

MULTIPACTOR DISCHARGE IN THE ELINAC ACCELERATOR

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Abstract

This paper concerns numerical simulations and experimental investigation of multipactor discharge in accelerating cavities and the feeding waveguide section of the eLINAC accelerator. The threshold values of the accelerating gradient and of the input power, at which the discharge may occur in these structures, have been obtained experimentally and compared to predictions of numerical simulations. The issues of the influence of secondary emission yield on a discharge growth were also considered.

INTRODUCTION

TRIUMF has recently embarked on the construction of ARIEL, the Advanced Rare Isotope Laboratory [1]. The superconducting electron linear accelerator (eLINAC) was developed under this project. It will be used as a photo-fission driver for the production of short-living rare isotopes. The TRIUMF eLINAC layout with the construction phases is shown in Fig. 1. The elliptic 9-cell accelerating cavities were developed in the TRIUMF laboratory [2] based on the well-known TESLA cavities [3]. The cavity will accelerate 10 mA current up to energy of 10 MeV. Two input CPI couplers [4] with an average operating power of about 60 kW are used for each cavity.

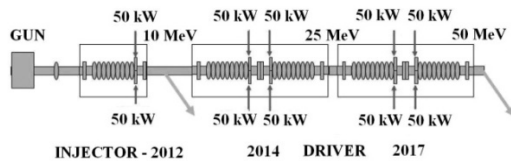


Figure 1: TRIUMF eLINAC layout

Each 9-cell cavity will operate with an acceleration gradient of $E_a = 10$ MV/m. It is quite safe goal for production. This class of cavities achieved operation gradients of 25-30 MV/m. However, it is necessary to study this structure with respect to the probability of multipactor discharge.

Multipactor discharge (secondary electron discharge) is the undesirable resonant particle number growth in the vacuum space of the RF structure. It may lead to a series of negative effects. The electron avalanche could consume RF power and limit level of the accelerating field. The electron bombardment may cause an overheating of the structure and a quench effect, when the material becomes normal conducting. Therefore, multipacting investigations are important for the RF structure development.

MULTIPACTING SIMULATIONS FOR THE 1-CELL ELLIPTIC TEST CAVITY

The Simulation Results

The investigations were carried out for the elliptic 1-cell superconducting Niobium TESLA cavity. The cavity model and main geometry parameters are shown in Fig. 2 and Table 1.

The special code for multipacting simulations Multp-M has been used [5]. The dependence of secondary particle count vs. accelerating gradient (considering the transit-time factor $TTF = 0.52$) was obtained for different secondary electron yields (SEY) which correspond to the various methods of the surface treatment (Fig. 3).

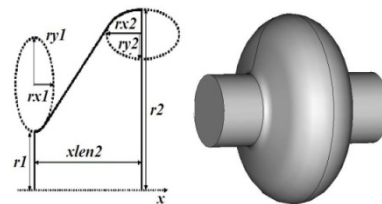


Figure 2: The 1-cell cavity geometry.

Table 1: Main geometry parameters of the 1-cell cavity

xlen2, MM	r1, MM	r2, MM	rx1, MM	ry1, MM	rx2, MM	ry2, MM
56.7	39	103.3	9	12.8	42	42

The generalized plot for the accelerating gradient in the range of 0-30 MV/m is shown in Fig. 4. The main peak of particle growth is obtained at low levels of the accelerating field. The influence of the SEY is insignificant for this kind of calculations; the dependence is the same and the difference is only in the height of the main peaks.

Stable multipacting trajectories of order 2-4 were obtained in the range of 2.6 - 6.3 MV/m and 27.9-35.5 MV/m of the accelerating gradient for over 40 RF periods. The stable 1-2 order multipacting trajectories are obtained in a range of 6.3 - 27.9 MV/m of the accelerating gradient. The latter are the most dangerous.

The direct multipacting simulations were performed in order to find the structure areas which undergo multipacting.

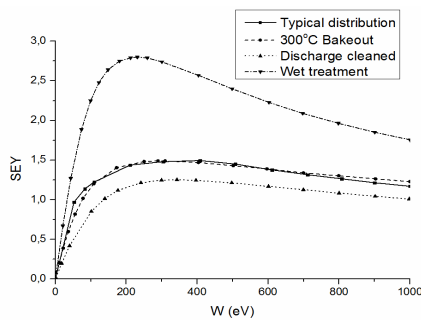


Figure 3: SEY for Nb (various methods of treatment)

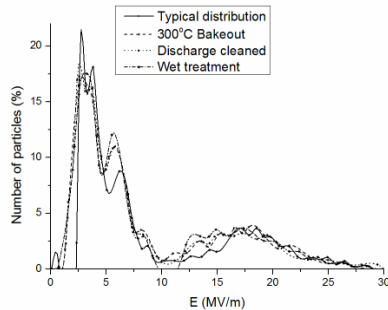


Figure 4: The number of secondary electrons in the cavity as a function of the accelerating gradient for different SEY.

The results show that the exponential increase in particle number is obtained in the range of 2.6 – 24 MV/m of the accelerating gradient. This growth indicates the probability of multipacting. Multipacting occurs in the equatorial region of the accelerating cavity. Various SEYs influence the rate of an electron avalanche formation.

THE EXPERIMENTAL RESULTS

The 1-cell superconducting cavity tests were performed by the Canadian laboratory TRIUMF. The geometry of this cavity is shown in Fig. 2 and the vertical installation (facility) for the cavity testing is depicted in Fig. 5. Two series of experiments for various methods of the cavity treatment were done. The dependence of cavity quality Q_0 vs. accelerating gradient E_a is shown in Fig. 6. These experimental data were obtained during the conditioning of the structure.

The cavity quality factor reached $1.4 \cdot 10^{10}$ at the operating temperature 2 K and an accelerating gradient up to 16 MV/m. The results showed that the cavity is capable to provide the specified operating parameters: value of the cavity quality factor was about 10^{10} at operating accelerating field of 10 MV/m. The line marked by a star in Fig. 6 corresponds to a power dissipation of 1.1 W in the 1-cell cavity. This value corresponds to the nominal value of the dissipation 10 W in the 9-cell accelerating structure. Intersection of this line with Q-curve shows value of accelerating gradient which can be obtained in the 9-cell cavity with the same degree of treatment as the tested one. The value of this field is 9 MV/m. This parameter can be improved by further conditioning of the cavity. However, it was not possible due to the power limit for the test input coupler.

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Figure 5: Vertical stand for 1-cell testing.

The conditioning will be done after the test input coupler modification. Multipactor discharge was obtained at levels of the accelerating field above 11 MV/m. Multipacting limited the accelerating gradient without field emission (radiation).

The Q-curve shows that the quality factor starts to decrease at a field level of about 6 MV/m. Possible reason of the quality decrease is stable multipacting in this case. Presumably, multipacting appeared in the regime which was close to the stationary one.

Comparing the experimental Q-curves with the simulation results, one can make the conclusion that the reason of the quality factor decrease in the first series of measurements was stable multipactor discharge. An initial stage of the quality factor decrease corresponds to the accelerating field region in which dangerous 1st and 2nd order multipacting trajectories are obtained numerically.

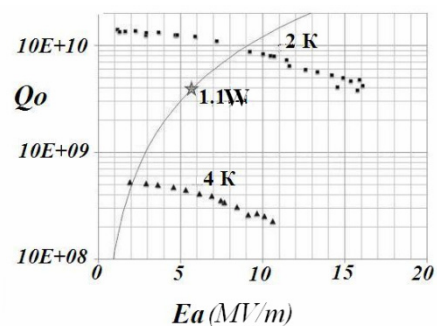


Figure 6: The quality factor as a function of the accelerating gradient

THE 9-CELL ACCELERATING STRUCTURE

Multipacting simulations were performed for the 9-cell superconducting accelerating cavity which was developed by TRIUMF laboratory for the eLINAC [2].

Multipacting occurs in the equatorial region of the elliptic cavities at lower levels of the accelerating field in comparison to the 1-cell structure. Stable multipacting trajectories of order 2-4 were obtained in the range of 1.32 - 3.08 MV/m of the accelerating gradient over 40 RF periods. The stable 1-2 order multipacting trajectories are obtained in a range of 3.08 – 17.16 MV/m of the accelerating gradient.

INPUT COUPLER

Multipacting simulations were performed for the CPI input coupler [4]. The ceramic window is the most dangerous part of the input coupler, which may undergo multipacting. Overheating due to multipactor discharge may lead to serious structural damage of the window.

The simulations were performed for the “cold” ceramic window area. The input coupler consists of the coaxial line with diameters of the outer and inner conductors $d_{out} = 62$ mm, $d_{in} = 28.8$ mm (an area between the “warm” and “cold” windows) and the conical transition part, which contains the ceramic window and the coaxial line with diameters $d_{out} = 62$ mm, $d_{in} = 22.8$ mm (an area between the window and the cavity). The simulations have been carried out in two steps: firstly for the coaxial lines and then for the conical part containing the ceramic window.

The dependence of secondary particle count vs. power for two kinds of the coaxial lines were obtained. Multipacting appears in the coaxial line with a smaller gap between the outer and inner conductors at lower transmission power levels (above 15 kW). This power level for the coaxial line with a bigger gap is above 49 kW. The motion of the particles has been investigated in detail. The simulation results showed that the stable trajectories at power levels of about 60 kW are high order multipactor trajectories, which are not so dangerous as 1st or 2nd order trajectories in the cavities.

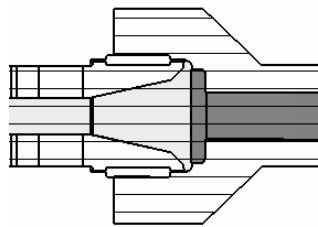


Figure 7: The coupler geometry

However, the multipactor trajectories were obtained on a surface of the ceramic window at power levels of about 50 kW being the most dangerous.

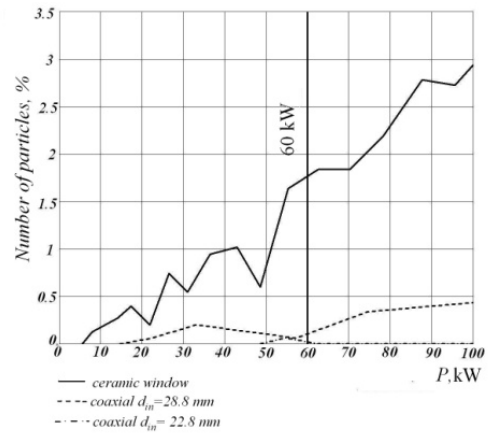


Figure 8: Number of particles as a function of the power.

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