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OPTIMIZED WAKEFIELD SUPPRESSION & EMITTANCE DILUTION-IMPOSED ALIGNMENT TOLERANCES IN X-BAND ACCELERATING STRUCTURES FOR THE JLC/NLC

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Abstract

In order to prevent electrical breakdown occurring in the JLC/NLC (Japanese Linear Collider/Next Linear Collider) X-band structures several new structures are under investigation. These accelerating structures represent an evolutionary design of the DDS series of structures [1]. The phase advance per cell has been varied and the detailed elliptical shape of the cell has been varied in order to simultaneously minimize the group velocity, the surface electromagnetic fields and the pulse temperature rise on the copper surface [2]. It is also important to ensure that the wakefield induced by multiple bunches traversing the accelerating structures does not disrupt trailing bunches. The wakefield must be damped adequately in order to prevent a BBU (Beam Break Up) instability occurring and to ensure that emittance dilution due to the higher order modes is kept to acceptable levels. The long-range wakefield is forced to de-cohere by detuning all of the frequencies such that the mode density of frequencies is approximately Gaussian. In order to minimize the impact of the wakefield on the beam dynamics we change the bandwidth and the standard deviation of the Gaussian distribution of frequencies such that a "cost function" is minimized. Interleaving of cell frequencies of adjacent structures is required to adequately damp the wakefield of each particular structure under consideration. The resulting alignment tolerances imposed on the cells and structures is calculated. Utilizing the optimization code is seen to result in significantly looser alignment tolerances and well-damped transverse wakefields.

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[1] R.M. Jones et al, PAC97, also SLAC-PUB 7537
[2] Z. Li et al, WPAG027, these proceedings.

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Optimized Wakefield Suppression & Emittance Dilution-Imposed Alignment Tolerances in X-Band Accelerating Structures for the JLC/NLC[1]

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Abstract

In order to prevent electrical breakdown occurring in the JLC/NLC (Japanese Linear Collider/Next Linear Collider) X-band structures several new structures are under investigation. These accelerating structures represent an evolutionary design of the DDS series of structures [1]. The phase advance per cell has been varied and the detailed elliptical shape of the cell has been varied in order to simultaneously minimize the group velocity, the surface electromagnetic fields and the pulse temperature rise on the copper surface [2]. It is also important to ensure that the wakefield induced by multiple bunches traversing the accelerating structures does not disrupt trailing bunches. The long-range wakefield must be decreased adequately in order to prevent a BBU (Beam Break Up) instability occurring and to ensure that emittance dilution due to the higher order modes is kept to acceptable levels. The long-range wakefield is forced to de-cohere by detuning all of the frequencies such that the mode density of frequencies is approximately Gaussian. In order to minimize the impact of the wakefield on the beam dynamics we change the bandwidth and the standard deviation of the Gaussian distribution of frequencies such that a "cost function" is minimized. Interleaving of cell frequencies of adjacent structures is required to adequately damp the wakefield of each particular structure under consideration. The resulting alignment tolerances imposed on the cells and structures is significantly looser alignment tolerances with the use of the code.

1. INTRODUCTION

We report on manifold damping and detuning of the wakefield in the X-band accelerating structure known as H60VG3S17 which forms the baseline design for the JLC/NLC [3]. In particular we discuss damping of the long -range wakefield which, if left unchecked, will result in severe emittance dilution of the beam.

The 55 cells of the 60 cm structure, H60VG3S17, incorporate a 5π/6 phase advance per cell and four manifold are attached to couple out the wakefield. It is an evolutionary design from the original R/DDS series using the same method to detune and damp the wakefield. The average group velocity of the accelerating structure is 0.02c and the a/λ (iris radius to free space wavelength) has an average value of 0.17. The value of a/λ has been reduced from 0.18 in H60VG3S18 order to reduce the pulse temperature heating that occurs on the surface of the copper structures. Reducing the iris radius increases the shunt impedance of the accelerating mode and also increases the short range wakefield (~ $a^{-3.8}$) and requires slightly tighter tolerances on the structure-to-structure alignments and also a slightly larger BNS energy compensation requirement [2]. These effects do not put severe constraints on the overall design of the linac as they are relatively small changes.

Interleaving of the frequencies of neighbouring structures is discussed in section 2 as a means to damp the wakefield to levels that do not appreciably dilute the emittance of the beam. Beam dynamics issues are discussed in section 3 in which the progress of the charged particle bunch train is monitored in phase space throughout the linac using the particle tracking simulation code LIAR [4]. The 4th section addresses the cell and structure alignment tolerances that are imposed on the accelerator for a specified emittance dilution

2. WAKEFIELD OPTIMIZATION

The dominant dipole deflecting mode in H60VG3S17 is confined to the first frequency band. As we have a limited number of cells, namely 55, for each H60VG3S17 structure then the mode separation is larger by a factor of approximately four compared to that of the DDS series (which consisted of 206 cells). Thus, we interleave the frequencies of the modes of adjacent structures in order to

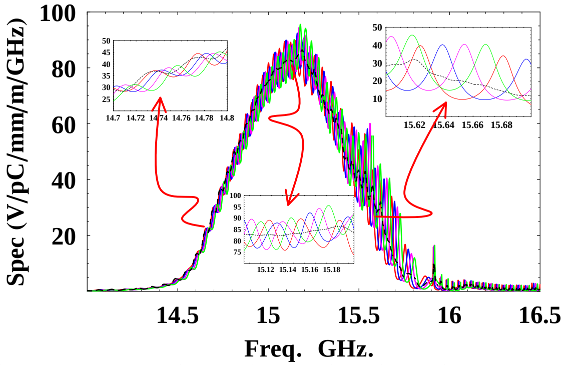

Figure 1: Spectral function of interleaved H60VG3S17. Reflections from the HOM (Higher Order Mode) coupler are not included in the simulation. The spectral functions of the individual structures oscillate about the interleaved overall distribution (shown in black and dashed). The middle and ends of the band are shown inset for clarity.

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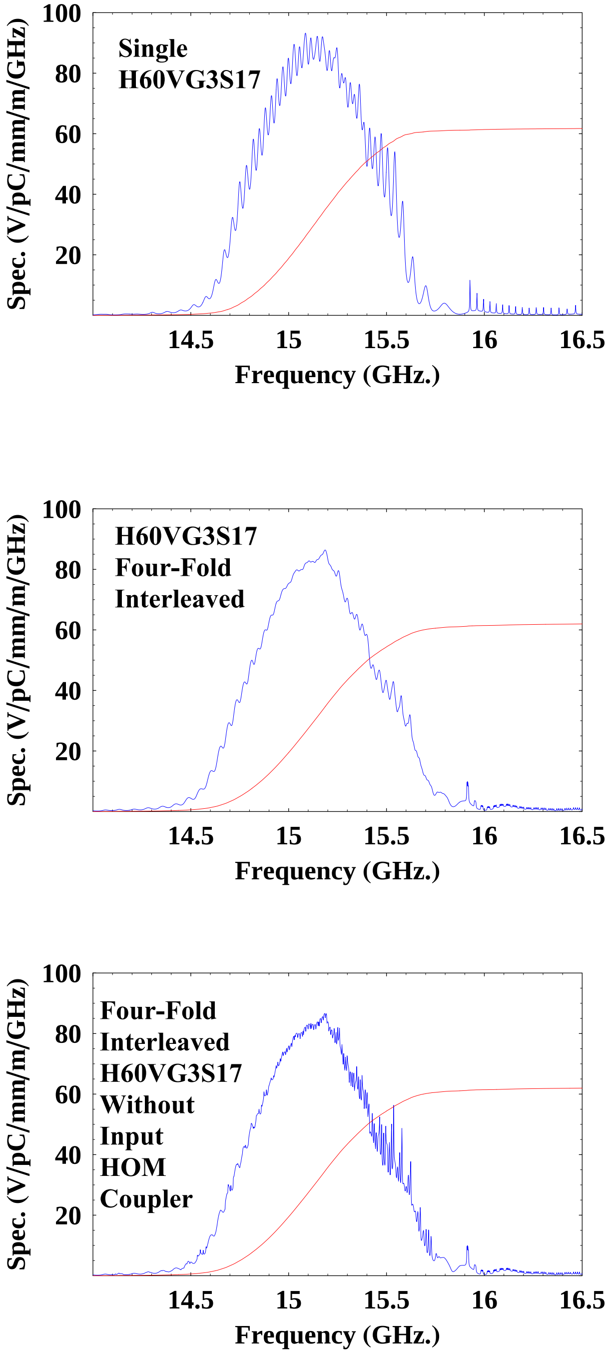

Figure 2. Spectral function for HDDS under three different conditions. Shown uppermost is a single structure in which the cost function has been minimized when all the cells are coupled to the manifold. The bandwidth is 7.80% and the total frequency width is 3.71σ. Four-fold interleaving of the frequencies of adjacent structures is shown in the middle figure. The re-optimised bandwidth for the middle fig. is 9.88% and 4.68 units of σ. The spectral function which results when the input HOM coupler is removed is shown as the lowermost fig.

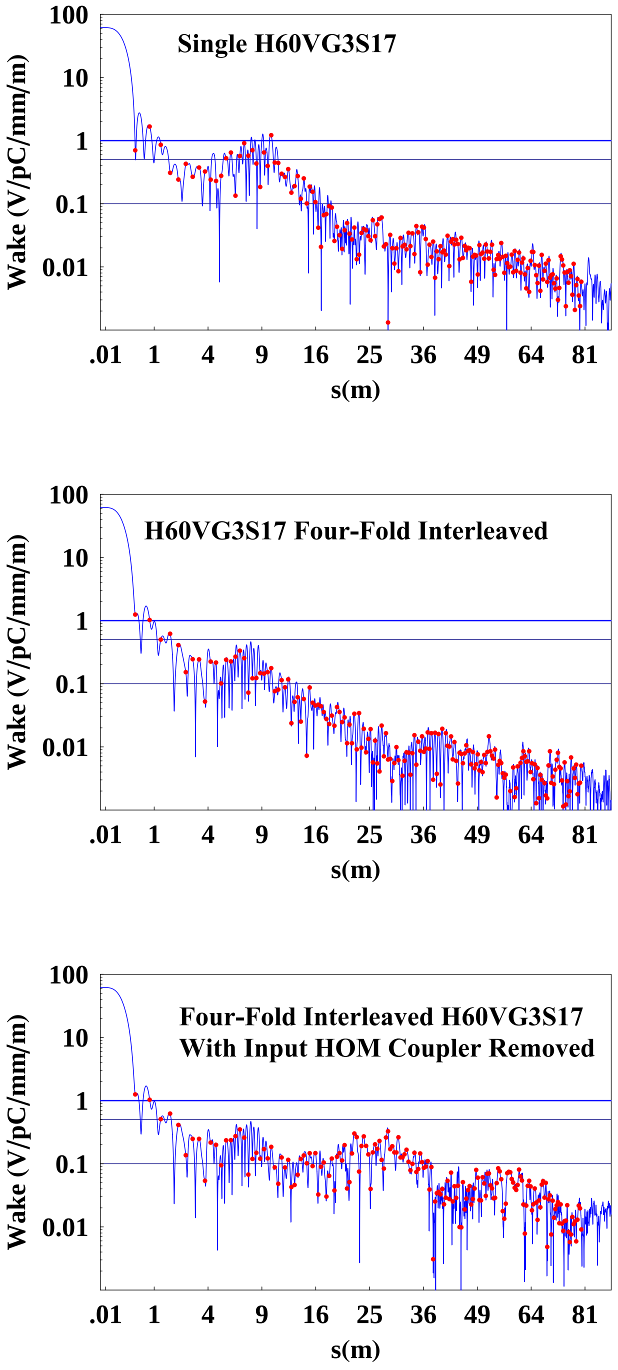

Figure 3. Envelope of wake function for the conditions given in the adjacent figure. The points are at the location of the bunches. Each bunch is separated from its neighbour by 42cm and there are 192 of them in each bunch train. The wake which incorporates 4-fold interleaving of structures is below 1V/pC/mm/m for all bunches apart from the first.

damp the wakefield to an acceptable level. The frequency separation of three of the four structures is based on the separation of the maxima in the oscillatory function of one of the four spectral functions. The individual spectral functions, together with the overall, interleaved function, are illustrated in fig 1. The uncoupled kick factor density function is a Gaussian function and its bandwidth is determined with a computer code that automatically minimizes the "cost function" [5]. The optimised non-interleaved versus four-fold interleaved spectral function and wakefield are compared in fig 2. Also indicated is the effect of removing the input HOM coupler on the wakefield. It is clearly a small effect and thus it may be feasible in future structures to dispense with the upstream HOM coupler entirely.

3. BEAM DYNAMICS

The sum wakefield is defined as the wake evaluated at the location of the bunch summed over all bunches that have proceeded that bunch. The RMS value of the sum wakefield serves as a guide as to whether or not BBU will occur and provided it is less than unity BBU has been found to be suppressed. The RMS of the sum wakefield, $S_{RMS,}$ for the three cases corresponding to the wakes of fig 3 is evaluated as a function of fractional change in the bunch spacing. A change in the bunch spacing corresponds to a systematic error in the frequencies of all cells. The emittance growth as the beam traverses the linac is shown in fig 4 for identical offsets of 25% of σ_y. Each of these curves is obtained for systematic errors in the cell frequencies of 7.5MHz, 33.5MHz and –10.5MHz for A, B, C respectively and are chosen such that a local maxima in S_{RMS} is achieved. The non-interleaved structure is not desirable. However, both four-fold interleaved structures show no more than a 6% dilution of the beam emittance. Also, the emittance dilution at the *nominal bunch spacing* (42cm, and no frequency errors) shows no more than 4% in *all* cases, including the non-interleaved case. However small systematic errors strongly influence the sum wakefield and hence the emittance would readily grow in this situation. Four-fold interleaving of structures is planned for the NLC with considerably relaxed tolerances in frequency errors and also in alignments as will be seen in the next section.

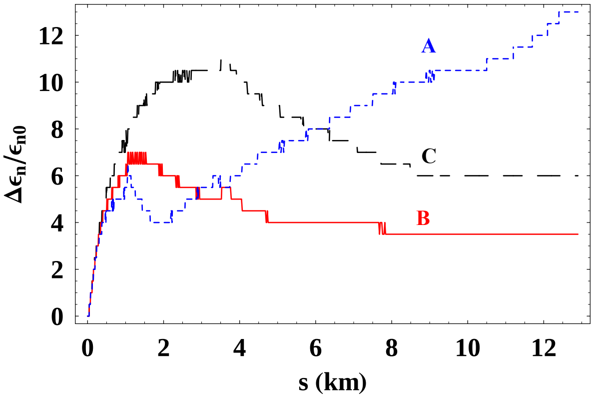

Figure 4. Simulation of $\Delta\varepsilon/\varepsilon_0$, the percentage emittance growth for a single accelerating structure (A), four-fold interleaving of adjacent structures with (B) and without input HOM couplers attached (C)

4. ALIGNMENT TOLERANCES

The transverse long-range and short-range wakefield dilute the final emittance of the beam and it imposes a tolerance requirement on the alignment of groups of cells. The tolerance due to the transverse long-range wakefield is calculated both with an analytical method [6] and by numerically tracking the beam down the linac and moving groups of cells transversely in a random manner (for a specified rms offset) with the computer code LIAR [4]. The tolerances that result from this procedure for a maximum emittance dilution of 10% are shown in Fig 5 for the linac parameters given in [7], modified to take into account 4-fold interleaving of structures. Excellent agreement between the analytical model and the tracking method is obtained. The long-range wake imposes a cell-to-cell and structure-to-structure alignment tolerance of 33μm and 160μm, respectively.

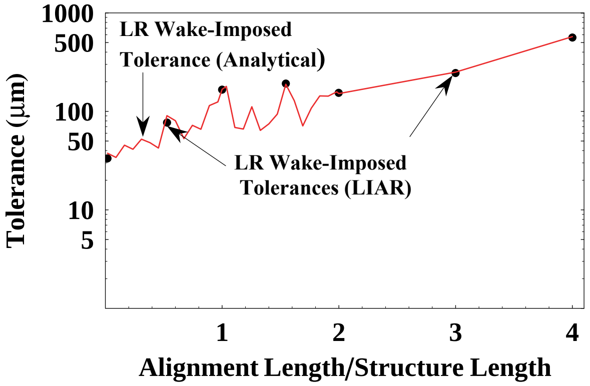

Figure 5. Alignment tolerances for H60VG3S17.

5. ACKNOWLEDGMENTS

These results were first presented at the SLAC structures group meeting and we thank all members of the group for stimulating discussions. We are pleased to acknowledge particularly useful comments from Dr. David Burke

6. REFERENCES

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