Some thoughts about beam loading

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Outline

Beam Loading

- Definition
- Particle dynamics – energy droop & HOM
- RF control
- Bunch train dependencies

Beam Loading

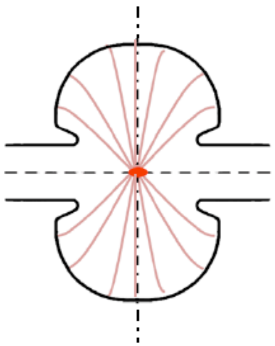
Following W.A. Barletta:

- If you can kick the beam, the beam can kick you

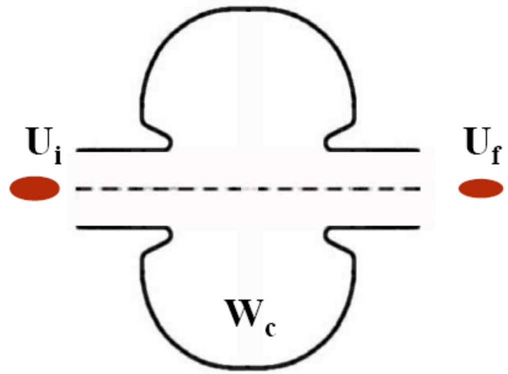
==>

Total cavity voltage $= V_{\text{generator}} + V_{\text{beam-induced}}$

Fields in cavity $= \mathbf{E}_{\text{generator}} + \mathbf{E}_{\text{beam-induced}}$



- Total energy in the particles and the cavity is conserved
  - → Beam loading



$\Delta W_c = U_i - U_f$

Beamloading is describing the exchange of energy between particle and cavity……what does this mean ?

Beam Loading

- RF in cavity before beam bunch
- As short bunch of particles arrives at cavity
- Generates an electric field in cavity (and is itself accelerated)
- In the cavity remains a phase shifted “distorted field distribution” with decreased amplitude

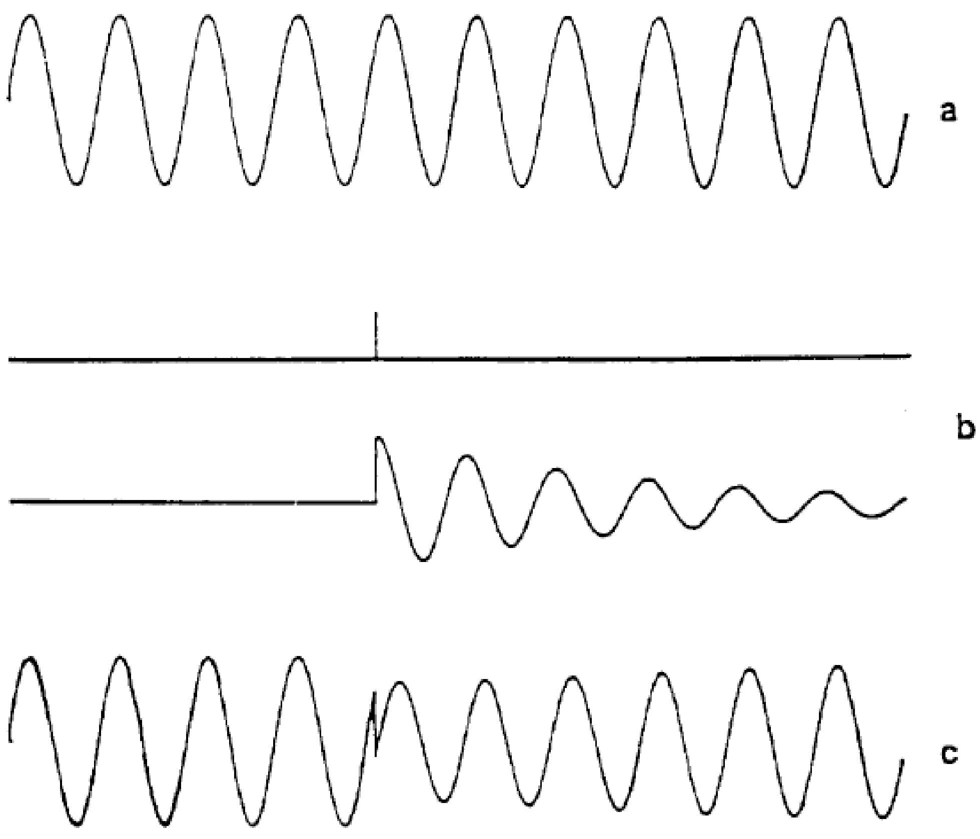


Fig. 1 Single-bunch passage in a cavity

Beam Loading

- Energy transferred to the particle:

  $W=e*U$

  $W_{cav,after}=W_{cav,before}-\Delta W_{particle}$

  $Wcav,before=Wcav,after+P_{RFgen}*\Delta T$

  stored energy scales with volume and electric field strength

  Power transferred from generator to cavity is Q factor dependent

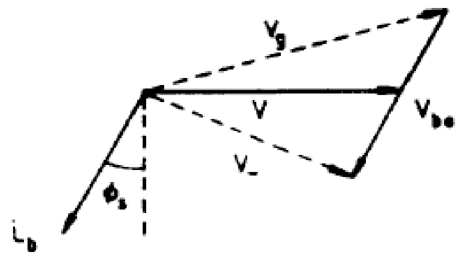
- NF Numbers :
  - 10^{21} Neutrinos/year of 10^7 sec at 50 Hz = $2*10^{12}$ / bunch train
  - 201 MHz ~ 5ns – 88 bunches per train = $2.3*10^{10}$ p/bunch in 440 ns

  $7.7*10^9$ p/bunch for 3 pB <40 μs, $4.6*10^9$ p/bunch for 5 pB <40 μs

- Comparison with ILC

  1300 MHz ~ 0.8ns
  1330-5640 bunches per train
  $5.6*10^{13}$ p/ train -> $1*10^{10}$ p/ bunch up to $4.3*10^{10}$ p/ bunch in 1-4 μs

Beam Loading – RF voltage and phase

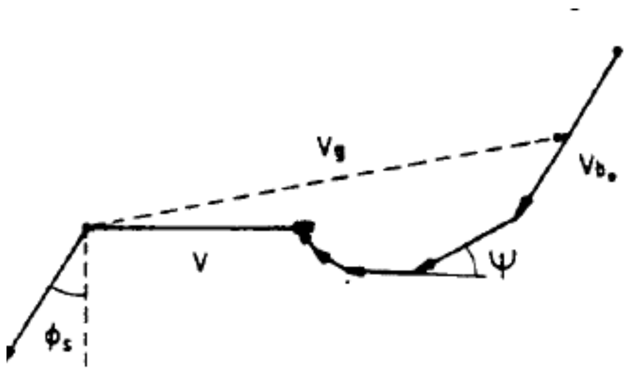


V_g: generator driven voltage

V_-: voltage after bunch passage

V: net voltage experienced by the beam

Fig. 2 Vector diagram – single-bunch passage in a cavity



Vector diagram – multiple-bunch passages

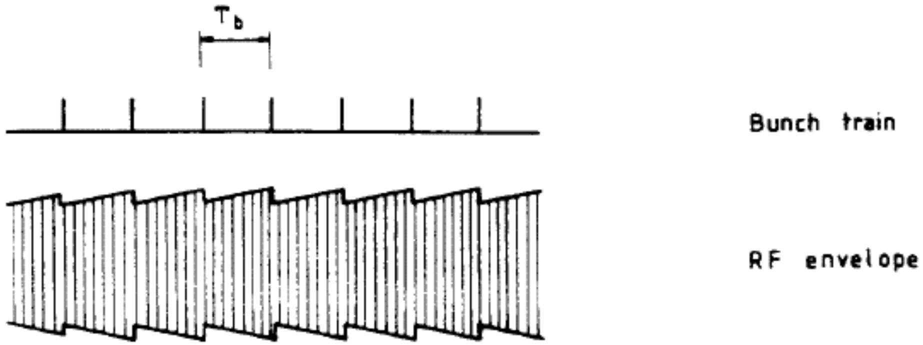
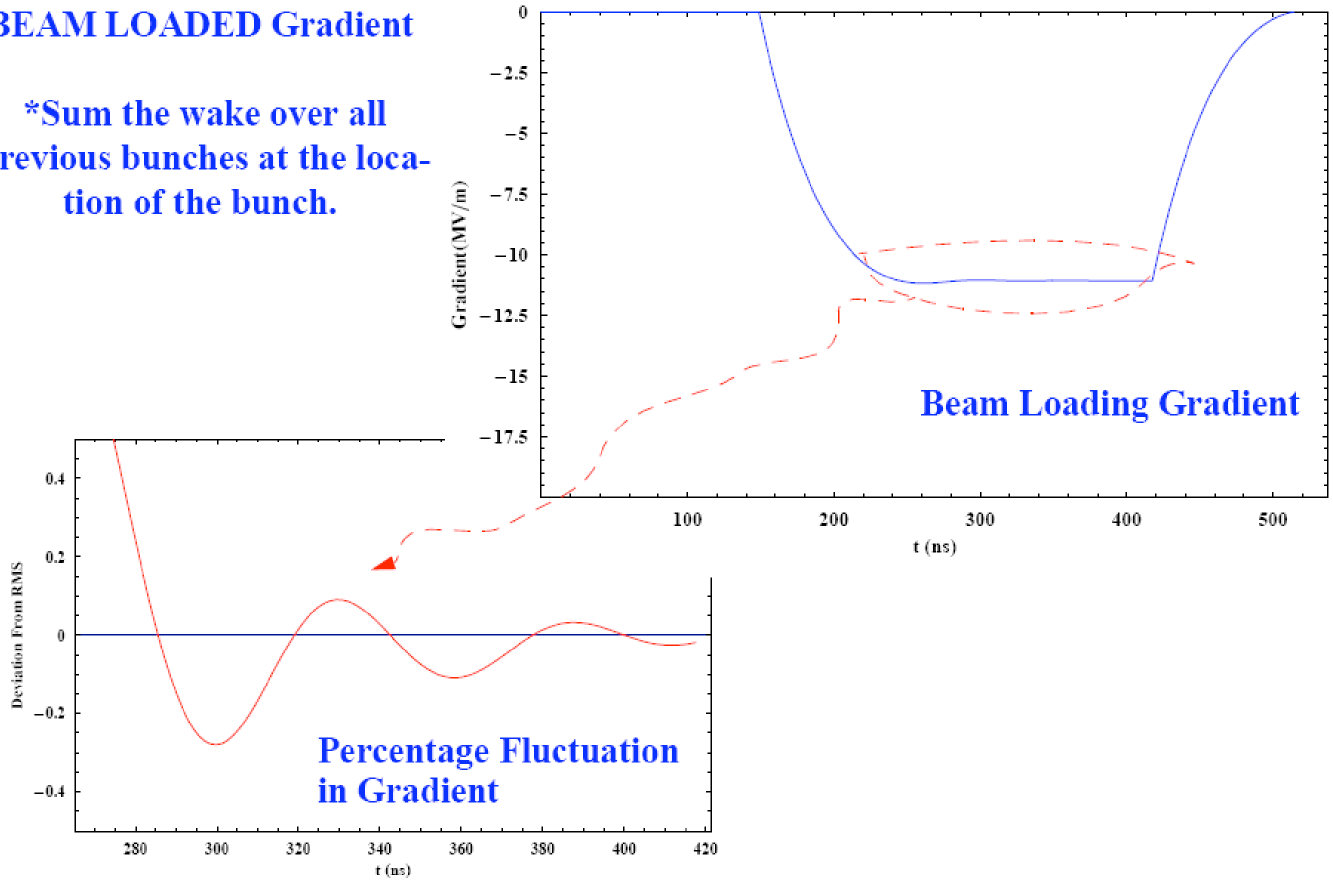


Fig. 4 Case $\delta_0 \cong 0$. The RF waveform is a quasi sinusoid

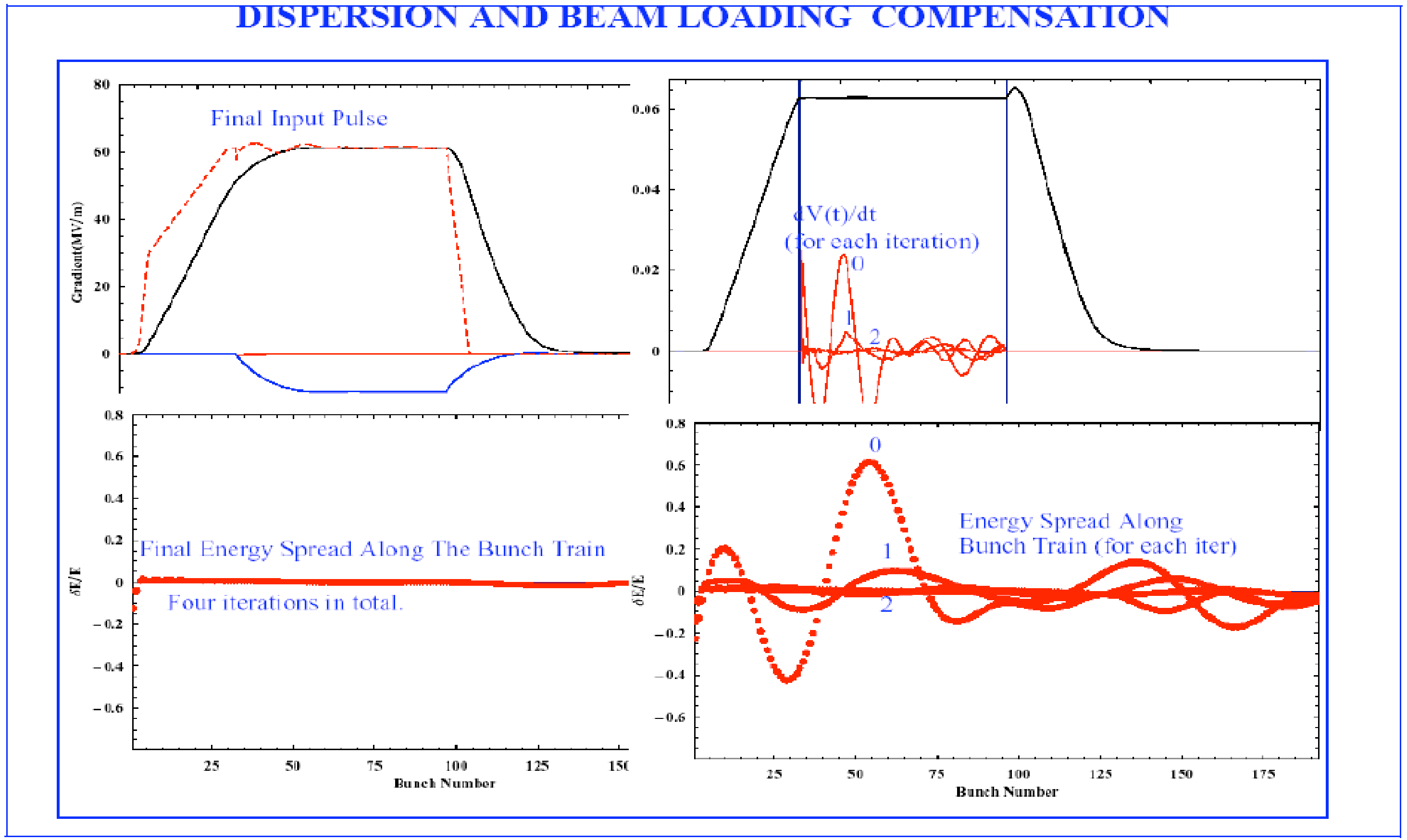
Beam Loading – influence on gradient

BEAM LOADED Gradient

*Sum the wake over all previous bunches at the location of the bunch.



Beam Loading – energy variation along beam pulse



Roger M. Jones (ISG11, KEK, December 16th - 19th, 2004)

Beam Loading – HOM

A particle travelling through a cavity produces wakefields.....

Quasi delta pulse contain flat frequency spectrum

All Higher Order Modes can be excited simultaneously and the energy will stay in cavity for a while

Field components of HOM modes interacts with following bunches

Effect increases with

- charge per bunch
- bunch train length
- RF frequency and 1/beam size
- Q value of cavities
- => should be much less than for ILC

Beam loading Linac

- Each cavitiy sees bunch once
- For RLA several cavity crossings per bunch but as long as order of bunches is the same the influence on each will be the same
- In every bunch train the first bunch will see a larger field than the last (without RF correction)
- Influence on RF fields within bunch train decreases linear with number of bunch trains
- Between the bunch trains fields in cavity can partly recover
- Due to RF feeding problem larger in SC cavities

Beam loading FFAG

- More complex as no relation between position of bunch within bunchtrain and crossing of cavity as in linac
- Bunches in bunch train should see same total acceleration but acceleration decreases in acceleration cycle
- Influence on RF fields within bunch train decreases linear with number of bunch trains
- Between the bunch trains fields in cavity can partly recover

Beam Loading - conclusions

– For a maximum particle number the beam loading effect is lowest for a ratio of average to peak current of 1.

– While for the NF the charge per pulse is equal to ILC the length of the bunch train is for all scenarios significantly smaller.

– For CLIC a active RF system seems to suppress the energy degradation :

***The resulting spread in energy over all 192 bunches can be compensated for by suitably shaping the input shape profile. There is a penalty to be paid in shaping the pulse, namely, there is some, albeit small, loss in the overall energy gain (efficiency). It is possible that the compensation can be done along the linear ramp. Further work is needed in this area to confirm this.**

  – But a more detailed analyses taking the stored energy into account is required.

  – Due to low frequency, short bunch train and large beam size major difficulties from the influence of HOM are not expected