NUMERICAL STUDIES ON A MODIFIED CATHODE TIP FOR THE ELBE SUPERCONDUCTING RF GUN*

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Abstract

Future light sources such as synchrotron radiation sources driven by an Energy Recovery Linac (ERL), Free Electron Laser (FEL) or THz radiation sources have in common that they require injectors, which provide high-brilliance, high-current electron beams in almost continuous operation. Thus, the development of appropriate highly brilliant electron sources is a central factor. A promising approach for this key component is provided by superconducting radiofrequency photoinjectors (SRF guns) [1]. Since 2007, the free-electron laser FELBE at HZDR successfully operates such a SRF gun under real conditions and equipped with all components [2]. Nevertheless, there are limitations caused by multipacting (MP) which should be overcome in order to further improve the gun [3]. One aspect in order to reach this aim lies in studying various modifications of the cathode tip [4]. This contribution will present the effectiveness of isosceles triangular grooves with respect to MP.

INTRODUCTION

In MP, undesirable primary electrons first escape from one of the structure's wall due to some favourable conditions. The electrons are then accelerated by the RF fields and if they impact the structure's wall, secondary electrons may be generated. The latter depends on the impact energy and the angle. Subsequently, multiplication of the number of electrons takes place in that area by repeated impact on the structure's wall. Exponential growth in the number of electrons requires a specific resonance condition of the trajectory of the secondary electrons due to the pattern of the fields in the structure. A further condition is that the secondary emission yield (SEY) of the wall material should be greater than unity. This phenomenon of resonant electron multiplication may finally lead to thermal breakdown in the SRF cavities [5].

The effect of one-point MP in the SRF cavity was tackled by developing a spherical/elliptical cavity shape in the 1980s [6]. In most cases, a two-point MP does not affect the cavity performance since it eliminates after processing. However, MP is still an issue in other RF structures, e.g. for RF coupler waveguides [7]. Moreover, MP has been observed in many recent high intensity rings [8]. Due to that, intensive analytical and experimental studies have been carried out to understand this phenomenon in different structures and to obtain curing methods. Subsequently, there are a number of possible existing remedies in order to supress MP, such as e.g. a weak solenoid in a drift region, clearing electrodes (stripline type electrode, wire type electrode, etc.) for magnets, beam scrubbing, surface treatment (coatings, conditioning, surface cleaning and surface roughness). Moreover, rectangular and triangular grooved surfaces in a magnetic field have also been investigated in order to reduce the SEY [8, 9]. The DC biasing method is another suppression method of MP for RF couplers [10].

Yet, MP critically occurs in the photocathode unit of the ELBE's SRF gun. This limits the accelerating gradient in the cavity. From simulation results, a strong MP is observed in the cathode region at the gradient of 1.53 MV/m [11], which is in a good agreement with the experimental value. Thus, extensive numerical investigations have been performed in order to develop a new appropriate design of a photocathode unit, which can suppress MP. Currently, the ELBE SRF gun operates up to 18 MV/m [12]. The newly designed SRF gun is considered to operate up to the accelerating gradient of 50 MV/m. After analysing MP in the vicinity of the cathode, we had previously investigated three possible remedies to supress MP in that area, such as DC biasing voltage (static electric perturbation), geometric modification (frusto-conical cathode) and periodic rectangular grooving of the cathode's surface [4]. In this paper, we will present simulation results of a systematic multi-objective optimization with respect to MP of isosceles triangular anti-multipactor grooves on the cathode surface.

OVERVIEW OF THE MODEL

The ELBE SRF gun, which is designed using CST MICROWAVE STUDIO® (CST MWS), comprises a choke filter, a photocathode unit and a three and half cells Tesla-like cavity (see Figure 1a). It operates at 1.3 GHz. In order to achieve a better electromagnetic (EM) field resolution and faster computational times, a simplified model comprising just the cathode region with a half-cell cavity (see Figure 1b) has been considered in our numerical studies. The cathode region, where MP is observed critically, consists of a copper cathode (yellow), a niobium cavity wall and a gap between the cathode and the cavity wall as illustrated in Figure 2a. The latter (the vacuum gap) is used for thermal and electrical insulation. The radius of the standard cathode (r) is 5 mm and the gap between the outer and the inner conductor is 0.75 mm.

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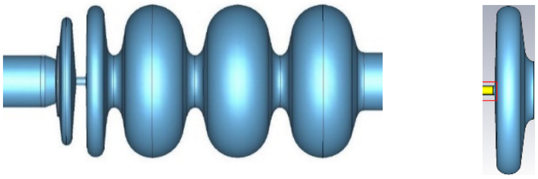
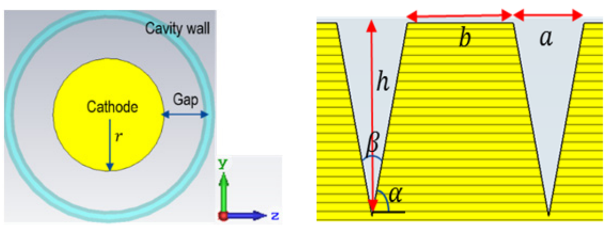


(a) (b)

Figure 1: Geometry of (a) the ELBE SRF gun, (b) a simplified model of the ELBE SRF gun.

We investigated the influence of the isosceles triangular grooves on the cathode surface (shown in Figure 2b) on MP in the photocathode region of ELBE SRF gun. The simulation results show that the isosceles triangular groove surfaces suppress MP sufficiently in the critical area. The geometric parameters of the isosceles grooves, such as groove width 'a', distance between the grooves 'b' and groove depth 'h' are taken into account in the simulation.

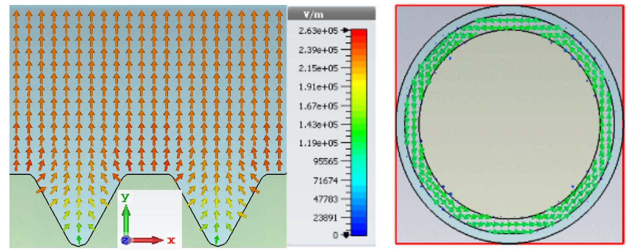


(a) (b)

Figure 2: (a) Vicinity of the cathode of the ELBE SRF gun where MP is critical, (b) geometric parameters of the isosceles triangular groove surface ($\alpha + \frac{\beta}{2} = \frac{\pi}{2}$).

SIMULATION SET UP AND RESULT

The frequency and the corresponding EM field pattern are calculated in the isosceles grooved model of the coaxial line structure and half-cell cavity using the Eigenmode Solver of CST MWS (see Figure 3 for some field plot). In order to achieve an accurate result, proper mesh settings and appropriate boundary conditions are applied in the simulated model. Moreover, a local mesh setting is used in the cathode region - especially in the groove structure where a very dense mesh is required in order to achieve a precise particle tracking. The pre-calculated EM field is imported into the PIC solver of CST PARTICLE STUDIO® (CST PS) to perform a simulation of MP. The variation of the magnitude of the EM field is scaled by a factor *am* in the PIC solver to obtain the desired field. Previously, in order to find the threshold for MP, the gradient scan was done with a factor *am* between 0.025 and 0.205 in steps of 0.02. Subsequently, the highest number of secondary electrons are produced at *am* = 0.085 (or E_{pk} = 1.53 MV/m) where the on axis electric field is 18 MV/m and the result is published elsewhere [11]. The gauss emission model is used for the initial particles with kinetic energy of 2 eV. It is defined on the surface of the cathode.



(a) (b)

Figure 3: (a) Electric field distribution for an isosceles triangular surface (longitudinal view), (b) Magnetic field distribution for the isosceles triangular surface (cross-sectional view).

For the secondary electron emission calculation, Furman's probabilistic model is considered for both, the niobium (Nb) (300°C Bakeout) cavity with 1.49 max SEY at 300 eV and the copper (Cu) cathode with 2.1 max SEY at 250 eV (see Figure 4). Furthermore, in order to minimize computational time, the space charge effects are neglected in the PIC simulation which is recommended [13]. It is also possible to detect the occurrence of multipactor without space charge effect [14].

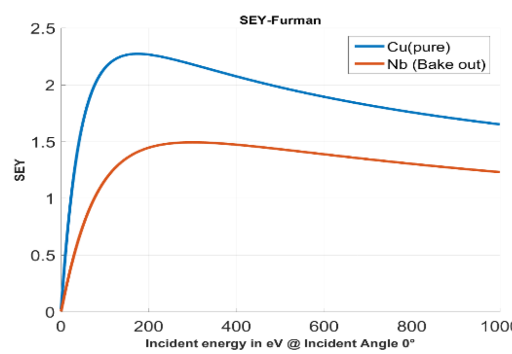


Figure 4: True secondary emission yield as a function of incident energy from Furman's model for Cu and Nb surfaces as used for the simulations.

The simulations have been performed varying only one geometric parameter at a time, while considering other parameters constant. Initially, the MP dependence on the parameter h has been studied. The h parameter has been varied from 0.2 mm to 0.8 mm in the simulation while the parameters 'distance between grooves' b =0.5 mm and 'width' a =0.3 mm are considered constant. Here the parameters b and a are chosen randomly. Figure 5 shows that a groove depth of h = 0.4 mm can supress MP sufficiently. Additionally, it displays that a groove with smaller h (0.2mm) has a high probability of MP occurrence. Deep grooves on the cathode disturb the electron trajectories and attenuate the fields inside the grooves, and therefore, they do not allow the secondary electrons to gain sufficient energy. Thereby the resonant electron production will be prevented.

Next, the parameters 'depth' h = 0.4 mm and 'distance between grooves' b = 1 mm are kept constant while varying the width of the groove a. MP can be suppressed with a = 0.4 mm and a = 0.2 mm sufficiently as illustrated in Figure 6. Moreover, wider widths (0.6 mm and 0.8 mm) resulted in a significant raise in particle number over time. This is probably because the electrons can escape easily from the groove the wider it gets.

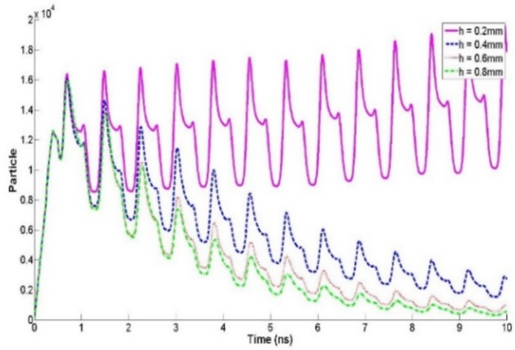


Figure 5: Particle vs time graph by varying the depth of the isosceles triangular grooves.

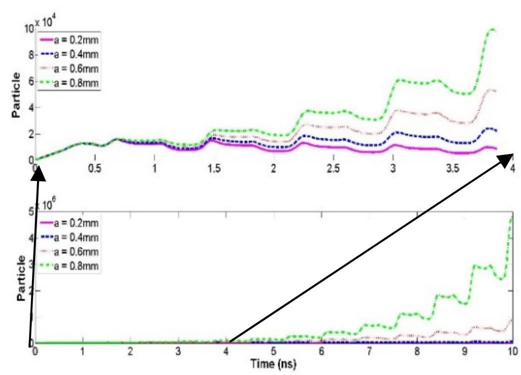


Figure 6: Particle vs time graph by varying the width of the isosceles triangular grooves.

Finally, the parameters 'depth' h = 0.4 mm and 'width' a = 0.2mm are considered constant while varying the distance between the grooves from 0.2 mm to 1 mm. Nevertheless, no significant changes in number of particles is observed within 10 ns while varying the parameter b (see Figure 7).

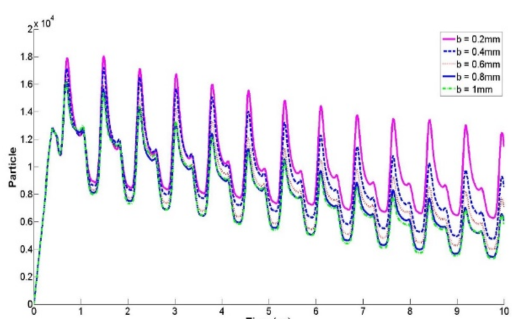


Figure 7: Particle vs time graph by varying distance between isosceles triangular grooves.

CONCLUSION

The effect of isosceles triangular grooved surface on MP in the cathode unit of the Dresden SRF gun has been numerically studied. An isosceles triangular groove surface of the copper cathode proved to be an efficient technique in order to suppress MP in the critical area of the SRF gun. The three parameters of the groove surface, such as the width of the groove 'a', the depth of the groove 'h' and the distance between the grooves 'b' were taken into account in the simulation. The results show that the isosceles triangular surface has only a weak dependence on the parameter b but is very sensitive to the parameter a. Moreover, it is effective in a rather wide range of the parameter h (0.8 mm to 0.4 mm). Moreover, extrusion is one of possible way in order to produce such isosceles triangular surface [15].

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