NEWTRAJ, A COMPUTER CODE FOR THE SIMULATION OF THE ELECTRON DISCHARGE IN ACCELERATING STRUCTURES

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Abstract

The NEWTRAJ code for the computation of electron discharges in R.F. cavities and structures is presented.

The code is mainly oriented to the computation of the R.F. resonant discharges in the TM monopolar modes of accelerating structures and cavities. Nevertheless the code could be used for the simulation of the non resonant electron loading of R.F. structures operating on the same modes. The code uses the R.F. fields as obtained by the OSCAR 2D code to compute the trajectories of an electron starting from a cavity wall. The field emitted electron is followed until it strikes a cavity wall. At the impact point a true secondary or a backscattered electron is generated. The energy and direction of the new electron are randomly generated accordingly to the distribution of the reemission process.

A comparison among analytical computations, experimental measurements and resonant discharges as computed by our code is presented.

Introduction

People working on the design of resonant cavities and structures for particle accelerators often experienced the bitter taste of a structure plagued by the Multipactoring, the resonant electron loading which occurs at well defined R.F. fields levels.

Only on few simple geometries the multipactoring levels can be predicted by simple rule of thumb computations, and often a Multipactoring discharge so badly affect a "nice cavity" that the cavity may never reach the desired accelerating field.

Sometimes, in "lucky situations" the goal of the foreseen accelerating field level is reached only after a painful, costly and long R.F. conditioning of the cavity surface. But the Multipactoring ghost is only sleeping, waiting for some small perturbations inside the cavity to start again; or some useful accelerating field levels are forbidden by a Multipactoring level.

Working on Superconducting R.F. cavities the Multipactoring phenomenon becomes more and more severe, because the field unstability is enhanced by the high Qo value of the resonator and by the sensitivity to the heating of the superconducting materials.

For that reason, working on S/C cavities for selection acceleration, we have developed a computer code, NEWTRAJ, to simulate the resonant R.F. electron discharge.

The Newtraj code

The Newtraj code uses the R.F. fields of a monopolar TM modes, as computed by our OSCAR 2D [1] simulation code, to follow the motion of the electrons inside any reasonable shape of axially symmetric accelerating cavity or structure.

A typical cavity shape with the E-field distribution is shown in figure 1.

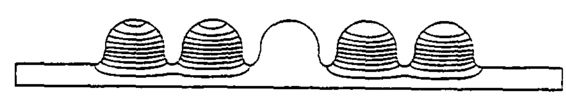

Fig.1 Field distribution in a compensated 5 cell cavity.

Since the problem to be solved has a rotational symmetry around an axis, we restricted ourselves to compute the motion of the electrons in a plane through that axis.

This choice comes out from the following argument:
a) the electric field in the cavity lies in the symmetry plane, and the electrons field emitted from the surface move along the field lines.
b) Secondary electrons reemitted by the surface could in principle have the starting velocity not lying in the symmetry plane, but the value of the starting velocity is low,(the typical energy is few electrons volts) so the motion in the φ direction can be neglected without a significant change in the results.
c) The reemission direction of the backscattered electrons lies in the symmetry plane if the direction of the primary electron does and, for the aforementioned arguments, the velocity of the primary electron can be considered lying in the simmetry plane.

The relativistic equation, in vector form, for an electron moving in the R.F. field of a resonator is

$$\dot{\vec{v}} = \frac{e}{m_0 \gamma}\left(\vec{E} + \vec{v}\times\vec{B} - \frac{\vec{E}\cdot\vec{v}}{c^2}\vec{v}\right)$$

where m_0 is the electron rest mass, e the electron charge. $\vec{E},\vec{B}$ the electric and magnetic fields.

With our assumption of TM monopolar modes and electron motion in the r,z plane, we obtain:

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$$\dot{r} = v_r$$
$$\dot{z} = v_z$$
$$\dot{v}_r = e/m_o\gamma \left(E_r - v_z B\varphi - \frac{\vec{E}\cdot\vec{V}}{c^2} v_r\right)$$
$$\dot{v}_z = e/m_o\gamma \left(E_z - v_r B\varphi - \frac{\vec{E}\cdot\vec{V}}{c^2} v_z\right)$$

this set of differential equations is easily integrated by a step by step Euler method.

The trajectory is followed until the electron strikes the metallic wall.

At the impact point a secondary electron is generated.

The energy and the direction of the new electron are randomly generated accordingly to the distributions of the secondary emission of the cavity wall and of the backscattering process.

At each impact the electron yeld is stored; the tracking of the electron trajectories is stopped when:

a) the electron leaves the cavity via any coupling hole.

b) the product impact energy by yeld is lower than a fixed value.

c) the number of R.F. cycles is higher than a value given as an input datum.

d) the R.F. phase lag between two impacts is less than 10°.

Secondary emission model

When an electron, accelerated by the R.F. field of the structure strikes the cavity wall a new electron is generated by a random process taking into accaunt the probability, related to the value of the impact energy, of producing true secondaries or backscattered.

First we assume the secondary yeld distribution δ as a function of the impact energy U_{EN}

$$\delta = \frac{2\delta_o \,(U_{EN}/U_{MAX})^{1.2}}{\left(1+(U_{EN}/U_{MAX})^2\right)|\cos\vartheta|}$$

where

U_{MAX} = energy where the maximum of the secondary yeld is reached (preset in input)

δ_o = maximum value of the secondary yeld distribution (preset in input)

ϑ = is the impact angle of the electron.

The backscattered yeld is

$$\eta = \eta_o + (1-\eta_o)|\sin\vartheta|$$

where ϑ is again the impact angle of the electrons.

The first term takes into account the true backscattered yeld for the material used to build the cavity.

The second term is the contribution to the yeld due to the enhanced backscattered inpinging the surface at glancing angle.

For the reemission direction trues backscattered and secondaries are treated in the same way.

In both cases the reemission direction is randomly generated with a cos ϑ distribution around the normal direction to the surface at the impact point.

The enhanced backscattered are specularly reflected at the impact point.

The energy of the emitted electrons depends on the reemission process in the following way:

a) for the true secondaries, for the impact energy $U_{EN} > U_{MAX}/10$ the energy of the reemitted electron is a value preset in input (typically $2 \div 4$ eV) for $U_{EN} < U_{MAX}/10$ the energy of the secondaries is randomly distributed in the range $0 \div U_{EN}$.

b) for the enhanced backscattered the reemission energy is fixed to a value of $0.8\,U_{EN}$

c) for the true backscattered the reemission energy is randomly distributed with the distribution

$$U_{OUT} = y\,U_{EN} \qquad 0 \le y \le 1$$

$$f(y) = \frac{5 + 2\log_{10}(U_{EN}/U_{MAX}) - 2y}{1+\left(5/2\log_{10}(U_{EN}/U_{MAX}) - y\right)^2}$$

Results

The first check of the code was performed on a Multipactoring discharge for which an analytical solution is known; a two point discharge between the opposite end plates of a cylindrical cavity or in a gap of a capacitively loaded cavity.

In that case, to fulfil the resonant condition the time of flight for an electron, starting from a side of the cavity and inpinging the opposite wall, must be an integer multiple of an half of the R.F. period T.

From the previous assumption the discharge field and the impact energy of the electron are easily written as a function of the cavity length, L, the free space wavelength of the R.F. field λ and the number of half period n

$$\mathcal{E}_n = \frac{4\pi}{e} m_o c^2 \frac{L}{\lambda^2} \frac{1}{2n-1} \;\mathrm{V/m}$$

$$E_n = 8 m_o c^2 \left(\frac{L}{\lambda}\right)^2 \frac{1}{(2n-1)^2} \;\mathrm{eV}$$

using for $m_o c^2$ (the electron rest mass) the energy value of 5.1×10^5 eV.

The comparison between the analytical computation and the results found by our NEWTRAJ are reported in Table I.

Table I

n	$\mathcal{E}_{om}$ [MV/m]	$\mathcal{E}_{NEWTRAJ}$
1	6.42	6.4
2	2.14	2.1
3	1.28	1.3
4	0.92	0.8

$\lambda = 10$ cm $L = 1$ cm.

The code was widely used to predict the Multipactoring levels of a prototype cavity for the ADONE storage ring. [2]

By using our code the impact region of the resonant trajectories was found and the barrier was overcome by painting the impact region by a graphite block, reducing the secondary emission yeld in that region [3]

Based on the previous experience we used our NEWTRAJ to find the trajectories of the electrons in the R.F. 1 cavity of ADONE.

We used the information got for the computer simulation to find the cavity regions to be painted with our"blqck magic" in order to reduce the secondary coefficient in the impact region of the resonant trajectories and weaken the MP barriers.

Since then the cavity has been working perfectly (i.e. without MP troubles), for about one year. [4]

Finally we report the result of a simulation that explains the discharge in a 5 cell structure operated at 4.5 GHz. The unit cell of the structure is a door-bell cavity which is Multipactoring free[5]

Nevertheless the five cell structure operated on the $2\pi/3$ mode showed a MP level at an Emax field level of 2.1 MV/m.

Running the simulation code NEWTRAJ the resonant discharge was explained as an empty cell electron trapping at a 2MV/m Ep level, producing a secondary yeld able to keep up electron multiplication.

Figure 2 shows the resonant trajectories of that discharge.

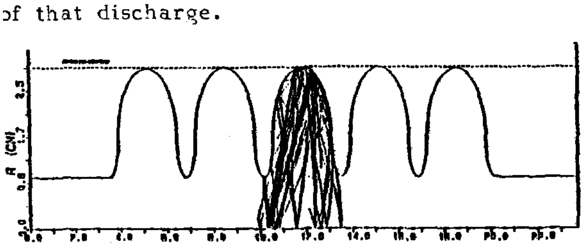

Fig.2 Empty cell Multipactoring discharge of a 2 /5 accelerating structure.

Conclusions

The NEWTRAJ code has been successfully used to find the regions and the field level of Multipactoring discharges in R.F. structures and cavities for particle acceleration.

The agreement between the computed MP levels and the resonant discharges measured on cavities is very good.

NEWTRAJ has proved very useful to predict the discharge behaviour of cavities and to remove Multipactoring levels by some "ad hoc" solution as graphite painting or by definitive solutions as reshaping of critical parts of cavities in order to push out the electron trajectories and break the resonant conditions generating the electron multiplication and the R.F. discharge.

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