SIMULATION OF THE PRESSURE RECOVERY TIME IN A CLIC STANDARD MODULE

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Abstract

Vacuum pressure inside the CLIC accelerating structures (AS) is crucial for both beam and RF stability. Gas molecules released during RF breakdown must be evacuated from the cells of the AS before the arrival of the next train of particles. Due to its complex geometry, accurate analytical calculations are not viable. In this paper we introduce a calculation method based on the combination of analytical vacuum equations with Monte Carlo test particle simulations, implemented in a PSpice environment via the vacuum-electrical network analogy. Pressure recovery times are calculated for the main gas species released during a breakdown. The number and type of molecules used for the calculation is the result of measurements performed in the DC spark test system.
1 INTRODUCTION

CLIC (Compact Linear Collider) is a study for a future electron-positron collider that would allow physicists to explore a new energy region beyond the capabilities of today's particle accelerators. It aims at a center-of-mass energy of 3 TeV and, in order to reach this energy in a realistic and cost efficient scenario, the accelerating gradient has to be very high (100 MV/m). A reliable accelerating structure must provide this gradient with low breakdown rate ($10^{-7}$), long lifetime (more than 10 years) and sufficiently low pressure to avoid RF and beam instabilities due to the ionization of the residual gas.

In static regime, (absence of RF power and beam), the pressure will depend on the thermal outgassing rate of the AS and on the effective pumping speed available. In the presence of RF power, additional outgassing occurs induced by sparks and particle bombardment of the AS surface (electrons and photons). This causes pressure bursts and the vacuum system must be able to recover to $10^{-8}$ Torr, the maximal admissible dynamic pressure, before the arrival of the next train of particles. This recovery time depends on the amount of molecules released per spark, the geometry of the accelerating structures and the vacuum system and on the pumping speed.

In this work we present the simulation of the dynamic pressure in a standard CLIC module (Fig.1), for different pumping speeds.

![Figure 1 – Standard CLIC module by February 2008(drawing by Alexander Samoshkin)](image)

2 THE MODEL

A standard module consists in 8 11 GHz CLIAAS110001 accelerating structures (Fig.2) inside a vacuum tank with a length of 2 meters and a diameter of 400 mm. The 20 cells of each AS are considered as volumes connected to the tank by 4 channels (the absorbers channels) and to its two adjacent cells by an orifice (the cell’s iris). The molecular transmission probabilities of these channels are computed by Monte Carlo test particle and used to calculate the corresponding vacuum conductance. Since the dimensions of the absorbers are not yet defined, we considered that only half of the channel’s volume is available for pumping (the other half filled with the absorbers). This assumption has a strong impact in the pumping time.

In our model, the vacuum conductance method is a good approximation to calculate molecular flows because each channel and orifice connects relatively large volumes, assuring near equilibrium and random entry conditions. This assumption was verified by Monte Carlo simulation and an over estimation of about 10% in pressure is expected. Similar results were obtained by Gordon B. Bowden in analogous calculations at SLAC [1].
The vacuum model is then transformed into its equivalent electrical network and implemented in PSpice environment. The vacuum-electrical network analogy was first proposed by Knudsen [2] in 1909 and became particularly useful with the advent of software for electrical circuits calculations. A molecular flow through a conductance is analogous to a flow of electrons through a resistor and filling/pumping molecules into/from a volume is equivalent to charging/discharging a capacitor [3]. In this frame, the molecular throughput during a spark is simulated by a current pulse, with the duration of the spark.

Figure 3 shows the equivalent electrical sub-circuit for a single cell. Each structure is composed of 20 cells sub-circuits and the whole module of eight structures in series. The volume of the vacuum tank is simulated by a large capacitor drained through a resistor corresponding to the pumping speed available.

3 RESULTS

The data used to model the spark outcomes from the DC spark test system [4,5]. Two materials were investigated, copper and molybdenum, and in both cases hydrogen and carbon monoxide were the main outgassed gases. For the case of molybdenum, $2.9 \times 10^{15}$ molecules of hydrogen and $2.1 \times 10^{15}$ molecules of carbon monoxide were released per spark while for copper 30 times more hydrogen and 30% more carbon monoxide was observed. The duration of the sparks was measured by optical spectroscopy and most of the energy is released between 50 ns and 100 ns. For the cases studied here we consider all the molecules released in a 75 ns pulse.

Figure 4 shows the pressure recovery time for different amounts of released gas. The quantity of gas is expressed in multiples of the amounts measured for molybdenum, $n$. For this material $n=1$ and the recovery time $t_r$ for hydrogen and carbon monoxide are 6 ms and 20 ms respectively. In the case of copper, $n=30$ for hydrogen and the recovery depends on the pumping speed $S$ available in the vacuum tank: $t_r=40$ ms for 500 l/s, 70 ms for 1000 l/s and 103 ms for 2000 l/s. For carbon monoxide, $n=1.3$ and $t_r$ is just slightly higher than for the case of molybdenum, 25 ms.
Figure 4 – The 11 GHz CLIAAS110001 accelerating structure

4 DISCUSSION

It can be seen from Figure 6 that a module with copper made CLIAAS110001 structures would not be reliable to work at 50 Hz repetition rate. At this rate, the recovery time must not exceed 20 ms. For the case of molybdenum, the recovery time for carbon monoxide is 20 ms, not allowing any security margin.

Two pumping regimes, i) and ii), can also be clearly identified in the plots of figure 6. While the pressure in the vacuum tank remains below $10^{-8}$ Torr, the system operates in regime i) and the molecules are evacuated from the AS by expansion to the tank. In this case, $t_r$ is limited by the geometry of the AS, independently of the pumping speed $S$ available on the tank. Once the pressure in the vacuum tank exceeds $10^{-8}$ Torr, the system passes to regime ii) and $t_r$ is dominated by the ratio between the tank’s volume and the applied pumping speed $V_{tank}/S$. Regime i) has the fastest possible response and it can be extended for higher quantities of released gas by increasing $V_{tank}$ and/or $S$. But special care must be taken if this extension is made by increasing only $V_{tank}$: in this case, if the system enters regime ii) becomes very slow.

Performance on regime i) can only be improved by altering the geometry of the structures. Shorter channels with larger cross section and smaller cell volumes will provide a faster evacuation of the molecules released by the sparks.

The calculation method presented in this paper is a useful tool for the evaluation of the dynamic vacuum in complex accelerating structures.
REFERENCES


