DESIGN OF THE CLIC QUADRUPOLE VACUUM CHAMBERS

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Abstract

The Compact LInear Collider, under study, requires vacuum chambers with a very small aperture, of the order of 8 mm in diameter, and with a length up to around 2 m for the main beam quadrupoles. To keep the very tight geometrical tolerances on the quadrupoles, no bake-out is allowed. The main issue is to reach UHV conditions (typically 10^{-9} mbar static pressure) in a system where the vacuum performance is driven by water outgassing. For this application, a thin-walled stainless steel vacuum chamber with two ante chambers equipped with NEG strips, is proposed. The mechanical design, especially the stability analysis, is shown. The key technologies of the prototype fabrication are given. Vacuum tests are carried out on the prototypes. The test set-up as well as the pumping system conditions are presented.

INTRODUCTION

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. These two linacs have a FODO cell structure. For the main beam, the quadrupoles have a length depending on their location in the linac (from 350 to 1850 mm) and have a gradient of 200 T/m. They have to be precisely positioned with respect to the nominal axis (30 µm). These requirements lead to a small aperture and also to a non-baked solution. The pressure has to be lower than 10^{-8} mbar during operation.

VACUUM SYSTEM

The simplest vacuum chamber that could be considered would be a tube with radius equal to the quadrupole aperture, i.e. around 4 mm. A uni-dimensional model of the vacuum chamber can be used to define the pressure profile. By accounting for the number of particles entering or leaving a infinitesimal tube length and writing the gas flow through a tube cross section as a function of the pressure gradient and the unit conductance of the tube, *c*, the balance of particles (conservation of number of particles) leads in the steady state to the following differential equation in pressure, *p*:

$$c\frac{\partial^2 p}{\partial^2 x} = -A$$

with A the thermal outgassing of the wall per unit length. The pressure profile is parabolic and the average pressure in the tube can be determined as a function of the boundary conditions. For a non-baked system, the thermal outgassing is dominated by water. A specific thermal outgassing of 10^{-10} mbar.l/(s.cm^2) has been considered to fix an order of magnitude. The lowest average pressure over a 1 m long tube would be of the order of 3.10^{-8} mbar, considering one pump with infinite pumping speed at each pipe extremity. This is not sufficient, so a distributed pumping is required to achieve this pressure level. The vacuum chamber can not be heated up to the NEG activation temperature; so the vacuum chamber cannot be NEG coated [1, 2]. A concept with 2 NEG strips installed in 2 antechambers has therefore been proposed. This principle is illustrated in Fig. 1. Two NEG strips are centred in the antechamber by ceramic supports. The strips are coated with Zr-V-Fe alloy (St707 trade name) produced by SAES GETTERS SPA [4,5]. The main advantage of this alloy is a low activation temperature. Spacers are used to maintain the gap of the chamber under vacuum.

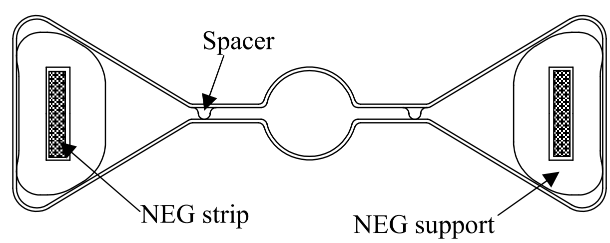

Figure 1: Concept of the vacuum chamber

The effective pumping speed per unit length of the central part is defined as:

$$\frac{1}{S_{eff}} = \frac{1}{S} + \frac{1}{C_g}$$

with S the pumping speed of unit length of NEG strip. C_g stands for the unit conductance of the gap between the central part and the antechamber. It is obtained from the conductance of a rectangular duct:

$$Cr = \frac{2}{3}\frac{h^2 w^2}{(h+w)L}\bar{v}$$

with L the length of the duct. h and w denote the height and the width of the duct, respectively. $\bar{v}$ is the average molecular velocity. In our case, $h << w$ thus the unit conductance of the gap C_g can be written as:

$$C_g = \frac{2}{3}\frac{h^2}{L}\bar{v}$$

Typically, for our application Cg is around 0.025 l/(s.cm) that is one order of magnitude less than the pumping speed of the getter strip. Therefore, the effective pumping speed is driven by the conductance of the gap. If a specific thermal outgassing of 10^{-10} mbar.l/(s.cm^2) is considered, a pressure in the range of $4\cdot10^{-9}$ mbar is achievable. It is worth to mention that thermal outgassing of water depends on time.

MECHANICAL DESIGN

Main Requirements

From a vacuum point of view, we have shown that the performance of the system is driven by the conductance of the gap that varies with the square of the gap height. To improve the performance, the gap has to be increased. This means that the maximum available space between magnet poles has to be used and the vacuum chamber has to be as thin as possible. For thin wall structures, mechanical stability issues have to be taken into account.

Proposed Design

To assure the stability of the thin wall vacuum chamber, 316LN stainless steel has been chosen due to mainly a high Young's modulus. For beam considerations (resistive wall wake fields), it should be copper coated. A Finite Element model has been made to estimate the mechanical behaviour of the vacuum chamber under vacuum and possible thermal loads. The evolution of the buckling pressure as a function of the temperature increase are shown for several thicknesses in Fig. 2. A typical buckling mode is shown Fig. 3 for which a collapse of the antechamber is observed.

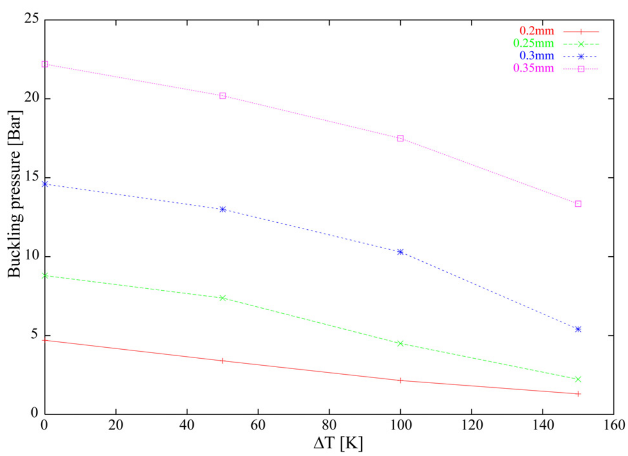

Figure 2: Evolution of buckling pressure as a function of the wall thickness and the temperature difference

The analysis has been carried out up to 150 K which would induce thermal stresses of the order of the yield stress. Thus, from a mechanical point of view (to avoid elastic-plastic buckling) and from a cavity point of view, it has been assumed that the maximum allowable temperature increase is 50 K. Safety coefficients for stability are usually higher than 3.5 therefore the thickness has to be higher than 0.2 mm. Due to availability, a 0.3 mm 316LN stainless steel sheet has been used for the prototype.

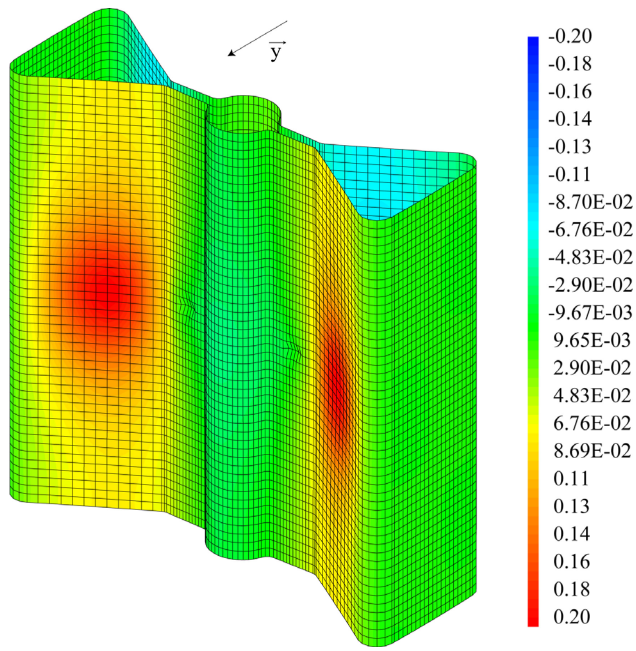

Figure 3: Typical buckling mode and related displacement in the y direction

A rough estimation of the heat transfer from the NEG strips at 300 °C to the chamber wall at room temperature by radiation and conduction through the supports leads to a heat load of around 50 W/m for the vacuum chamber. This can be removed by an air flow between the vacuum chamber and the coils of around 10 m/s (which can easily be achieved by a standard fan for the experiment).

Fabrication Considerations

The prototype of the vacuum chamber has been fabricated in the CERN workshop. Initial pieces of 500 mm have been made to define the tooling parameters before making the final 1500 mm long prototype. The vacuum chamber is build from two half shells. They are formed by stamping a stainless steel strip. Two tools are required at this level: one to form the central part and a second one to form the wing. Then, the spacers are pressed in one half shell. The lateral parts are machined to provide a good mechanical precision required by the longitudinal laser weld. Finally, two Conflat flanges are welded at the extremities by a micro TIG process.

The ceramic supports have been cut with a laser machine.

EXPERIMENTAL RESULTS

Presentation of the Test Set-up

The test set-up is shown in Fig. 4. The vacuum chamber has been assembled on 6 supports with the quadrupole shape. The St707 NEG strip has been inserted in the chamber together with the ceramic support. A tool has been used to ensure tension in the strip during activation.

Two thermocouples have been installed on the NEG strip to control the activation temperature and two on the external wall of the vacuum chamber to control the maximum temperature allowable of the chamber. Fans have been installed to create an air flow to keep the vacuum chamber close to room temperature. Three cold cathode vacuum gauges have been mounted on the chamber: two at the extremities and one in the middle of the central part. A turbo-molecular pump is connected to one extremity of the vacuum chamber with a 1.5 m long metal hose. A stabilized power supply is used to heat the strips by the Joule effect. The current leads are tack welded and bolted to the NEG strip.

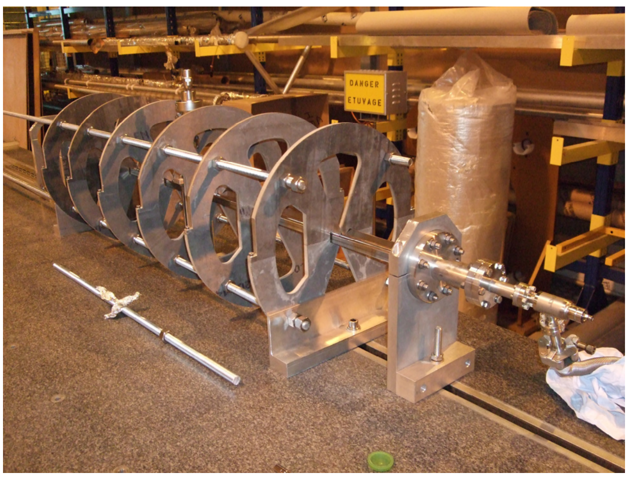

Figure 4: Test set-up of the vacuum chamber

Test Procedure

The vacuum chamber prototype will be tested under different scenarios. A common procedure will be used to ensure the same initial conditions. The chamber is opened to ambient air for 24 h by removing one extremity. Then, the chamber is pumped out during 24 h. The activation of the NEG is done at a temperature of 265 °C maintained for 2 h.

Several tests are planned:

- A test without NEG activation or bake-out. The vacuum chamber is only pumped down. This test can be considered as the reference.
- A test with the activation of the NEG strips and without bake-out. At that time, this test should is considered as the baseline for the CLIC installation.
- A test with a bake out at 70 °C for 24 h and NEG activation. The aim is to analyse the potential benefit of a bake-out at low temperatures.

CONCLUSION

A prototype of the vacuum chamber for the main quadrupole of CLIC has been designed, manufactured and assembled. The design has been optimised taking into account the available space, mechanical strength and vacuum performance. It is based on a concept with two NEG strips in two antechambers. It should fulfil the requirements for vacuum as well as beam dynamics. The tests of the chamber are in preparation at CERN.

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