TW-STRUCTURE DESIGN AND E-FIELD STUDY FOR CLIC BOOSTER LINAC*

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Abstract

Using the SUPERFISH code we present a design for a traveling wave (TW) structure of the Booster Linac for CLIC. The structure, consisting of thirty asymmetric cells attached to the beam pipes at two ends, works in $\frac{2\pi}{3}$ operating mode at working frequency 2 GHz.The RF field transmitted through the designed cavity is prepared in an RF field data file to be used in the PARMELA code. We will then compare the resultant output PARMELA field with that of the ideal RF field which obtained from the usual method for a traveling wave structure.

BOOSTER LINAC OF THE CLIC INJECTOR COMPLEX

The Compact Linear Collider (CLIC) is a linear collider facility for a future electron-positron collider working at high frequency traveling-wave structures at room temperature. The CLIC main Beam Injector Complex consists of several parts including two sources of $e^+$and e^-, pre-injector e^+ and e^- Linacs, a single 2 GHz Injector Linac which accelerates both electron and positron beams [1], bending magnet separates the electrons and the positrons, pre-damping and damping rings, Buncher and Booster Linac. A layout of the CLIC injection complex may be found in *e.g.* [2]. A first design of the Injector Linac was described in [3,4].

In this structure a common 2 GHz Booster Linac is used to accelerate the beams up to 9 GeV. Based on primary design of the Booster Linac [5] the detailed design has been worked out in [6]. In this design the Booster consists of several Linacs each of which has 1.5 m length. Each Linac has thirty non-periodic cells which is designed with the assumption of quasi constant gradient structure for each cell. The cell parameters for the first, middle and the last cells are roughly calculated in [5] using the HFSS code. The general feature of the linac is as follows. The length of each cell is 5 cm, and the iris thickness of it is 8 mm. The working frequency is 1999 MHz for $\frac{2\pi}{3}$ operating mode. The aperture size of the cells is tapering from 2.0 to 1.4 cm so that the group velocity decreases through the structure and the gradient goes up cell by cell.

The aim of this paper is to study the detailed design of the TW structure of the CLIC Booster Linac, using the SUPERFISH code. In the following, having found the geometry, different parameters of the cavity and the RF field configuration, we prepare the E field data file for the whole structure importing to PARMELA code. Finally we will make a comparison between this E field with the ideal E field that will be obtained using the usual method for a traveling wave structure.

GEOMETRY OF BOOSTER LINAC

To find the desired design, we shall first find the size of each cell such that it has $\frac{2\pi}{3}$ operating mode with the working frequency 1999 MHz. Then we connect all cells to build the thirty non-periodic cells structure. In general we will have to tune the size of the cells to make sure that the whole system still works at the desired mode and frequency. Finally one needs to attach the structure to the beam pipes from both ends and fine tune the sizes once more to get the corrected mode and frequency.

As a first effort to obtain the TW structure, one needs to obtain the desired frequency and mode for each cell, separately. To proceed following [7] one should tune the cell size, b, for a three symmetric cells with given aperture size so that the obtained structure exhibits a $\frac{2\pi}{3}$ mode at the desired frequency. Practically, one first obtains the zero and π modes of the three cells structure which in turn can be used to read the frequency of $\frac{2\pi}{3}$ mode from the following formula

$$f_n^2 = (1 + k(1 - \cos\frac{n\pi}{3})f_0^2, \qquad n = 0, 1, 2, 3. \tag{1}$$

where k is a coupling constant which can be found if one knows the frequencies of zero and π modes. Then the result may be used to read the frequency of $\frac{2\pi}{3}$ mode for $n = 2$.

Having found the frequency, one can take it as an input data for the SUPRFISH code to find the desired $\frac{2\pi}{3}$ mode field configuration. This can be done by imposing a proper boundary condition and tuning the cell size too.

One has to redo the same procedure for all thirty cells. A typical on axis electric field configuration of the three periodic cells geometry extracted from the SUPERFISH code is depicted in the figure 1.

It is worth noting that for a given $\frac{2\pi}{3}$ mode of the standing wave (SW) structure of the three periodic cells, there are two field configurations corresponding to two different boundary conditions one may imposed. We note, however, that since the electric field map in the snapshot $\omega t = 0$ of the TW structure, up to a numerical factor, is the same as that of the cosine solution of the SW with the Neumann boundary condition, one can uniquely find the TW electric field map from the Neumann boundary condition of the SW structure.

Of course for these two SW and TW structures, the corresponding field configurations of magnetic fields are different [7].

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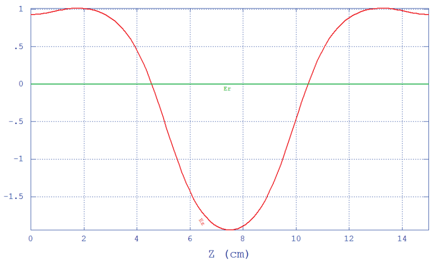

Figure 1: The on axis electric field with the geometry of three periodic cells for 3rd cell extracted from SUPERFISH.

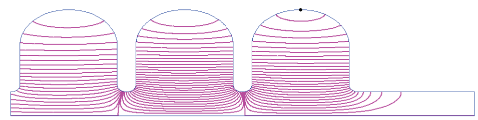

Figure 2: The E field configuration for the last cell attached to the beam pipe, tuned for the $\frac{2\pi}{3}$ mode at the frequency 1998.9966 MHz

Using the above procedure we can find the size of thirty cells of the Booster Linac. The results are presented in reference [6].

In order to maintain the constant gradient structure we have used the tapering aperture size for the cells. It also cause to have a group velocity which decreases as one passes from one cell to the next one.

It is however important to note that the whole desired structure contains the beam pipes as well. As we have already mentioned adding the pipe will affect the mode and the frequency of the structure and therefore further tuning is needed.

In what follows we will re-consider the first and the last cells when the beam pipes are also attached to the cells. In general adding the beam pipes causes a change in the mode and frequency of the cells and a new tuning is needed.

The tuning must be done in a way that while the geometry maintains the desired mode and frequency, the minimum filed is leaked into the bore tube. Taking these requirements into account we have found the corresponding geometry as given in the table 1.

Table 1: The first and last cells sizes and their frequencies for $\frac{2\pi}{3}$ mode

Beam pipe	Pipe radius (cm)	Cell size (cm)	Frequency (MHz)
Input pipe	1.98	6.4376	1999.0254
Output pipe	1.42	6.2904	1998.9966

We have presented the field configuration of the last cell attached to the bore tube for the $\frac{2\pi}{3}$ mode in the figure 2 . Of course one may do the fine tuning in every three other modes with the corresponding frequencies.

So far we have found the geometries of middle cells and the end cells, separately. Now in this subsection we would like to study the the whole structure of the Booster Linac consisting of thirty non-periodic cells connected to two beam pipes at two ends.

Actually due to the fact that we are dealing with a non-periodic structure after connecting all cells and the beam pipes, typically, we will lose both the mode and the frequency. Therefore one will have to look for a new frequency of the structure for $\frac{2\pi}{3}$ mode which will be slightly different form the thirty symmetric cells with the beam pipes. In the present case the ultimate frequency we will find for the corresponding $\frac{2\pi}{3}$ mode is 1998.4673 MHz.

The obtained structure with the E field configuration of the 30 cells Booster Linac after tuning of the whole structure for $\frac{2\pi}{3}$ mode has been shown in [6] .

Having found the geometry of the Booster Linac one may study different properties of the structure from the output file of the SUPERFISH code. In particular the on axis electric field along the Booster Linac is given in the figure 3.

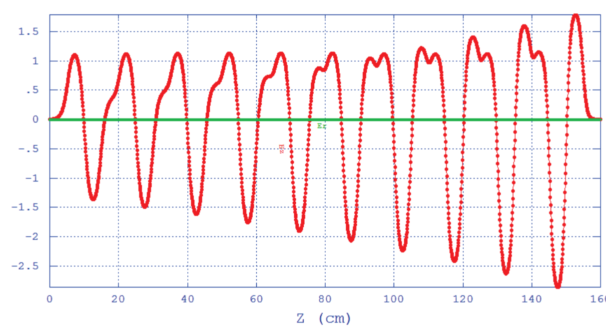

Figure 3: The axial electric field for the Booster Linac obtained from SUPERFISH

From the figure 3 one observes that the obtained E field is slightly different from the ideal field. The difference might be due to reflections from the aperture and the beam pipes taking into account that we are dealing with a non-periodic structure with . Indeed we have checked that for a symmetric periodic structure the reflections disappear yielding to an ideal E field configuration.

ELECTRIC FIELDS FOR PARMELA

The output file of the SUPERFISH code can be used to study beam dynamics of the Booster Linac using the PARMELA code. To do so, one needs to prepare an appropriate input file for the PARMELA.

Actually having SUPERFISH results there are several ways one may import the electric fields of a TW cavity into the PARMELA code. Here we have constructed an electric field data file compatible to PARMELA in such a way that the whole Linac structure is taken as one cavity field line.

More precisely we have used just one cell line to introduce the entire non-symmetric RF cavity instead of using several

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TRWAVE lines. To do so, one should consider the whole cavity as a cell in the SUPERFISH code and also normalize the average E field of the "cell" to one. We have plotted different fields extracted from PARMELA in the figure 4 for the snapshot $\omega t = 0$. Note that the on axis E field is exactly the same as that obtained from SUPERFISH, as expected. It is also constructive to compare the above results

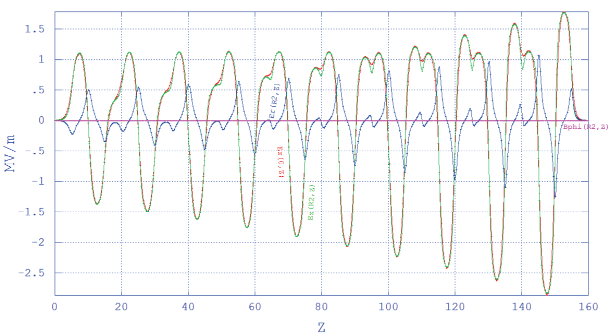

Figure 4: The RF field extracted from PARMELA at $\omega t = 0$ for designed booster

we obtained from PARMELA with those we could have gotten using usual method for importing a traveling wave structure E field to PARMELA. In this method one needs to consider E field related to the first and last half cells of 30 cells while the bore tube is also attached to the structure. Moreover we will have to find an interpolation of Sine and Cosine solutions of one and half cell structure of the first cell. The fields of the middle cells may be also interpolated from the *.Acc* input file's TRWAVE lines, separately.

Having found the cell parameters of each cell at 1999 MHz at $\frac{2\pi}{3}$ operating mode, the output power of n th cell is given by :

$$P_{\text{in}}^{(n)} = P_0 \prod_{i=1}^{n-1} e^{-2L\alpha_i} \tag{2}$$

where P_0 is the input power and the attenuation constant α can obtained by:

$$\alpha = \frac{\omega}{2v_g Q} \tag{3}$$

The group velocity of each cell has been calculated in [6]. For the 1 MW input power, the $E_0 T$ value for each cell is calculated . By making use of this method one can find the traveling wave E field which has been plotted in figure 5, up to a normalization factor.

One observes that using this method we have obtained the ideal E field without reflection effects.

Of course in reality, due to the non symmetric cells, there will be some reflective effects as we have already seen in the figure 4.

Note also that the ideal fields shown in the figure 5 has $\omega t = 300$ phase difference with those in the figure 4.

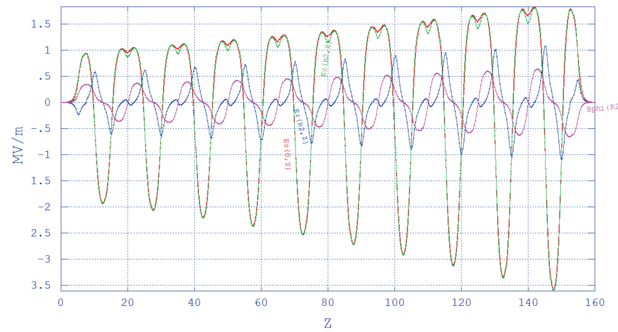

Figure 5: The RF field extracted from PARMELA at phase $\omega t = 300$ using usual method

CONCLUSIONS

In this note by making use of the SUPERFISH code we have designed the TW structure of the Booster Linac for CLIC. We have found the geometry of thirty non-periodic cells attached to two beam pipes at two ends. The whole structure works in $\frac{2\pi}{3}$ operating mode at the frequency 1998.4673 MHz. We have also prepared two distinct RF field data files to be used in the PARMELA code. While in the first method the effects of reflection can been seen, from the second one we have found the pattern of ideal fields.

ACKNOWLEDGMENTS

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