MULTIPACTOR SIMULATIONS IN 650 MHz SUPERCONDUCTING SPOKE CAVITY FOR AN ELECTRON ACCELERATOR*

T. Kubo†, T. Saeki, KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan
SOKENDAI (The Graduate University for Advanced Studies), Hayama, Kanagawa, Japan
Y. Iwashita, H. Hokonohara, H. Tongu, Kyoto University, Uji, Kyoto, Japan
R. Hajima, M. Sawamura, National Institutes for Quantum and Radiological Science and Technology, Tokai, Ibaraki, Japan
E. Cenni, CEA/IRFU, France

Abstract

In order to realize a compact industrial-use X-ray source based on the laser-Compton scattering, a superconducting spoke cavity for an electron accelerator operated at 4K is under development. While the initially proposed operating frequency was 325 MHz considering the 4 K operation, we decided to start from the half scale model at 650 MHz to accumulate our production experience of spoke cavity within our limited resources. In the present contribution, procedures and results of multipactor simulations for 650 MHz spoke cavities are briefly introduced.

INTRODUCTION

A 325 MHz superconducting spoke cavity for electron acceleration is currently under development in order to realize an industrial-use laser-Compton scattering compact X-ray source [1, 2] (see also Ref. [3]). It has half a diameter of an elliptic cavity with the same frequencies, and furthermore a surface dissipation at 4 K nearly equals to that of 1.3 GHz elliptic cavity at 2 K.

Sawamura et al [4, 5] designed the 325 MHz spoke cavity by using the genetic algorithm (GA) known as a method of multi-objective optimization. Cavities with minimized E_{pk}/E_{acc} and B_{pk}/E_{acc} were generated by GA, from which geometries that maximize the achievable E_{acc} were extracted. A detailed design, such as a corner radius of the end-plate, a spoke-base radius, and so on (see Fig. 1), can be modified with keeping RF characteristics. These degrees of freedom can be utilized to pursue a better design that suppresses a risk of multipactor (MP). Previous results of MP simulations in the cavities obtained by GA have been reported in conferences [6, 7, 8]. The present project has already been at the stage of cavity fabrication. We are fabricating a half scale cavity with 650 MHz prior to the 325 MHz cavity for accumulating our cavity production experience within limited resources [9]; the 650 MHz half scale cavity can be fabricated almost in-house at the KEK machine shop. MP simulations in 650 MHz half scale cavities are also being carried out parallel to the fabrication.

In the present contribution, we report the results of MP simulations for the 650 MHz half scale models. Let us re-

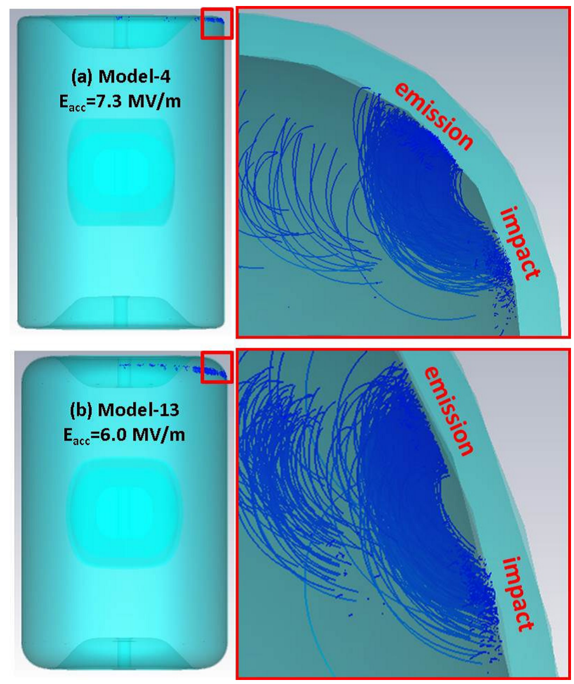

Figure 1: Examples of MP electron trajectories on the end-plate corners in the 325 MHz spoke cavities with corner radii (a) R_c = 20 mm and (b) 75 mm [8]. [Originally published in *Proceedings of IPAC2015, Richmond, VA, USA* (2015), p. 2892, WEPMA053.]

mind the previous results obtained in the MP simulations in 325 MHz cavities [8]. The important observation obtained in Ref. [8] was that an increase of the end-plate corner radius R_c does not necessarily lead to a suppression of MP. This result is contrary to common belief, but is rather natural. A change of R_c generally leads to that of field distribution, which changes the impact energy K for a given E_{acc}, and furthermore leads to that of the electrons-wall impact angle θ as shown in Fig. 1. Since the secondary emission yield (SEY) is a function of K and θ as shown in Fig. 2, a change of R_c affects an SEY value through changes of K and θ. Whether changing R_c relaxes MP or not depends on how K and θ are varied by the change of R_c. For example, when an increase of R_c changes θ from $\theta = 0°$ to $\theta = 45°$, an SEY value is significantly increased as shown in Fig. 2, and a range of K that yields SEY > 1 becomes

* The work is supported by Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sports, Science and Technology, Japan.
† kubotaka@post.kek.jp

ISBN 978-3-95450-147-2

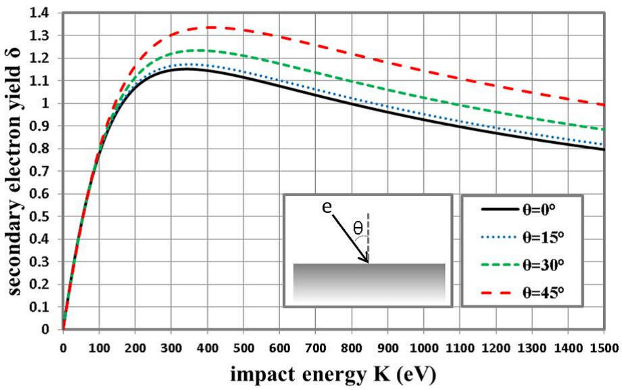

Figure 2: Furman model SEY [10] as functions of impact energy. Each curve corresponds to an impact angle.

wider: both an intensity of MP and a range of E_{acc} that suffers MP increase. To find a better corner geometry that can suppress MP, we need to sweep a parameter space that defines the corner geometry rather than simply increase the corner radius. In the present study, we carry out MP simulations in 650 MHz half scale models with corner geometries expressed by elliptical arcs, which are more general than simple circular arcs used in the previous study [8].

SIMULATION PROCEDURE

We use the half scale model of the cavity optimized in previous studies [4, 5, 6, 7, 8]. In this study, we vary only the corner geometry, which defined by an elliptical arc with axis lengths a and b shown in Fig 3. The length b is fixed at $b = 20$ mm, which corresponds to the half scale of the optimum corner radius $R_c \simeq 40$ mm obtained in the previous study [8]. The length a is varied between $a = 0.2b = 8$ mm and $a = 3b = 120$ mm.

MP simulations were carried out by using CST studio suite. We adopted the same procedure as before [8, 11, 12]:

1. Calculate the electromagnetic-field distribution by using CST MW studio (MWS) Eigenmode solver.
2. Set a secondary emission yield (SEY) of a cavity material on CST Particle Studio (PS) (see Fig. 2).
3. Put primary electron sources on a cavity surface. Set a number of primary electrons and their energies $O(10^3)$ and several eV, respectively.
4. Import the electromagnetic-field distribution obtained by MWS, and simulate electron-dynamics by using PS TRK solver (see Fig. 1).
5. Repeat 4 with changing E_{acc}.
6. Repeat 1-5 with changing a model geometry.

Note that we are interested in MPs that can not be processed, so-called hard barrier. Thus, at least, an SEY of cavity material must be small enough to suppress MPs in TESLA

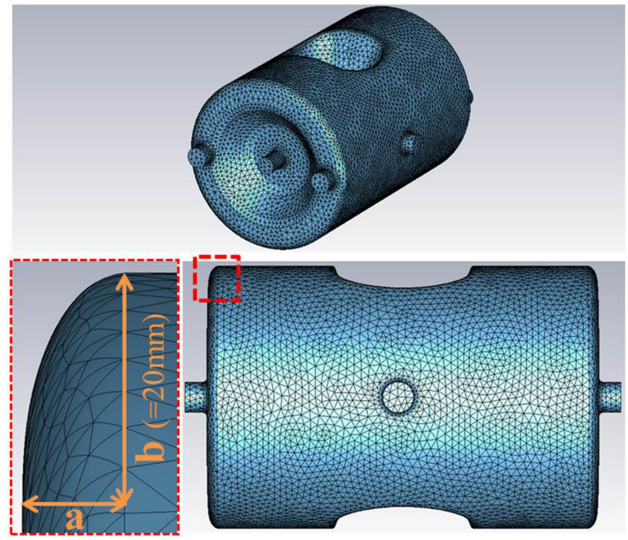

Figure 3: The end-corner geometry expressed by an elliptical arc with axis lengths a and b.

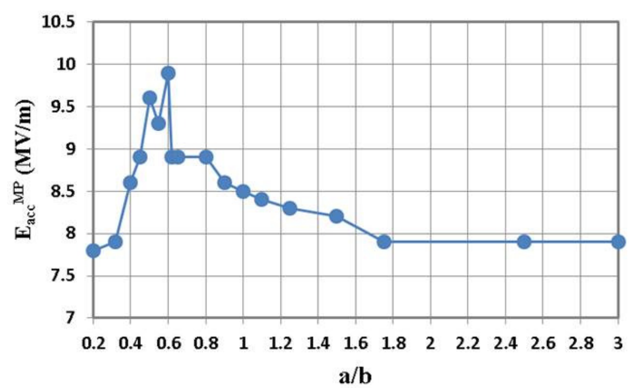

Figure 4: The lowest gradient that invokes MP as a function of a corner geometry, a/b.

shape cavity, because we know they are easily processed during a performance test. We use the SEY given by Fig. 2, which is so small that MPs do not occur in TESLA shape cavity [8].

In this study, primary electrons are put on the end-plate corner. Even if primary electrons are placed on parts at which no MP occurs, some secondary electrons moves to the place that MP occurs and finally trigger MP, but such a configuration of primary electrons might miss an existence of MP. Putting all primary electrons near the place of MP is recommended.

RESULTS

Fig. 4 shows E_{acc}^{MP} as a function of a/b, where E_{acc}^{MP} is the lowest E_{acc} that invokes MP: there is no MP at $E_{acc} < E_{acc}^{MP}$ (e. g. the cavity with $a/b = 0.2$ does not suffer MP at $E_{acc} < 7.8$ MV/m). As a/b increases, E_{acc}^{MP} increases and reaches its maximum $\simeq 10$ MV/m. Then, at $a/b > 0.6$, E_{acc}^{MP} decreases and approaches $\simeq 8$ MV/m. The moderate

ISBN 978-3-95450-147-2

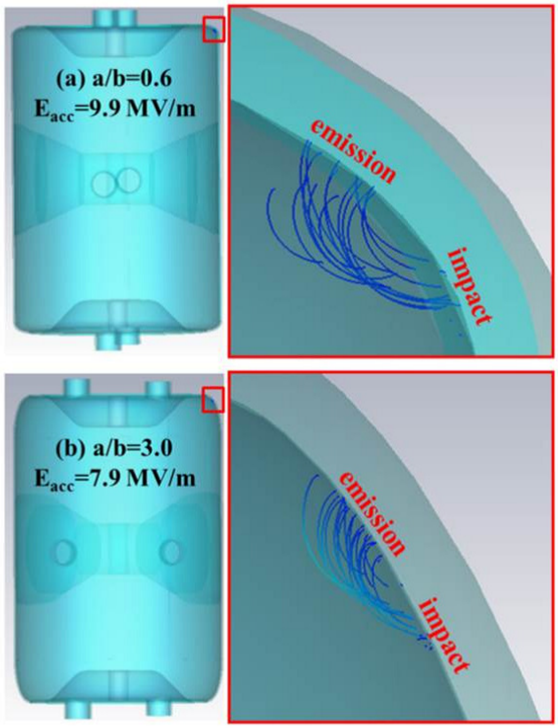

Figure 5: MP electron trajectories on the end-plate corners with (a) $a/b = 0.6$ and (b) $a/b = 3.0$.

elliptical arc with $a/b \simeq 0.5$-0.6 leads to a better suppression of MP than the circular arc ($a/b = 1$) or extreme elliptical arcs ($a/b \gg 1$ or $a/b \ll 1$).

Fig. 5 (a) and (b) show examples of electron trajectories during MPs in cavities with $a/b = 0.6$ at $E_{\rm acc} = E_{\rm acc}^{\rm MP} = 9.9\,{\rm MV/m}$ and $a/b = 3.0$ at $E_{\rm acc} = E_{\rm acc}^{\rm MP} = 7.9\,{\rm MV/m}$, respectively. Two-point MPs are seen in both figures. We can see that the change of corner geometry significantly affects the impact angle θ, in common with Fig. 1, which was obtained in the previous study [8].

Comments

While the MP simulations in 650 MHz half scale model revealed that $a/b \simeq 0.5$-0.6 leads to a better suppression of MP, those for 325 MHz spoke cavities with elliptical arc corners have not been carried out yet. We need to implement them and confirm whether $E_{\rm acc}^{\rm MP}$ exceeds 7 MV/m, which is the operation gradient proposed in the original 325 MHz spoke cavity.

We have not yet carried out MP simulations at $E_{\rm acc} > E_{\rm acc}^{\rm MP}$, but we can expect that the cavity with $a/b = 3.0$ suffers more intense MP than that with $a/b = 0.6$ because of the difference of θ (see Fig. 2). It should be noted that the difference of $E_{\rm acc}^{\rm MP}$ between the two cavities comes from not only that of θ but also that of K.

Detailed discussions will be presented elsewhere.

SUMMARY

We are developing a 325 MHz superconducting spoke cavity for the electron acceleration to realize a compact industrial-use X-ray source with the laser-Compton scattering. Now a 650 MHz half scale cavity is being fabricated for accumulating our cavity production experience. In this contribution, results of multipactor simulations in 650 MHz half scale models were reported.

Procedures of the simulation were briefly summarized, where we emphasized that an appropriate secondary electron yield should be used for studying the hard barrier. We used SEY of processed Nb that does not induce the multipactor in TESLA shape cavity (Fig. 2).

We carried out multipactor simulations with changing the end-plate corner geometry expressed by an elliptical arc (Fig. 3). We found the optimum ratio between the two axis length is given by $a/b \simeq 0.6$ (Fig. 4). Electron trajectories during multipactors were also examined. We found a corner geometry significantly affects the impact angle (Fig. 5) in common with our previous MP simulations in 325 MHz cavity.

REFERENCES

[1] R. Hajima, T. Hayakawa, N. Kikuzawa, and E. Minehara, J. Nucl. Sci. Tech. **45**, 441 (2008).

[2] R. Hajima, M. Sawamura, T. Kubo, T. Saeki, E. Cenni, Y. Iwashita, and H. Tongu, in *Proceedings of IPAC2015, Richmond, VA, USA* (2015), p. 2902, WEPMA056.

[3] C. S. Hopper and J. R. Delayen, Phys. Rev. ST Accel. Beams **16**, 102001 (2013).

[4] M. Sawamura, R. Hajima, R. Nagai, T. Kubo, H. Fujisawa, and Y. Iwashita, in *Proceedings of IPAC2014, Dresden, Germany* (2014), p. 1946, WEPRO005.

[5] M. Sawamura, R. Hajima, R. Nagai, and N. Nishimori, in *Proceedings of SRF2011, Chicago, IL USA* (2011), p. 165, MOPO036.

[6] Y. Iwashita, H. Fujisawa, H. Tongu, R. Hajima, R. Nagai, M. Sawamura, and T. Kubo, in *Proceedings of IPAC2014, Dresden, Germany* (2014), p. 2543, WEPRI030.

[7] T. Kubo, E. Cenni, H. Fujisawa, R. Hajima, Y. Iwashita, T. Saeki, M. Sawamura, and H. Tongu, in *Proceedings of LINAC14, Geneva, Switzerland* (2013), p. 1030, THPP075.

[8] T. Kubo, T. Saeki, E. Cenni, Y. Iwashita, H. Tongu, R. Hajima, and M. Sawamura, in *Proceedings of IPAC2015, Richmond, VA, USA* (2015), p. 2892, WEPMA053.

[9] M. Sawamura, R. Hajima, T. Kubo, T. Saeki, Y. Iwashita, H. Tongu, H. Hokonohara, and E. Cenni, in *Proceedings of SRF2015, Whistler, BC, Canada* (2015), p. 1196, THPB046.

[10] M. A. Furman and M. T. F. Pivi, Phys. Rev. ST Accel. Beams **5**, 124404 (2002).

[11] G. Romanov, private communications.

[12] G. Romanov, in *Proceedings of LINAC08, Victoria, BC, Canada* (2008), p. 166, MOP043.

ISBN 978-3-95450-147-2