Experimental evidence of MP. discharges in spherical cavities at 3 GHz

P.Fabbricatore,G.Gemme,R.Musenich,R.Parodi,S.Pittaluga
INFN-GENOA

Introduction

The superconducting cavities foreseen for the futures applications to the TeV Linear Colliders as TESLA, will be designed for accelerating fields in the 15-25 MV/m range

The experimentation at high field on bulk niobium cavities operating at accelerating fields in the 10-20 MV/m range showed some anomalous increasing of the RF power at well-defined field levels, together with an increase of the electron current inside the cavity.

This behaviour is very similar to the one found in the early S/C cavities on a Multipacting level.

In the paper we will compare the results found in the experimentation on several cavities operating at 3 GHz, a poor man model for a possible two point Multipacting resonant discharge at high field, and computer simulation of resonant trajectories leading to electron multiplication

From that comparison we will show that also in a rounded cavity a two-point MP barriers are allowed close to the outer radius of the cavity.

Experimental results

In superconducting cavities the basic limitations to achieve high fields are coming either from electron loading and quench of the superconductor, the two limitations come usually together and till now no people can clearly state the reason for the ultimate field.

For that reason we started an experimental investigation on a quite large sample of single cell bulk niobium cavities operating at 3 and 4.5 GHz to get information about the limiting fields at different frequencies on homotheticaly similar spherical cavities.

The relevant RF properties of the cavity at 3 and 4.5 GHz are reported in TABLEI

TABLE I

frequency	3 GHz	4.5 GHz
Γ	230 Ω	230 Ω
R/Q	133 Ω	148 Ω
E_p/E_a	1.9	1.9
E_a/H_p [MV/mT]	$1/3.5$	$1/3.5$

The cavities were built by the usual deep drawing method forming half cups from a high RRR (200) Niobium (Teledyne Wa Chang) sheet two millimetres thick for the 3GHz cavities and one millimetre thick for the 4.5 GHz cavities.

The half cups were machined on a CNC Lathe to the final dimension and chemically polished CP in the standard $HF\text{-}H_3PO_4\text{-}HN0_3$ (1:1:1) etching solution removing the 100 µm layer of niobium affected by the mechanical stresses due to the rolling procedure.

The beam tubes of the cavity were obtained by machining and polishing a niobium rod of same quality of the half cups.

The pieces of the cavity were electron beam welded together by two different suppliers (Babckok and Wilcox - NNFD Lynchburg Va and ETTORE ZANON SpA Schio VI) to check the influence of different welding conditions on the cavity behaviour.

In that way we produced a quite large statistical sample of cavities (20 operating at 3GHz and 12 at 4.5 GHz) to test.

After the Welding the cavities were again CP removing 80-100 μm before starting the RF tests .

To obtain lower dissipation in the cavities and higher field we used the standard procedure, assessed in our lab since the 1973, of firing the cavities at high temperature in our UHV furnace.

The temperature of the furnace is increased in a smooth way (keeping the pressure in the furnace lower than 10^{-7} Torr at any temperature) up to 1950 °C and kept constant (within 40 C) at that level for a time of at least six hours. After the cool down of the furnace the cavity was installed in the cryostat for the RF tests keeping to a minimum (30-40 minutes) the exposure of the cavity to the atmosphere.

The firing resulted very effective in improving the Q_0 value at low field of the cavities up to 3 10^9. The maximum achievable accelerating field in the 4.5 GHz Cavities was 20MV/m or slightly more in all the measured cavities.

In the case of the 3 GHz cavities the behaviour of the losses versus the accelerating field is completely different.

The least square fit of Power dissipation versus the surface field gives a very good agreement with the power dissipation produced by a field emitted current following the Fowler-Nordheim law modified for the RF fields resulting in a work function for the niobium Φ=4 eV and an enhancement coefficient for the Surface electric field β=220 in agreement with the usual values obtained on similar cavities

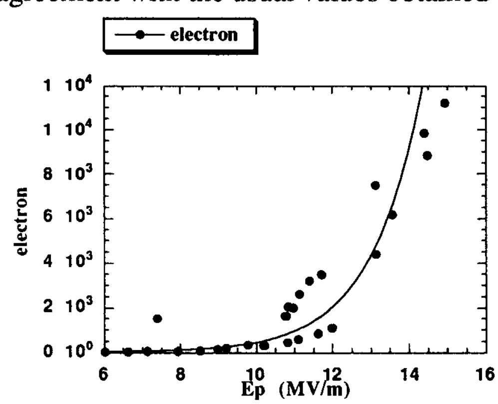

Figure 1. Best fit of the power disipation due to electron emission

This fit is even better if we remove the dissipation peaks coming up at well-defined field levels; in our case 15, 20 and 24 mT corresponding to 4.8 , 5.7 and 7.3 MV/m of accelerating field..

This enhanced dissipation looks very similar to the one due to One Point Multipacting.

Nevertheless the usual one point MP in the equator region of spherical shaped accelerating cavity is kinetically forbidden by the field distribution.

To explain the adsorption of RF power at the aforementioned field levels a different resonant discharge process must be foreseen.

Resonant discharges in RF cavities a Survey

The discharge found in our cavity must be clearly supported by the magnetic field at the equator because was widely shown by J.Halbritter [1]J.Halbritter,"On Electron Loading In Tm010 Mode" cavities KFK Primarberict 08-02-02 P01e 1978 that in wide gap cavities, for high beta electrons ,the electric field assisted two point Multipacting can't be sustained due the high impact energy of the electrons.

Because the one point MP at the equator was also proven to be forbidden [2]R.Parodi et. al "Measurements Of Superconducting C_band Cavities For Linear

Accelerator Applications" IEEE Trans On magnetics MAG 15-1 the only way of obtaining a resonant discharge is a two point MP at the equator.

Let suppose that an electron is produced close to the equator cavity with a negligible starting energy .(this assumption is already valid for secondary electrons).

Under the effect of the RF fields the electron is accelerated inward to the center of the cavity by the E-field and bent outward by the Lorentz force due to the B-field.

The effect of the two forces can produce an impact on the opposite side of the cavity wall (always close to the equator) and give enough energy to the impinging electron to produce secondaries with a yield greater than one.

Under this assumption, if the time of flight of the electron is an odd number of half RF cycles a Two point resonant discharge can be sustained.

Where $f = \frac{eB}{2\pi m}$ the Cyclotron frequency, with the obvious identifications **B** magnetic field, **e** Electron charge, **m** electron mass.

Let us consider now that the time of flight of the electron between two impacts is an odd number of half periods of the resonant frequency of the cavity. This condition gives us an equation for the magnetic field giving resonant cyclotron trajectories with a possible two points magnetic field assisted Multipacting in the equator region.

$$(2n-1)T/2 = f \qquad (1)$$

Giving the values for the values for the resonant magnetic field B

$$B = \frac{4fpm}{(2n-1)e} \qquad (2)$$

From this very simple model based on static fields it comes out a resonant condition of roughly **78mT per GHz** in the **n=1** case

The above formula gives us an upper limit for the resonant field. No information about the energy gain by the electron along the trajectories is given. Nonetheless it gives us a hint for a more careful investigation.

A first order correction for the RF Is straightforward. Tacking the RMS value for the resonant filed resonant field we gets a resonant condition for about **55 mT per GHz** in the **N=1** case.

The two points MP levels for cavity operating at 3 GHz are reported in the following table together with the first 10 MP levels of the usual one point MP barrier for same cavity obtained under similar assumptions.

MP order	B [mT]2 point	B[mT] 1 point
1	170.5	85.3
2	56.8	42.6
3	34.1	28.4
4	24.4	21.3
5	18.9	17.0
6	15.5	14.2
7	13.1	12.2
8	11.4	10.7
9	10.0	9.5
10	9.0	8.5

By inspection of figure 3 it is easy to verify the good agreement between the computed levels for n=4,5,6 and the anomalous dissipation found in the cavity under test.

Computer simulations

The consideration on the magnetic field of the previous section gives us only a hint about the kinematics of the discharge because gives us no information about the energy gain of the electrons along the trajectory and about the possibility of multiplication through secondaries.

To get a more clear picture of the discharge we extensively performed computer simulations of the discharge process by using our TWTRAJ code. The typical MP discharge with N=6 is shown in figure 6

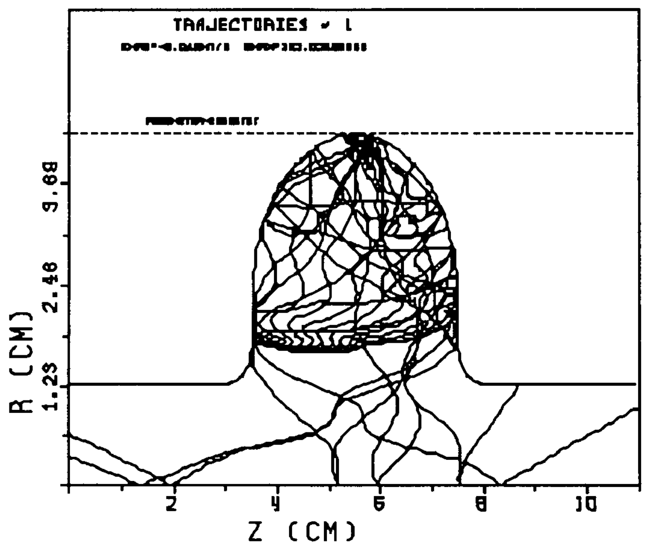

Figure 6 computer simulation of the MP discharge at 15.5mT

This field value is very close to the value of 15 mT found for same order of 2 Points magnetic Multipacting by using the simple considerations of the previous section.

For this trajectory the impact energy of the electrons is in the range of few hundred eV giving for the niobium a secondary Yield greater than one [3]A Septier ,Proceedings of Ist Workshop on RF Superconductivity Karlsruhe 1980.

Similar results were obtained for the N=5 and N=4 trajectories occurring at 24 and 37 mT. The impact energy of the electrons is always in the range giving a large secondary yield.

The two points MP discharge at the equator found in our cavity and our results are in very good agreement with the ones often found at CERN by Weingarten in a 500 MHz cavities.

References

[1]J.Halbritter,"On Electron Loading In Tm010 Mode" cavities KFK Primarberict 08-02-02 P01e 1978

[2]R.Parodi et. al "Measurements Of Superconducting C_band Cavities For Linear Accelerator Applications" IEEE Trans On magnetics MAG 15-1,1979

[3]A Septier ,Proceedings of Ist Workshop on RF Superconductivity Karlsruhe 1980

[4]W.Weingarten, "Electron Loading"Proceedings of 2nd Workshop on RF Superconductivity, Geneva1984