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WAKEFIELD AND HOMS PRELIMINARY CHARACTERIZATION OF THE FOUR-QUADRANT MULTI-CELL RF ACCELERATING STRUCTURE FOR THE ASTERIX PROJECT

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Abstract

The goal of the ASTERIX project, proposed at INFN-LNF and funded by the CSN5, is the first-time demonstration of a practical, meter-long X-band RF structure for real linear accelerators made of hard copper and four quadrants. Our joining technique will be the TIG welding for the prototype. During the feasibility study, in the first year, we will proceed to the RF cavity design of two full structures (~ 1m long and ~100 cells), one with optimized geometry for single-bunch and the other one for multi-bunch operation. We will perform the RF design optimization, including thermo-mechanical analysis, of the multi-cell TW cavity and the RF mode-launcher (which will be integrated with the cavity in the most compact way possible) for both structures' geometries. In this paper, we show the preliminary characterization of the higher-order modes (HOMs) and wake-fields, which are detrimental for the particle beam with high-quality parameters typically accelerated in such structures, in the case of single-bunch operation. The electromagnetic designs will be performed by using the 3D numerical codes Ansys-HFSS and CST-Microwave Studio.

INTRODUCTION

This research is part of a world-wide collaboration involving SLAC, CERN, INFN-LNF, KEK, and Tsinghua University, focused on the study of advanced X-band (11-12 GHz) accelerating structures [1-8]. These structures, made of hard copper, which show better high-gradient performance with respect to soft-copper ones [9], employ different geometries, including "**open-type**" structures, and alternative "**braze-free**" joining techniques like TIG welding. The demand for advanced accelerating structures with **accelerating gradients exceeding 100 MV/m** is driving this research, which is crucial for the next generation of linear particle accelerators for research (such as linear colliders and light sources [10-13] like EuPRAXIA@SPARC_LAB [14,15]), industrial, and medical applications.

The analysis of higher-order modes (HOMs) and wakefields, EM fields detrimental for the particle beam with high-quality parameters typically accelerated in such structures, will be conducted by INFN-Roma1, collaborating with INFN-LNF and LNS, by using CST-Microwave Studio. Another important aspect which will be analyzed is multipactoring (MP), a phenomenon that can disrupt vacuum integrity and lead to RF breakdowns. We will study the content of the HOMs inside this type of open cavity and follow an optimization procedure to ensure their mitigation from the beam dynamics requirement of the EuPRAXIA linac in single-bunch operation; for multi-bunch operation, we will employ: mitigation methods, for example by using on-cell ad-hoc slotted waveguides.

In this paper we show the initial results from the analysis of the cavity in single-bunch operation mode.

ACCELERATING STRUCTURE DESIGN

The accelerating cell geometry made with four quadrants is shown in Fig.1. Details are reported in [16,17]. The iris aperture radius is fixed at 3.5mm. To ensure the efficiency of the full 1-meter structure with 120 cells, the disk thickness is designed to be 2mm. This leads to a filling timeof 123ns and input power of 78 MW to reach an accelerating gradient of 100 MV/m. The rounding on the top increases the quality factor and thus the shunt impedance by about 10%. The elliptical shape of the iris is optimized to obtain low surface fields. Then a rounding of 0.5mm at the gap aims to reduce the surface magnetic field enhancement. After careful optimizations, the parameters of the full structure are listed in Table 1.

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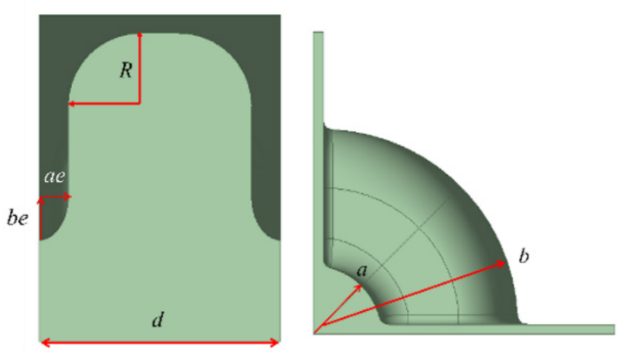

Figure 1. The geometry of the quadrant cell with gap size of 1mm.

The RF optimization of the full meter-long four-quadrant structure was performed with CST code, as shown in Fig.2. The structure is constant impedance and the average accelerating gradient of 100 MV/m is obtained with an input RF power of 77 MW.

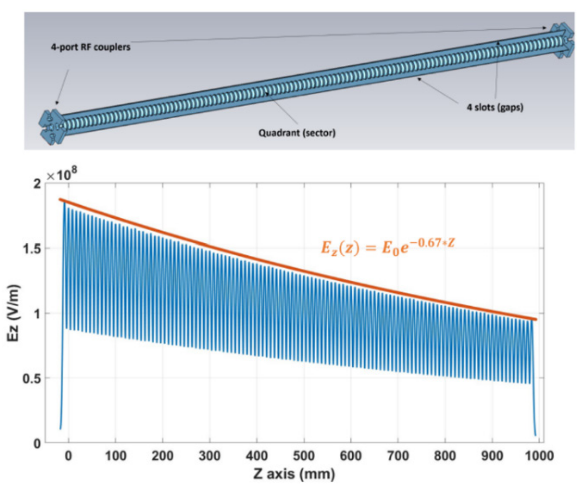

Figure 2: Top, full 1m long four-quadrant structure; bottom, on-axis electric field profile.

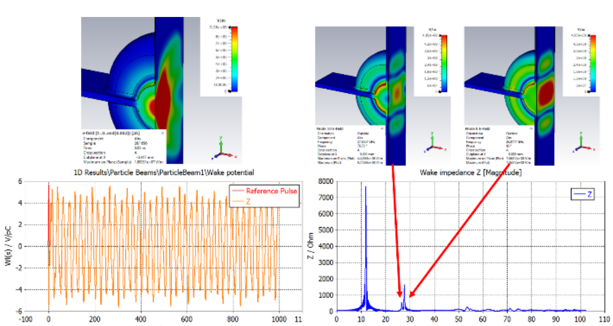

Figure 3: Longitudinal wakefields and impedance generated by a Gaussian beam of length 1 mm rms, electric charge 200 pC.

PRELIMINARY HOM AND WAKEFIELD ANALYSIS

Table 1: Parameters of the Full Structure

Parameter	Value
Frequency [GHz]	11.994
Gradient [MV/m]	100
Input power [MW]	77
Operating mode [rad]	2π/3
Cell length [mm]	8.333
Cell Number	120
Full structure length [m]	1
Disk thickness [mm]	2
Quality factor	6931
Iris radius [mm]	3.5
Shunt impedance [MΩ/m]	97.3
Group velocity [c%]	0.027
Filling time [ns]	123
Attenuation factor	0.6545
Peak S_c [W/μm^2]	8.8
Pulse Heating [K]	24.6
E_p [MV/m]	245

The analysis of HOMs and Wakefields have been very preliminary so far. However, the simulation results for the short range longitudinal wakefields in the single cell, for the case of single-bunch operation, are reassuring.

The longitudinal wakefields generated by a Gaussian beam of length 1 mm rms, electric charge 200 pC, injected at the speed of light in the single cell, induce an unwanted energy spread of the order of 1keV, as shown in figure 3, which is negligible compared to the energies involved.

Figure 4 shows the preliminary results of the longitudinal wakefields generated by the same beam in the case of a 5-cell structure, consistent with the single cell case.

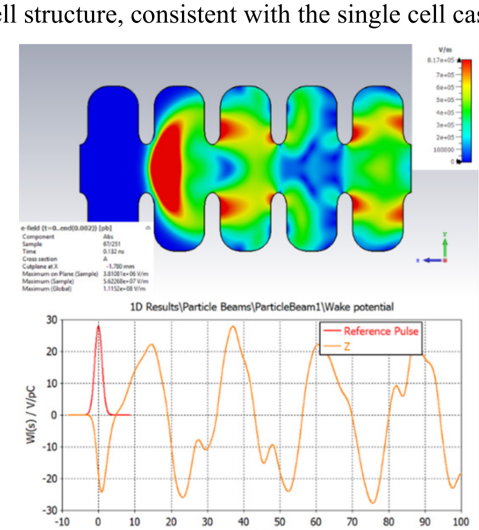

Figure 4: Longitudinal wakefields generated by the same beam in the case of a 5-cell structure.

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In the near future, the transverse wakefields and the long range effects will also be investigated in view of a multi-bunch operation. Furthermore the length of the beam will be decreased to the nominal value of tens of μm.

CONCLUSIONS

We have presented the RF design optimization of the ASTERIX four-quadrant structure for the single-bunch case. In particular, the preliminary results from HOM and wakefield analysis show that the short range longitudinal wakefields in the single cell, for the case of single-bunch operation, are reassuring. Nevertheless, the detailed effect on the beam will be discussed later.The analysis of the transverse wakefield analysis and multi-bunch operation are in-progress.

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