A STUDY OF COUPLER-TRAPPED MODES IN X-BAND LINACS FOR THE GLC/NLC†

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Abstract

Each of the X-band accelerating structures for the GLC/NLC (Global Linear Collider/Next Linear Collider) consists of 55 cells which accelerate a train of charged bunches. The cells are carefully designed to ensure that the transverse wakefield left behind each bunch does not disrupt the trailing bunches, but some modes are trapped in the region of the coupler cells. These modes can give rise to severe emittance dilution if care is not taken to avoid a region of resonant growth in the emittance. Here, we present results on simulations, cold test experimental measurements and beam dynamics simulations arising as a consequence of modes trapped in the coupler. The region in which trapped modes have little influence on the beam is delineated.

INTRODUCTION

In the design of a next generation linear collider operating at room temperature there are two main issues that must be faced: firstly, operating at high gradients with minimal electrical breakdowns and secondly, damping the wakefield that the charged bunches leave behind such that disruptive Beam Break Up (BBU) instabilities do not develop. Means of controlling electrical breakdown is under intensive investigation at SLAC [1] and is not the subject of this paper.

Here we study the second major issue, namely, wakefield effects. The short range, or intra-bunch, wakefield affects particles within a given bunch and it is proportional to $a^{-3.8}$ (where a is the average iris radius of the accelerator structure). An $a/\lambda \sim 0.17$ (where λ is the free-space wave number at the accelerating frequency) gives rise to manageable short-range wakefields and this is the number used in several designs for the GLC/NLC. The long-range wakefield affects trailing bunches and it falls by almost two orders of magnitude by the time of the first trailing bunch (separated from its neighbor by 1.4 ns). This decay is achieved by varying the geometry of the accelerator cells in a careful controlled manner [2]. We have investigated Gaussian and Sech functional behavior in the fall-off of the long-range wakefield. Eventually the modes would re-cohere and, in order to damp these modes [3] down to acceptable levels we couple out a significant fraction of the remaining wakefield to 4 attached manifolds.

These detuned and moderately damped accelerating structures have been verified to behave as expected from simulations in several ASSET (Accelerator Structure Setup) experiments [4] conducted in the SLC. However, modes can readily become trapped in the regions of the fundamental mode RF couplers. We refer to these modes being trapped in the sense that they are localized in the waveguide coupler [5] and the next cell. They are weakly coupled to the regular cells and output waveguides. We make the distinction between these modes and the structure modes with some fields in the coupler region [3]. The trapped modes can cause transverse instabilities which may significantly dilute the beam emittance. It is the purpose of this paper to carefully analyze these modes and ascertain their influence on the beam dynamics.

The following section provides an analysis of these modes based on experimental measurements of the scattering matrix properties of the coupler and on *HFSS* [6] modeling of the eigenmodes of the structure. The impact of the trapped modes on the beam dynamics is presented in the final main section.

MEASUREMENT AND SIMULATION OF TRAPPED EIGENMODES

Reflection and transmission were measured using one port of the fundamental coupler and an antenna inserted into the beam pipe. To measure the frequency and Q of the trapped mode it was necessary to insert the probe in the field of the trapped mode. The inserted probe, obviously perturbs the frequency and Q of the mode. The perturbation is minimized by withdrawing the probe to the extent that the resonance in S_{11} is just discernable. We observed two highest Q modes in this accelerator structure: each are located in the regions of the input and output coupler. The Qs of these modes are determined entirely by the copper losses.

The eigenmodes together with their Q values were calculated with its eigenmode module of *HFSS*. The complete set of modes simulated for a waveguide coupler, a matching iris and the first iris of the structure, are shown in Fig. 1. Further modes were observed during the experimental measurements but only those we believe to be modes trapped in the region of the coupler are shown in Fig. 1. The highest Q modes are illustrated in Fig. 1A and Fig. 1B. All of the modes displayed are dipole-like in character, except the mode in Fig. 1F. This mode is monopole-like with a finite quadrupole field. This mode has some focusing in one plane and defocusing in the other. Properties are of such modes are discussed in [7]. A summary of the experimentally determined frequencies and those computed with *HFSS* is given in Table 1. Additionally we have made limited *Omega3P* [8] simulations of the high Q input and output modes. These *Omega3P* calculations indicate that the input fundamental coupler has a mode frequency of 10.658 GHz and the output fundamental mode coupler is 11.534 GHz. These values are in better agreement with the experimentally determined frequencies. This may be due to the *Omega3P*

† Supported by the DOE, grant number DE-AC03-76SF00515

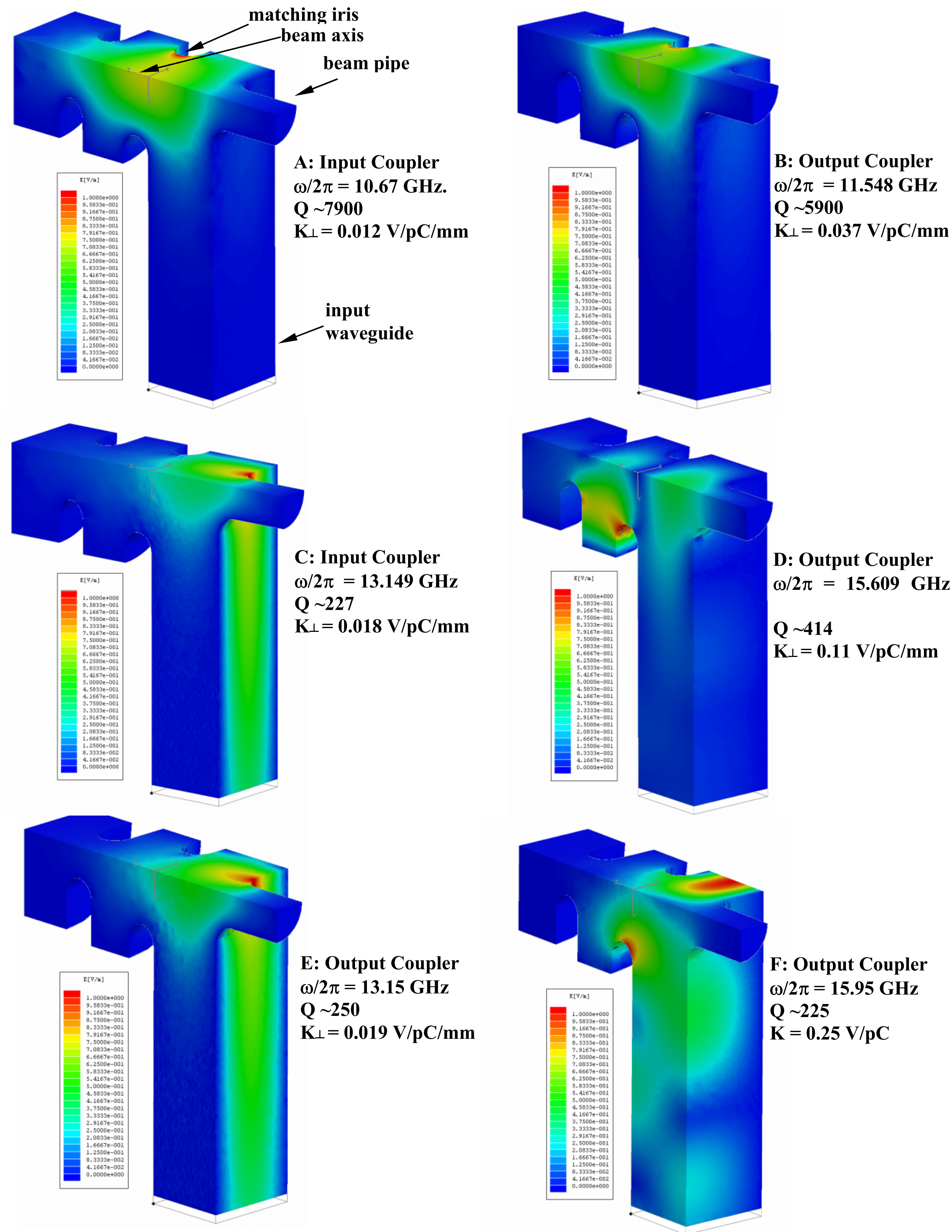

Figure 1: Surface electric fields of the trapped modes in the input and output fundamental couplers of the accelerator structure known as H60VG4S17-III-SN2. The resonant frequency (ω/2π), Q value and the dipole mode kick factor (**K⊥**), are indicated except for the monopole-like mode in F, where the monopole loss factor (**K**) is indicated. One quarter of the geometry was simulated with appropriate boundary conditions.

code allowing a more natural representation of the structure geometry, although it is not altogether clear that this is the case. It is also notable that frequencies in the *HFSS* simulations in the neighborhood of 16 GHz are also in remarkably good agreement with the experimental measurement. In the next section the affect of these modes on the beam dynamics is investigated.

Table 1: Experimentally measured and *HFSS* calculations of mode frequencies (GHz) for both the input and output mode coupler

Measured Freq., Output Coupler	11.530	13.101	15.600	15.954
Calculated Freq., Output Coupler	11.548	13.151	15.609	15.950
Calculated Q, Output Coupler	5900	250	414	225
Measured Freq., Input Coupler	10.651	13.114		
Calculated Freq., Input Coupler	10.672	13.149		
Calculated Q, Input Coupler	7900	414		

BEAM DYNAMICS

The degree which the modes disrupt the beam is represented by the beam kick factor [9] and this is indicated next to each field pattern in Fig. 1. These results are shown collated in Fig. 2, where, for the purpose of comparison, the kick factor of the center cell is also shown. The largest trapped-mode kick is at 15.6 GHz and it is notable that it has a rather low Q value (~414) as it radiates out through the waveguide coupler. The other kick factors are all almost an order of magnitude smaller than the centre cell's kick factor and

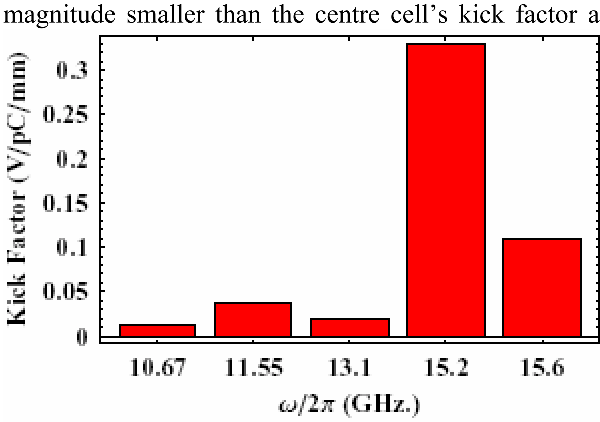

Figure 2: Comparison of trapped mode kick factors with cell 28, the middle cell of the accelerating structure. The middle cell has a mode frequency of approximately 15.2 GHz.

all have relatively low Qs. The effect on the beam is further elucidated by considering the sum of the wakes of all bunches preceding a particular bunch (computed at the locations of each preceding bunch) and this is defined as the sum wakefield. The RMS of the sum wakefield for the GLC/NLC baseline design [10] with the kick factor given in Fig. 1A added to it, is shown in Fig. 3. The nominal bunch spacing is varied in order to ascertain the sensitivity to systematic frequency errors (since varying the bunch spacing by a small fraction is equivalent to changing all cell frequencies by a fixed amount). The mode frequency ($\omega/2\pi$) is varied from that of Fig. 1A (~10.67 GHz) in order to reveal the location of any neighboring peaks in the S_{RMS}. Earlier work [11] has indicated that large a S_{RMS} gives to a BBU instability and thus the peak values must be avoided. There are indeed large trough regions in S_{RMS} and the present trapped modes are rather fortuitously confined to these regions.

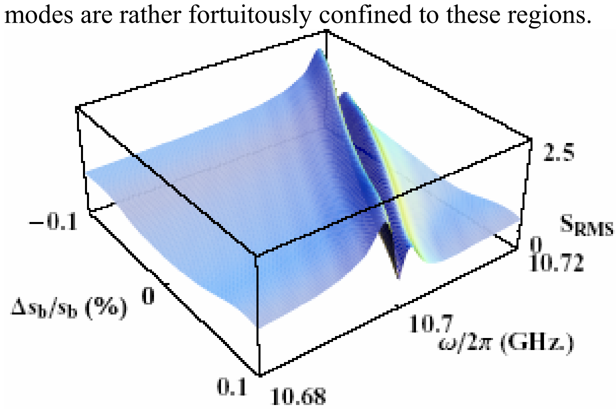

Figure 3: Surface of S_{RMS} (V/pC/mm/m), the RMS of the sum wakefield in the vicinity of the peak value. The trapped mode frequency is given by $\omega/2\pi$ and, $\Delta s_b/s_b$ is the fractional change in the bunch spacing from 1.4 ns. The large peaks occur close to harmonics of the bunch frequency (714 MHz at the nominal bunch spacing).

Beam tracking simulations were undertaken with the computer code LIAR [12] in which all trapped modes were included in the wakefield. The resulting emittance is diluted by less than 0.1%. Thus, provided the mode frequencies of the trapped modes with high Qs do not lie in the vicinity of harmonics of the beam frequency (*i.e.* multiples of 714 MHz.) little emittance dilution is expected to occur over the length of the complete linac.

Additional simulations indicate that the effect of well-damped modes ($Q \leq 500$) on the beam dynamics is rather benign as S_{RMS} is below unity for the full frequency range considered (10.5 GHz to 16 GHz).

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