BBU LIMITATIONS FOR ERLS

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Abstract

The BBU threshold in ERLs is a limitation on the maximum beam current due to the interaction of the electron bunches and the Higher Order Modes (HOMs) contained within the RF cavities. Several factors are involved in determining the threshold current; from the cavity the Q, R/Q and degeneracy of the modes all play an important part. From the beam transport the values of the lattice functions α, β and μ have an effect. We will discuss the limits on these variables to provide a BBU current threshold greater than 100 mA for a multiple cavity machine and what will be required to provide higher currents. Also three different cavity profiles were investigated with the aim of reducing the BBU threshold. The TESLA 9-cell cavity was used as a baseline for comparison against possible 7-cell cavity designs, using the TESLA cell shape for their inner cells. The ends of the 7-cell cavities join to different sized beampipes, with radii of 39 mm and 54 mm, to allow most of the HOMs to propagate to a broadband HOM absorber. Two different beampipe to cavity to transitions were investigated. The optimised 7-cell cavity will be shown to provide an increase in the BBU threshold.

INVESTIGATING RF PARAMETERS

HOM Degeneracy – Threshold Calculations

In [1] the threshold is calculated for the Cornell ERL where each cavity has only two HOMs orientated 90° apart. It is shown that when the frequency of these HOMs differs by 60 MHz a threshold of 2A is achievable.

In this paper we show results from a monte-carlo model of a 40-cavity system where the degeneracy of two HOMs has been randomised. Models were produced where the pair of HOMs could differ by ±1MHz, ±2MHz, ±5MHz, ±10MHz, ±15MHz, ±20MHz, ±30MHz, ±40MHz, ±50MHz. The model was run 250 times and different HOMs were used in each cavity and each run. An arbitrary recirculation was used for these calculations. Figures 1 and 2 below show the average and minimum threshold as a function of the strength of linac focusing magnets. A factor of two increase can be seen between the ±1 MHz and ±50 MHz cases.

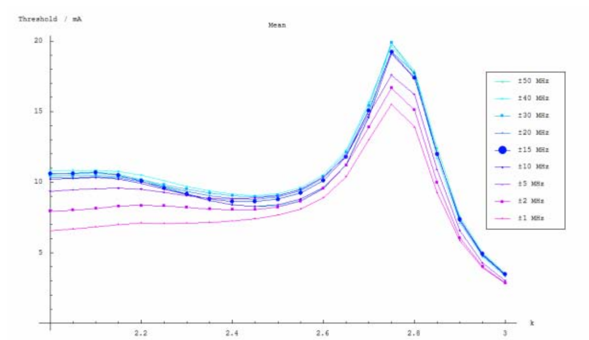

Figure 1: Average threshold for a multi-cavity system for HOMs with different degeneracy.

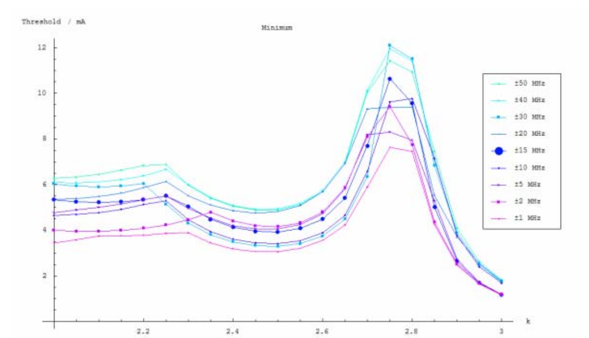

Figure 2: Minimum threshold for a multi-cavity system for HOMs with different degeneracy.

HOM Degeneracy – Altering the Cavity

To split the degeneracy of the dipole HOMs the cavity has to be deformed. This can be done by denting the cavity or extending it in one dimension. A pillbox cavity with a resonant frequency of 1.3 GHz was modelled in CST's Microwave Studio [2]. To dent the cavity a small spherical section is taken from either the top or the side of the cavity – Figures 3a and 3b respectively; symmetry is preserved when denting the side of the cavity by making dents in both sides. These changes to the cavity will require fine meshing to investigate such a small change in frequency. To reduce the amount of simulation time required only one cell of the cavity was modelled.

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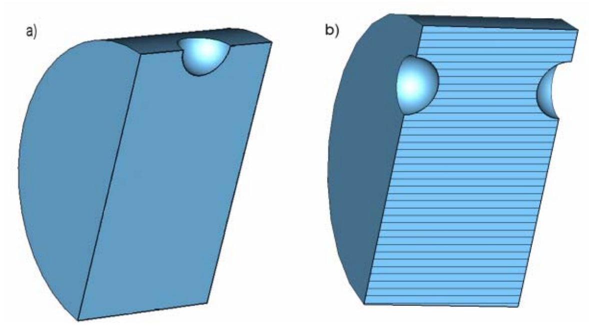

Figure 3: Pillbox cavity with top a) and side b) dents.

By denting the cavity at the top a maximum split of 35 MHz can be achieved, this requires a dent with a radius of 34 mm. However by denting the cavity at the sides a split of 140 MHz can be achieved with a radius of 28 mm. Plots of the split frequency as a function of the dent radius can be found in figures 4 and 5. Each plot shows the data for different mesh densities to confirm that this is not an effect of the meshing.

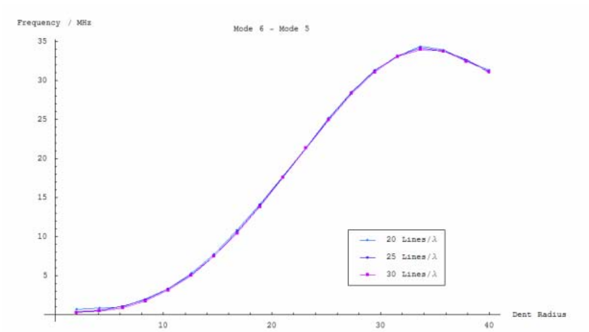

Figure 4: Mode degeneracy for a pillbox cavity with dent at the top.

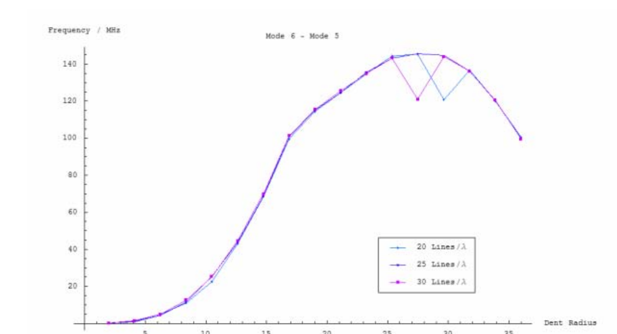

Figure 5: Mode degeneracy for a pillbox cavity with dent at the sides.

However, a dent of this size would affect the fundamental mode of the cavity. The results in Figures 6 and 7 below show that the change in the frequency of the fundamental mode is equivalent to the frequency difference of degenerate dipole mode.

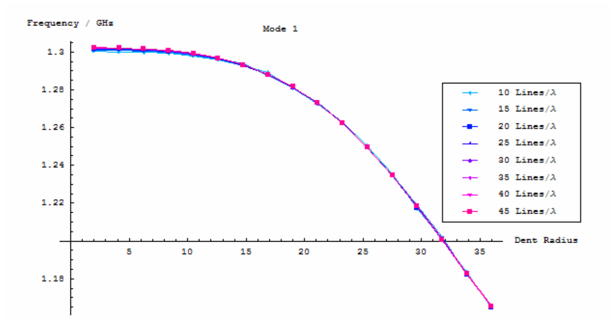

Figure 6: Change in fundamental frequency for a pillbox cavity with a dent at the top.

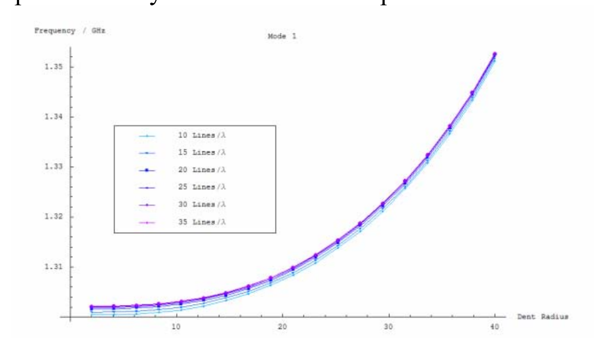

Figure 7: Change in fundamental frequency for a pillbox cavity with a dent at the sides.

Squashing the cavity has a similar effect to denting; elongating the cavity in one direction by 10% can provide a 80 MHz split in the dipole mode frequency. This can be seen in Figure 8. Figure 9 shows a similar change in the fundamental frequency as was seen with the dented cavity.

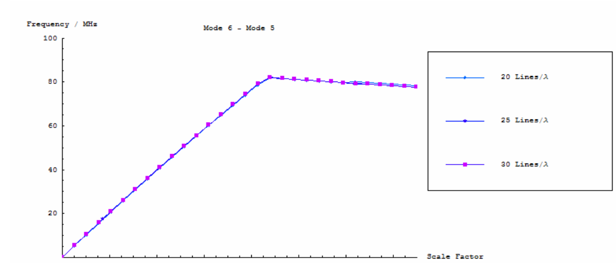

Figure 8: Mode degeneracy for a pillbox cavity extended in one dimension

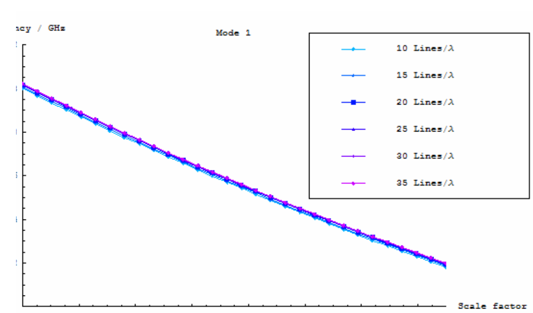

Figure 9: Change in fundamental frequency for a pillbox cavity extended in one dimension

Cavity – Beam Pipe Transition

A 7-cell cavity with broadband HOM dampers has been designed for use within an ERL. One of these dampers is designed to fit around a 56 mm diameter beam pipe (a standard TESLA cavity has a 39 mm beam pipe) therefore a new transition between the cavity and the beam pipe is required. Two options were investigated; these are shown in figure 10a and 10b below.

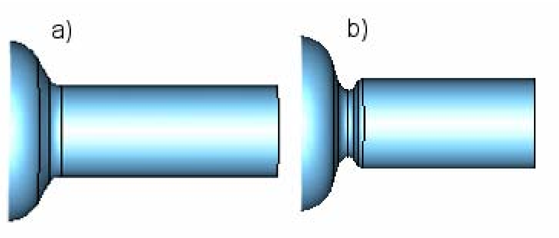

Figure 10: Transition from the cavity to a larger beam pipe for a TESLA type cavity.

The HOMs from these models were used to calculate the BBU threshold; an arbitrary recirculation was used in this model. The results are shown below in Figure 11; the data for a TESLA 9-cell cavity is also shown. It is clear that from the point of view of the BBU threshold, that transition a is the better option. For the fundamental mode the shunt impedance is 772 Ω for transition a and 776 Ω for transition b.

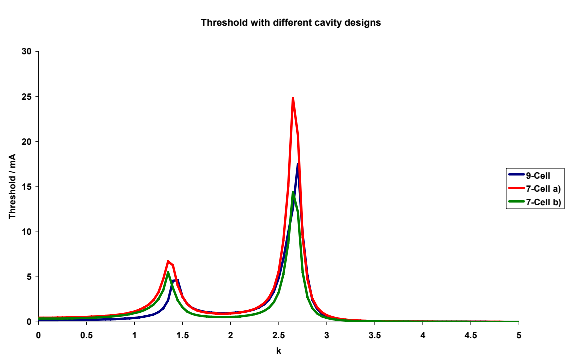

Figure 11: BBU Threshold for different transition from the cavity to a larger beam pipe for a TESLA type cavity.

INVESTIGATING BEAM TRANSPORT

Beam Transport is also important in suppressing the BBU instability. A model calculating the threshold from the equation in [3] was created in Mathematica [4] and the threshold was calculated for a multi-cavity system. Using the threshold equation in this form is useful for investigating trends in the maximum current whilst using only the lattice parameters.

The threshold for various values of α and β against μ for the first cavity in the linac have been plotted in figures 13 and 14 below. Using the assumption from [3] that any negative threshold is unconditionally stable only the positive values of the threshold have been plotted here.

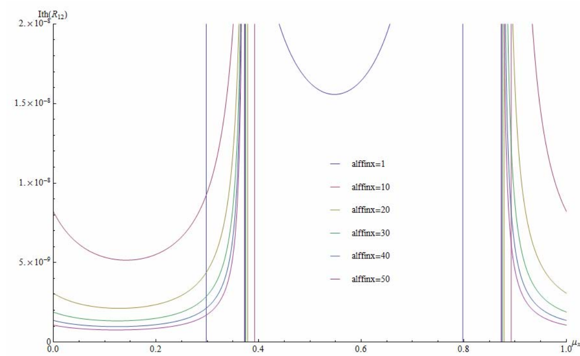

Figure 12: BBU threshold as a function of α and μ.

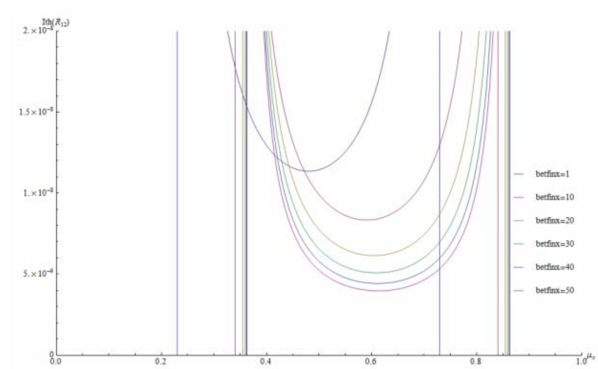

Figure 13: BBU threshold as a function of β and μ.

SUMMARY

Splitting the degeneracy of the dipole mode does increase the BBU threshold and such splitting can be achieved by deforming the cavity. However, the increase in the threshold is minor and the effect on the fundamental mode of the cavity is quite large. Using this method to control the HOMs will require the cavity to be redesigned so as to not disturb the fundamental mode. Where possible the values of α and β for the recirculation back to the linac section should be as small as possible.

REFERENCES

[1] G. Hoffstaetter, I. Bazarov, C. Song, "Recirculating BBU Thresholds for Polarised HOMs with Optical Coupling", Phys. Rev. ST Accel. Beams **10,** 044401 (2007)
[2] Microwave studio www.cst.com
[4] Mathematica, http://www.wolfram.com/
[3] E. Pozdeyev, "Regenerative multipass beam breakup in two dimensions" Phys. Rev. ST Accel. Beams **8**, 054401 (2005)