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A STUDY OF HIGHER-BAND DIPOLE WAKEFIELDS IN X-BAND ACCELERATING STRUCTURES FOR THE G/NLC †

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Abstract

The X-band linacs for the G/NLC (Global/Next Linear Collider) have evolved from the DDS (Damped Detuned Structure) series. The present accelerating structures are 60 cm in length and incorporate damping and detuning of the dipole modes which comprise the wakefield. In order to adequately damp the wakefield, frequencies of adjacent structures are interleaved. Limited analysis has been done previously on the higher order dipole bands. Here, we calculate the contribution of higher order bands of interleaved structures to the wakefield. Beam dynamics issues are also studied.

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Abstract

The X-band linacs for the G/NLC (Global/Next Linear Collider) [1] have evolved from the DDS (Damped Detuned Structure) [2] series. The present accelerating structures are 60 cm in length and incorporate damping and detuning of the dipole modes which comprise the wakefield. In order to adequately damp the wakefield, frequencies of adjacent structures are interleaved. Limited analysis has been done previously on the higher order dipole bands. Here, we calculate the contribution of higher order bands of interleaved structures to the wakefield. Beam dynamics issues are also studied.

INTRODUCTION

In the operation of the X-band linacs of the G/NLC, wakefields left behind a train of charged bunches can disrupt particles within bunches and can cause severe emittance dilution. For this reason the wakefield is damped by detuning the cell frequencies and by coupling out a portion of the wake to four manifolds that surround the accelerator structure [3].

All previous analyses of the interleaved wakefields for the G/NLC accelerating structures have been exclusively concerned with the 1st dipole band [4]. Herein, this is extended to higher order bands using a mode matching code *Smart2D* [5]. This is applied to the accelerating structure H60VG3 which consists of 55 cells and has an initial fundamental group velocity of 0.03c. Prior to applying the mode matching method we require the geometrical parameters of each cell. The method used to obtain the cell geometry is discussed in [6].

The detailed geometry of the cells is not taken into account with the mode matching method (the curvature of the irises for example is approximated by sharp transitions). However, previous analysis [7] of higher order modes has indicated that making these approximations in the geometry have a small effect on the synchronous frequencies and kick factors [8].

The following section presents the results of calculations on the dipole wakefield for interleaved and non-interleaved accelerating structures. Beam dynamics issues are discussed in the final main section.

TRANSVERSE WAKEFIELDS

Single structure wakefield

Smart2D is used to calculate the beam impedance of H60VG3 and the results are presented in Fig. 1. The 1st band is the dominant one. Significant impedances are also located in the 3rd and 6th bands. The kick factor is

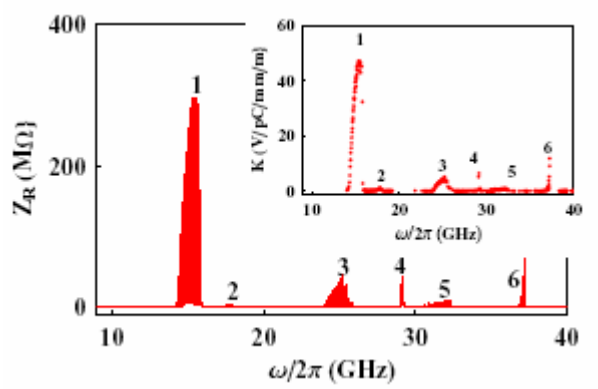

Figure 1: Real part of the beam impedance (Z_R). Kick factors (K) versus synchronous frequencies are shown inset. The approximate band locations are numbered.

calculated from the beam impedance by the expanding the impedance into a summation of Lorentzian functions over all modes. A single Lorentzian for the n^{th} mode is:

$$L_n(\omega) = \frac{2Q_n}{\pi\omega_n}\frac{\mathcal{K}_n}{1+4Q_n^2\left(\omega/\omega_n - 1\right)^2}. \qquad (1)$$

Here $\omega_n/2\pi$ is the resonant frequency of a mode with a quality factor Q_n and loss factor $\mathcal{K}_n = \int_{-\infty}^{\infty} L(\omega)\,d\omega$. The kick factor is given in terms of the loss factor by $K_n = \mathcal{K}_n c/\omega_n r_{off}^2 P$, where P is the period of a cell, and r_{off} the offset of the particle from the axis. Kick factors that result from this fitting procedure are shown inset to Fig. 1. The envelope of the long-range transverse wakefield for N modes is calculated from the absolute value of the sum:

$$\hat{W}(s) = 2\left|\sum_{n=1}^{N} K_n e^{i\omega_n s/c} e^{-\omega_n s/2Q_n c}\right| \qquad (2)$$

Various components of this wakefield are illustrated in Fig 2. We impose a Q of 700 for the first dipole band and 4000 for all subsequent bands. The optimized first-band wake is also shown in Fig 2 A (for the sake of clarity the wake at the location of the bunch is not shown in this case). This wake has been calculated with the spectral function method [9] which directly incorporates manifold-cell coupling (eliminating the need for an *a posteriori* imposition of a damping Q). Up until the first 20 m or so both wakes are quantitatively similar. However, the 1st band wake calculated with *Smart2D* is significantly larger for the 1st trailing bunch where it is more than 2 V/pC/mm/m. For both calculations in Fig. 2A the wakefield is larger than 1 V/pC/mm/m in the neighborhood of 10 m and this will readily drive the beam into an unstable BBU mode [10]. In order to prevent this we interleave the frequencies of neighboring accelerator structures.

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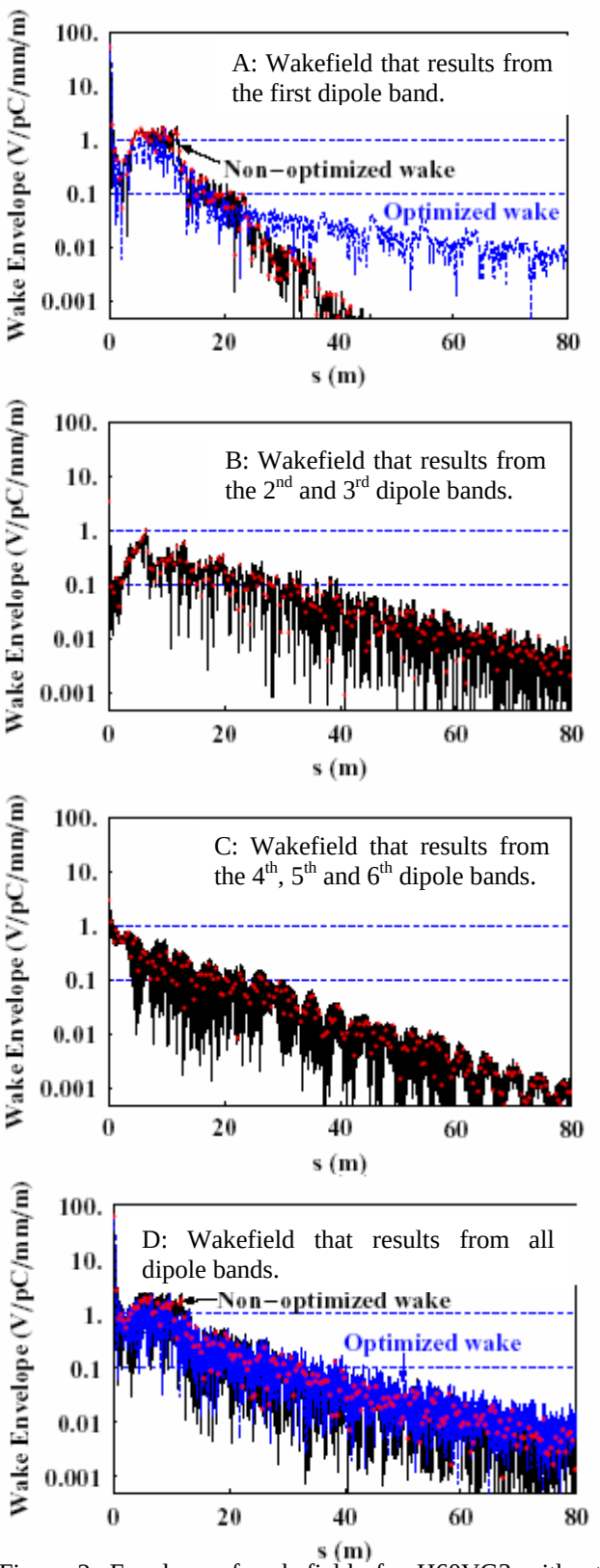

Figure 2: Envelope of wakefields for H60VG3 without any interleaving of the cell frequencies of accelerator structures. The red dots indicate the location of each bunch (spaced 42 cm from their immediate neighbours). The solid black curve corresponds to the wakefield calculated with *Smart2D* and the dashed blue curve is calculated with the spectral function method.

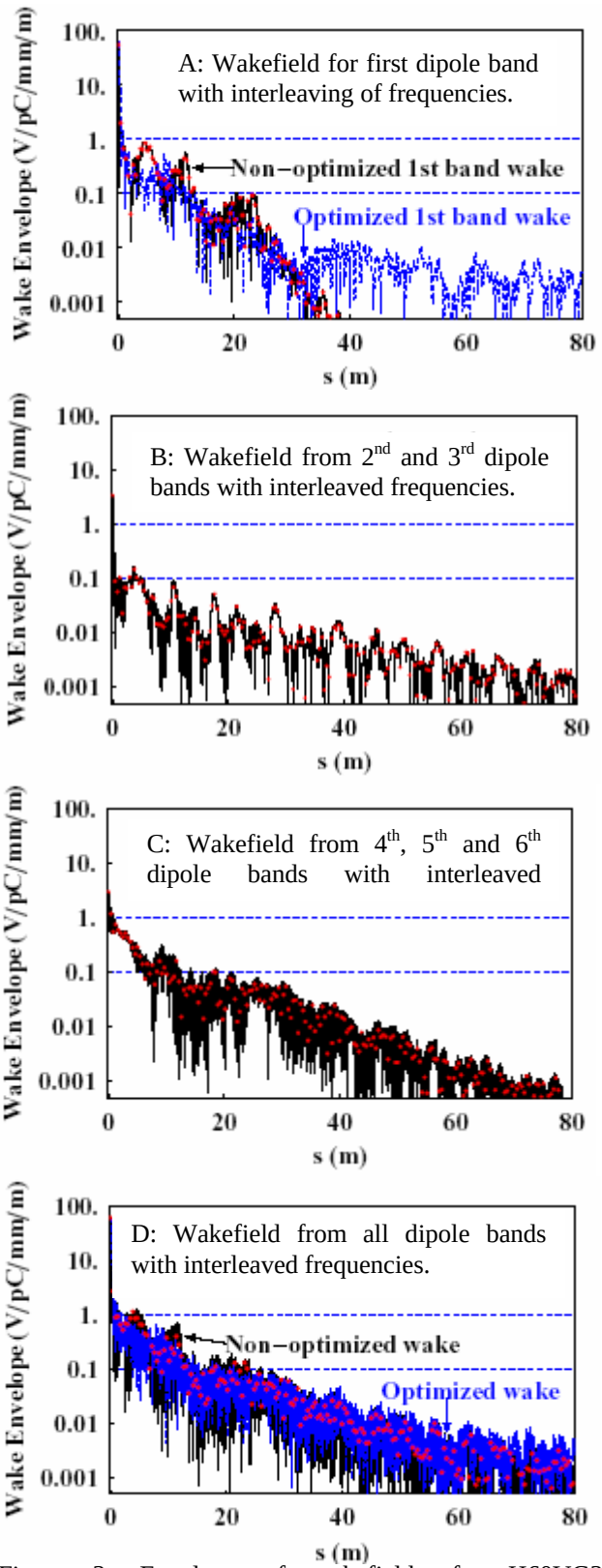

Figure 3: Envelope of wakefields for H60VG3 demonstrating the wake fall-off that occurs due to interleaving of the frequencies of accelerator structures. Here we use 3-fold interleaving of the frequencies of neighbouring structures. The interleaving is affected by changing both iris radius by ± 15 μm and the iris thickness by ± 40 μm.

Interleaved structure wakefield

In order to force the wakefield to continue to decay we fill-in frequencies between mode frequencies. This is achieved by shifting the frequencies of neighbouring accelerator structures such that the frequencies effectively become interleaved. For the first dipole band this is affected by systematically increasing (or decreasing) the iris radius and by changing the iris thickness for the higher order bands. In our simulation we considered 3-fold interleaving. The results of this simulation are shown in Fig 3, where they are shown side-by-side with their non-interleaved counterparts (Fig. 2). Clearly, interleaving improves the decay of the wakefield of all bands. In particular, the wakefield of the first band is now below 1 V/pC/mm/m for all bunch locations apart from the first trailing bunch. The first trailing bunch is important with regard to determining the progress of the beam down the linac and in the case of the wakefield calculated with *Smart2D* the wake for the first trailing bunch is above 2 V/pC/mm/m. This will readily drive the beam into an unstable BBU [10] regime and for this reason we will utilize the 4-fold optimized wake calculated with the spectral function and add higher bands calculated with *Smart2D*. In reality an optimized linac will be used in the final G/NLC design.

BEAM DYNAMICS

The sum wakefield [11] provides an indication as to whether BBU will occur. We evaluate the RMS of the sum wakefield in Fig. 4 for small changes in the bunch

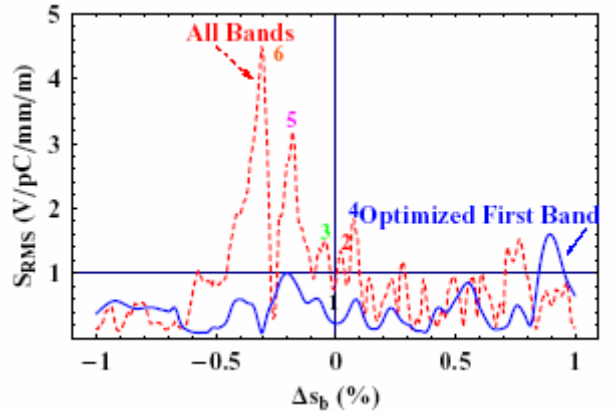

Figure 4: RMS of the sum wakefield (S_{RMS}) versus the percentage change in the bunch spacing from the nominal value. The optimized first band is illustrated by the solid blue line. S_{RMS} for the first (optimized) band and all additional higher order band components up until the 6th band is indicated by the dashed red line. Peak values used in tracking simulations are numbered 2 to 6

spacing for both single and multi-band wakefields. A small change in the bunch spacing represents a systematic change in all cell frequencies and in effect it models systematic errors that are liable to occur in fabricating several tens of thousands of accelerating structures. However, in practice, we would expect errors of less than 15 MHz and this limits the percentage bunch deviation to

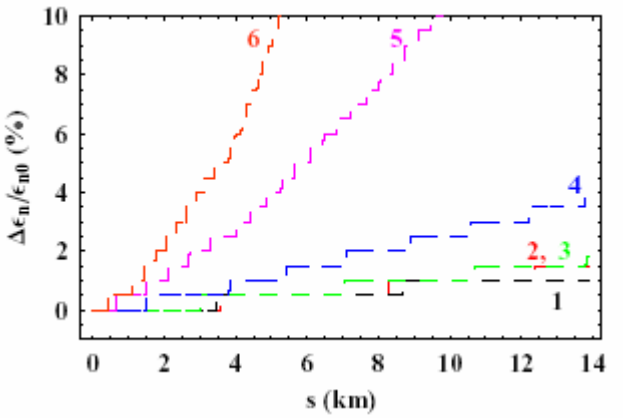

Figure 5: Percentage emittance dilution from the injected emittance of 20 nm.rads versus the distance down the linac for various fractional deviations in the nominal bunch spacing for a beam subjected to the interleaved wakefields. Curve 1 is for the nominal bunch spacing and curves 2 to 6 correspond to the peaks in S_{RMS} indicated on the dashed curve in Fig. 4

~ ± 0.1%. In this region there are 4 peak values in the multi-band S_{RMS}

The emittance of the beam is monitored as proceeds down the complete linac for the peak values in S_{RMS} indicated on the curve in Fig. 4. The results of this tracking simulation for a beam initially offset by 1 μm from the axis of the accelerator structure are illustrated in Fig. 5. Provided the change in the bunch spacing is confined to 0.1% then we are limited to curves 1 to 4 where no more than 4% emittance occurs. For larger peaks located in the neighborhood of 4 and 5 in Fig. 4 the emittance grows quadratically along the linac and at the end reaches a maximum value of 18 % and 56 % respectively. However, errors in fabricating the structures are not expected to be this large and thus emittance dilution will be kept below 4%.

In conclusion, the beam emittance will not be diluted appreciably provided the frequencies of the 1st though 6th dipole bands are interleaved.

ACNKOWLEDGEMENTS

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