DEVELOPMENT OF AN HIGH GRADIENT, S-BAND, ACCELERATING STRUCTURE FOR THE FERMI LINAC

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Abstract

The FERMI seeded free-electron laser (FEL), located at the Elettra laboratory in Trieste, is driven by a 200 meter long, S-band linac routinely operated at nearly 1.5 GeV and 10 Hz repetition rate [1]. The high energy part of the Linac is equipped with seven, 6 meter long Backward Traveling Wave (BTW) structures: those structures have small iris radius and a nose cone geometry which allows for high gradient operation [2]. Nonetheless a possible development of high-gradient, S-band accelerating structures for the replacement of the actual BTW structures is under consideration. This paper investigates a possible solution for RF couplers that could be suitable for linac driven FEL where reduced wakefields effects, high operating gradient and very high reliability are required.

INTRODUCTION

The high energy part of the Linac is equipped with seven Backward Traveling Wave (BTW) structures. Small beam apertures and nose cone geometries allow for high gradient operation.

Each structure is powered by a 45 MW, Thales klystron. Pushing the klystron at full power, a gradient of more than 30 MV/m should be achievable. As a matter of fact, BTWs have been found to suffer from increased breakdown activity even when operated at 25-26 MV/m and 50 Hz repetition rate (see Figure 1).

Figure 1: Breakdowns on inner surfaces.

Therefore, a development of new, low wakefields, high gradient and high reliability S-band accelerating structures for the replacement of the existing BTWs is under consideration.

This paper presents the design of an RF coupler that could be suitable for linac driven FELs. After a brief introduction to the field asymmetries and the quadrupole kick in the RF couplers, a dual-feed, electric-coupled (EC) RF coupler is then discussed.

FIELD ASYMMETRY ANALYSIS

The actual impact on the electron beam dynamics produced by field asymmetries in the coupler region can be studied by analyzing the transverse momentum change experienced by the particles passing through the RF coupler [3] [4].

In order to fully evaluate the residual field asymmetries in the coupler region, the following function $F_\varphi(z)$ is introduced [5]:

$$F_\varphi(z) = \left[F_x(r_0, \varphi = 45°, z) - F_y(r_0, \varphi = 45°, z)\right]$$

where $F_x(r_0, \varphi = 45°, z)$ and $F_y(r_0, \varphi = 45°, z)$ are the x- and y-components of the Lorentz force on a charged particle q, moving with velocity $\vec{v}$ at a position given by the cylindrical coordinates $(r_0, \varphi = 45°, z)$ as shown in Figure 2.

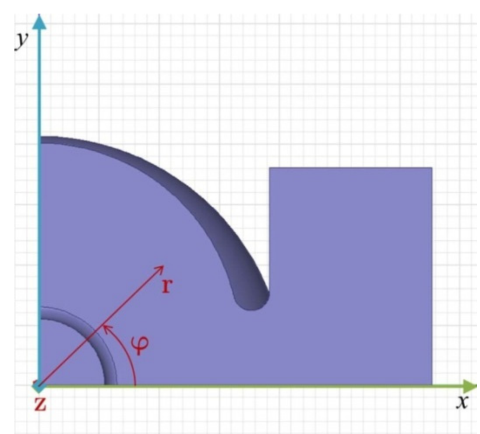

Figure 2: Transverse section of an RF coupler and circular cylindrical coordinates.

This function is then integrated along a line of length L contained in the coupler region. This yields to the quantity:

$$k_q = \frac{1}{qr}\left|\int_0^L F_\varphi(z) e^{j\frac{\omega}{c}z} dz\right|$$

For any ideal quadrupole, the x- and y-components of the Lorentz force at a position $(r_0, \varphi = 45°, z)$ should be equal to zero. So, minimizing the value of k_q will reduce the residual quadrupole kick in the coupler.

ELECTRIC-COUPLED RF COUPLER

In the development of high gradient accelerating structures, the high electromagnetic fields arising in magnetic-coupled couplers, where the power is transferred to the accelerating structure through a slot aperture between the wall of the waveguide and the coupling cell, could represent a bottleneck.

To remove possible limitations to the achievable operating gradients, novel changes in the couplers' design have been introduced [5] [6] [7]: the input power coming from the source is directly coupled to the accelerator through a circular iris in the broad wall of the WR284 waveguide. The electric coupling requires a matching cell to match the input waveguide to the periodic structure as shown in Figure 3.

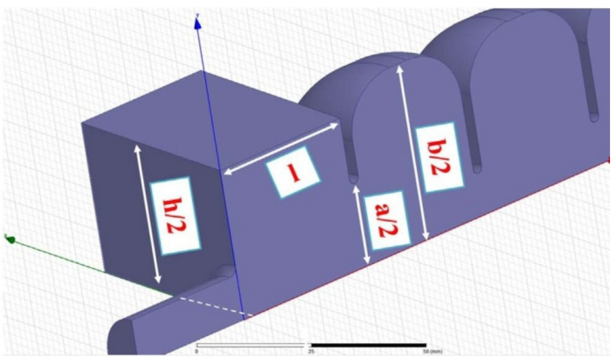

Figure 3: Layout of an electric-coupled RF coupler.

As it is evident from Figure 4, the input waveguide and the matching cell present an E_z field component lower than in regular cells. So the electric-coupled solution sacrifices some acceleration efficiency. Nonetheless, this could be partially recovered by stepping down the narrow size of the input rectangular waveguide.

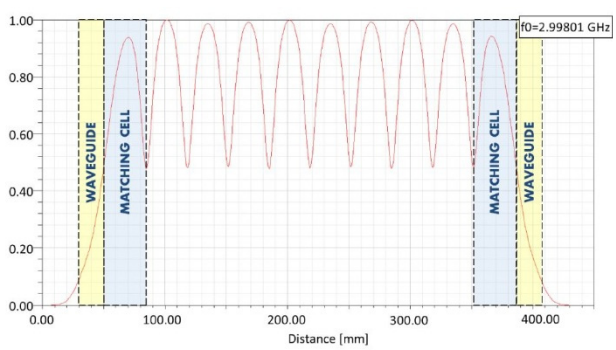

Figure 4: Axial electric field E_z .

An accurate analysis of the residual field asymmetries has also been done. While dipole components of the fields have been cancelled recurring to a dual-feed solution, residual quadrupole components have been minimized adjusting the geometric parameters of the coupler. Figure 5 shows the value of k_q as a function of the wider dimension of the input waveguide h.

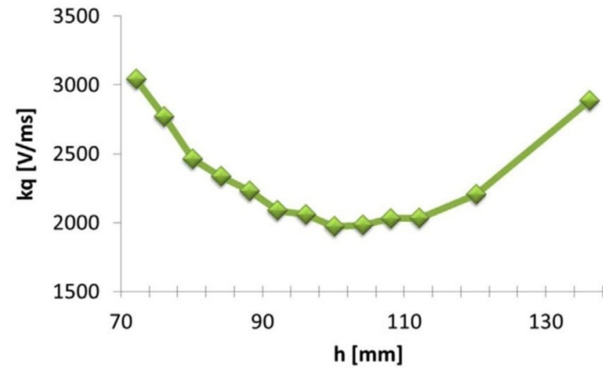

Figure 5: k_q as a function of the waveguide width h.

Surface fields have also been deeply investigated. All the field values have been evaluated for an input power of 65 MW.

The surface electric field has its maximum value of 81 MV/m on the first beam iris. As shown in Figure 6, the surface magnetic field is instead much lower in the coupler region than in the following cells, where the value is approximately 78 kA/m.

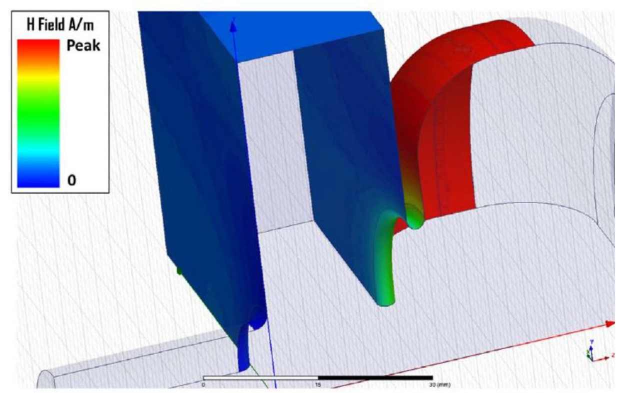

Figure 6: Surface magnetic field for an electric-coupled RF coupler.

An estimate of the expected breakdown rate has also been calculated considering the modified Poynting vector S_c [8]. The maximum value of S_c is nearly 0.57 W/μm^2. Based on experimental evidence, this results in a breakdown rate probability of approximately 10^{-12} bpp/m if operating with an RF pulse of 700 ns.

CONCLUSION

FERMI is a Linac-driven, seeded free-electron laser, operating in the VUV to soft X-rays range. The high energy part of the Linac is equipped with seven BTW structures. Small beam apertures and nose cone geometries allow for high gradient operation.

Nonetheless, BTWs have been found to suffer from increased breakdown activity even when operated at 25-26 MV/m and 50 Hz repetition rate. Therefore, the development of low wakefields, high gradient and high reliability structures is under consideration.

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To remove possible limitations to the achievable operating gradients, in the development of such structures, a dual-feed, electric-coupled RF coupler has been adopted.

Because of lower field in both input waveguide and coupling cell, a drawback of electric-coupled RF couplers is in general a reduction of the acceleration efficiency. Nonetheless, stepping down the narrow size of the WR284 rectangular waveguide, the acceleration efficiency could be partially recovered. Of course, considering the total length of the structure, the loss in efficiency results to be negligible.

High frequency simulations also showed that the residual quadrupole field is not as low as in magnetic-coupled solutions. This makes the electric-coupled ones more suitable for use in the high energy part of a linear accelerator, where thee beam is already compressed and its longitudinal momentum is high enough to not be affected by the quadrupolar kicks of the couplers.

Since the new accelerating structures are foreseen to replace the existing BTWs, actually installed in the high energy part of the machine, and given the low surface fields which make the EC couplers suitable for high gradient operation, the electric-coupled RF couplers revealed to be the most appropriate choice in the development of the new structures.

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