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DESIGN OF AN X-BAND CONSTANT IMPEDANCE LINAC FOR COMPACT LIGHT PROJECT

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Abstract

Within the framework of Horizon 2020 project, Compact Light, in order to provide a high performance, high-gradient X-band technology, for the new generation of hard X-ray FEL, a constant impedance travelling wave (TW) Linac, working on 2pi/3 mode at 11.9952 GHz, has been designed. Simulations were conducted using CST Microwave Studio. Two iris shapes has been considered in order to minimize the modified poynting vector and then reduce the breakdown probability. A single fed z-type coupler including a racetrack geometry has been chosen in order to compensate the dipole and quadrupole component. Finally an analysis of breakdown phenomena has been performed, take into account both RF pulsed heating and BDR scaling law.

INTRODUCTION

In the Framework of compact Light Project, in order to provide a new technology based on X-Band for the future generation of hard X-rays high brightness FEL's, a constant impedance travelling wave Linac has been designed. Principal parameters design are illustrated in Table 1.

Table 1: Compact Light Project Specifications

Design parameters	
Accelerating gradient [MV/m]	65
Frequency [GHz]	11.9952
Working mode	$2\pi/3$
Length [m]	0.6
Iris radius [mm]	4

In this paper we illustrated the EM simulations of the Linac for two cases of single cell geometry. Then a brief analysis of breakdown phenomena is described to better understand the trade-off between complexity realization of the cell and breakdown probability.

EM STRUCTURE DESIGN

Starting from Compact Light Project requirements, the first step has been chosen the single cell. Two types of geometries have been considered, one is the simple circular iris cell, the second, according with [1], in order to minimize the modified poynting vector and then reduce the breakdown probability of the structure, and maximize the shunt impedance, is the edge rounding elliptical cell. Then couplers have been designed and simulations has been performed using CST Microwave Studio

Single Cell Design

The geometries of the single cell are shown in Fig. 1. The tuning of elliptical cell is aimed to minimize the quantity Scmax/Eacc2 [2] with the right chose of elliptical ratio r1/r2. The plot of this quantity in function of the elliptical ratio is shown in Fig. 2. The minimum value has been obtained for r1/r2=1.3. The main cells parameters are specified in Table 2. Each simulation in CST has been performed with 1 joule of energy density. In Fig. 3 module and phase of accelerating electric field is shown.

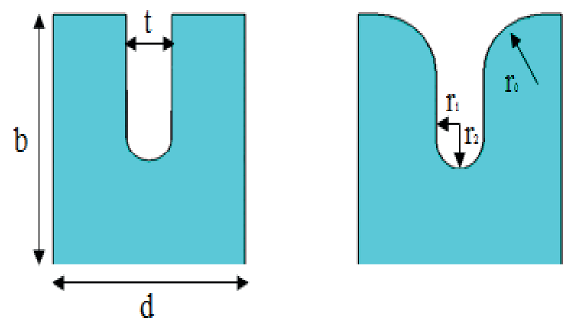

Figure 1: Geometries of the single cell.

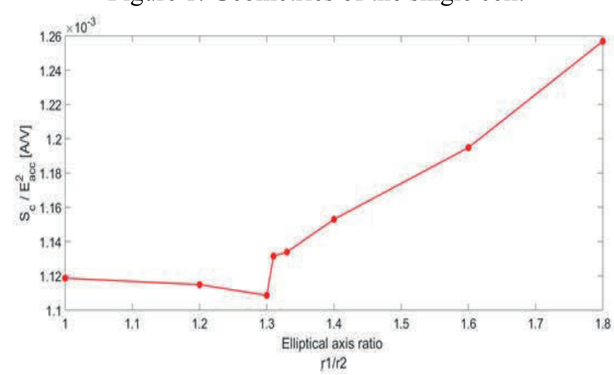

Figure 2: Modified poynting vector as a function of elliptical ratio.

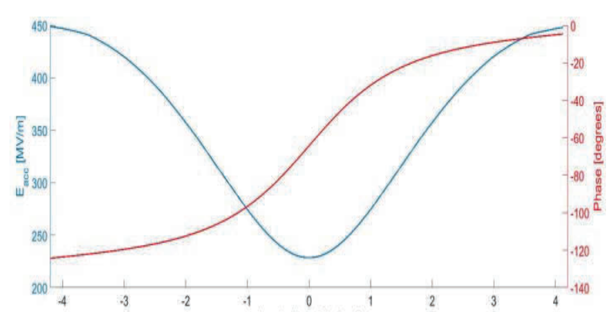

Figure 3: Phase and module of the single cell (elliptical cell case).

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Table 2: Single Cell Parameters

	Circular	Elliptical
Iris radius [mm]	4	4
Iris thickness t [mm]	2	2
Elliptical ratio r_1/r_2	-	1.3
Edge rounding radius r_0 [mm]	-	2.5
Outer radius b [mm]	10.	10.
Cell length d [mm]	8.398	8.398
Shunt Impedance [MΩ/m]	87	96
vg/c [%]	3.7	3.8
Filling time [ns]	0.76	0.73
Quality Factor	6550	7292
Modified Poynting Vector [MW/mm^2]	132.35	122.15

Coupler Design

A single fed z-type coupler has been chosen for both geometries cells because of its compactness with respect to the waveguide and mode launcher ones [3]. Racetrack geometry has been implemented in order to compensate the residual quadrupole field components. The coupler tuning has been performed using short circuit method according with [4]. The coupler geometry is shown in Fig. 4.

At the first order, the azimuthal magnetic field near to the longitudinal axis is given by:

$$B_\phi(r,\phi,z) \cong A_0(z)r + \sum_{n=1}^{\infty} A_n(z)\cos(n\phi)\, r^{n-1}$$

In order to delete the quadrupole component, the term A_2 (gradient of quadrupole) must to be zero. The plot of this term, in the case of circular iris cell, as a function of the DRT parameter is shown in Fig. 5. The value of 0,1 has been obtained for DRT=9.5 mm in the circular iris case and for DRT=10 mm in the elliptical case. A comparison of the azimuthal magnetic field at 2 mm from the longitudinal axis at the center of the coupler is shown in Fig. 6.

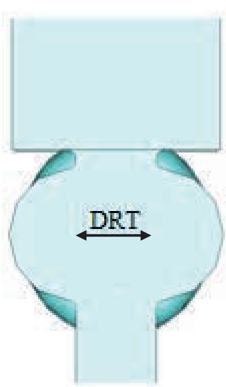

Figure 4: coupler geometry. DRT parameter is indicated.

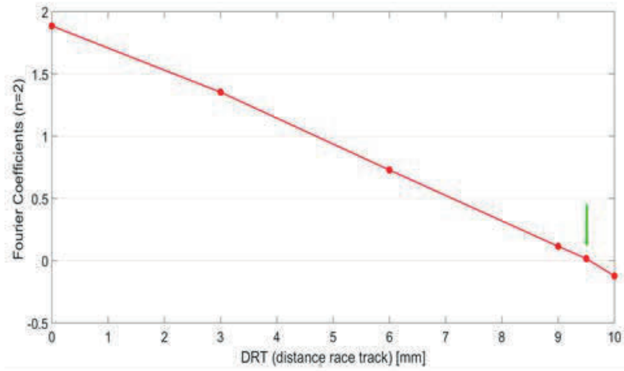

Figure 5: Quadrupole Gradient as a function of distance race track.

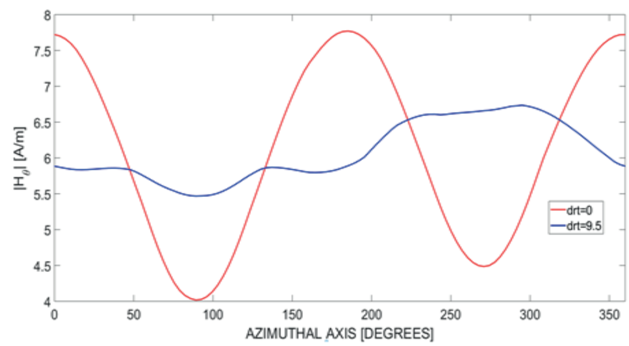

Figure 6: Azimuthal magnetic field at 2 mm from longitudinal axis.

EM Simulation

Module of accelerating electric field in the elliptical iris case is shown in Fig. 7. Simulations has been performed with 64 cells plus couplers according to length requirement. In both cases the reflection coefficient at the input port is below -30 dB. In Table 3 average accelerating gradient is shown for the corresponding input port power. The material chosen for simulations is copper annealed.

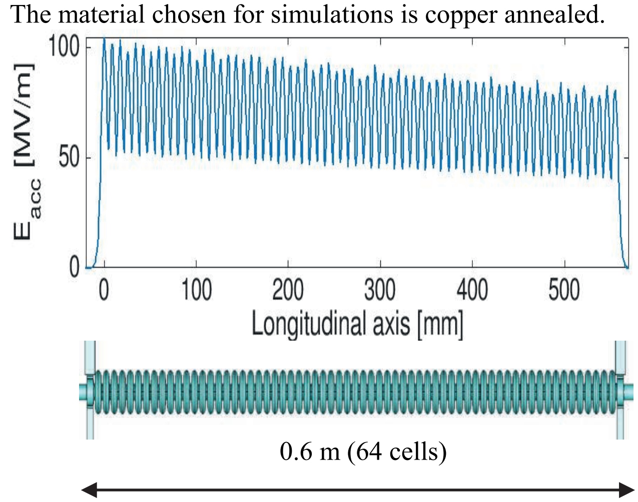

Figure 7: Accelerating field as a function of longitudinal axis.

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Table 3: Accelerating Field and Input Power for Both Cases

	Average Accelerating Field [MV/m]	Input Power [MW]
Circular iris	64,5	33
Elliptical iris	63,3	30

BREAKDOWN ANALYSIS

The principal limitation Linac's is the RF breakdown. In this work the main cause of this phenomena, RF pulsed heating, has been take into account. At first, an analysis of pulse heating at the edge of the slots couplers has been done then using scaling law by [1] an estimation of BDR has been calculated.

Coupler Breakdown

The RF power flows thought the coupler slots generate a surface current flow along the edges of the slots. Here the RF currents reaches his maximum value. The temperature rise is given by the well know formula:

$$\Delta T[°C] = 127\left|H_{\parallel}[MA/m]\right|^2 \sqrt{f_{RF}[GHz]}\sqrt{t_p\ [\mu s]}$$

If the temperature remains below 50°, damages in copper are practically avoided. If the temperature remains between 50° and 100° the breakdown probability increases. Over 100° breakdown occurs. Tangential magnetic field at the edges of the slot coupler is shown in Fig. 8. In both cases the maximum value is about 0,6 MA/m. The raise temperature as a function of pulse time square is shown in Fig. 9. In order to avoid coupler breakdown, a flat RF pulse of the duration below 77 ns is needed. In our case the filling time of the structure is below 50 ns, then using a RF pulse of this duration, breakdown in coupler is avoided.

Scaling Law

According with [1], it is possible to establish a dependence between modified poynting vector, pulse duration and BDR given by:

$$\frac{S_c^{15} t_p^5}{BDR} = const$$

BDR is defined as the probability to have a breakdown event and it is measured in breakdown per pulse per 1 meter of structure. For the new RF structures, Sc should not exceeds $4MW/mm^2$ in order to obtain a BDR of 10^{-6} bpp/m for a 200 ns pulse length. Using this scaling law it is possible to estimate the BDR for our cases.

The results are shown in Table 4. As we expected the BDR in the elliptical case is smaller than circular iris case.

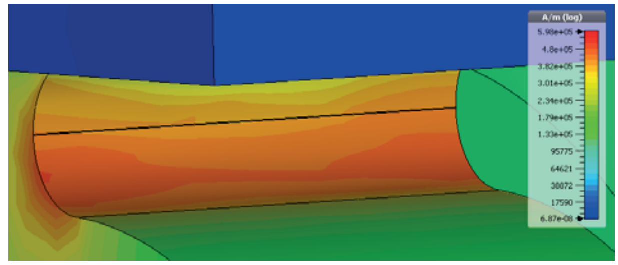

Figure 8: Tangential magnetic field at slot edge.

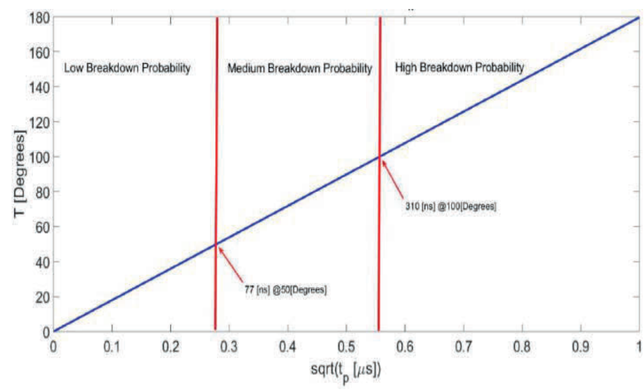

Figure 9: Raise temperature as a function of pulse time square.

Table 4: Temperature Raise and BDR for Both Cases

	Circular	Elliptical
Filling Time [ns]	48.64	46.72
H_{max} [MA/m]	0.64	0.63
Temperature [degrees]	**40°**	**38°**
Modified Poynting Vector [MW/mm^2]	6.78	5.83
Breakdown per pulse per meter [bpp/m]	**2.33e-06**	**0.2e-06**

CONCLUSION

In this paper we have illustrated the designed for the new generations of X-Band technology for compact light project. First of all, we have implemented to cells geometries in order to better understand the best trade-off between complexity in realization and breakdown probability. Z-type couplers have been designed and then the structure simulated obtaining the desired accelerating field. Finally, a breakdown analysis has been performed taking into account pulsed heating phenomena.

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