SIMULATION OF MULTIPACTING IN HINS ACCELERATING STRUCTURES WITH CST PARTICLE STUDIO*

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Abstract

Recently high power tests of the room temperature cross-bar H-type resonators (CH resonators) and high gradient tests of a superconducting single spoke resonator (SSR) have been performed under the High Intensity Neutrino Source (HINS) project at Fermilab. The resonators have shown a tendency of having multipacting at various levels of input power and therefore longer processing time. To provide insights for the problem, detailed numerical simulations of multipacting for these resonators have become necessary. New generation of accelerating structures like superconducting spoke resonators and room temperature CH resonators need a full 3D treatment. Simulations and study of multipacting in the resonators have been carried out using CST Particle Studio. The problematic regions and power levels have been identified for both types of resonators. This presentation will give the result of simulations and comparison with experimental data.

INTRODUCTION

Within the framework of the High Intensity Neutrino Source (HINS) program, we plan to build and operate a portion of the Front End (up to energy of 62 MeV) as a technical feasibility proof of the proposal. A detailed description of the project and the current status is given in [1]. The Front End of HINS, operating at 325 MHz, uses a mixture of warm copper structures and superconducting spoke resonators. After a standard RFQ [2], room-temperature crossbar H-type resonators are used to accelerate the beam from 2.5 to 10 MeV [3]. The use of short normal conducting resonators up to ~10 MeV reduces the number of different types of SC cavities and provides adiabatic beam matching. Three types of superconducting spoke resonators are used to accelerate protons from 10 MeV to 400 MeV [4].

Recently high power tests of the room temperature cross-bar H-type resonators (CH resonators) and high gradient tests of a superconducting single spoke resonator (SSR) have been performed [5,6]. The resonators have shown a tendency of having multipacting at various levels of input power and therefore longer processing time. To provide insights for the problem, detailed numerical simulations of multipacting for these resonators have become necessary. Simulations and study of multipacting in the resonators have been carried out using CST Particle Studio. Since CST PS is probably the first commercial code that can simulate realistic electron multiplication, the result of study is useful also as the code benchmarking.

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MODEL PREPARATION

A general approach for mulipacting simulation was developed a while ago and it can be mapped to the three steps. These steps are performed in every case, with variations in execution, strategies for detailed implementation and numerical methods. The first step is the definition of the geometry and the calculation of the RF and static fields in this geometry. In a second step, a motion of large number of particles is tracked in the structure. And in a third and final step a multipacting behavior in the collection of particle tracking data is identified [7]. In CST PS, all three steps are smoothly integrated in one code.

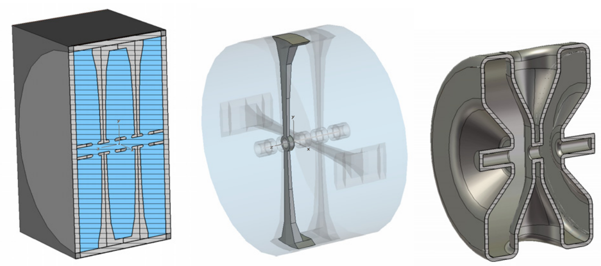

Figure 1: RT CH model consisting of background PEC, cavity components and vacuum filling is on the left. In the center a separate half of spoke is shown. Model of single spoke superconducting cavity SSR is on the right.

RF design for all HINS cavities was done with CST MicroWave Studio. The standard “vacuum” solid models from MWS can not be used “as is” in PS and additional manipulations are needed. First of all, the models before importing into PS from MWS had to be converted to more realistic models with metal walls (or developed from scratch). This is because the secondary emission properties in PS can be assigned to metal surface only, and PS does not recognize Perfect Electric Conductor background as a metal surface. Besides creating a model with metallic walls it is recommended to fill it with vacuum and make background of PEC as shown in Fig.1. This eliminates parasitic mode simulation outside a cavity. Usually several locations are suspicious as MP ones, so it is useful to build a cavity model consisting of separate parts and provide them with independent initial particle sources. It helps to evaluate MP on different surfaces independently.

The prepared models were imported first into MWS for field calculations (it is preferable because MWS has more advanced eigenmode solvers than PS), and then into PS for particle tracking.

In this study the Furman probabilistic model of secondary emission for copper was used with default PS parameters. Usually 50 generations of secondary electrons were tracked and maximum of secondaries per hit was 1.5-2.5. The particle sources provided the simulations with primary electrons uniformly distributed over source area and uniformly distributed over the energy range of 0-4 eV. Number of primary electrons per source was from 200 to 5000. Unfortunately there is no possibility to distribute primary electrons in time, so all initial electrons were launched simultaneously at the same phase of RF field.

MULTIPACTING IN CH RESONATORS

The goal of MP simulations is to find a location of multipacting activity in a cavity and determine the RF power levels or zones where MP conditions are fulfilled. After analyzing field pattern and trying particle sources on different surfaces, a location of stable multipacting activity in RT CH was found in area shown in Fig.2.

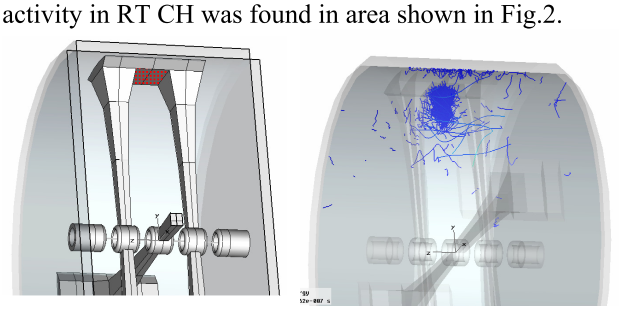

Figure 2: Initial electron source and particle trajectories in CH1 after 40 RF periods (crashed particles are not shown).

PS evaluates particle number in a cavity volume vs time, which is a natural parameter to indicate and verify electron multiplication (see Fig.3).

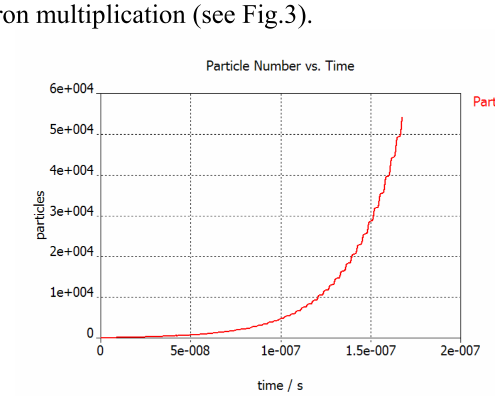

Figure 3: Exponential growth of particle number in a cavity when MP conditions are fulfilled.

PS stores information on emission and collision for every separately defined surface. This data allows to calculate integral secondary emission yield defined as <SEY>=(Total Number of Secondaries)/(Total Number of Hits) and evaluate MP probability, its intensity and zones for each separate surface. Simulations for all RT CH cavities have been performed and shown essentially similar MP behavior. Typical curves <SEY> vs input power are shown in Fig. 4.

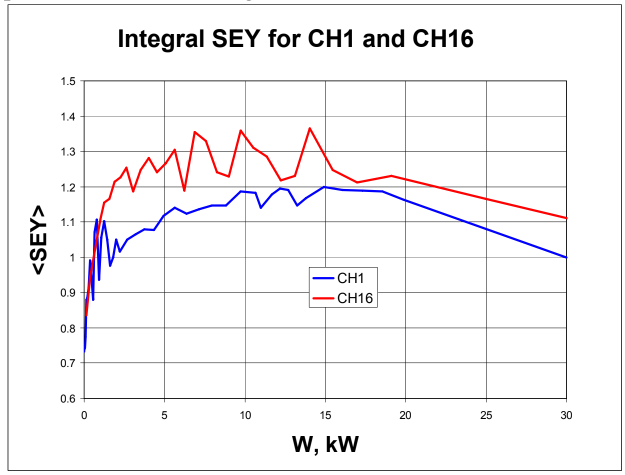

Figure 4: Results of the MP simulations in CH1 and CH16.

Single trajectory simulations show that multipacting is of 5-6 order, and therefore the MP can not be very powerful. It can exist only due to the specific field "trap" for electrons plus flat surface between spokes. In practice it takes time to process a CH resonator first time through 2-10 kW barrier, but eventually MP disappears [5].

MULTIPACTING IN SSR1

Multipacting seems to be a common problem for low beta SC spoke cavities. Once a particular case of multipacting was simulated in a single spoke cavity [8], but existence of several levels of MP and its broad band character were not explained.

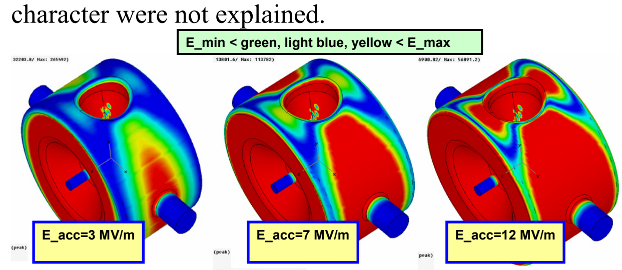

Figure 5: Electric surface field distribution at different accelerating gradients.

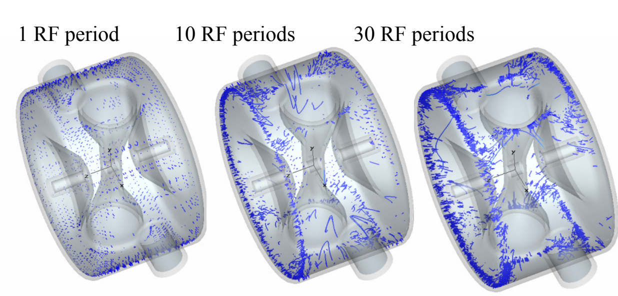

Figure 6: Development of multipacting in time at accelerating gradient of 7 MV/m.

To understand locations of multipacting in SSR1 the upper and lower limits of RF electric field, where MP can exist, were defined in accordance with [9]. Corresponding areas, where electrons can gain right incident energy, are shown at different accelerating gradients in Fig.5. These areas are just approximate locations of potential MP because only surface field is considered. But since MP is a near surface process it is an accurate approximation.

In Fig.6 development of multipacting in the cavity is shown. Uniformly distributed initial electrons were launched from cylindrical surface of the cavity. After 30 RF periods the MP concentration reproduced the surface field pattern. So, the surface field distribution predicts correctly probable locations of multipacting, and one can conclude that MP should migrate from one area to another with accelerating gradient increase.

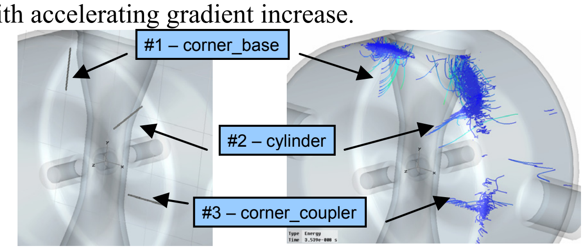

Figure 7: The initial electron sources in different locations.

To evaluate MP in different locations and track the MP migration around the cavity three sources of initial electrons were introduced (Fig.7). Each source allows studying MP in particular area. Simulations were performed for all sources simultaneously and the trick was to stop simulation before MP spreads over the cavity. Then the integral secondary emission yield can be calculated for each source separately.

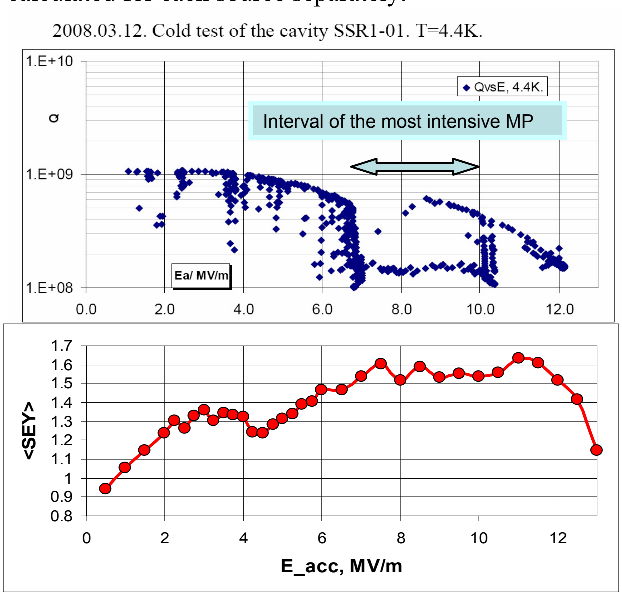

Figure 8: Comparison with experiment.

The simulations confirmed that the most intensive spot of multipacting migrates from location to location with accelerating gradient increase. While moving to the new areas the spot sees "fresh" unconditioned parts of surface and this explains the broad interval of mulipacting. The spatial stability of MP is poor, so rather high re-emision coefficient (>1.7) is required to sustain the process. The intensity of multipacting drops when areas with favorable for MP conditions start shrinking due to high fields (see Fig.5).

Combined <SEY> for all three sources is plotted in Fig.8 along with quality factor Q measurements made during first high gradient test of SSR1 cavity [6]. The drops of Q correspond to the MP levels and zones. The simulations correctly indicate that MP zones.

CONCLUSIONS

The multipacting in CH resonators and SSRs is a broadband phenomenon. There are not many chances to rid of it by reshaping the problem spots because it is related to the operating field distribution and basic geometry. Fortunately, the MP is not persistent and very powerful in both cases due to the mentioned above reasons, so the effect is no show stopper, but just annoying for operation/start-up.

CST PS proved to be a good tool for MP study. To make it more effective a development of tracking in real time, distributing of primary electrons over RF phases and more advanced evaluation of particle data to identify multipacting, is recommended.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R.Webber, Overview of the High Intensity Neutrino Source Linac R&D Program at Fermilab, this conference.
[2] G.Apollinari et al., The Fabrication and Initial Testing of the HINS RFQ, this conference.
[3] L.Ristori et al., "Fabrication and Test of the First Normal-Conducting Cross-Bar H-Type Accelerating Cavity at Fermilab for HINS, PAC'07, Albuquerque, New Mexico, USA, WEPMN110, 2007.
[4] G.Lanfanco et al., Production of 325 MHz Single Spoke Resonators at FNAL, PAC'07, Albuquerque, New Mexico, USA, WEPMN099, 2007.
[5] G.Romanov et al., High Power Test of HINS RT CH Cavitites, this conference.
[6] I. Gonin et al., "High Gradient Tests of the HINS SSR1 Single Spoke Resonator", HB2008, Nashville, Tennessee, August 2008.
[7] F.L.Krawczyk, Status of Multipacting Simulation Capabilities for SCRF Applications, Proceedings of the 10th Workshop on RF Superconductivity, Tsukuba, Japan, 2001.
[8] L.V.Kravchuk, G.V.Romanov and S.N.Tarasov, Multipactoring Code for 3D Accelerating Structures, LINAC'00, Monterey, California, THB12, 2000.
[9] В.Г.Мудролюбов, В.И.Петрушин, Обобщённые соотношения для областей существования модификаций резонансного ВЧ разряда с учётом кулоновского поля, ЖТФ, т.XL, вып.5, май 1970, стр.1017.