Two beam power loss analysis

F. Giordano
B. Salvant

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Outline

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Background

There are cavity like structures seen by two beams, and it would be interesting to understand the impact on the power loss:

• Start with a simple cavity and choose the cavity so that there is only 1 mode in the frequency range of interest.

Main difficulty is the full beam creation in CST and how to extract the info: new power loss signal that we had asked some years ago to Monika Balk.
Model definition: Pillbox resonant cavity

- \( f_r = 1 \text{ GHz} \)
- \( Q = 10^4 \)
- \( \sigma = 10^4 S\text{m} \)
- \( a = 0.115 m \)
- \( h = 1.812 mm \)

High sigma needed to have wakefield interaction between bunches. Q and \( f_r \) are designed to hit at least one of the main line of the power spectrum.
The resonance frequency is 10% higher than the computed one because of the presence of the beam pipe. The pillbox cavity formulae do not take in account the beam pipe. → Next step: reduce the beam-pipe to mitigate this effect.

\[ P_{loss} = M^2 l_b^2 \sum_{p=-\infty}^{\infty} \text{Re}[Z(pw_0)]\Lambda(pw_0)^2 \]
Model definition: mesh checking

Very long simulation time $\rightarrow$ Best trade off convergence/sim. time is 20 cells per wavelength with symmetry planes. The figure shows that the symmetry planes are not affecting the wakepotential at all.
Model definition: beam parameters

Fill number: 5979
Bunch spacing: 25 ns
Proton per bunch: 1.10e11
Bunches: 2556
Total beam charge: 4.51e-5 C
Model validation

Standard power loss computation:

\[ P_{\text{loss}} = M^2 I_b^2 \sum_{p=-\infty}^{+\infty} \text{Re}[Z(pw_0)]|\Lambda(pw_0)|^2 \]

With Z computed by CST.

The model data gives: 8.11 W

CST power loss computation:

\[ P_{\text{loss}} = \text{Avg}(P^\text{CST}_{\text{loss}}) \]

Where ploss computed by CST is the instantaneous power loss versus time.

The model data gives: 8.05 W

Error = 0.8%

More scan ongoing to be sure that this error remains constant.
Offset impact on the power loss: results

The power loss of the two beam increase with the offset.

Even if the increase is sharp, the total power loss remains quite low.

→ It has to be investigated if the phase shift has an impact on this (see next slides)
Offset impact on the power loss: transverse impedance

Around 1.9GHz a transverse mode appears that could explain the increase in power loss. The quadrupolar impedance from the longitudinal mode could also explain this.
Phase impact on the power loss: what is it?

The phase shift is time that passes after one bunch of one beam enter a cavity until the correspondent bunch of the other beam enters it.

In figure is represented a phase shift of 0 ns (top) and a phase shift of 1 ns (bottom).
Phase impact on the power loss: Beam selection

The power loss has been computed varying the phase between two beam.

The beams do not enter the cavity at the same time.

The same scan has been performed both on single bunch case and on the multi-bunch case. Because the result are very similar but the multi-bunch case has very long computational time the firsts studies have been carried out on the single bunch case.
Phase impact on the power loss: cavity radius sweep

The resonance frequency of the fundamental mode of an RF pillbox cavity is obtained by:

\[ a = 0.383\lambda \]

Where ‘a’ is the radius of the cavity and \( \lambda = \frac{c}{f} \) is the wavelength.

‘a’ has been varied from 9cm to 15cm with a step of 2cm.
Phase impact on the power loss: impedance

The resonant mode of each cavity shift accordingly to the value of the radius.

Even if not carefully investigated, the increase in shunt impedance is probably related to the increase of lossy surface due to the increase of the radius of the cavity.
The phase shift has a strong impact on the total power loss dissipated by the two beams. In particular it seems there is a strong correlation between the resonance frequency of the cavity and the period of the power loss with:

\[ T = 1/f_r \]
Conclusion and next step

• The phase shift has a strong impact on the power loss in cavity-like structures where 2 beams are present.

• The maximum of this power loss is reached when the $T/2 = 1/fr$, where $T$ is the phase shift and $fr$ is the resonance frequency of the cavity.

Next step:

• Find a more solid physic explanation to the phase shift impact on the power loss

• Find an analytical formula for the two beam spectrum.
Phase impact on the power loss: possible explanation

The main explanation that we have at the moment is:

Due to the perfect symmetry of the structure the fields of the 2 beam face the cavity perfectly perpendicular from both sides. The directions of the field does not allow them to enter the cavity. With a delay, the left and right side of the cavity sees fields with different intensity that allows them to rotate and enter the cavity and therefore dissipate into it.

Phase shift: 0 ns

Phase shift: 0.6 ns