEBT-3 and the linac.

The next status is the line after bake out and with spoke cavities at 293 K. The results of this configuration are shown in Fig. 4.

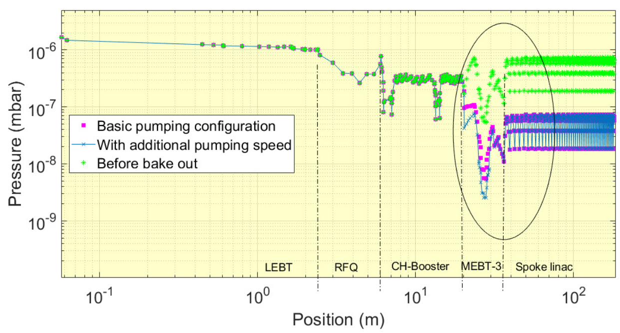

Figure 4: MINERVA pressure tracking after 50 hours pumping at T = 293 K.

In this configuration, we can notice that the pressure in the MEBT-3 is quite high (Fig. 5) compared to the vacuum levels required in Table 1. Cooling down the cryogenic cavities will help but it may not be enough to gain two decade on the vacuum level of the warm sections.

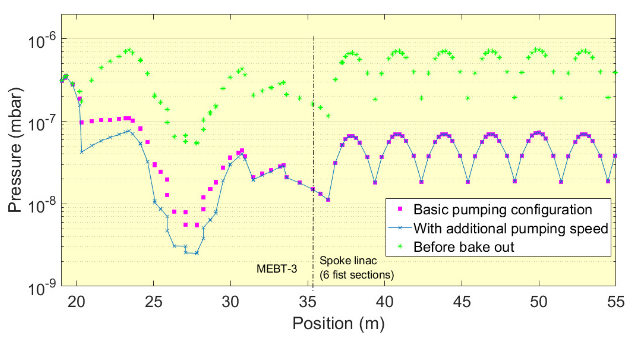

Figure 5: MINERVA MEBT-3 and linac pressure tracking after 50 hours pumping at T = 293 K.

Results after baking out MEBT-3 and linac and cooling down to 2 K the spoke cavities, are shown in Fig. 6. In this case, the injection of 0.01 mbar.l/s of gas into the LEBT is simulated.

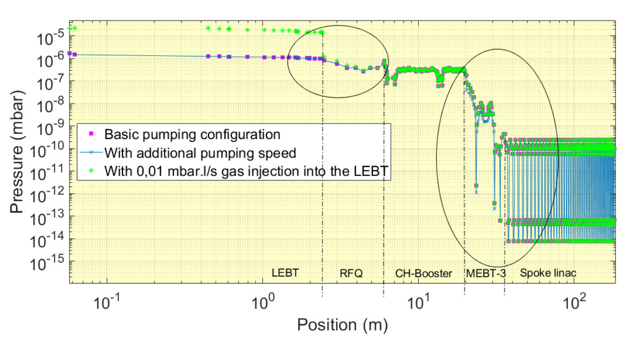

Figure 6: MINERVA pressure tracking after 50 hours pumping at T = 2 K in the linac cavities.

A zoom on LEBT and RFQ vacuum levels simulations (Fig. 7) highlights that, even with gas injection into the LEBT, RFQ vacuum levels are conserved.

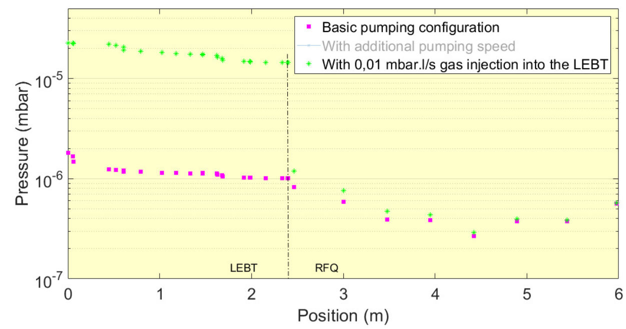

Figure 7: MINERVA LEBT and RFQ pressure tracking after 50 hours pumping.

Concerning MEBT-3 vacuum levels estimated, even after cooling down the spoke cavities, remains high (>10^{-9} mbar) due to the gas flow from the CH-Booster (Fig. 8). This transition from NC to SC is clearly a point of attention and the pumping capability will have to be increased at this location.

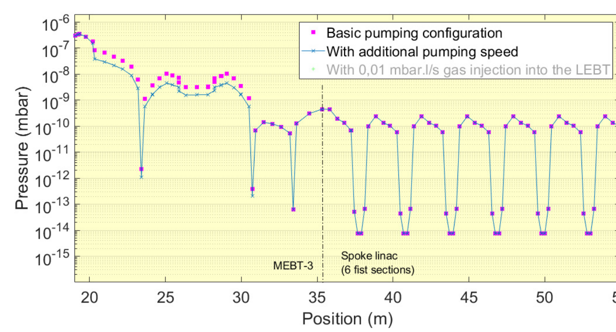

Figure 8: MINERVA MEBT-3 and linac pressure tracking after 50 hours pumping at T = 2 K in cavities.

CONCLUSION

To conclude, the vacuum layout of the LEBT ensures sufficient pumping to allow gas injection without impacting the RFQ pressure levels.

Simulations are presented after 50 hours pumping. This does not allow to achieve the required vacuum levels into the RFQ and the CH-Booster. The pumping time should be doubled to achieve the required vacuum levels, as confirmed during the RFQ commissioning [7].

Concerning the MEBT-3 section, vacuum levels at the entrance are too high to maintain a good vacuum quality into the first SC spoke buncher. It is envisaged to add pumping groups at transition. In addition the first buncher (located just after the CH booster) will be replaced by a warm buncher. This would ease vacuum transition. Additional studies will be carried out to valid the vacuum design of MEBT-3.

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