LINAC FOCUSING AND BEAM BREAK UP FOR 4GLS

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Abstract

As part of the design for 4GLS the linac focusing and its effect on the beam break up (BBU) threshold have been studied. The choice of graded gradient focusing scheme is discussed and initial models of the focusing, using a triplet of quadrupoles between each of the modules within the linac, are presented. The quadrupoles were set-up in a defocusing – focusing – defocusing format with strengths of -1/2k, k, -1/2k. Using these models the BBU threshold was computed using available codes assuming a 9-cell TESLA cavity within the linac and a 7-cell design with HOM dampers. A sweep of the magnet strength with respect to the BBU threshold showed that there is an optimum setting.

INTRODUCTION

The 4GLS design for 100 mA current is challenging from the point of view of BBU. The beam will pass through 5 superconducting modules, each containing eight 7-cell cavities, in 77 pC bunches to accelerate the beam from 10 MeV to 600 MeV. Since 4GLS is an energy recovery linac these accelerating bunches will be interlaced with decelerating ones. This means that the first and last modules will be the most vulnerable to BBU. The choice of focusing scheme throughout the linac will be of importance to avert beam break issues and this paper will look at the focusing scheme solely on this issue.

GRADED GRADIENT SCHEME

The graded gradient scheme [1] was chosen for 4GLS. By choosing this scheme the focusing magnets are always matched to the low energy beam, the accelerating beam for the first half of the linac and the decelerating beam for the second half of the linac. The initial implementation was with a triplet of quadrupoles between each linac module [2], to allow for greater flexibility. Subsequently, quadrupole focusing as provided by doublets was found to be sufficient.

CALCULATING THE BBU THRESHOLD

For a single cavity with recirculation, the threshold current may be given by the analytical formula below

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

where $(R/Q)_m$ and Q_m are the shunt impedance and quality factor for the transverse higher order mode (HOM) m with frequency ω_m, $k_m = \omega_m/c$ 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. This formula may readily be extended to longitudinal HOMs for the case of longitudinal BBU, however this is believed to be a much weaker effect when compared to transverse BBU so it is not considered in this paper.

To obtain a value for the current threshold for an entire linac, it is necessary to consider possible interactions of HOMs from one cavity to the next so it is necessary to use a computer model. The most practical computer code available was found to be the bi code from Cornell [3]. For these calculations HOMs from a 9 cell TESLA cavity were used [1,4].

FOCUSING SCHEME

As stated earlier the original design for 4GLS included a triplet for focusing between each linac module. For this study doublet focusing was also investigated and the results were compared and a focusing scheme chosen. To complete the investigation singlet focusing was also considered although an adequate solution was not expected. Along with the number of magnets required the magnet strength was also varied as was the allowed drift space from module to quadrupole and in between quadrupoles. For the doublet and singlet focusing cases, the module to quadrupole drift space was allowed to vary so as to see the effect on the current threshold.

SCANNING THE FOCUSING MAGNET STRENGTH

To investigate the effect of magnet strength on the BBU threshold the k value was altered between 0 and 5 m^{-2} and bi was run via a script, to facilitate processing of the output, at each setting a threshold current was obtained. To produce a solution, once the best values 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 in order to find the best values which kept the beam size small throughout the linac.

Triplet Versus Doublet Versus Singlet Focusing

For the triplet case the magnets were set up in a defocusing – focusing – defocusing format with strengths of -1/2k, k, -1/2k in one plane. This is shown schematically in Fig. 1 where modules are shown in yellow and quadrupoles in red.

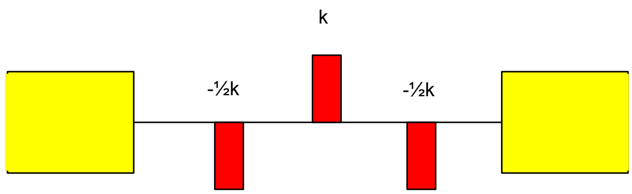

Figure 1: Triplet setup with quadruoles in red and modules in yellow.

Each magnet was assumed to be 0.3 m long and they were separated from each other by a drift of 0.3 m.

The doublet case is similar with a focusing – defocusing setup with strengths of –k, k, Fig. 2. Again the magnet was assumed to be 0.3 m long but there were two options available for the positioning, the first is to decrease the length between linac modules by the length of a drift and a magnet, the short case, or to increase the drift space between the two magnets, the long case.

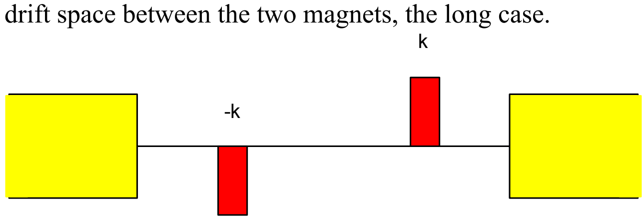

Figure 2: Doublet Setup.

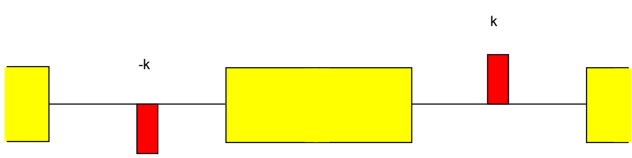

Figure 3: Singlet Setup.

A similar option is available for the singlet case, where the magnets alternate between focusing and defocusing between each module.

These three schemes gave significantly different answers, as expected the singlet produced the worst results with a threshold peaking at 16 mA for both the short and long cases. The triplet gave a broader spread or good threshold region than the other two with a threshold above 30 mA when 2.15 < k < 3.7, however only allowing for a peak current of 56 mA. The doublet had a slightly narrower peak with a threshold above 35 mA over a range of 1.2 < k < 2.9 and a peak of 98 mA for the short case and remains above 35 mA for a range of 1.2 < k < 2.4 and a peak of 85 mA for the long case. The singlet, doublet and triplet results can be seen separately in Figs. 4, 5 and 6 with Figs. 4 and 5 showing both the short and long cases on the same plot.

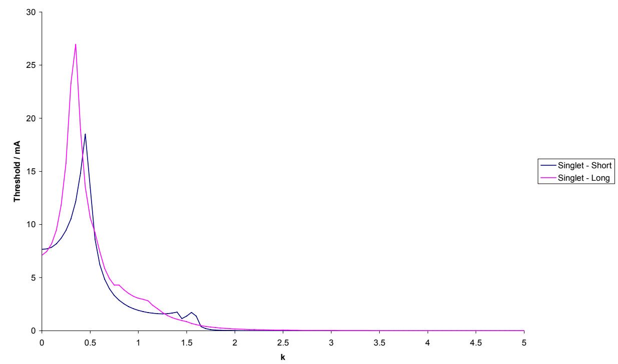

Figure 4: Singlet Case, Current threshold vs. k value.

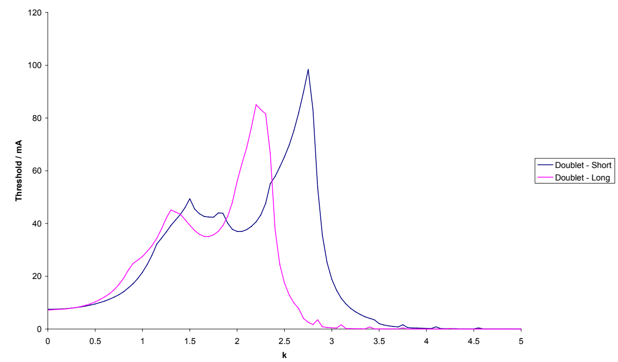

Figure 5: Doublet Case, Current threshold vs. k value.

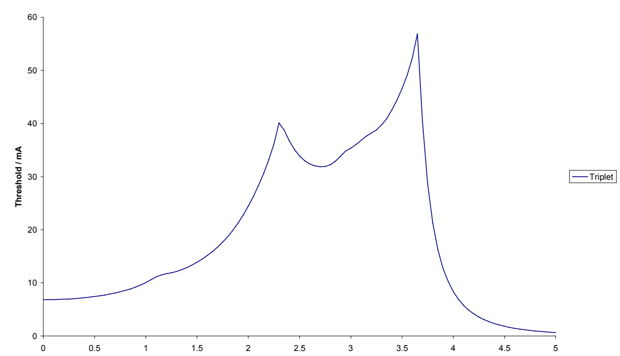

Figure 6: Triplet Case, Current threshold vs. k value.

When the distance between the modules is decreased to accommodate the lesser number of magnets, instead of replacing them with drift tube, the basic shape of the curve stays the same but the threshold increases slightly and shifts along the k axis. This shift is due to the corresponding change in recirculation path length. This effect is best seen in Figs. 4 and 5 where the different doublet and singlet models are compared. To compare the focusing schemes, the short case is plotted in Fig. 7 and the long case in Fig. 8.

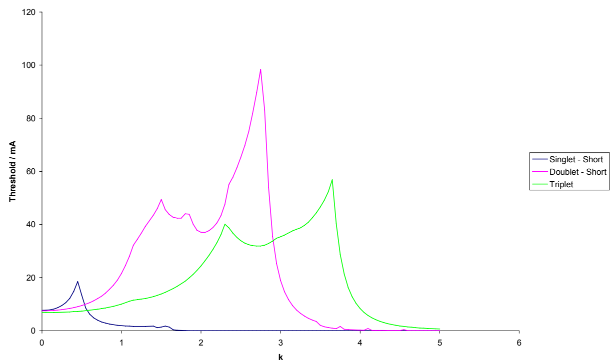

Figure 7: Threshold for changing k value with gap between modules decreasing.

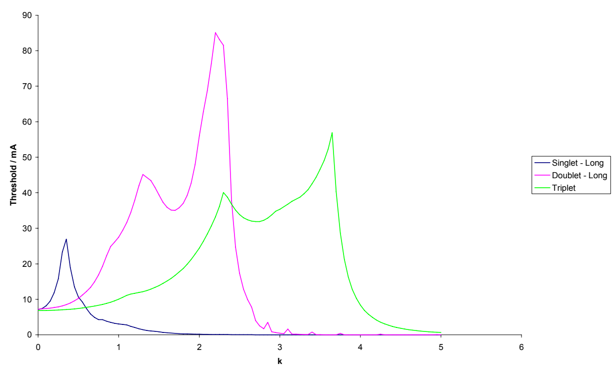

Figure 8: Threshold for changing k value with gap between modules staying the same.

As may be seen from the last two figures, the best option appears to be the short doublet focusing case giving a relative broad current threshold which peaks at 98 mA. The aim of this work was to understand the quanitative impact of different linac focussing schemes on the BBU threshold, which would provide an indication of whether the cheaper option of doublets between the modules could be chosen at this stage in the design study. The further simulations will be required to estimate the BBU threshold as the 4GLS cavity design progresses. It is expected that the calculated thresholds will be much greater in the final cavity design which aims to minimise the HOMs through improved dampers and couples in a 7-cell configuration. The possibility to futher improve the threshold through the use of skew quadrupoles [5, 6, 7] will also be considered.

MODELLING THE 7-CELL CAVITY WITH HOM DAMPERS

The 4GLS CDR [2] recommends the use of 7 cell cavites with HOM dampers at each end of the cavity. To obtain an initial estimate of the BBU current threshold with this design, a preliminary estimate of HOMs was produced using a rough Microwave Studio (MWS) model of a 7-cell cavity as shown in Fig. 9. It contained a cavity with 7 TESLA type cells and two rings of TT2-112R ferrite, one of 76 mm and the other of 106 mm radius. The rings of ceramic are an approximation since the dampers will require cooling to 80 K and will be made from small tiles rather one large chunk of material.

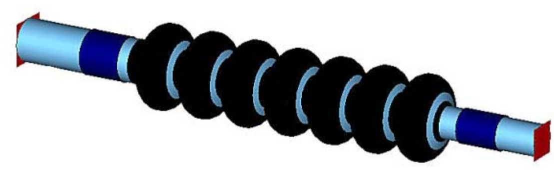

Figure 9: Crude 7 cell cavity model.

The HOMs from this model gave a peak current BBU threshold of 130mA using a doublet of focusing magnets between the cavity modules. This threshold is very encouraging and refinement of this simulation model will provide the starting point for future work.

CONCLUSION

Different focusing schemes were looked at for the 4GLS linac and an optimal one containing doublet focusing between the modules was shown to be the better option giving a peak BBU current threshold of 100 mA

The use of the 7 cell cavity should improve this further. Further modelling of this cavity is required to get a more accurate value of the threshold. The model will need to include power and HOM couplers and far more accurate representation of the HOM dampers.

This threshold can be pushed higher by use of optical and feedback systems to obtain a value with a large safety margin.

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