HIGH FIELD MULTIPACTING OF 1.3 GHZ TESLA CAVITY

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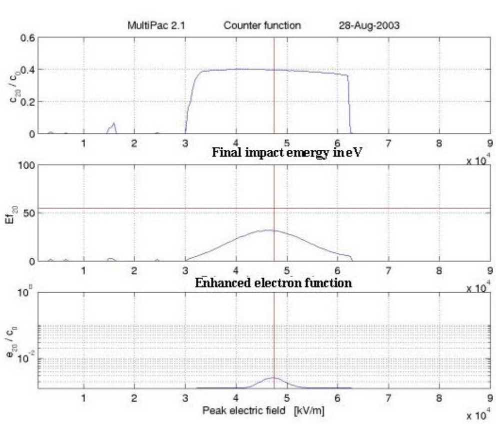
Abstract

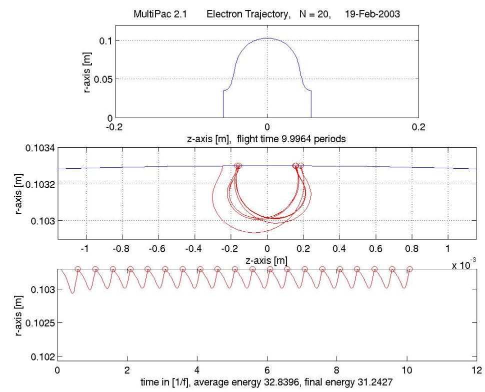
Recently multipacting (MP) recalculation of TESLA cavity was done at DESY. In addition to the normal multipacting, which occurs at a peak electric field of around 40 MV/m for the TESLA cavity, another type of multipacting with resonant electron trajectory that is far from the equator is also seen. It occurs at a gradient around 60 MV/m to 70 MV/m. At this field level, field emission, or breakdown can limit a cavity. Now it seems that the analysis of limitation is more complicated if this high field multipacting also exists. This type of multipacting is more likely to exist in lower-beta cavities, but the latest calculation shows it could also occur in TESLA cavities.

INTRODUCTION

As we know, multipacting, field emission and thermal breakdown are the three limitations of a superconducting (s. c.) cavity. Since the cavity shape is changed from cylindrical to elliptical, multipacting is no longer a major limitation. Sometimes multipacting even does not exist. Most times when it occurs, it can be processed after some time. Figure 1 is the typical multipacting analysis of a TESLA middle cell cavity [1]. We use electron counter function, electron enhanced counter function, final impact energy and electron trajectory to describe and analyze MP.



a) From top to bottom, the electron counter, the average impact energy of the last impact in eV and the enhanced electron counter for the Tesla 1.3 GHz middle cell cavity. The horizontal axis gives the peak electric field in kV/m. The impact energy is less than 35 eV (the figure in the middle) and for those impact energies the taken secondary yield function is less than one, there is no multipacting. But if the surface of the cavity is not ideal (the secondary yield function may be larger than 1) or the initial energy is more than 2 eV, multipacting will take place. So it is called weak multipacting around the peak surface field of 47MV/m.



b) A two-point first order electron trajectory in the TESLA cavity when the peak electric field is 47.5MV/m. On the top is the trajectory in (r, z) coordinates, in the middle is the zoomed plot of the same trajectory and on the bottom is the trajectory in (r, t) coordinates, where t is the time in rf period. The circles indicate impacts on the walls of the cavity.

Figure 1: MP analysis of Tesla middle cell cavity.

In Figure 1a, we can see that multipacting probably occurs around the peak electric field of 40 - 45 MV/m, with which we are familiar from the RF test. At this field level, we call it normal MP. Recently in some cavities at DESY, radiations are observed at the peak electric field of higher than 60 MV/m during the RF test, and reduced as processing. This phenomenon is usually a characteristic of Multipacting. But it is hard to explain with the normal multipacting that happens always near the equator and usually around 40 MV/m. Because of this experimental observation, MP calculation was redone.

HIGH ENERGY HIGH FIELD MULTIPACTING WITH RESONANT ELECTRON TRAJECTORY

Parameters of MP Calculation

Multipacting calculation of 1.3GHz TESLA cavity was redone with MultiPac 2.1 (Helsinki 2001 version) at DESY [1]. The input parameters are as following. Mesh constant of the cavity is 5mm. Initial energy of the electrons that are launched from given initial sites on the boundary of the structure is 2eV. The phase step is 5 degree. The number of impacts of every initial electron is 20. The program creates initial points whose z co-ordinates (cavity axis) satisfy $-0.04 \le z \le 0$m. All the calculations assume magnetic boundary conditions. A typical secondary electron yield curve for a niobium surface is used, which displays in Figure 2 [2].

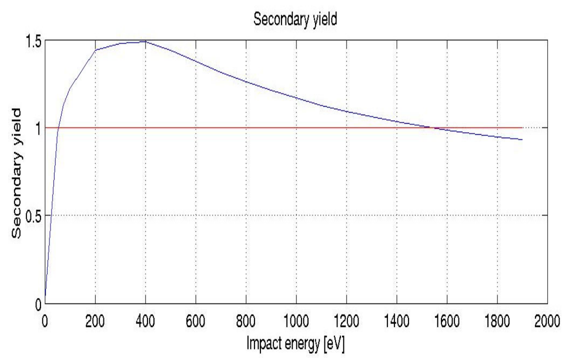
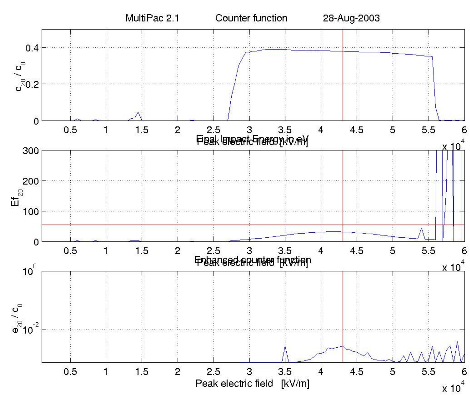


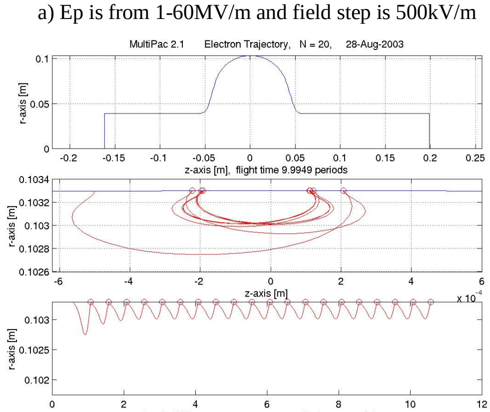
Figure 2: The secondary electron yield at different impact energies (in eV) for a niobium surface baked at 300°C.

Existing Normal Multipacting

For the TESLA TDR (technical design report) designed middle cell cavity (see Table1) [3], the MP analysis is the same as the previous calculation (Figure 1). Figure 3 is the MP analysis of an asymmetric single-cell cavity formed by cutting all the middle cells of a TESLA 9-cell cavity. We can see that the electron trajectory happens near the equator at the peak electric field of 43 MV/m, and this is the normal multipacting.



a) Ep is from 1-60MV/m and field step is 500kV/m

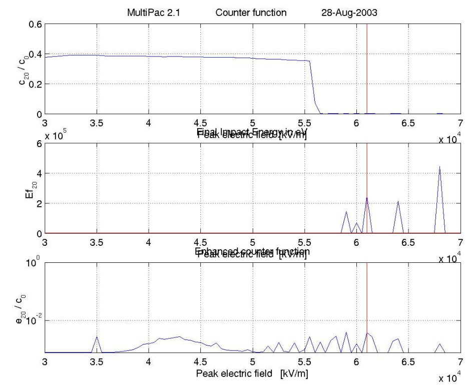


b) Electron trajectory when Ep is 42.5MV/m (similar to that of the Tesla middle cell)

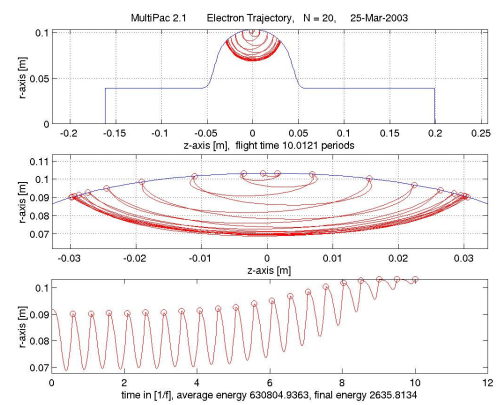
Figure 3: asymmetric single-cell cavity made by two end half cells of a TESLA 9-cell cavity.

Zoom of High Field Trajectory

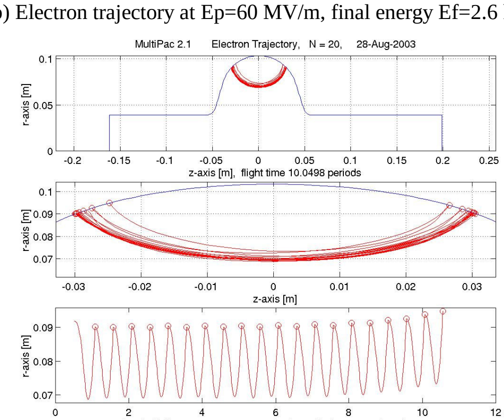
Except the normal multipacting, we still can see some high-energy peaks in the middle graph of Figure 3a. These high-energy peaks appear at the peak electric field of more than 55MV/m. Figure 4a is the zoomed graphs of Figure 3a when the peak electric field is from 30 to 70 MV/m. Under most gradients, the energy of the simulated electrons for the first few impacts is very high and then gradually becomes lower and lower; at last the electrons stop at the equator (see Figure 4b). But under some other fields, the electron trajectory can be resonant between two points of the cavity wall (see Figure 4c).



a) Zoomed from Figure 3a, Ep is from 30-70MV/m, field step is 500 kV/m



b) Electron trajectory at Ep=60 MV/m, final energy Ef=2.6 keV



c) Electron trajectory at Ep=61MV/m, final energy Ef=740keV

Figure 4: Zoomed MP analysis of Figure 3.

In figure 4a, the final impact energy can reach 1MeV; MP trajectory may take place far from the equator and can even be stable between two points of the cavity wall under some electric field. This kind of MP occurs at higher field compared to the normal multipacting. So we call it high field multipacting.

Independence on Cavity Mesh Size, Boundary Step Size and Field Step Size

In order to see whether this happens occasionally or not, effect of field step size, mesh size of the cavity and step size of the cavity boundary were studied on this asymmetric single-cell cavity.

Mesh size of the cavity is changed from 5mm to 3mm, 4mm and 6mm. Field step size of the simulation is changed from 25 to 500 kV/m. The electron counter functions, final impact energy and electron trajectories give similar graphs (see Figure 5).

The coordinate of the cavity boundary is given by (r, z) for the input geometry file of the MP program. The input file has about 80 points to form the boundary of the cavity in the previous calculations. Here we change the step size in order to have different total boundary points (45 points, 60points, and 100 points) for the input file. The MP analysis shows that the two-point high-energy multipacting with resonant trajectory can still happen in the Ep range of 50 – 70 MV/m.

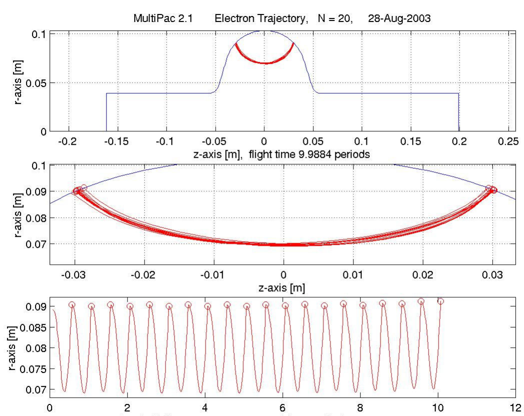
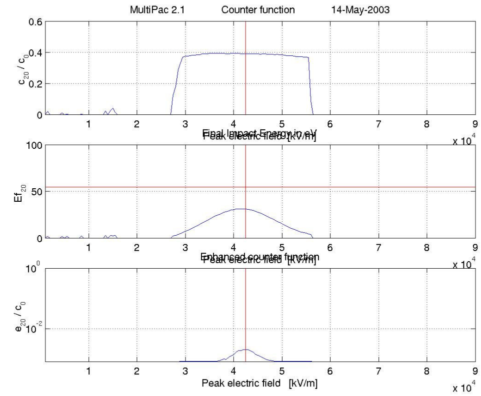


Figure 5: mesh size=6mm, field step size=100kV/m, at Ep=61.5MV/m, the final energy Ef=890keV.

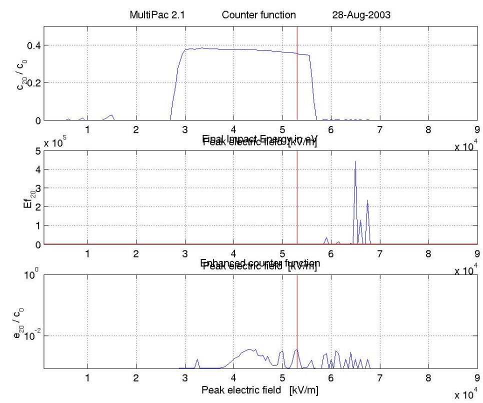
These analysis show that the high field multipacting with resonant electron trajectory is independent on the cavity mesh size, field step size and boundary step size.

HIGH FIELD HIGH IMPACT ENERGY MP DEPENDS ON CAVITY GEOMETRY

As we mentioned before, high field multipacting does not exist in the TESLA TDR designed middle cell. Calculations of the designed single-cell cavity at DESY, which is symmetrically fabricated according to the parameters of Endcup2 of a 9-cell cavity (see Table 1), shows no high field MP, either (see Figure 6a). But it exists in the single-cell cavity made by symmetric Endcup1 of a 9-cell cavity (see Figure 6b).



a) Single-cell cavity made from symmetric Endcup2



b) Single-cell cavity made from symmetric Endcup1

Figure 6: electron counter functions and final impact energy at peak electric field (1-90MV/m).

In order to find when this kind of MP takes place, MP analysis was done on a lot of cavities by slightly changing the geometry from TDR parameters. Table 1 lists the calculated cavities. The name of a cavity starting with M is a symmetric middle-cell cavity with parameters changing a little from the Midcup of the Tesla 9-cell cavity. The name of a cavity beginning with R means a symmetric single-cell cavity produced by changing parameters a little from the Endcups of a Tesla 9-cell cavity. All dimensions are in cm. In table1, the last column “y/n” stands for whether this high field multipacting occurs in the cavity or not.

From the calculations, we can see that high field high impact energy MP depends on cavity geometry parameters, just like the normal MP. Many middle-cell cavities and single-cell cavities produced by changing a little from the Midcup or Endcup of a 9-cell TESLA cavity can also have this high filed multipacting, and the peak electric field range is 60-70MV/m. Table 1 shows that the radius of the circle Rc is the most effective parameter among all geometry parameters. The high field high impact energy MP coincides when Rc is smaller than 4.2cm.

Table 1: relation between two-point high field MP and cavity geometry parameters

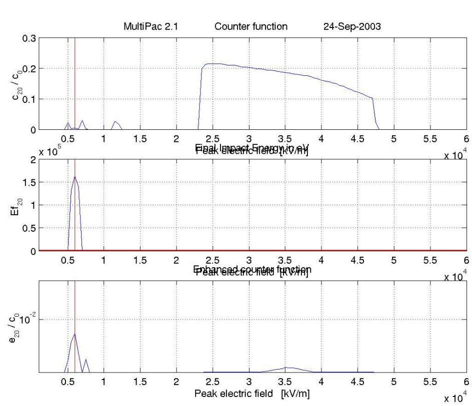
Group	Name	Rc	Horizontal half axis a	Vertical half axis b	Iris radius Riris	Half cell length L	Y/n
	Midcup	4.2	1.2	1.9	3.5	5.77	N
Modification from Midcup	M1	4.221	1.18	1.663	3.7	5.77	N
	M2	4.303	1.081	1.708	3.5	5.77	N
	M3	4.395	1.046	1.464	3.6	5.77	N
	M4	4.03	1.076	1.56	3.6	5.77	Y
	M5	4.138	1.074	1.654	3.6	5.77	Y
	Endcup2	4.2	0.9	1.28	3.9	5.7	N
Modification from Endcup2	R1	4.2072	0 .8999	1.2798	3.9	5.7	N
	R2	4.2282	0.8576	1.2264	3.9	5.7	N
	R3	4.1250	0.9156	1.2910	3.8	5.7	Y
	R4	4.1505	0.9129	1.2781	3.9	5.65	Y
	R5	4.1704	0.9299	1.3019	3.9	5.68	Y
	Endcup1	4.03	1	1.35	3.9	5.6	Y
From Endcup1	R6	4.1259	0.9215	1.2809	3.9	5.63	Y
	R7	4.0673	0.9321	1.2956	3.8	5.65	Y

COMPARATION TO LOWER-BETA CAVITY

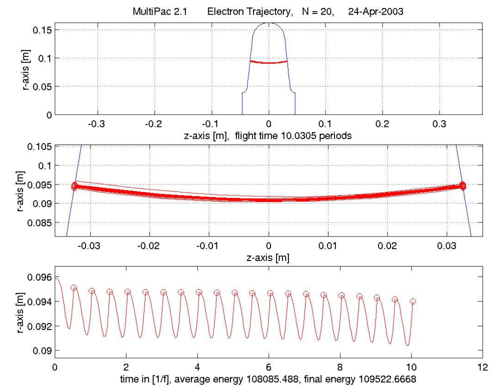
MP were also calculated in 805MHz beta=0.8, beta=0.6, beta=0.5 cavities. All these cavities are designed by BUILDCAV [4] and SUPERFISH program. Similar multipacting were also found. Table 2 lists the geometry parameters of beta=0.5 elliptic cavity. All dimensions are in cm. For this cavity, this type of high impact energy MP is even continuous under a field range. Figure 7 displays this result.

Table 2: Geometry parameters of a beta=0.5 cavity

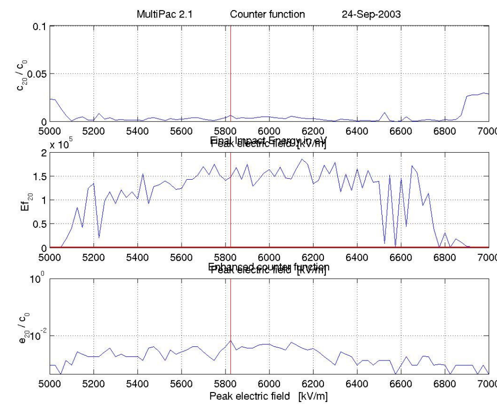
Rc: radius of equator circle	a: horizontal half axis	b: vertical half axis	Riris: iris radius	L: halfcell length
2.838	0.926	1.297	3.85	4.658



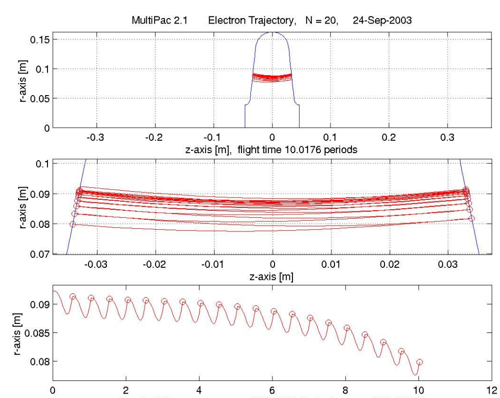
a) Ep is from 1-60MV/m, field step is 500kV/m



b) Electron trajectory at Ep=6.1MV/m, final energy is 110keV



c) Zoomed from a) Ep is from 5-7MV/m, field step is 25kV/m



d) Electron trajectory at Ep=5.8MV/m, final energy is 133keV

Figure 7: MP analysis of a beta=0.5, f=805MHz cavity.

DISCUSSION

MP analysis was calculated with Multipac 2.1. Calculations show that there exists another kind of multipacting with resonant trajectory at high electric fields. High impact energy and trajectory far from the equator are the two characteristics of this kind of multipacting. From Figure 4a, we can see that the maximum of the enhanced electron counter function under high fields is the same level as that under the normal multipacting field. It seems that if the normal multipacting could occur, this high field multipacting could also occure. To understand it better, let us first have a look how multipacting takes place. As we know, multipacting has two conditions:

1. An electron emitted from the cavity wall is driven by the electromagnetic field and returns back after an integral number of rf cycles to the same point of the cavity wall.
2. The impacting electron produces more than one secondary electron, which means the secondary electron yield should be larger than one.

This high field MP is fulfilled with the first condition. For the second, there are no published measured values of the second electron yield δ in the impact energy level of about 1 MeV. The program takes a value of a little smaller than 1 for δ when impact energy is so high.

The calculations also indicate this high field MP is independent on the field step, mesh size of the cavity and step size of the boundary, but depends on the cavity geometry. At DESY, both TESLA TDR designed 9-cell cavity and single-cell cavity that is designed from symmetric Endcup2 don't have this type of multipacting from the analysis. However, it still may be observed during some cavity RF tests, because the geometry changes during fabrication or tuning and maybe have a smaller radius of the circle. In order to make sure that the observed γ rays from the experiments are caused by this high field multipacting, we need more quantified measurements, and compare to our multipacting calculation results.

CONCLUSION

MP analysis of TESLA type cavities was conducted with Multipac 2.1. New resonant trajectories were found at peak surface levels around 70 MV/m. Those trajectories were stable if the ideal TESLA cavity contour is slightly changed. The impact energy of these trajectories is as high as 900 keV. There are no experimental data on the secondary yield at such high impact energies. A secondary yield of larger one is required for the existence of a multipacting barrier. But experimental observations of sudden γ rays at these cavity fields give a hint to the existence of such high impact energy multipacting resonances.

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