Emittance Imposed Tolerances in X-Band Linacs

1. Short-range wake effects (wake over bunch).
=> Structure-structure alignment tolerances
=> Beam-based alignment

2. Long-range wake effects
=> Structure-structure and cell-to-cell alignment tolerance
& machining tolerances

Emittance Imposed Tolerances in X-Band Linacs

Minimization of emittance dilution
=> Maintain reduced long-range wakefield

1. Frequency errors result from machining errors in fabrication

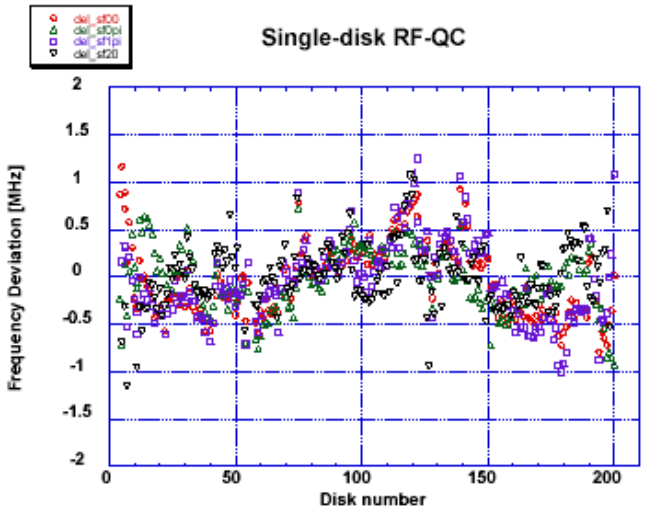
=> In general, a bad thing (particularly if the errors are repeatable)!
=> reduces the effect of detuning (reduces destructive interference)

=>Errors that are random from one structure to the next, allow for some relaxation in frequency (and hence machining) tolerances

2. Missaligned accelerating structures, and cells therein enhance the overall wakefield Imposes cell-to-cell and structure-to-structure alignment tolerances.

3. Both frequency and alignment tolerances should be evaluated together, when considering the mass production of X-band acceleraing structures.

1. Frequency Errors => Fabricational Tolerances

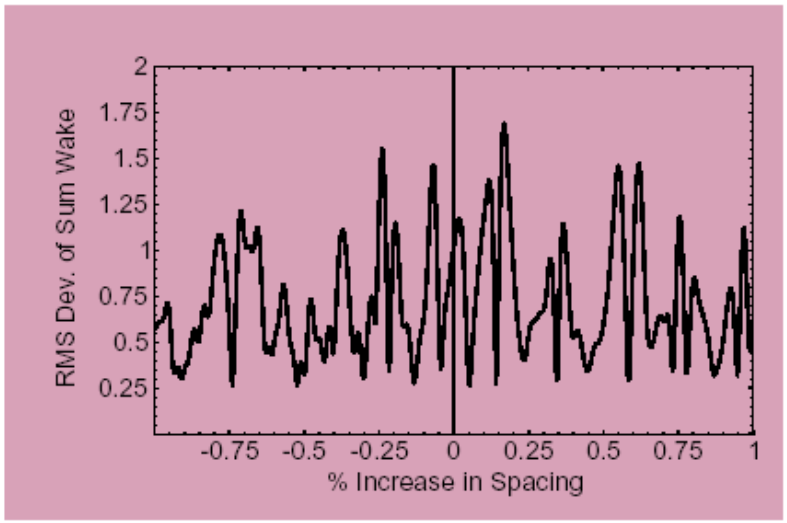


- Small dimensional errors, generated when fabricating the irises and cavities of an accelerator structure, give rise to errors in the synchronous frequencies.
- For RDDS1 it was possible to machine the cells to an accuracy of better than 1 μm
- However, when fabricating several thousand such structures, looser tolerances may reduce the fabrication costs

- The linac H90VG5 will consist of 9440 nominally identical 90cm structures, each of which contains 83 slightly different cells. Shown here is an automated measurement of critical cell dimensions performed at KEK

=>Random errors negatively impact the RMS sum wakefield
=>In general we have found it neccessary to keep RMS sum wake below 1V/pC/mm/m.
=>Random errors that are *not* repeatable from structure relax this tolerance

•An error type which is repeated in every cell of a structure but differs in every structure is referred to as: a systematic-random error.
•An error that is repeated in every structure, but varies from cell-to-cell, we refer to as a random-systematic error. We also consider random-random and systematic-systematic (potentially the most damaging) error types making a total of 4 error types.

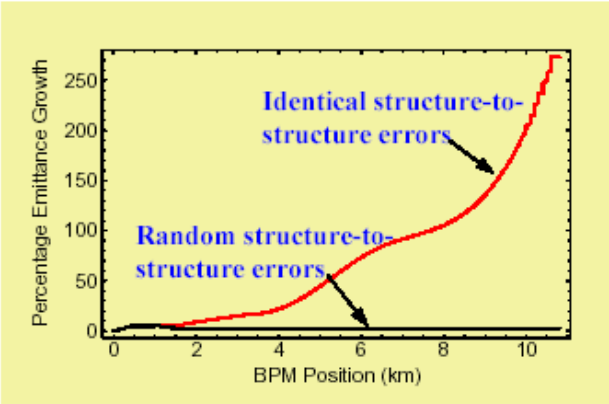


RMS sum wakefield for 3MHz RMS errors

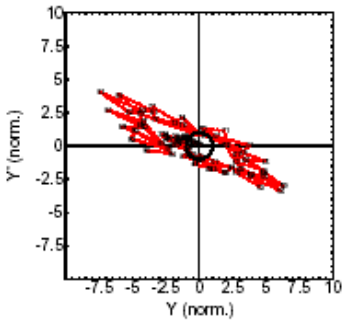
•An indicator for the onset of BBU is provided by the wakefield at a particular bunch which is formed by summing all wakefields left behind by earlier bunches which is denoted as the "sum wakefield".
• BBU will likely arise when the RMS of the sum wake is the order of 1 V/pC/mm/m or larger.
•When not in the BBU regime, the sum wakefield also provides an accurate method of calculating the dilution

***Random errors with a given structure that are repeatable from one structure to the next are a bad thing!**

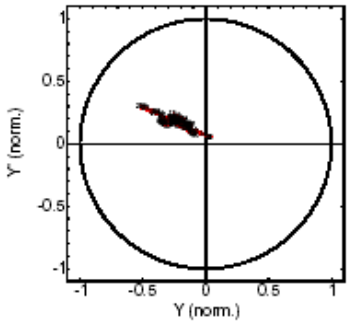
***Random errors with a given structure that are also random from one structure to the next is very helpful to in mimimizing emittance dilution**



Emittance growth due to 3MHz RMS errors that are (a) reproduced in every structure and (b) random from structure-to-structure



Phase Space (3MHz RMS error). Phase space for a linac composed of 4720 structures assumed to have identical random errors in each structure



Phase space for a linac composed of structures with a different random error in the synchronous frequency (non-identical structures).

Minimum Modal Separation in (R)DDS Accelerators was ~7MHz
=> Similar dimensional tolerance (>5MHz was used for DDS)
=> Important to maintain a smooth dipole distribution

In the H60VG3/4 structures minimum modal separation is ~20MHz
=> looser fabrication tolerances??

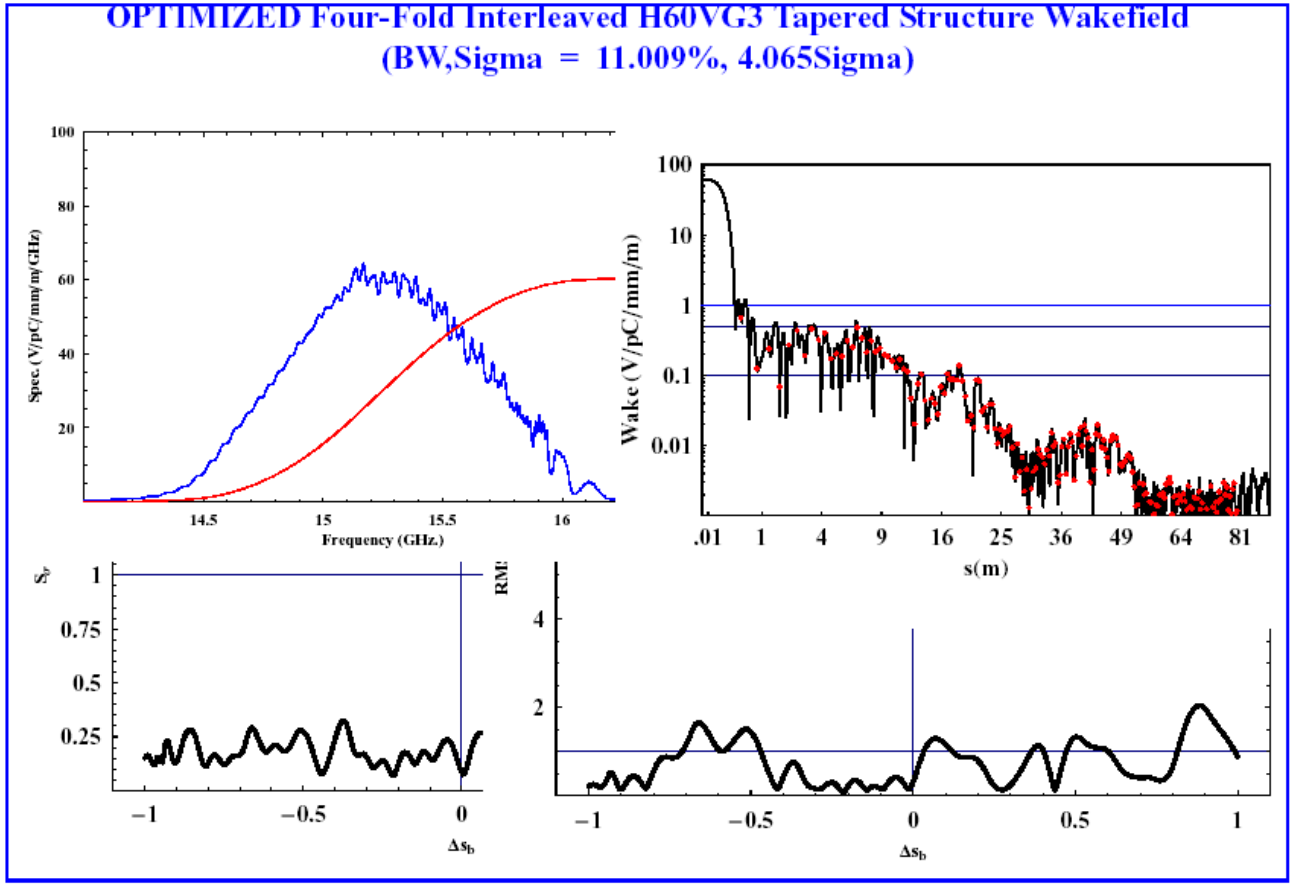
We have investigated H -150, M -135 structures with a view to curing breakdown effects!
NLC baseline is now 8 X-band accelerators per girder
and 4-fold interleaving of structures.
Time to focus on a given structure and assess frequency tolerances!

The systematic errors are much looser than the random errors

H60VG4S17 Optimized 4-Fold Interleaved Wakefield

*RMS of sum wakefield
=> systematic error tolerances
*Loose systematic error tolerances
=> +/-0.5% bunch spacing errors
=> more than +/-30MHz.....

*Random error tolerances require study
=> random from cell-to-cell and random from structure-to-structure. And, a combination of both!



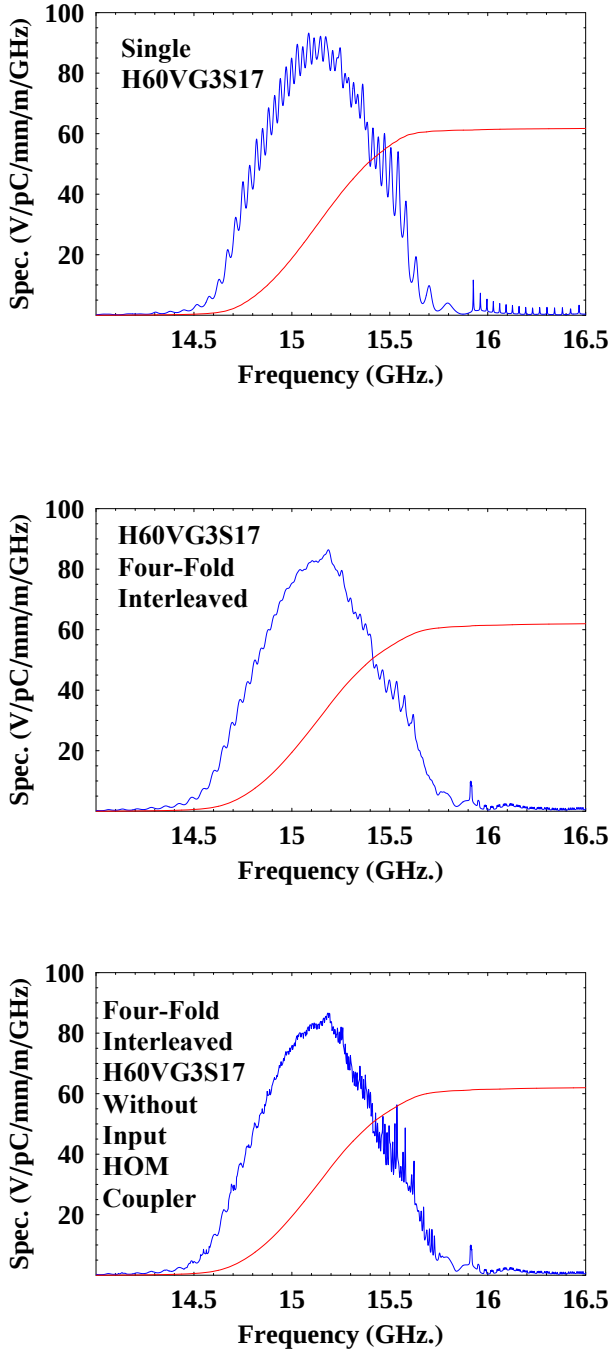


Figure 2. Spectral function for HDDS under three different conditions. Shown uppermost is a single structure in which the cost function has been minimized when all the cells are coupled to the manifold. The bandwidth is 7.80% and the total frequency width is 3.71σ. Four-fold interleaving of the frequencies 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.

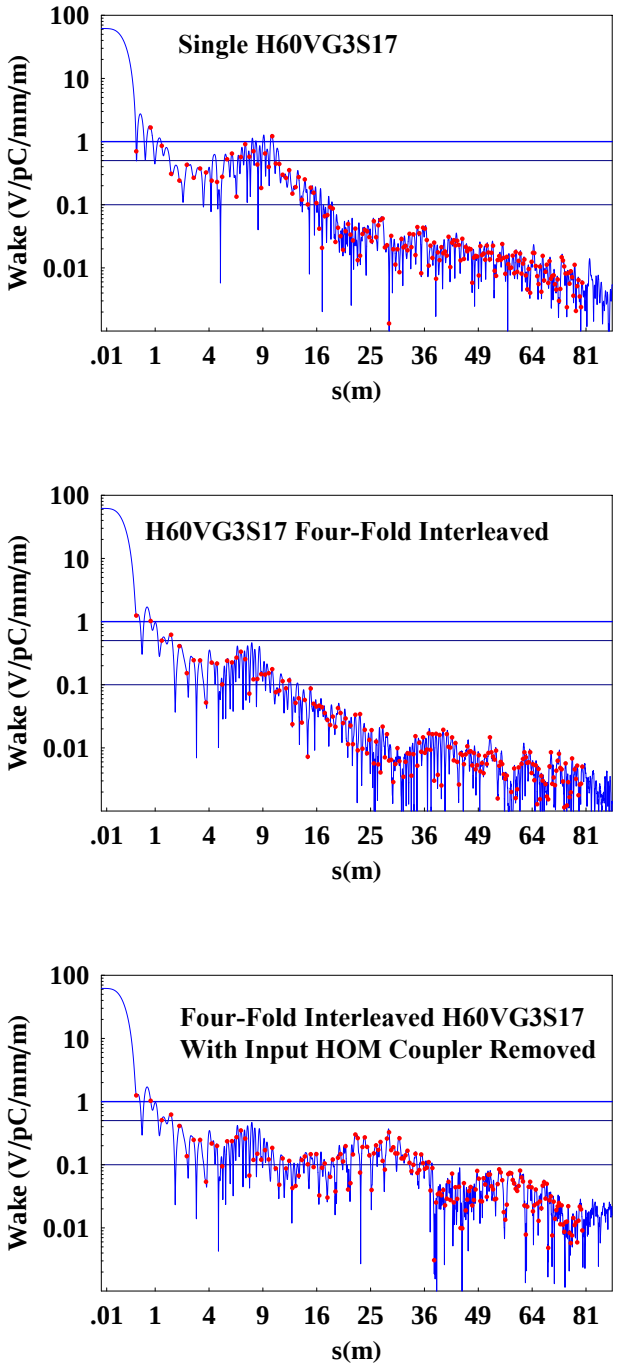


Figure 3. Envelope of wake function for the conditions given in the adjacent figure. The points are at the location of the bunches. Each bunch is separated from its neighbour by 42cm and there are 192 of them in each bunch train. The wake which incorporates 4-fold interleaving of structures is below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

Alignment Tolerance for H60VG3S17

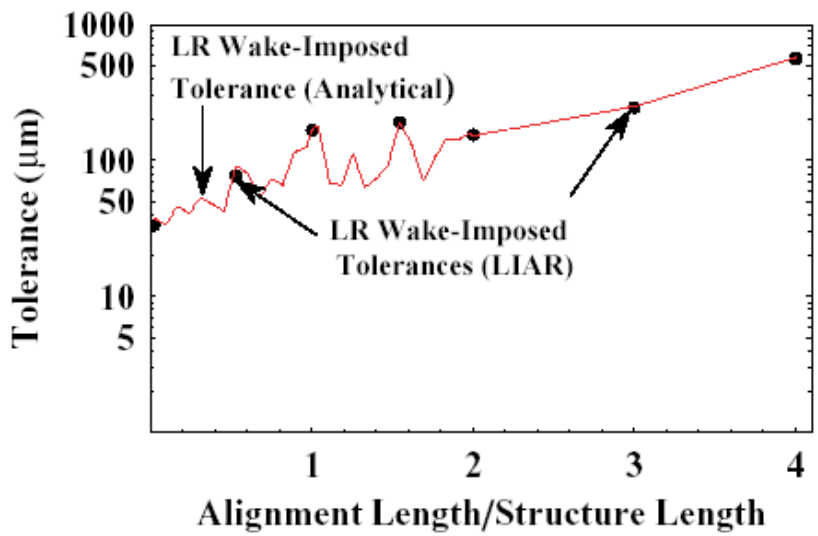
=>We allow the emittance to be diluted by 10% from its nominal value and move groups of cells and structures in a random manner.

$$\langle \Delta\varepsilon \rangle = r_e^2 N^2 \overline{\beta}_0 L_s^2 \langle \Delta S_k^2 \rangle \frac{1-(\gamma_0/\gamma_f)^{1/2}}{\gamma_0^{1/2}\gamma_f^{3/2}}$$

Emittance dilution ~ to standard deviation of sum wakefield

=>Using optimization spectral code the frequency bandwith and coupling have allowed a looser tolerances.

**** Cell-cell alignment tolerance - ~30 microns**
(DDS was ~10 microns)
**** Structure-to-structure ~ 160 microns**



Summary

1. Loose systematic errors imposed by long-range wakes (>30MHz for what may be the new baseline structure pending new breakdown results).

2. Random cell-to-cell, structure-structure and combinations thereof need to be systematically investigated for H60VG3/4

3. Alignment tolerances for H60VG3 with 4-fold interleaving are looser than previous structures. A good thing!
This is because the cell-to-manifold coupling is quite strong and this stabilizes the mode against any shift in the frequencies.
=>For a 10% maximum allowed emittance dilution:
Cell-to-cell alignment tolerance ~30 microns
Structure-structure ~160microns

4. Important to realise these wakefield imposed tolerance are not independent of the monopole imposed tolerances. We still need to accelerate the beam efficiently!