ALTERNATE CAVITY DESIGNS TO REDUCE BBU

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Abstract

An investigation was undertaken to find alternate cavity designs with the primary aim being to decrease the effect of the higher order modes (HOMs). The cavities were modelled in CST's Microwave Studio™. The number of cells per cavity was examined and the data produced was used in available beam break up (BBU) codes. The results from the BBU codes are presented.

INTRODUCTION

The aim of this paper is to examine cavity design solely from the point of view of BBU for Energy Recover Linac (ERL) accelerators and particularly with regards to the SRF accelerating cavities for the 4GLS shape [1]. The cavity models are based on the TESLA/TTF geometry [2] although no effort has been made to ensure that these models have similar results. The purpose of this study has been to identify general trends; further studies hope to refine the models to produce values closer to those of the TESLA cavity. The modelling begins single-cell geometry and the number of cells is increased and the effect on BBU instability threshold is then observed.

ALTERING THE NUMBER OF CELLS

Generating the Model

3D Models were created in Microwave Studio (MWS) [3] and the number of cells was gradually reduced and their respective of R/Q and Q were recorded. Some of the cavity geometries used are shown in figures 1 and 2 below.

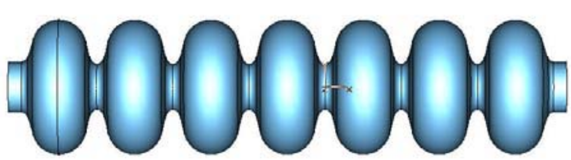

Figure 1: 7-cell cavity.

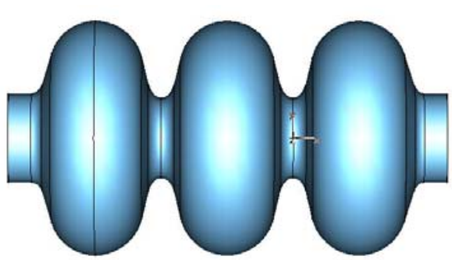

Figure 2: 3-cell cavity.

The HOMs in question have fields like those in figure 3. This is a TM110 mode. These modes can be either in the x or y plane, assuming the beam is travelling along z, and both orientations are often found together separated by anything from a few Hz to a many MHz.

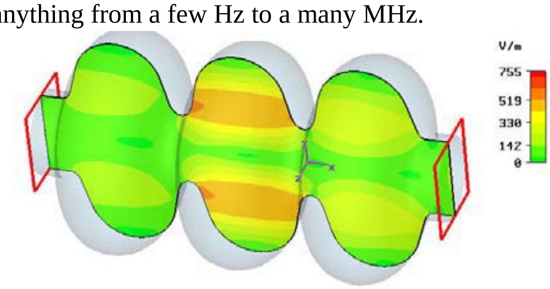

Figure 3: Dipole Field

Microwave Studio Results

The cut-off frequency for the beam pipe is given by [4]

$$\lambda_c = \frac{2\pi a}{U_{m,n}}$$

Where λ_c is the cut off frequency, a is the beam pipe radius and $U_{m,n}$ for a TM110 mode is 1.841 which gives a cut off frequency of 2.25 GHz. Above this frequency the trapped modes are quadrupole, and higher, modes which couple less to the beam and are not a concern for BBU. The frequency, Q and R/Q of dipole HOMs below 2.25 GHz were recorded.

As expected the number of HOMs decreased as the number of cells decreased, since there are fewer cells for the HOMs to be trapped in. Moreover with more cells there are more permutations available, a 2-cell cavity can only trap modes in one or other cell or both cells. A 5-cell cavity can trap HOMs in just 1 cell, 2-cells, 5 cells and any combination there in. This means for a 7 cell cavity there are 2272 combinations, excluding any modes that can be mirrored in the x-y plane. The number of dipole HOMs below 2.25GHz for each cavity configuration is given in table 1 below.

Table 1: HOM Data

Number of Cells	Number of HOMs
1	1
2	4
3	8
4	9
5	11
6	12
7	16

The Q of each HOM was found to be similar, with a value of the order of 1×10^8. In the majority of cases the Q was found to decrease as the HOM frequency increased. This is shown in figure 4 below which shows a Q versus frequency plot for all the cavities studied. This pattern is repeated in figure 5 below which plots R/Q versus frequency for all the cavities studied.

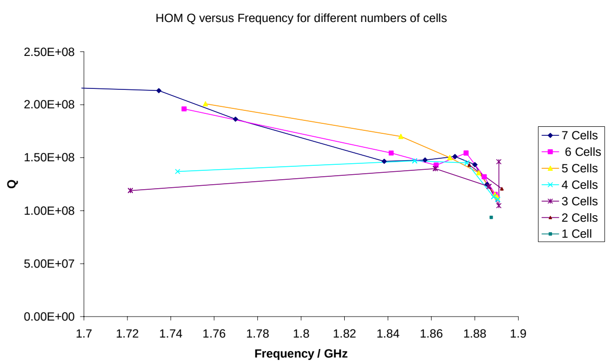

Figure 4: HOM Q as a function of frequency.

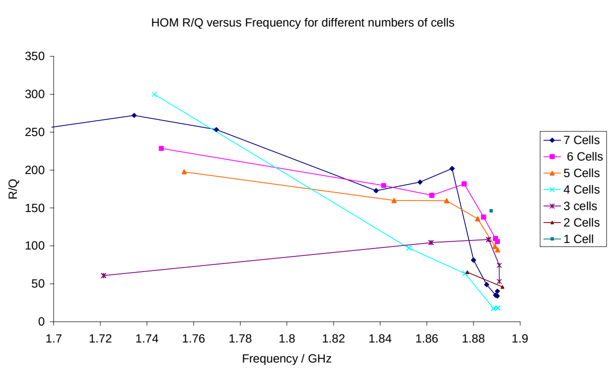

Figure 5: HOM R/Q as a function of frequency.

The frequencies, Q and R/Q of the HOMs from 3-cell cavity are given below in table 2, these show a slight increase in the R/Q and Q until approximately 1.85GHz when they start to decrease.

Table 2: 3-Cell HOM Data

HOM frequency (GHz)	Q	R/Q (Ω)
1.72141	1.19E+08	60.85327616
1.72142	1.19E+08	60.8323712
1.8618	1.40E+08	104.2840178
1.86181	1.40E+08	104.3141729
1.8865	1.23E+08	108.5236457
1.88652	1.23E+08	108.3920108
1.89105	1.05E+08	74.41817014
1.89107	1.46E+08	53.14851453

BBU Results

The HOMs created from these models were run through the ERLBBU [5] BBU code from Thomas Jefferson lab. It is a transverse, two dimensional BBU code that includes the effects of arbitrary angled HOMs in a two pass accelerator. It calculates the transverse regenerative BBU limiting current. The recirculation matrix and the cavities are entered in TRANSPORT notation. Arbitrary recirculation matrix and injection energy was chosen for these calculations. A threshold was calculated for each cavity, figure 6. Given the high Q values of these HOMs, in the region of 1×10^8, the thresholds calculated are small, of the order of μA. Using the 10 HOMs commonly used for this calculation [6, 7] with a TESLA/TTF 9-cell cavity a threshold of 603mA is achieved with the same setup. With further work on this model more realistic HOM Q and R/Q values will be obtained which will give more realistic thresholds.

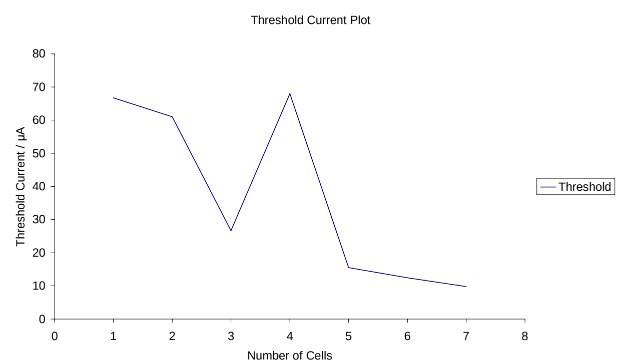

Figure 6: Threshold using ERLBBU as the number of cells is changed.

Figure 6 shows a trend of decreasing threshold as the number of cavities increases. There is a peak for the 4-cell model but this is a small effect and could be due to a number of other factors. One possible factor is a 180° phase shift of the most destructive HOM when the bunch travels through the cavity on its return pass. Hence this threshold could be a factor of the recirculation time chosen rather than the cavity geometry. Table 3 below shows the threshold for each of the 3-cell cavity HOMs individually. The second column gives the threshold when the same recirculation as to produce the data in figure 6 is used. The third column gives the threshold when the length of the recirculation is changed slightly. When all the HOMs are considered in the 3-cell case a threshold of 26μA is obtained using the original recirculation but this jumps to 766mA when altering the recirculation length slightly. The difference this change in length can make is shown in table 3 where the current for some of the HOMs increases from μA to A. However when the HOM frequencies are close to each other they can interfere with each other as in both cases the threshold when all the HOMs are considered is significantly lower than the lowest threshold of any individual HOM in table 3.

Table 3: 3-Cell Individual HOM Thresholds

HOM frequency (GHz)	**Threshold using above recirculation (A)**	**Threshold using above recirculation but with different length (A)**
1.72141	0.000070	10.31875
1.72142	0.000071	10.23125
1.8618	0.000062	5.703125
1.86181	0.000060	5.746875
1.8865	2.473438	1.6859375
1.88652	2.392188	1.6046875
1.89105	4.328125	7.15625
1.89107	6.228125	10.19375

FUTURE WORK

The models discussed above need further work to obtain reasonable values for the Q and R/Q. Additional modelling will include investigating the effects of deforming the cavities to split the degeneracy of some dipole modes to the extent that it will increase the threshold. These will start with deforming the cavities in the x plane, figure 7, then on to deforming them alternately in and y plane, figure 8, before modelling the effect or altering the deformation so that over the length of the cavity it will rotate 360°, figure 9. Should this prove successful the modelling will then go on to include randomly deforming the cavity.

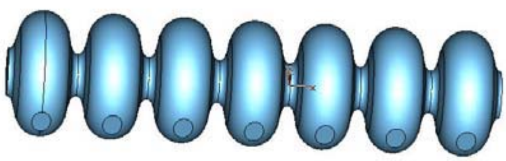

Figure 7: Cavity deformed in 1 dimension.

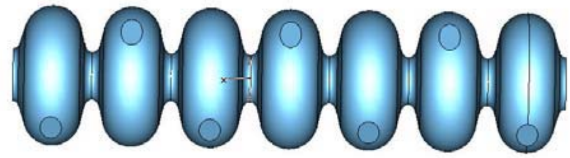

Figure 8: Cavity deformed in 1 dimension.

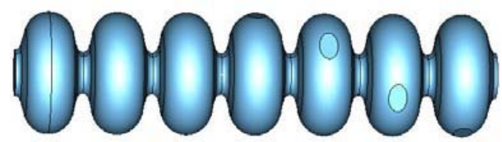

Figure 9: Cavity deformed over 360°.

CONCLUSION

The modelling of cavities with differing numbers of cells has provided interesting results. Further modelling is required to provide realistic values for the cavity Q and R/Q. The number of cells appears not to have a large effect on the threshold. The Qs of the HOMS are very large, which leads to a small threshold and therefore the effect itself is small. Also this is a simple model containing only one cavity; in a larger model containing many cavities this effect may be more pronounced.

REFERENCES

[1] "4GLS Conceptual Design Report", CCLRC Daresbury Laboratory. (2006), available at www.4gls.ac.uk.

[2] B. Aune et al. "Superconducting TESLA cavities", Phys. Rev. ST Accel. Beams, **3**, 092001 (2000)

[3] CST Microwave Studio Code, more information at www.cst.de.

[4] T. Moreno, "Microwave Transmission Design Data" 1st Edition, McGraw-Hill (1948).

[5] E. Pozdeyev, "Regenerative multipass beam breakup in two dimensions" Phys. Rev. ST Accel. Beams **8**, 054401 (2005).

[6] J. Sekutowicz (1994), 'Higher order mode coupler for TESLA', TESLA94-07, DESY, Hamburg, Germany.

[7] S.M. Gruner et al. (2001), `Study for a proposed Phase I Energy Recovery Linac (ERL) Synchrotron Light Source at Cornell University', CHESS Technical Memo 01-003 and JLAB-ACT-01-04.