SIMULATIONS AND VACUUM TESTS OF A CLIC ACCELERATING STRUCTURE

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Abstract

The Compact LInear Collider, under study, is based on room temperature high gradient structures. The vacuum specificities of these cavities are low conductance, large surface areas and a non-baked system. The main issue is to reach UHV conditions (typically 10^{-7} Pa) in a system where the residual vacuum is driven by water outgassing. A finite element model based on an analogy thermal/vacuum has been built to estimate the vacuum profile in an accelerating structure. Vacuum tests are carried out in a dedicated set-up, the vacuum performances of different configurations are presented and compared with the predictions.

INTRODUCTION

CLIC study

The Compact Linear Collider (CLIC) study aims at a center-of-mass energy range for electron-positron collisions of 0.5 to 5 TeV, optimised for a nominal center-of-mass energy of 3 TeV [1]. High accelerating gradients are necessary to limit the length of a multi-TeV machine and its price tag. A RF frequency of 12 GHz aiming to achieve a gradient of 100 MV/m has been selected. Conventional high frequency RF sources do not provide sufficient RF power for this high gradient and CLIC relies upon a two-beam-acceleration concept: The 12 GHz RF power is generated by a high current electron beam (drive beam) running parallel to the main beam. This drive beam is decelerated in special power extraction structures (PETS) and the generated RF power is transferred to the cavities of the main beam. The 21 km long linacs are equipped with complex modular 2-m two beam modules that integrate RF components and all technical systems, such as vacuum, magnets, alignment and beam instrumentation.

The Vacuum in the CLIC two beam modules

The field ionization studies resulted for fast ion beam instability to a vacuum specification of 10^{-9} mbar [2]. Each accelerating structure is characterized by a large surface areas (of the order of 5000 cm^2) and small vacuum conductance. An additional specificity of the vacuum for these two beam modules is that heating is not allowed in order to keep the good geometrical accuracy of the RF system. This results to an unbaked system with high gas load, dominated by water with a limited vacuum conductance and constrained by space restriction within the module. The aim of this paper is to show the feasibility of different technological solutions, to determine their performances and study the influence of different parameters as well as check the suitability of the vacuum model for pressure predictions.

STUDY OF THE STATIC VACUUM IN AN ACCELERATING STRUCTURE

Vacuum simulations

A vacuum model has been developed to simulate vacuum profile in the accelerating structure and later on in the two-beam modules. It is based on the diffusion equation (eq .1) and a vacuum/ thermal analogy [3].

The diffusion equation reads:

$$\phi \frac{dP}{dt} = A + \frac{d\left(c(x) \frac{dP}{dx} \right)}{dx} - TP \qquad (1)$$

with Φ the cross section of the vacuum chamber, P the pressure. A and T correspond to the outgassing rate and the pumping speed, respectively, per unit length. c stands for the unit conductance of the vacuum chamber.

This equation is compared to the heat transfer equation for a one dimension problem. Finally the analogy vacuum/thermal equation is summarized in table 1.

Table 1: Vacuum thermal analogy

Geometry: [cm] Cross section: Φ [cm^2] Perimeter: W [cm]	
Vacuum	Thermal
Pressure: P [mbar] Gas flow rate: q [mbar.l/s] Unit conductance: c [l.cm/s]	Temperature: T Heat flux: q Unit conductivity: k Φ with k the conductivity of the material → $k \leftarrow \frac{c}{\phi}$
Gas flow rate: q [mbar.l/s] $q = -c\frac{dP}{dx}$	Heat flux: q $q = -k\phi\frac{dT}{dx}$
Vacuum capacity: Φ [cm^2]	Heat capacity: $\rho c_p \phi$ → $\rho c_p \leftarrow 10^{-3}$ The term 10^{-3} is needed to convert cm^3 in liter
Outgassing rate: a [mbar.l/s/cm^2] Outgassing rate per length unit: A=aW [mbar.l/s/cm]	Heat source per length unit: → $R \leftarrow A = aW$ Specific heat source: → $r \leftarrow \frac{A}{\phi} = \frac{aW}{\phi}$
Distributed pumping speed per area: t [l/s/cm2] Distributed pumping speed per unit length: T=tW [l/s/cm]	$T_0 \leftarrow 0$ Heat exchange per length unit: → $H \leftarrow T = tW$ Convection coefficient: → $h \leftarrow \frac{T}{\phi} = \frac{tW}{\phi}$

Lump pump S [l/s]	$\frac{k\phi}{\Delta L} \leftarrow S$ For example: $k \leftarrow S$, $\phi \leftarrow 1$, $\Delta L \leftarrow 1$

A parametric thermal model of the accelerating structure has been done in a FE code and is used to estimate the pressure profile. It is worth to point out that standard non-linear FE code allows easily time and pressure dependent simulations.

Vacuum test set-up

The set-up is composed of a specific accelerating structure dedicated to these tests. The internal geometry of the cavity has been simplified to ease the fabrication (and thus limit the cost). It has nevertheless the possibility to insert damping loads in SiC inside the cavity. 4 RF manifolds are brazed to the cells allowing the installation of the damping material. The accelerating structure can be equipped with dismountable vacuum manifolds or caps. The sealing is done with an indium wire.

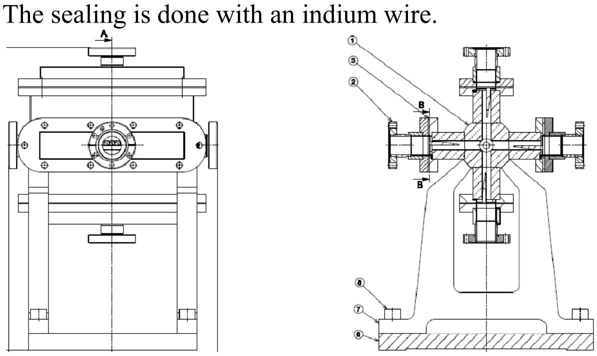

Figure 1: Design of the accelerating structure dedicated to the vacuum tests

For the pumping, different systems or combination of systems are considered: a NEG cartridge, a NEG cartridge combined with an ion pump and a turbo molecular pump.

For the turbo molecular pumping system, a vacuum valve is installed on the DN35 CF flange of the vacuum manifold. Then a turbo molecular pump, 60 l/s, is mounted on the valve. The effective pumping speed is driven by the conductance of the tube, 28 mm in diameter and 30 mm long, between the vacuum manifold and the DN35 flange (35.6 l/s). The conductance of the assembly tube, transition DN35/63, and valve is around 28.5 l/s. Therefore, the effective pumping speed is equal to 19.3 l/s. The conductances have been evaluated by a Monte Carlo simulation.

Vacuum gauges (1 Pirani and 2 Penning) are installed on the test set-up whereas a RGA is foreseen in a next step to study the pressure and gas composition evolution in time. A gate valve is installed between the accelerating structure and the turbo-molecular pump. It is based on an O'ring sealing. The valve and the turbo-molecular are baked-out at 150 and 100 °C during 24 hours, respectively, after every venting of the pumping group. Different tests are considered to study the influence of geometrical configuration and pumping system. In the paper, 3 tests are presented: 2 with a standard pumping group and with 2 different vacuum manifold sizes and 1 with a small pump installed in the vacuum manifold.

VACUUM MEASUREMENTS AND SIMULATION RESULTS

External lump pump configuration

The simulation results for the standard configuration with the pumping group connected to the vacuum manifold of 25*28 mm cross-section are presented in Fig. 2. They correspond to a pumping time of 100 hours. The figure shows the difference of pressure in the accelerating structure and at the vacuum gauges locations. The pressure on the P1 gauge, directly connected to the accelerating structure extremity, represents quite well the average pressure in the accelerating structure along the beam and is 30 % below the pressure P2, installed after an elbow.

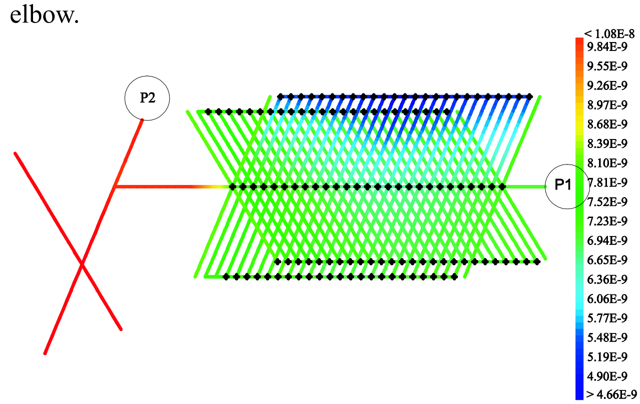

Figure 2: Pressure field in the standard configuration after 100 hours of pumping

The measurements of the pressure in time are shown in Fig. 3. The predictions are in a rather good agreement with the measurements.

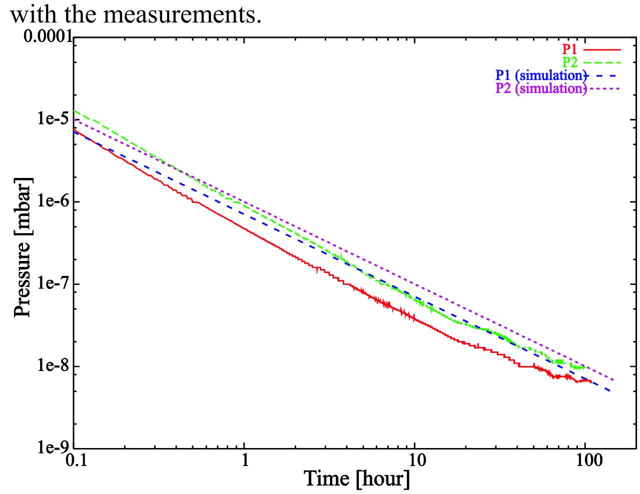

Figure 3: Measurements and estimations of the pump down curves

A second test has been carried out in the same conditions with a manifold size of 35*35 mm. Even if the specific conductance of the manifold is almost doubled, the difference with the standard configuration remains negligible for the measurements and the estimations (few percents).

Internal lump pump

A small NEG cartridge pump combined with an ion pump (NEXtorr pump provided by SAES Getters) has been installed on the test set-up. The NEG cartridge is located inside the vacuum manifold. Therefore the vacuum speed is not limited by the pumping port conductance. The test configuration is shown in Fig. 4.

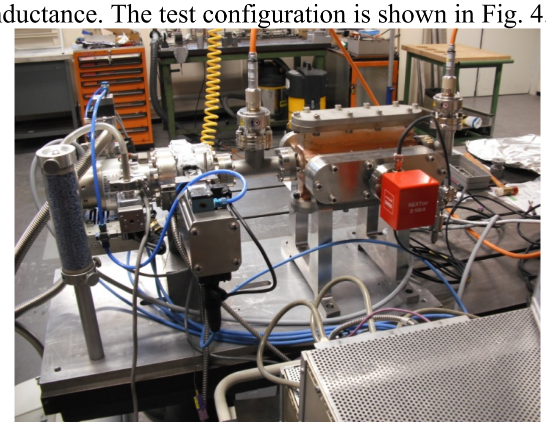

Figure 4: set-up with the NEG cartridge pump

After around 3.3 hours of pumping with the group, the NEG cartridge based on a St 172 alloy (ZrVFe) has been fully activated according to the manufacturer suggestion to reach at least 450 °C during 1 hour. During the cartridge heating, the temperature increase in the surrounding copper pieces remains marginal. After this operation, the ion pump is switch on and the gate valve is closed (4.3 hours). The sharp pressure increase close to the valve after the closure indicates an important gas load from the valve (Fig. 5). This gas load parameter has been determined in such a way that the pressure estimation and measurement in the vacuum gauge close to the valve (P1) fit. The pressure at the opposite side (P2) is obtained by simulation and is in good agreement with the measurements.

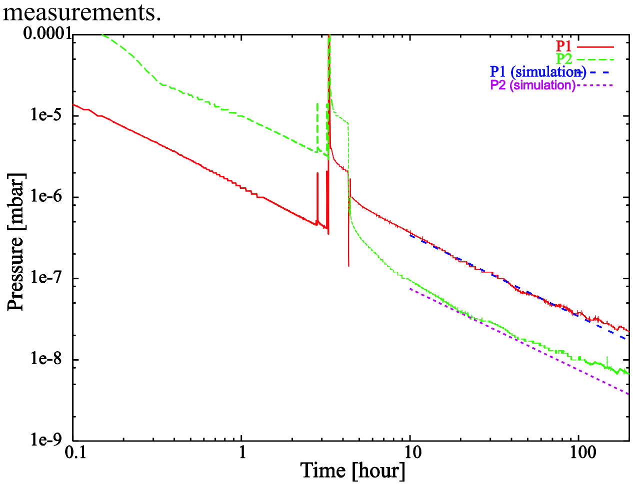

Figure 5: Pressure evolutions with the NEG pump configuration

The average pressure along the beam axis is at 6.10^{-9} mbar for this test (Fig. 6) whereas for a configuration without these boundary effects a pressure of 3.10^{-9} mbar is expected after 100 hours of pumping (to be compared to the 7.10^{-9} mbar obtained for the standard configuration).

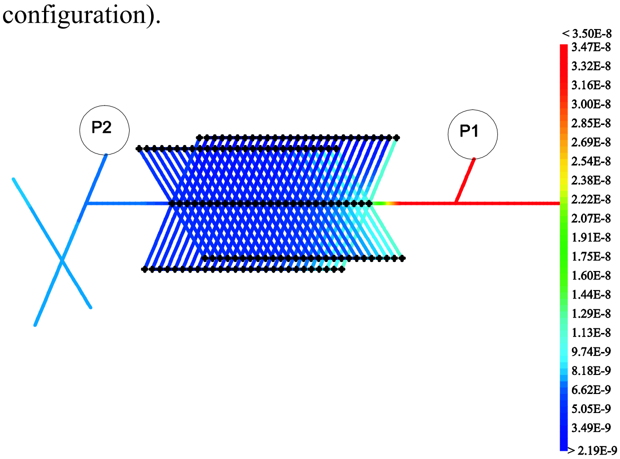

Figure 6: Pressure field after 100 hours of pumping for the NEG cartridge configuration

CONCLUSION

In this paper, first measurements done on a dedicated CLIC accelerating structure have shown that the vacuum model based on a thermal analogy gives good estimations in agreement with the measurements.

First test with the Nextorr pump shows the feasibility and promising results of a solution based on a small cartridge installed in the vacuum manifold.

The tests will go on and the next steps will be:

- The addition of an all-metal valve between the accelerating structure and the pumping group to not have important boundary effect,
- The installation of the damping material in the cavity to study their influence (gas load increase and conductance reduction).

Other tests are foreseen also to analyse the gas composition in time (water driven behaviour), to determine the influence of air exposure on pump down time and to study the effect of methane (NEG cartridge alone). Finally, it is foreseen to extend this vacuum model to a whole CLIC module to study the pressure field.

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