THE DESIGN OF THE R.F. CAVITIES FOR ELETTRA

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Abstract

This paper deals with the optimization of the RF cavities for the "Elettra" Storage Ring, the Synchrotron Radiation light facility now under construction in Trieste.

On the "Elettra's" cavities a very high accelerating voltage is needed due to the tight requirements on the beam quality, together with the very small dimension, of the electron bunches, the high bunch charge (.7 nCoulomb) and repetition rate and the 2.0 GeV of total energy of the Storage Ring.

At the operating frequency of 500 MHz, and at the accelerating voltage of 1 MV per cavity, 3.3 MV/m of accelerating field are needed.

Great deal of care was used in defining the cavity geometry in order to avoid electron discharges, resonant or not.

Our optimization results in a multipactor free cavity with a very low non resonant electron loading current.

Introduction

R.F. cavities for electron Storage Rings are often designed using as an optimization parameter the efficiency of the structure in converting RF power to beam energy.

This efficiency is, espressed by the Shunt Impedance of the resonator

$$ZT^2 = \frac{V^2}{P}$$

were P is the RF power fed to the cavity, T the transit time factor and

$$V = \int_0^L E(z) \sin\left(2\pi \frac{z}{\beta\lambda} + \varphi\right) dz$$

is the effective accelerating voltage seen by a particle travelling at speed βc along the axis of a cavity (of length L.) having a field distribution E(z).

The sinusoidal term takes into account the time variation of the RF field.

Designing high field accelerating cavities some different phenomena must be taken into account to optimize the structure for a smooth and reliable operation.

In fact for cavity operation at high field (few MV/m) at a frequency of some hundred megahertz the main limitation on the maximum achevable field comes out from the maximum Non Resonant Electron Loading (NREL) your cavity can sustain and from the time for conditioning of the cavity surface you can wait.

Typical RF conditioning time ranges from few hours to few days [1].

Furthermore you have to avoid the well defined (in field), but very dangerous for a cavity, RF resonant discharges appearing along the way to reach the design field.

Also in designing a high field cavity you have to take into account the need for an efficient cooling of the high dissipation regions, and to avoid, if possible, complex and cumbersome coolant ducts in the narrow regions close to the accelerating gap.

Finally you have to consider the effect of the wake fields excited by the bunches, on the beam stability and the beam quality.

The Design of a RF cavity is an optimization process and certainly some compromise is needed in order to fulfill at the best the design constraints.

We present in our paper the design of the RF cavities for "Elettra".

The cavities were designed trying to optimize simultaneously all the aforementioned key features of an R.F. cavity operating at high field (3.3 MV/m) in a high luminosity storage ring.

Our final design meet the starting requirements of an efficient R.F. cavity, multipactor free, with a very low electron loading (NREL), low local power dissipation, and Good behaviour in respect to the beam loading out the wake fields excited by the travelling bunches.

Cavity design

We started our design assuming that the most important condition to meet is a very regular RF behaviour at any field level within the operating range, avoiding, if possible, any electron discharge (resonant or not).

Given the operating frequency of 500 MHz and the ultrarelativistic beam energy, is straightforward to choose a wide Gap (L~ λ/2~ 30cm) cavity.

This choice immediately rules out any possibility of two point multipactoring in the gap region [2].

To break off any possibility of one point multipactoring we adopted a "spherical" shape, similar to the one developed in Genoa since the late '70, for Superconducting cavities; a shape universally adopted for superconducting Linacs [3].

We started then to shape the Gap region of our cavity.

In order to get the maximum of accelerating efficiency, nose cones in the gap region are suitable, because reducing the gap a better transit time factor is obtained leading to an higher shunt impedance.

Neverthless on the nose-cones the surface electric field is enhanced due to the small radius of the tips.

Now a large surface electric field means large electron currents due to cold emission.

To evaluate in a quantitative way the field emitted currents we developped a post-processor for our OSCAR2D[4] RF cavity simulation code.

This post-processor, using a modified FOWLER-NORDHEIM law, gives the value of the current density field emitted at any point along the cavity surface.

The RF Fowler Nordheim law is obtained starting from the D.C. law and taking the mean value on a RF cycle using a numerical method, similar to the one U.Klein used , to obtain the expression for the mean RF curent density valid in all the RF field range we investigated.

The current density plots, for two extreme geometries we investigated, are reported in figure 1. assuming a local enhancement factor of 200. The peak current values are respectivelly 10^{6} A/cm^{2} for the CERN500 cavity and 10^{-16} A/cm^{2} for the P500 cavyty at and energy gain of 1MV.

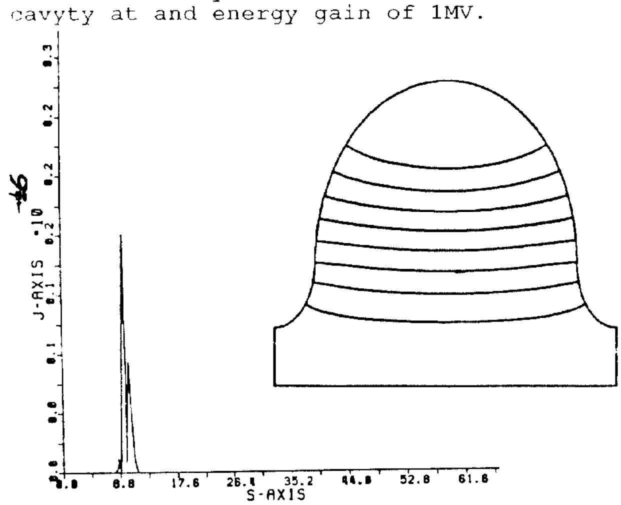

Fig.1-Field emission plot for the P500 geometry

The cavity geometry named in our files CERN 500 has the same geometry, scaled to the operating frequency of "Elettra", of the 200 MHz cavity used in the SPS ring at CERN for electron acceleration [1].

The obtained current density are not very surprising if compared with the large amount of current measured in the 200 MHz cavity during the investigation of electron discharges [1].

The P500 cavity has the geometry, scaled to 500 MHz, of the cavities developped and tested in Genoa for a small prototype of a Superconducting RF linac [5] in the early '80.

In designing our S/C linac we focused our attention, as usual for S/C cavities, to keep at a minimum the values of peak Surface electric and magnetic fields to avoid early superconductivity breakdown stimulated by electron emission or magnetic losses.

The high ratio of emitted current at 1 MV energy gain for the two cavities is not so astonishing, remembering the aforementioned arguments.

Resonant Discharges

To check the immunity of the two different geometries against multipactoring we run on both our NEWTRAJ [6] code to look for resonant discharge conditions.

For P500 it was a mere confirmation of the multipactoring free geometry with electrons drifting along the surface towards the outer region of the cavity and loosing the syncronism with the R.F. fields fig.(2).

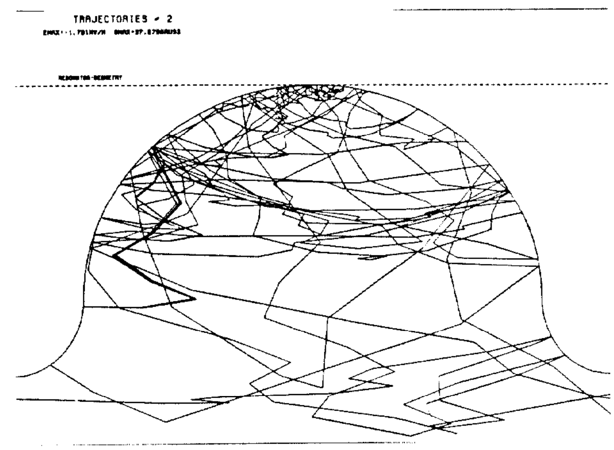

Fig.2-Typical trajectory plot for the P500 cavity.

For CERN 500 some strong one point multipactoring resulted from computation, mainly in the outer region close to the cavity corner.

Our simulation agree in field level and discharge position with the multipactoring levels found in the 200 MHz CERN cavity [2].

Moreover the nose-cones act like a trap for high energy electron emitted on the nose tip and accelerated by the cavity RF field.

This means that a large electron current could bounce back and forth inside the cavity producing a lot of backscattered or secondaries electrons that could feed the resonant trajectories starting a RF breakdown.

On the contrary in the open P500 structure a lot of electrons escape out from the cavity and are absorbed in the beam tube.

R.F. Parameters

The R.F. properties of the two cavities as computed by our OSCAR2D code are listed in TABLE I

TABLE I

	P500	CERN 500
T	.69	.899
Z	1.47e6 Ω	1.23e6 Ω
ZTT	.7e7 Ω	1.e7 Ω
Q	41506	31375

It is straightforward to see that the P500 cavity is about 30% less efficient, compared to CERN500 in converting RF power to beam energy, see the ZTT value.

This lower efficiency comes out from the broad distribution of the axial Electric field resulting in a 25% lower transit time factor T.

This lower transit time factor is partially compensated for P500 by a 15% higher Shunt Impedance Z.

Power density distribution on the walls.

After the previous evaluation of the electron emission and RF efficiency we looked at the power distribution along the cavity walls.

From inspection of the H plot along the cavity boundary it comes out that the peak value for a nose cone cavity is in the nose region and is a sharp maximum.

In the P500 the H field has a broad maximum in the outer region, where it is almost constant (fig.3).

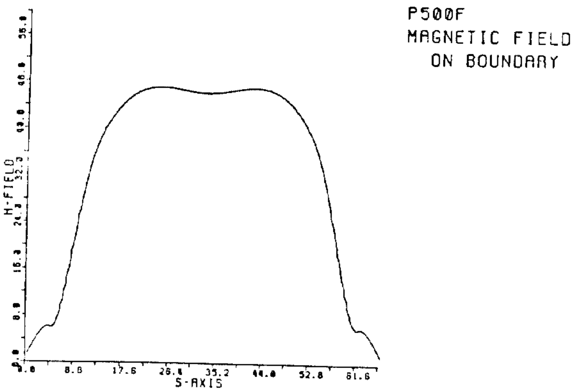

Fig.3-Magnetic field distribution on the cavity boundary.

This distribution for P500 allows for removing the heating due to RF dissipation without a too complex piping for the coolant flow.

High modes behaviour

Last we investigated the high mode behaviour computing the frequency pattern of the first 30 TM monopolar modes with our OSCAR2D code and the first 30 Hybrid dipolar and quadrupolar modes by URMEL-T (courtesy of T. Weiland, DESY) .

From the computed values of the Shunt impedance and frequency of the modes, by using an extension of the P.B. Wilson theory the loss parameters and wake potential for the two geometries are computed.

The wake potential for the P500 geometry as a function of the time is shown in fig.4.

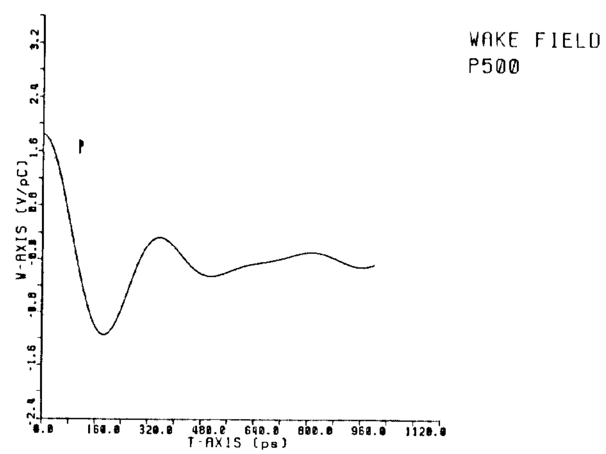

Fig.4-Longitudinal wake potential for P500

As a result of our preliminary analysis we can conclude that the behaviour of the P500 cavity is not substantially different from the CERN500 respect to the bunch cavity interaction.

Conclusions.

The R.F. cavity for the "Elettra" Storage Ring[7] has been designed trying to obtain a structure allowing for a smooth and reliable machine operation.

We focused mainly our attention on the RF electron discharges in the cavity; for that reason we designed a cavity with very low electric surface field.

The analysis done on the field emitted electron current showed extremely low Non resonant electron loading up to the operating field level of 3.3 MV/m.

Also the analysis of the Resonant discharges performed by using NEWTRAJ confirmed the immunity of our geometry against multipactoring .

Our cavity shape shows also the benefit of avoiding concentration of the R.F. losses in the beam hole region, allowing for a very efficient cooling.

Nevertheless to obtain that results we have to pay the price of a rather low shunt impedance, 30% lower, compared with the best nose cone cavity.

This is, in our opinion an affordable price to be paid to have a cavity running without electron discharge problems and avoid boring and time consuming RF conditioning of the cavity surface before reaching the operating field.

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