DESIGN OF A 3RD HARMONIC SUPERCONDUCTING CAVITY FOR BUNCH LENGTHENING IN ELETTRA

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Abstract

The beam lifetime in the 2 GeV low emittance storage ring ELETTRA is dominated by the Touschek effect. The present method of increasing the lifetime is to operate with a controlled amount of longitudinal coupled bunch instability, which also helps to stabilize the beam against transverse modes. In the future, with the foreseen elimination of both longitudinal and transverse modes, there is the requirement for a new solution to increase lifetime, which is a fundamental issue in ELETTRA since the energy is ramped from 1.0 to 2.0 GeV in the storage ring. A 3rd harmonic cavity, operating at 1.5 GHz, can increase the bunch length, and correspondingly the lifetime, by a factor 3 to 4. To achieve this result an idle, superconducting (SC) cavity seems the most attractive solution, since it can provide the required voltage at a reasonable field gradient (6.0 MV/m) with negligible beam energy loss, which can be easily restored by the normal conducting (NC) RF system. Furthermore the cavity can be designed in such a way as to almost eliminate the effects of its own Higher Order Mode spectrum. In this report we present the preliminary electromagnetic design of the cavity.

1 INTRODUCTION

Since ELETTRA lifetime is Touschek dominated an increase in lifetime can be obtained either by increasing the RF bucket size or by increasing the bunch length. The NC 500 MHz RF system provides presently about 1.8 MV of RF voltage, with a power dissipation of 120 kW. About 90 kW are delivered to the 300 mA of stored beam, and so we are close to the limit of the available power, which is 240 kW. An attractive solution to increase the RF bucket size could be a hybrid NC/SC system with the installation of a 500 MHz SC idle cavity as proposed by Marchand in [1]. In fact with the ELETTRA lattice this solution is less efficient than a 3rd harmonic cavity working in bunch lengthening mode. The hybrid system concept could then be transferred to the installation of an idle SC 3rd harmonic cavity [2], [3]. Idle NC Landau cavities have already been installed in the MAX-II storage ring, with good results in terms of Coupled Bunch oscillation damping and of lifetime increase [4].

The SC option would have the advantage of minimizing the extra power requirements on the NC system and of allowing the possibility of a HOM-free cavity design. A feasibility study has been carried out in the preliminary stage of the design and is discussed here. At the same time, since the issues of the SC technology are challenging for our laboratory, being new, a comparative analysis to a NC option is also going on. A final choice will be taken during the summer.

2 CAVITY DESIGN

2.1 Cell Optimization

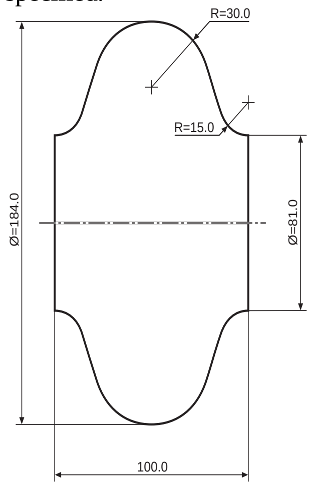
The 3rd harmonic idle SC cavity should provide about 1/3 of the accelerating voltage at 500 MHz, that is about 0.6 MV. The accelerating gradient is induced by the beam, with negligible RF losses, which are restored by the NC system.

The design issues are therefore:

- Resonant Frequency 1498.962 MHz
- Accelerating Voltage 0.6 MV
- Idle cavity
- HOM-free

The cell shape has been chosen with a circular hat and a circular iris, to minimize multipacting effects. For the same reason the cell length has been made equal to half a wavelength, that is 100 mm. The average accelerating gradient becomes then 6 MV/m. A single cell cavity design is therefore suitable.

In order to attain the goal of a HOM-free cavity design we have decided to follow the Cornell approach of extracting the HOM's from the cavity via the beam tubes [5]. The design of the cell has started with a beam tube opening of 100 mm. This is fairly large compared to the cell diameter of about 180 mm and is also the same of the 500 MHz cavities, so the same bellows and tapers could be used. However, even with the large aperture, the TE_{111} mode remains confined in the cell, resonating at 1616 MHz (beam tube cut-off 1758 MHz). To allow propagation, the cut-off frequency of the beam tube TE_{11} mode should be below 1.6 GHz, thus approaching the fundamental mode frequency. Since TE_{11} like components could be introduced in the TM_{010} mode by cell misalignments [5], this should be avoided. Therefore the beam aperture diameter has been reduced to 81 mm (cut-off 2171 MHz), which is the horizontal beam stay clear at ELETTRA. The cell geometry is shown in fig. 1 along with the parameters of the cavity. The peak surface electric and magnetic field should be not of particular concern for this cavity. Considering the magnetic field limit B_C of a niobium cavity equal to 200 mT, given the B_{peak}/E_{acc} ratio of 3.6 mT/MV/m, this would correspond to a maximum allowed average gradient of 55 MV/m, which corresponds in this case to a maximum accelerating voltage of 5.5 MV, that is almost 10 times what is specified.



fr	1500.05	MHz
(R/Q)	87	Ohm
Esp/Eacc	1.5	
Bsp/Eacc	3.6	$\frac{\mathrm{mT}}{\mathrm{MV/m}}$

Figure 1: The cell geometry.

The field distribution of the TM010 mode at 1500 MHz and of the first two dipole modes are shown in fig. 2. These two dipole modes are now confined to the cavity, the TE_{111} mode resonating at 1830 MHz and the TM_{110} mode resonating at 2016 MHz. To extract them, the cut-off frequency of the beam tube remains sufficiently far from 1500 MHz. An other advantage is that the number of HOMs which are resonating below the ELETTRA vacuum chamber cut-off is halved.

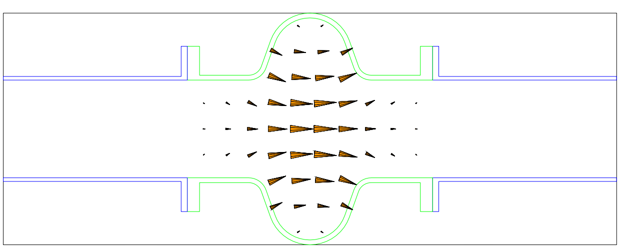


Figure 2a: Fundamental TM_{010} mode electric field distribution.

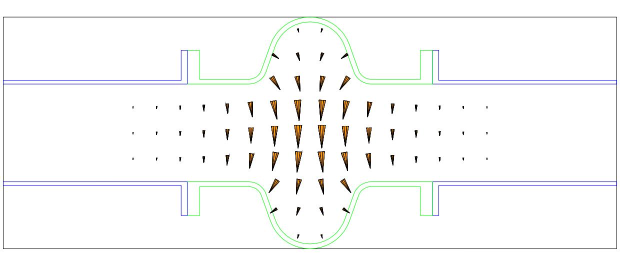


Figure 2b: Confined TE_{111} mode electric field distribution.

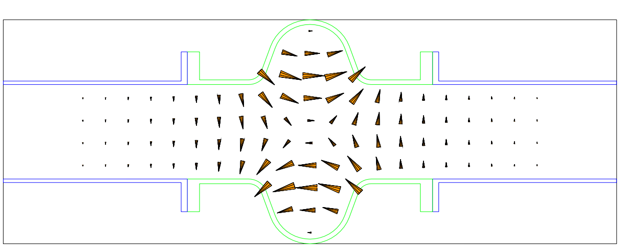


Figure 2c: Confined TM_{110} mode electric field distribution.

2.2 *ϕ-waveguide*

At this point of the design we have had to face what has been called the *dilemma* of the first two dipole modes not propagating [6]. To allow propagation also for these two modes the cut-off frequency of the beam tubes must be reduced. This has been done at Cornell following an idea of Kageyama [7], with the use of fluted beam pipes [5]. We have followed a similar approach, limiting however the number of ridges to 2 placed at 180°, instead of four placed 90° apart each other. The resulting structure is what we called a ϕ-waveguide. The extraction of the two polarizations of the dipole modes happens by positioning a ϕ-waveguide with the ridges in vertical direction on one port of the cavity, and the other one with the ridges in horizontal direction on the opposite port of the cavity. This is possible since for the idle 3rd harmonic cavity no power coupler has to be placed on the beam tubes. The solution gives also the necessary longitudinal asymmetry.

The ridges have been dimensioned with MAFIA, by computing the cut-off frequency of the TE_{11} mode vs. the height **h** and the width **w**. Results are shown in fig. 3.

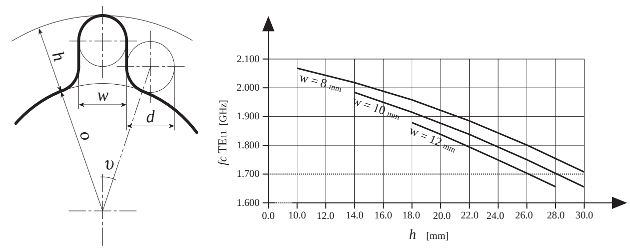


Figure 3: Dimensioning of the ridges.

The choice w=12 mm and h=26 mm gives a cut-off frequency of about 1700 MHz. This is sufficiently below the resonant frequency of the first dipole mode TE_{111}. The geometry of the cavity connected to the ϕ-waveguides can be seen in fig. 4.

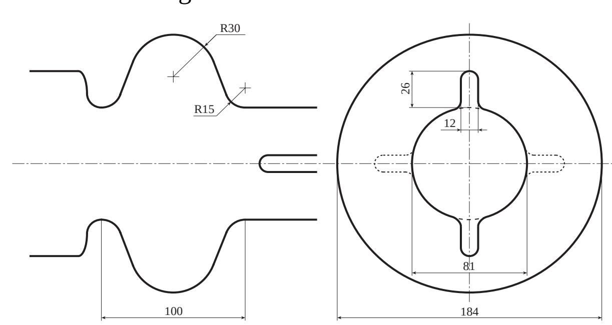


Figure 4: The cavity and the ϕ-waveguides .

The efficiency of the proposed solution is shown in figure 5, where the MAFIA plots of the electric and magnetic field show the propagation of the TE_{111} mode in the ϕ-waveguides placed on the left of the cavity.

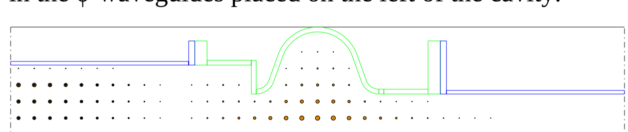


Fig. 5a: Electric field of the propagating TE_{111} mode.

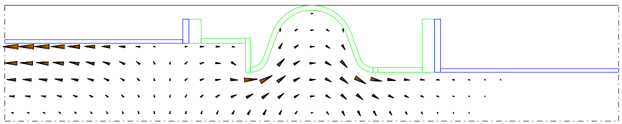


Fig. 5b: Magnetic field of the propagating TE_{111} mode.

2.3 HOM power extraction.

Those HOM's which propagate through the beam tubes but are confined by the tapers to the vacuum chamber (cut-off ~ 4.0 GHz) must be extracted. Three possible choices exist: insert ferrites inside the beam tubes, use of loop or antenna HOM couplers, use of waveguide HOM couplers. In this preliminary stage of the design this problem has not yet been carefully studied. For the moment only this last choice has been considered and the waveguide to coaxial cable transition has been analyzed, using the DAΦNE approach [8]. A possible geometry is shown in fig. 6 as given by the HFSS-code.

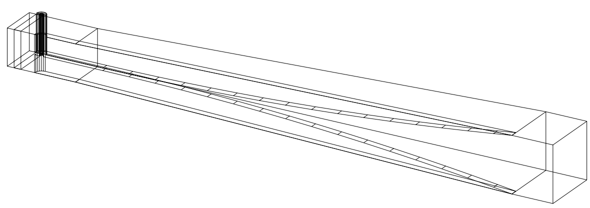


Fig. 6: Longitudinal cross-section of the transition.

A WR 340 rectangular waveguide with two circular ridges is used. The vacuum window is in the coaxial cable. The TE_{10} mode propagates from 1.8 GHz, that is below the TE_{111} mode frequency and has a good matching at 2835 MHz (TM_{011}-mode). The $|S_{11}|$ of the transition, plotted in fig. 7, is below 0.1 on a wide band.

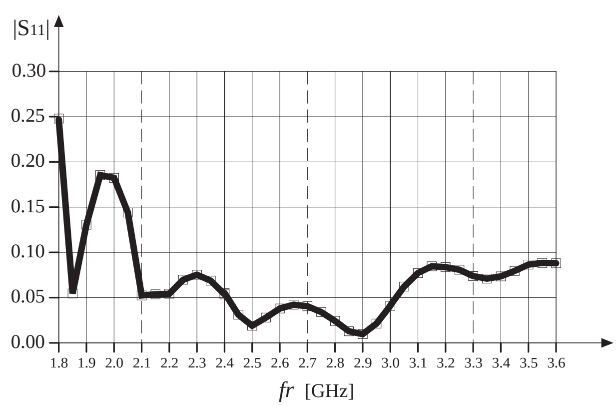


Fig. 7: Reflection coefficient of the transition.

3 PROTOTYPES

Simple aluminium prototypes, shown in fig. 8 have been fabricated in order to check the computed frequencies, the HOM's propagation in the ϕ-waveguides, the reflection coefficient of the waveguide to coax transition.

The results can be summarized as follows:

- The TM_{010} frequency is 1501.9 MHz.
- TE_{111} and TM_{110} dipole modes are propagating.
- The first two longitudinal modes are propagating.
- The $|S_{11}|$ module of the transition is about 0.1.

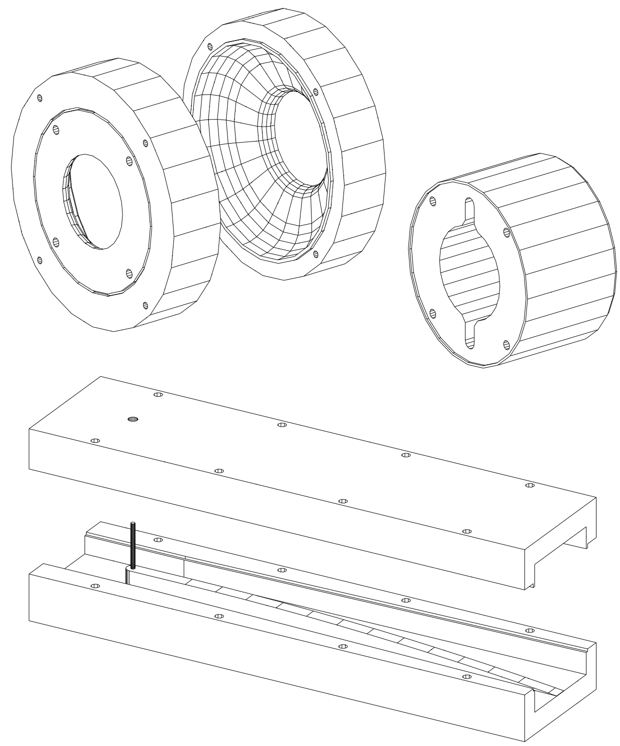


Fig. 8: Prototypes .

4 CONCLUSION

The feasibility of a SC 3rd harmonic cavity for ELETTRA has been discussed. The encouraging results are important for the final decision between a NC and a SC system which will be taken this summer.

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