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MODE LAUNCHER AS AN ALTERNATIVE APPROACH TO THE CAVITY-BASED RF COUPLER OF PERIODIC STRUCTURES

I. Syratchev

Abstract

Recent studies of the accelerating structures at a high gradient showed problems associated with high surface electric fields. In particular it was observed that the input RF coupler of the structure suffered more severely from the surface damage caused by local RF breakdowns than regular accelerating cells. A new design of the RF coupler with reduced surface electric and magnetic fields is presented.

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Recent studies of the accelerating structures at a high gradient showed problems associated with high surface electric fields. In particular it was observed that the input RF coupler of the structure suffered more severely from the surface damage caused by local RF breakdowns than regular accelerating cells. A new design of the RF coupler with reduced surface electric and magnetic fields is presented.

Introduction

The RF input/output coupler for the accelerating structure is a very important part of any linear accelerator design. In the past, various modifications of such a device were developed to enable good matching of the waveguide feeder to the structure [1-5]. In itself, matching is not the only problem to be solved. If the accelerating beam stability is an important issue, as in future Linear Colliders, then the coupler should provide a high grade of symmetry of the electric field in a coupling volume. Normally the coupler represents the cavity coupled to the waveguide feed through small coupling holes. In such a configuration the high concentration of the magnetic field is unavoidable. As a result the local surface temperature reaches levels that are a few times higher than in a regular structure cell. Recently, it was also found that during the conditioning of the accelerating structure the coupler suffered severely from surface damage caused by local RF breakdowns, more than regular accelerating cells [6]. All these effects require new efforts towards a robust design of the RF coupler. Several measures have been already introduced, more details can be found elsewhere [7-9]. In this paper we will discuss one of the approaches that can be considered as a candidate for the RF coupler.

The design presented here is based on the idea to split the RF coupler functionality into two separate stages [10]. In the first stage, we organize the mode conversion from H_{01} mode of standard rectangular waveguide into symmetric E_{01} mode of the circular waveguide. This type of junction (Mode Launcher, ML) is a broadband device that prepares the guided wave similar to that of the accelerating structure. Next we feed the accelerating structure through the special transformer cell that provides matching between circular waveguide and structure. This combination has demonstrated the highest possible electric field symmetry along with both reduced surface electric field and local surface heating.

Mode Launcher

A few considerations were taken into account in the Mode Launcher design: compactness, broadband properties, field symmetry and simplicity. Five different ML modifications were studied [11]. The adopted ML version is shown in Figure 1. Input beam pipe diameter as well as circular waveguide diameter were chosen to be compatible with different types of the accelerating structures. Two symmetric input ports provide the predefined excitation of the E_{01} mode of the circular waveguide. The residual reflection is compensated with a step in the input waveguide height. With asymmetry in two port RF phases, the rotating E_{11} in a circular waveguide can be excited. The splitter and waveguide arc lengths were optimized to reduce this effect. ML's S-parameters are shown in Figure 2. The two spikes in the reflection are the resonances of the splitter. They are detuned away from the operating frequency with the proper choice of waveguide arc length. One can see that even with 12 ° RF phase error, the mode purity at operating frequency 30 GHz is much better then –30 db.

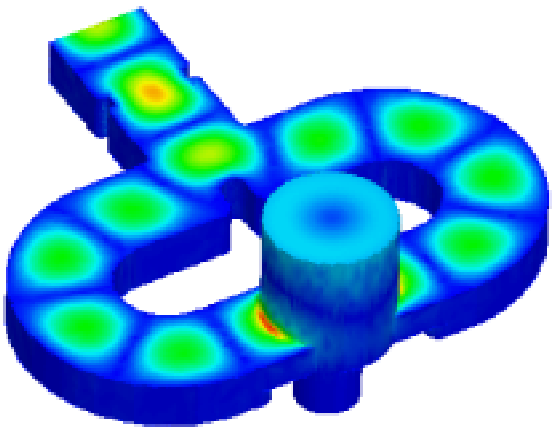

Figure 1: General view and electric field of the Mode launcher

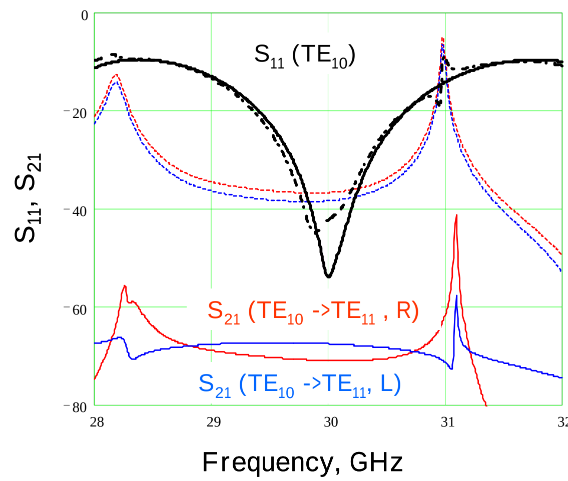

Figure 2: S-parameters of the ML. Dotted lines correspond to the 0.5 mm error in the length.

Another special type of the ML (MLB) was developed to couple to the structure with a large beam aperture. It is foreseen to use this kind of structure in the early stages of the CTF3 operation for the 30 GHz RF power production using a 3 GHz drive beam. The MLB will also be used as a coupler together with the dielectric accelerating structure [12]. In its design the resonant choke was installed, as shown in Fig. 3, to prevent the propagation of the backward wave in the circular waveguide.

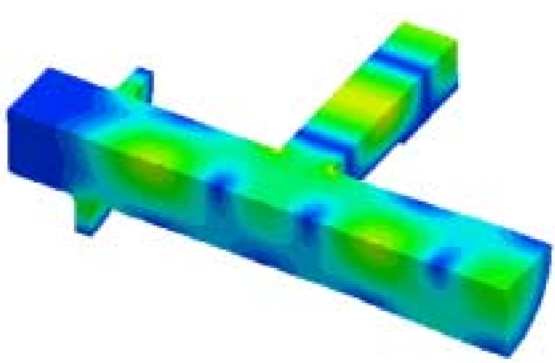

Figure 3: Electric field in the MLB

Figure 4: The view of the high power version of the MLB

The high power version of MLB, see Figure 4, has been tested successfully at 30 GHz up to 100 MW RF power in CTF2.

Accelerating structure matching

The matching of the periodic structure can be discussed in terms of the impedances. One should introduce the special impedance transformer that provides matching of the low impedance circular waveguide to the high impedance accelerating structure. It could be done with a special cell. Even a few cells can be foreseen, but normally the bandwidth of the accelerating structure is quite narrow, so that a single cell transformer is enough. An example of such a transformer is shown in Figure 5. The S-parameters, calculated for 18 accelerating cells plus two transformer cells including losses are shown in Fig. 6.

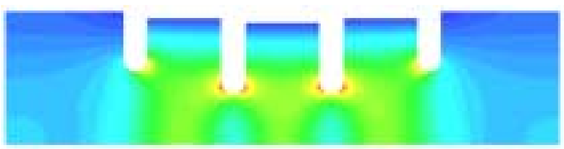

Figure 5: Electric field in two transformers plus a regular cell

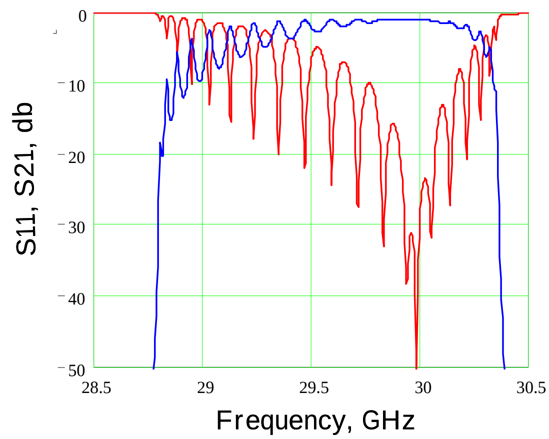

Figure 6: S-parameters calculated for 18 regular cells plus two transformers

This configuration provides certain advantages. Maximal surface electric filed in a transformer cell is smaller then in a regular accelerating cell (cf. Figures 5 and 7). In the given example the difference is about 15 %. If necessary, the further reduction of the surface field in a transformer cell can be achieved simply by an increase of the first iris thickness. Another important fact is that the fields in a matching cell are fully symmetric.

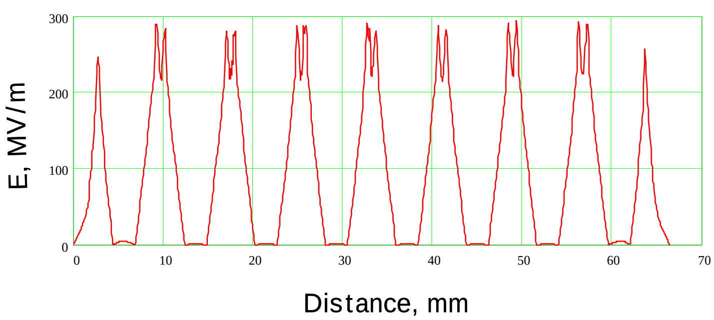

Figure 7: Electric field amplitude along the structure surface as calculated for 6 regular cells plus two transformers

Finally, the length of the ML's circular waveguide part has been optimized to provide the best matching to the accelerating structure. In Figure 8 the coupler assembly together with S parameters for the different ML's length are shown. The length *L*, about twice the length of a regular cell, was found optimal.

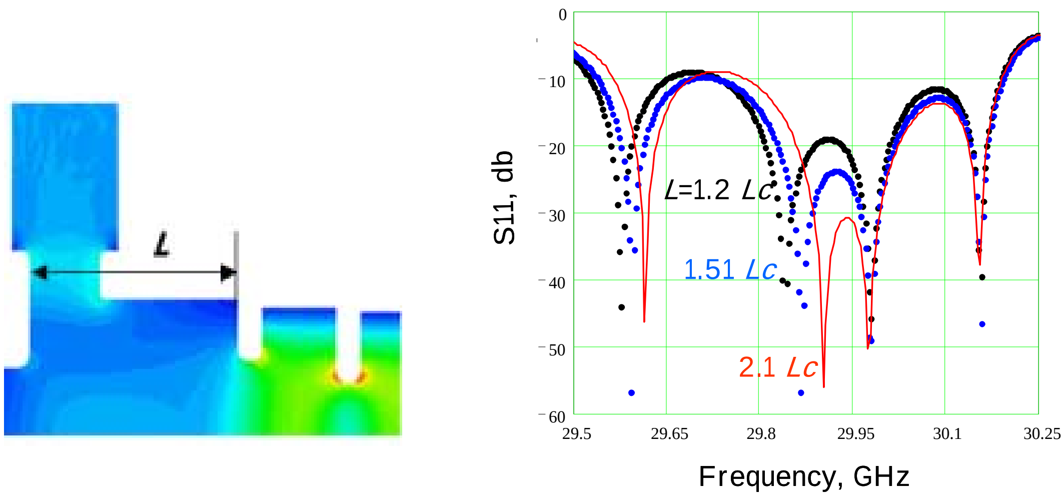

Figure 8: S-parameters of the coupler assembly for the different length (L) of the ML circular waveguide part (Lc – the length of the regular cell)

Comparison with the cavity-based RF coupler

For the comparison, we used the J-type RF coupler [4], which was specifically designed for the 30 GHz accelerating structure with 3.5 mm diameter beam aperture [11]. The electric fields plots in the ML-coupler and J-coupler are shown in Figure 9 for the case of 6 accelerating cells.

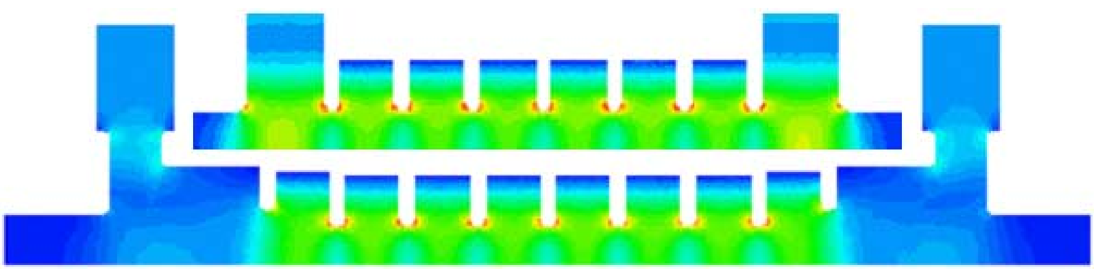

Figure 9: Electric field distributions in ML-coupler (lower) and J-coupler (upper)

A few advantages can be discussed following the field distributions plotted in Figure 9: The maximal surface field in the coupling area is, in the case of ML-coupler, substantially smaller than in the J-coupler. Due to the specific configuration of the ML-coupler, there is no EM energy stored in the upstream side of the transformer cell. That is why one can expect that the transformer cell iris will not be exposed to high-energy electrons. That will help to prevent the iris surface from damaging during conditioning and in operation. The probability of breakdown associated with high surface electric field is also reduced.

The accelerating gradient calculated per single structure appeared to be the same for both cases. This certainly brings some decrease of efficiency with the ML-coupler application, because the extra-length of the structure will be approximately the length of 4 regular cells. However, with a large number of accelerating cells in the structure (more than 100), this can be accepted due to the other benefits.

With detailed simulations of the different cavity-based couplers [11], we found that independently of the design, the RF current density on the surface of the coupling iris between the waveguide and the coupling cell is normally twice as high compared to that on the surface of a regular cell. This means that in this area the local pulsed temperature rise will be four times higher than in any place of the structure. This in turn will cause surface degradation due to the metal fatigue and can potentially change the overall matching during the lifetime of the structure. In the ML-coupler, on the other hand, the maximal magnetic surface field is about 80 % that of the regular cell.

Conclusions

The presented design of the ML-coupler shows good potential as a candidate for the RF coupler of high gradient accelerating structures. The reduced level of both the surface electric and magnetic fields in a coupling area, field symmetry and relative simplicity make the application of the ML-coupler favorable. One of the first prototypes of the ML-coupler (MLB) has been successfully tested at a high level RF power (100 MW) at 30 GHz. The other device (ML) is now under construction for high-gradient studies of various 30 GHz accelerating structures. It is important to mention here that once being designed, the same ML can be used for any accelerating structure at a given frequency.

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