

MULTIPAC - MULTIPACTING SIMULATION PACKAGE WITH 2D FEM FIELD SOLVER

P.Ylä-Oijala, Rolf-Nevanlinna Institute, Helsinki, Finland
D. Proch, DESY, Hamburg, Germany

Abstract

MultiPac is a multipacting simulation package for analyzing electron multipacting in axisymmetric RF structures with TM_{0n1} mode, such as RF cavities, coaxial input couplers and ceramic windows. The package includes a graphical MATLAB user interface and a 2D finite element electromagnetic field solver with third order basis functions. The multipacting simulations are carried out by combining the standard electron trajectory calculations in the electromagnetic fields by the Runge Kutta method with the systematic searching and analyzing methods for multipacting resonances. In addition, in coaxial input couplers the program can treat standing, travelling and mixed waves.

The simulations are carried out in three steps. First the program calculates the time harmonic electromagnetic fields in the given RF design. To this end an axisymmetric FEM field solver with an automatic mesh generator and eigenvalue solver has been developed. Then the program finds the multipacting field levels by tracking electron trajectories. Thirdly the program can locate and identify the multipacting trajectories. For the second and third step special counter and distance functions are applied.

1 INTRODUCTION

Multipacting (*multiple impact* electron amplification) is observed in radio-frequency components, which are operated under vacuum. It is a phenomenon of resonant multiplication of electrons under the influence of radio-frequency fields. Secondary electrons can be created by a primary electron impinging on a metal surface. The secondary yield δ counts the number of secondary electrons per incident electron. The yield number δ is larger than 1 for most metals at an impact energy of the primary electron in the range 100–1000 eV. It is usually enhanced for any ‘not clean’ surface condition. The secondary electron will be accelerated by the electric component of the radio-frequency field and will hit the surface elsewhere. If the time for the trajectory is synchronous with the radiofrequency period and if the impact energy is in the range of >1 , an avalanche of electrons can be created. The synchronous condition depends on details of the geometry and on the local electric and magnetic field values. Multipacting can be predicted analytically only for simple geometries. Resonant trajectories can be searched for with iterative numerical methods. This has been successfully applied for two-dimensional problems but it is still a challenge for

three-dimensional radiofrequency contours. The experimental signature of multipacting is as follows.

2 METHODS OF CALCULATION

2.1 RF Field Solver

The field solver of MultiPac is cable for computing the time harmonic RF fields in accelerator cavities (closed by magnetic walls) and coaxial input couplers possibly with ceramic windows. The field solver is based on the finite element method (FEM) with special third order elements [1]. These elements satisfy both the existence of the integrals at the axis of the structure and the continuity of the tangential components of the fields on the ceramic windows. The field solver includes also an automatic mesh generator. In the cylindrical symmetric structures the field problem for the TM_{0n1} resonant modes (also known as monopole modes) can be formulated by the Helmholtz equation for a scalar function. In the resonator cavities this in turn reduces to a generalized eigenvalue problem.

The accelerator cavities can be straightforwardly considered as resonator cavities. For the field computation in the input couplers, the computation domain is first closed by properly placed electric and magnetic walls. The locations of these walls are found by an iterative method so that the given frequency of the electromagnetic field is the eigenvalue of the closed cavity resonator. Thereafter, the field computation problem can be considered as an eigenvalue problem of a cavity resonator. By this method we can avoid the need for any special boundary conditions at the ends of the coupler. Furthermore, for the complete field solution in the input couplers we have to consider travelling and more general partially reflected waves, so called mixed waves, too. By appropriately combining the two resonant standing wave solutions, corresponding to the cavity resonator closed by the electric and magnetic walls, respectively, we can define all possible wave forms in the input coupler with discontinuities and windows.

2.2 Trajectory Calculations and Counter Functions

For a fixed field level the electron trajectories are calculated by integrating the equations of motion by the Runge-Kutta-Fehlberg method. Electrons are launched from given initial sites on the boundary of the structure at given phases of the time-harmonic field. The initial velocity is constant and usually a few eV. The initial

angle may be a constant or it may vary according to a specified distribution. The trajectory calculation is continued until the electron hits the wall of the structure. When the electron hits the wall, the impact point on the wall is located, and the phase of the field and the energy of the impacting electron are calculated. By the given secondary yield functions the number of secondary electrons is determined.

The trajectory calculation is continued if the field phase is such that the possible secondary electrons are able to leave the wall. After a given number of impacts N (usually $N = 20$ or 30) the number of free electrons, the number of secondary electrons and the number of all electrons, also those which have impacted the wall in a wrong field phase, are counted. These numbers are called electron counter function, enhanced electron counter function and total electron counter function. Also the average impact energy of those electrons which survive N impacts is calculated. The counter functions and the average impact energy are counted by repeating the trajectory calculation for a sufficiently large set of field levels [2].

The electron counter function shows the field levels at which the resonant condition for multipacting is satisfied, i.e., when the electron trajectories start to repeat resonant trajectories. The average impact energy shows when the impact energy is in appropriate range to procure more secondary electrons (in average). These two conditions are combined in the enhanced electron counter function. For those field levels where the enhanced counter function exceeds the number of initial electrons, multipacting occurs.

2.3 Distance Function

After the multipacting field levels are found, one usually wants to locate the multipacting processes. For a multipacting field level (e.g. the maxima of the enhanced counter function), the scaled distance in the phase space between the initial point and the last impact point is calculated. Obviously the minima of the distance function shows the initial points of those electron trajectories that survive N impacts and are able to multipact. Then the electron trajectories are recalculated by using these minima as initial points and the impact energy is computed. If the impact energy is such that the secondary yield is larger than one, a multipacting electron trajectory has been found.

3 INPUT DATA

The input data for the program is transformed via ASCII files and can be defined in the MATLAB user interface.

3.1 Input Files

The geometry of the structure, the secondary yield curves and the emission angle distribution are given in specified files. The geometry can be defined as a cavity,

coupler or a window. A geometry type cavity defines an accelerator cavity, which is closed by magnetic. A geometry type coupler defines a segment of a coaxial input coupler without ceramic windows, and a geometry type window defines a segment of a coaxial input coupler with a ceramic window. In the last two cases the reflection conditions on the coupler can be defined by a complex reflection coefficient.

3.2 Input Parameters

The input parameters for the program can be given in Input Window, see Figure 1. In Input Window the input parameters for the field solver and for the multipacting simulations are defined. The program automatically generates a mesh for the field computations and input sites and field levels for the multipacting analysis by using the data given in Input Window.

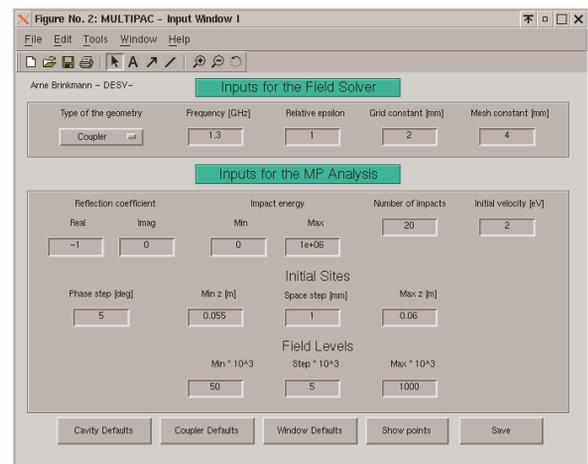


Fig. 1: Input window for defining parameters of multipacting calculation

4 OUTPUT DATA

The output data of the multipacting analysis are saved into ASCII files. There are specified output files for the counter functions, impact energy, distance function and for an electron trajectory. The output data can be displayed by the graphical user interface. As an example Figure 2 shows a "tripplot", i.e., the counter function, the enhanced counter function and the average impact energy of the last impact for a straight coaxial line with a standing wave. The inner radius of the line is 8.7 mm, the outer radius is 20 mm and the frequency is 1.3 GHz.

From Figure 2 we can conclude that multipacting exists on the field levels 95 kW, 150 - 180 kW, 290 - 350 kW and 400 - 405 kW, i.e., when the enhanced counter function exceeds unity.

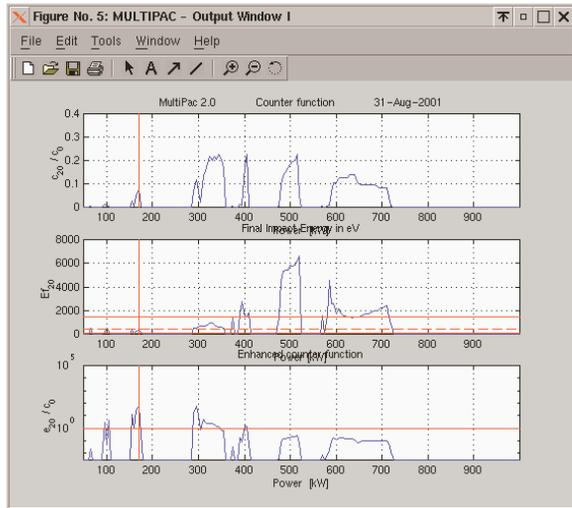


Fig. 2: typical output of multipacting calculation in a coaxial line upper trace: calculated counter function (with secondary yield equal 1) as function of RF power middle trace: impact energy as function of RF power lower trace: enhanced counter function (with realistic secondary yield function) as function of RF power

5 HOW TO GET THE PROGRAM

5.1.

The program MultiPac is available within the TESLA community and comparable national or international scientific laboratories. It is not allowed to be used by any commercial company. In this case a request for calculation can be addressed to the Rolf Nevanlinna Institute, P.O. Box 4 - Yliopistokatu 5, 00014 University of Helsinki, Finland.

For scientific use an e-mail request for register should be addressed to Dieter.Proch@DESY.de. The program will be distributed via e-mail from RNI (see next section). We intend to offer some e-mail help in case of trouble when running the code. But we cannot act as a "hot line" to cover any start up trouble. Careful reading the manual and running the installed examples is necessary to get acquainted with the code. The program has been carefully tested and should be free of severe bugs. But we expect need for continuous improvements. Therefore information about (hopefully only) minor problems should be communicated to DESY. Obvious improvements will be implemented into the code by RNI and the new release will be send to the registered users. It is strongly recommended not to change the source code by individual users but to communicate back to DESY any idea for improvements.

5.2 About the Software

The MultiPac simulation package is written in C programming language at Rolf Nevanlinna Institute (RNI),

University of Helsinki, Finland, in collaboration with DESY, Hamburg, Germany. The package is designed to run under the Linux operating system in PC and at the moment no Windows version exists. The program requires at least a 100 MHz Pentium processor, 32 MB of memory and 50 MB of free disk space. The needed amount of the memory depends on the size of the mesh applied in the field computations. The program will be sent as a compressed file and the manual [3] will be sent as a postscript file. Both files will be send via e-mail. The manual includes instructions on the installation of the program.

6 FURTHER READING

The computational methods, which are applied in the package, are described in [1] and [2]. How to use the package for multipacting simulations and some practical advises and examples are given in the user's manual [3]. Results of previously calculated simulations are presented in [2], [4], [5] and [6]. The results of the simulations using the same methodology to suppress multipacting by a biasing DC voltage are reported in [7], [8] and [9].

7 REFERENCES:

- [1] P. Ylä-Oijala and S. Järvenpää, "Finite element method for the electromagnetic field computation in cylindrically symmetric RF structures", to appear in *Electromagnetics*.
- [2] E. Somersalo, P. Ylä-Oijala, D. Proch and J. Sarvas, "Computational methods for analyzing electron multipacting in RF structures", *Particle Accelerators*, Vol. 59, 107 (1998).
- [3] P. Ylä-Oijala, J. Lukkarinen, S. Järvenpää and M. Ukkola "MultiPac 2.1 - Multipacting simulation toolbox with 2D FEM field solver and MATLAB graphical user interface", User's manual, Rolf Nevanlinna Institute, Helsinki (2001).
- [4] E. Somersalo, P. Ylä-Oijala and D. Proch, "Electron multipacting in RF structures", TESLA Report 94-14, DESY Print (1994).
- [5] P. Ylä-Oijala, "Analysis of electron multipacting in coaxial lines with travelling and mixed waves", TESLA Report 97-20, DESY Print (1997).
- [6] P. Ylä-Oijala, "Electron multipacting in TESLA cavities and input couplers", *Particle Accelerators*, Vol. 63, 105 (1999).
- [7] P. Ylä-Oijala, "Suppressing electron multipacting in coaxial lines by DC voltage", TESLA Report 97-21, DESY Print (1997)
- [8] P. Ylä-Oijala and Marko Ukkola, "Suppressing electron multipacting in TTF III cold window by DC bias", HIP-2000-27/TECH, Helsinki Institute of Physics (2000).
- [9] P. Ylä-Oijala and Marko Ukkola, "Suppressing electron multipacting in ceramic windows by DC bias", to appear in *Nuclear Instruments and Methods in Physics Research A*.