4GLS CAVITY CONSIDERATIONS FOR BBU

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Abstract

As part of the 4GLS [1] design study there is a requirement to investigate the effects of the ferrite dampers, cavity perturbations and linac focusing on the Beam BreakUp (BBU) threshold. Higher Order Modes (HOMs) trapped in long cavity structures can cause instabilities within the electron beam that could lead to BBU at lower currents than those required. This paper outlines some of the studies carried out to assess the limitations of the 4GLS design.

INTRODUCTION

This paper aims to discuss two methods for achieving the 100 mA current required for 4GLS. First it will discuss the HOM absorbers, their design and their effect on the BBU threshold. It then considers making the cavities slightly elliptical, by creating a distortion of 3mm in one axis, with the aim of splitting the degeneracy of the dipole modes. Finally the adjustment of the focusing between the modules of the main linac is discussed. Initial estimates of the threshold are made using the information for TELSA 9-cell [2] cavities before calculations are made for a basic 7-cell cavity model from Microwave Studio (MWS). The second method will look at altering the cavity shape to lower the threshold.

FERRITE DAMPERS

Ferrite dampers are to be used on the 4GLS cavities to minimise the Higher Order Modes (HOMs). These consist of a ring of ferrite and ceramic tiles. These are made of three different materials: TT2-112R is used to damp HOMs with frequencies lower than 10 GHz; the material CO2Z is used to damp the mid to high range of frequencies, with frequencies greater than 25 GHz; a ceramic, ceralloy, is used to damp the high frequency HOMs, those greater than 50GHz. The arrangement of these tiles is given in Figure 1 below [3, 4].

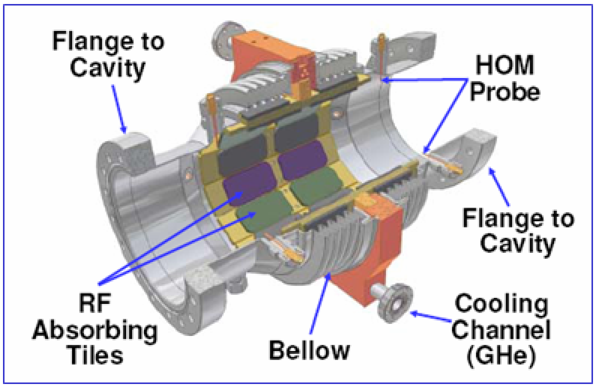

Figure 1: Ferrite Damper

One of these dampers is placed at each end of the cavity. In addition to the ferrite and ceramic tiles along the beam pipe there are also absorbers between the beam pipe and the bellows to trap the high frequency HOMs that can become trapped in this region. The beam pipe has been widened at one end to allow for greater HOM propagation. Figure 2 below shows a cryomodule containing two of these cavities. The larger beam pipes are situated at the end of the modules. The absorber from Figure 1 can be seen in the centre of the module.

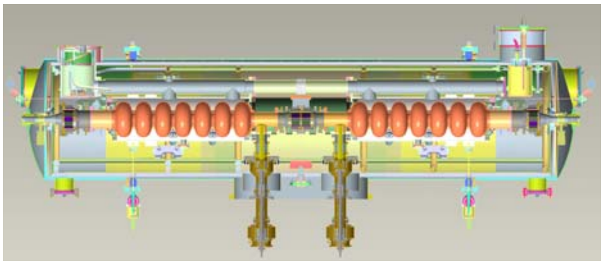

Figure 2: Cavity diagram showing enlarged beam pipe

A preliminary model of this cavity was created in MWS. This simple approximation, shown in Figure 3, contained a cavity with 7 TESLA type cells and two continuous rings of TT2-112R ferrite, one of 76 mm and the other of 106 mm radius.

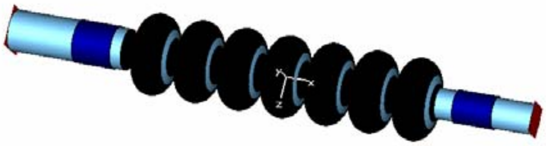

Figure 3: Initial cavity model

The damping of the HOMs provided a 30% increase in the BBU threshold previously calculated for 4GLS with a 9-cell cavity without broadband absorbers. The threshold for this model for various k values of the linac focusing quadrupoles is shown in Figure 5 (in the Linac Focusing section). It has a peak value of 130 mA in comparison to the same calculation with a 9-cell tesla cavity, which has a peak threshold of 98 mA. The electromagnetic solvers used for these calculations are unable to provide an accurate solution for these ferrite materials. The effect of the dampers can be modelled to a fair degree of accuracy by assuming an open port boundary allowing the majority of the modes to propagate through the beam pipes.

CAVITY PERTURBATIONS

It is possible to increase the BBU threshold by making small indentations to each cell of the cavity so as to split the degeneracy of any dipole modes. Three different options were studied in this preliminary investigation. The first involved making a deformation in one plane of the cavity (Figure 4a). The second was to deform the cavity alternately in y then the z plane (Figure 4b). Finally the deformation was made such that over the length of the cavity it will rotate 360° (Figure 4c). Alternative options, such as randomly orienting the indentations, have not been investigated yet.

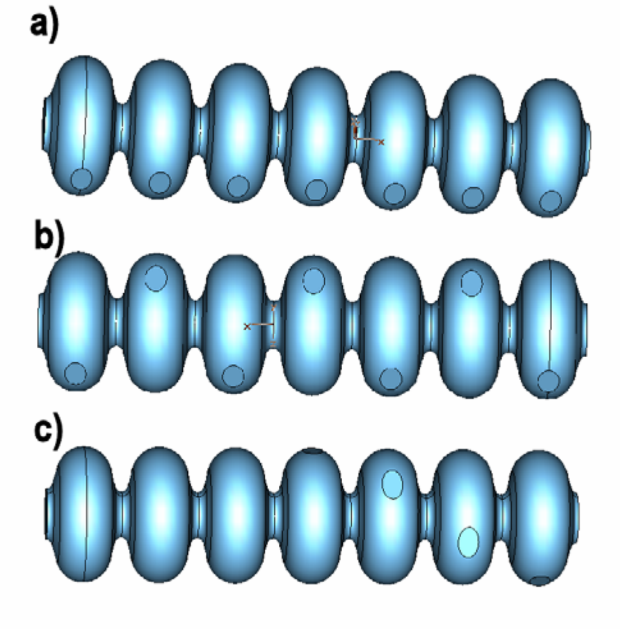

Figure 4: Different cavity configurations

By deforming the cavity in just one plane the BBU threshold is seen to double. The largest benefit was achieved by alternately deforming the cavity in the y and z planes, giving an order of magnitude increase. No change is seen in the threshold when the indentation is rotated around the cavity.

Further work will concentrate on confirming these results by further modelling in Microwave Studio and numerical methods.

LINAC FOCUSING

Focusing Schemes

The graded gradient scheme [5] was chosen for 4GLS [6]. In this scheme the focusing magnets are always matched to the low energy beam, therefore the accelerating beam is matched for the first half of the linac and the decelerating beam for the second half. The focusing was investigated with a triplet, doublet and singlet of quadrupoles between each module. The triplet was set up with a defocusing – focusing – defocusing format with strengths of -1/2k, k, -1/2k. This option should give the greatest amount of flexibility. The doublet was set up in a –k, k fashion and the singlet option alternated between –k and k in between each module. The singlet option was investigated for completeness as a useful threshold was not expected. The doublet and singlet cases were investigated twice, once replacing the magnet removed with a drift space (the ‘long’ case) and the second time reducing the distance between the modules (the ‘short’ case). Both magnets and drift spaces were assumed to be 0.3 m long.

Calculating the BBU threshold

The current threshold for a single cavity with recirculation has been calculated in many papers, e.g. [7], and is given by the analytical formula below:

$$I_{th} = \frac{-2p_{\mathrm{r}}}{e\left(\dfrac{R}{Q}\right)_m Q_m k_m R_{ij} Sin(\omega_m t_r)}$$

where $(R/Q)_m$ is a figure of merit and Q_m is the quality factor for the transverse higher order mode (HOM) m with frequency ω_m, while $k_m = \omega_m$,/c is the wave number of mode m and p_r is the momentum of the recirculating beam. R_{ij} is the transfer matrix for the entire recirculation from the cavity exit back to the cavity entrance. To obtain the threshold for a linac with many cavities the thresholds are calculated using the analytical BBU code; ‘bi’ developed at Cornell [8].

Scanning the Focusing Magnet Strength

The aim of this work was to understand the quantitative impact of different linac focussing schemes on the BBU threshold to see whether the cheaper option of doublets between the modules could be chosen at this stage in the design study.

The effect of magnet strength on the threshold was investigated. The k value was altered between 0 and 5 m^{-2} and bi was run via a script, to facilitate processing of the output, and at each setting a threshold current was obtained. Once the best value for the current threshold was obtained, a further matching was carried out using MAD8. In this additional matching, the Twiss parameters were varied at the start of the linac to find the values which kept the beam size small throughout the linac.

The singlet scheme produced the worst results with its threshold peaking at 16 mA for both the short and long cases. The triplet gave a broader spread of good threshold region than the other two with a threshold above 30 mA when $2.15 < k < 3.7$, however the maximum current was found to be only 56 mA. The doublet has a slightly narrower peak with a threshold above 35 mA over a range of $1.2 < k < 2.9$ and a maximum of 85 mA for the long case and 98 mA for the short case with the majority of the peak remaining above 35 mA for a range of $1.2 < k < 2.4$. The singlet, doublet and triplet results can be seen in Fig 5.

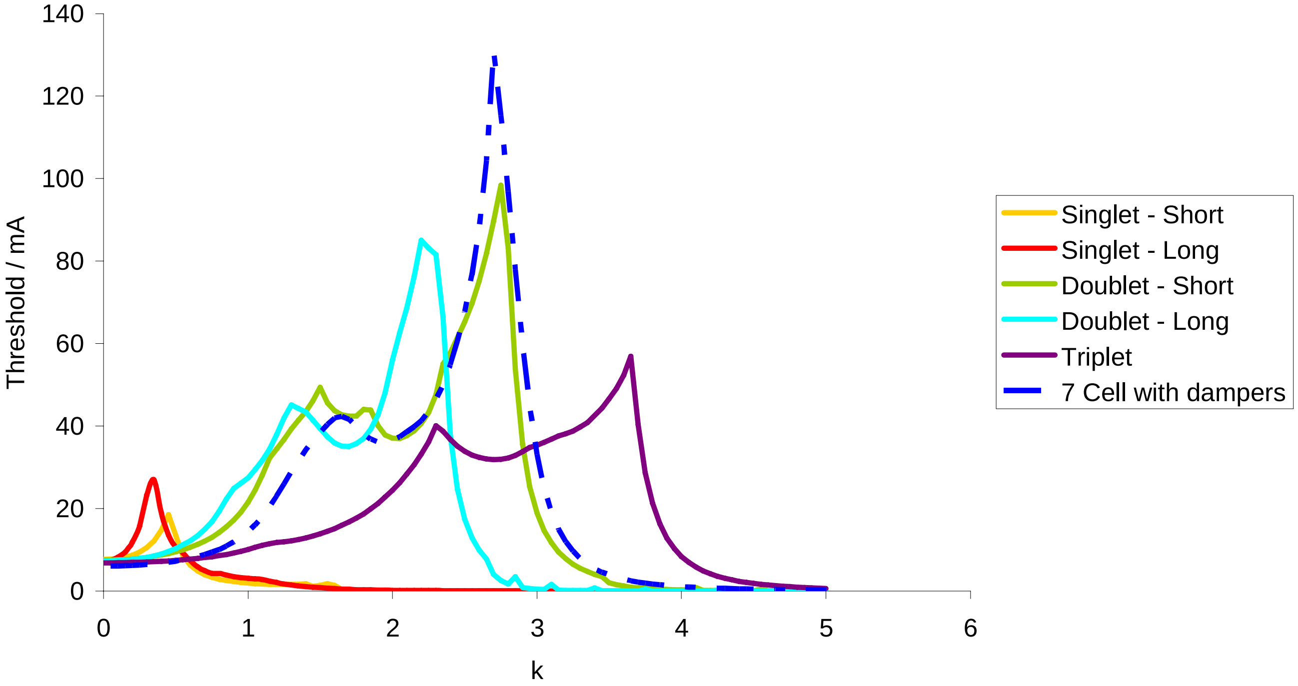

Figure 5: Current threshold vs. k value.

This plot suggests the doublet short focusing would be the best option since it has relatively broad region of high current threshold. These simulations will need to be updated as the 4GLS cavity design progresses. It is expected that the calculated thresholds will be much greater in the final simulations as these will include the 7-cell HOM damped cavities recommended in the 4GLS CDR [6] which will minimise the HOMs through improved dampers and couplers. The possibility to further improve the threshold through the use of skew quadrupoles [9, 10, 11] will also be considered.

CONCLUSION

Initial modelling for the 4GLS design study suggests that a BBU threshold of 100 mA is achievable although thresholds in the order of Amps reported by Cornell [12] and JAEA [13] will take further study. It is possible that random defects within manufacturing tolerances could improve the BBU threshold further.

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