DESIGN, SIMULATIONS AND COLD TESTS OF A PLANE WAVE TRANSFORMER (PWT) LINEAR ACCELERATOR

Arvind Kumar, K. K. Pant and S. Krishnagopal, Beam Physics & FEL Laboratory, Centre for Advanced Technology, Indore-451320, INDIA

Abstract

We have designed and built a 4-cell Plane Wave Transformer (PWT) linac structure, designed to operate at 2856 MHz in the π mode. The 210 mm long structure has been designed based on extensive simulations performed using the codes SUPERFISH and GDFIDL, which were used to obtain a tolerance map for the frequency and other electrical parameters of the structure. Two prototypes were made to address the various fabrication issues, and to compare results obtained from cold tests with those predicted by simulations. Based on this, the final structure now has been fabricated and cold tested, the results from which agree very well with those predicted by GDFIDL simulations.

1 INTRODUCTION

The PWT linac being built at CAT is proposed to drive a free-electron laser (FEL) at 80 μm using a 10 MeV electron beam. At such moderate energies, PWT linacs have proven to compare favourably with conventional linac structures in terms of their electrical properties like shunt impedance, quality factor etc. [1-3]. An additional advantage of the PWT linac is its ease of fabrication on account of its relaxed dimensional tolerances. This structure has high inter-cell coupling of electromagnetic fields. This was an important consideration in our choice to build a PWT structure for FEL experiments.

As the first step towards building a 10 MeV PWT linac at CAT, we designed and fabricated a 210 mm long, 4-cell (three full + two half cells) structure and performed 'cold-tests' on it. A schematic of this structure is shown in Fig.1.

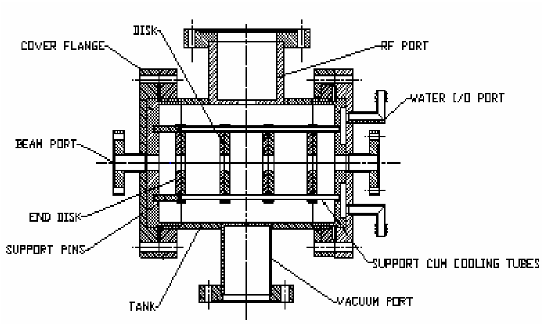

Figure 1. Schematic of 4-cell, PWT linac structure.

In order to have a good understanding of the agreement between simulations and cold-test results, disks of different diameters were assembled inside a tank structure and the resonant frequency thus obtained compared with those predicted by simulations. Based on this, and on the experience obtained from design and fabrication of two prototypes, the PWT structure was designed to resonate at 2856 MHz. A resonant frequency of 2855.7 MHz has been measured for this structure.

In the next Section, we discuss simulation results obtained using SUPERFISH and GDFIDL codes. Section 3 discusses the results from cold tests of the PWT structures, followed by discussion on the beam dynamics in Section 4 and conclusions in Section 5.

2 RF SIMULATIONS

The dimensions of the first prototype PWT structure were fixed using SUPERFISH simulations to resonate at 2856 MHz in the π mode. Although SUPERFISH is a 2-D code and cannot simulate the non-axisymmetric components like support tubes, the results are useful for a first study of the structure to understand its electrical properties. In addition, SUPERFISH gives the electric field distribution at every point inside the structure, which is used to fix the location of the support tubes in the region of minimum electric field to cause a minimum perturbation in the resonant frequency of the structure. For the first prototype PWT linac with the disk diameter of 85.2 mm, support tubes were fixed at a radius of 36.0 mm. This was the zeroth order approximation; the actual placement of tubes perturbs the electric field profile locally and could still perturb the resonant frequency quite significantly as confirmed using GDFIDL simulations. Figure 2 shows variation of the resonant frequency with the location of the support tubes for a fixed tube and disk diameter.

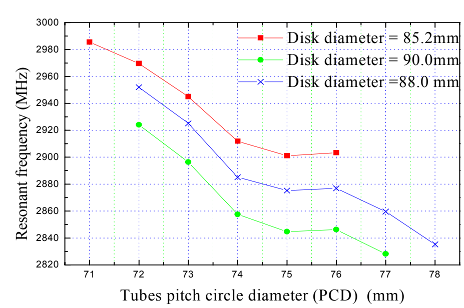

Figure 2. Variation of resonant frequency as a function of the location of the support tubes.

SUPERFISH simulations are also useful in fixing the location of the cooling channel machined inside the disks. Location of the water channel is chosen to match the region of maximum power dissipation on the disk surface. To evolve a mechanical engineering design of the structure, extensive simulations were done to generate a tolerance map of the resonant frequency of the structure to machining errors, by physically introducing inaccuracies in different dimensions of the structure [4]. Simulations predicted that the resonant frequency is more sensitive to any perturbation that causes an increase in the total length of the structure as compared to an increase in length of one cell compensated by a corresponding reduction in the length of the neighbouring cells. The resonant frequency varies by about 4 MHz/mm with the total length of PWT structure.

For the first prototype PWT linac, the resonant frequency of the operating mode was expected to be different from that simulated by SUPERFISH due to the presence of support tubes. Table 1 gives a comparison of the resonant frequency and electrical parameters of the PWT structure as predicted by SUPERFISH and GDFIDL.

Table 1: Comparison of various RF parameters with SUPERFISH and GDFIDL simulations

RF parameters	SUPERFISH	GDFIDL (3-D)
F_0	27676 MHz	2857 MHz
Q_0	26,339	22,226
R_s	67 MΩ/m	79 MΩ/m
r_s/Q_0	1392 Ω/m	2000 Ω/m

GDFIDL being a 3-D code is useful to determine the perturbations caused by support tubes, which is predicted as 90 MHz. GDFIDL also predicts a non-linear dependence of the resonant frequency on the radial position and diameter of the support tubes. These simulations were also used to study the effect of the RF and vacuum port openings on the resonant frequency of the structure. Since the vacuum port is a grid of small openings, which do not affect the electrical continuity of the structure, the resonant frequency is not affected much. The RF port opening, however, causes a perturbation of few MHz in the resonant frequency of the structure.

Figure 3 shows the frequency response with disk diameter. Based on these simulations, the disk diameter and pitch circle diameter of tubes was chosen as 90.0 mm and 74.5 mm respectively. The PWT linac operates in higher order mode TM_{02n}, where n is number of disks. Near the axis, the accelerating field is of TM_{01} type. In the TM_{01n} modes, the magnetic field circulates around the tubes indicating current flow through them, leading to more power dissipation. The field profile for the TM_{02n} mode shows no such feature and consequently, PWT linacs normally operate in this higher order mode. This affects the frequency separation between neighbouring modes and PWT linacs cannot be made very long. For the 4-cell PWT linac, the nearest mode to the operating mode is the $3\pi/4$ mode with a separation of about 225 MHz. The bandwidth of the structure is, f_π-f_0 is 365 MHz giving an inter-cell coupling coefficient of 0.15.

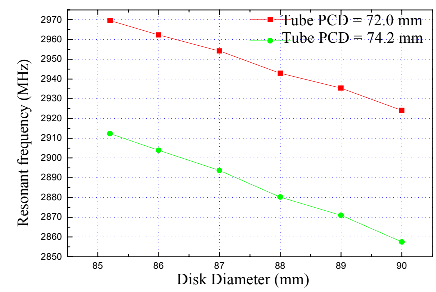

Figure 3. Frequency response with disk diameter.

3 COLD TESTS

In order to have a better idea of the agreement between cold-test results and those predicted by GDFIDL simulations, sets of dummy disks with different diameters were mounted inside a prototype tank envelope. The measured results are compared with those obtained from simulations of these structures in Table 2.

Table 1: Comparison of various RF parameters with SUPERFISH and GDFIDL simulations

Disk diameters (mm)	Resonant frequency (MHz)	
	GDFIDL prediction	Cold-test measurement
85.2	2916	2903
86.0	2911	2908
87.0	2905	2907
88.0	2897	2896
89.0	2892	2888
90.0	2883	2879

For the measurement of the resonant frequency of the PWT structure, an RF signal generator (Rohde & Schwarz, SMT03) was used to launch 10mW of RF power into the structure. A loop antenna was used to sample the field inside the structure, making sure that the perturbation to the fields because of the loop was minimum, i.e. under-couple. A power meter (Boonton, 4531) was used to measure the power level inside the structure. By increasing the total length of the tank, we could tune the frequency to the desired resonant frequency, at which the power level inside the structure is maximum, which for our case was measured to be 2855.7 MHz.

The PWT structure has a disk diameter of 90.0 mm and tubes are located at a pitch circle diameter (PCD) of 74.5 mm on the disks. Figure 4 shows the measured frequency spectrum of the PWT structure. Bead perturbation measurement was done to determine the operating mode of the structure and to determine its electrical parameters. Figure 5 shows the results of the bead perturbation measurements in the PWT structure. The loaded quality factor of this structure was measured to be 8,000 and the measured characteristic impedance was 487 Ω.

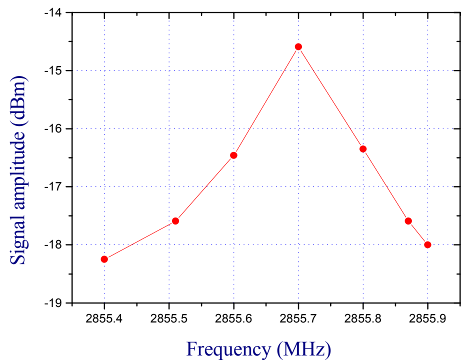

Figure 4. Frequency spectrum of the PWT linac structure.

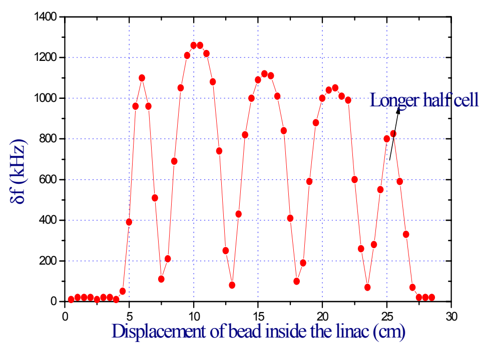

Figure 5. Frequency deviation from the resonant frequency in the bead pull test of the PWT linac structure.

4 BEAM DYNAMICS SIMULATIONS

The beam dynamics in the PWT linac was studied using PARMELA, which is a versatile multi-particle code. These simulations were performed to study the RF field and space charge effect on the transverse emittance of the beam as well as to study the energy gain and energy spread in the beam in transporting through the PWT linac structure [5]. Figure 6 shows the field gradient effect on the transverse emittance and its growth in the PWT linac structure. These simulations were performed by considering 10000 super particles and 10 ps beam pulse length with 1nC of charge.

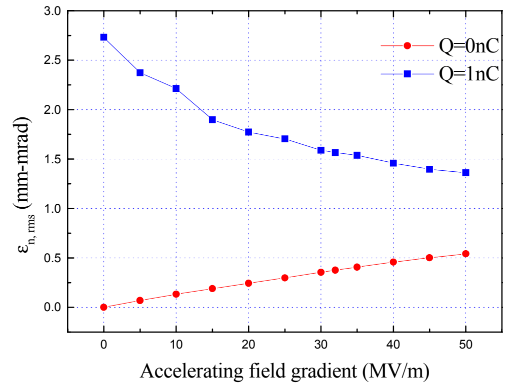

Figure 6. Emittance growth in PWT linac structure with field gradient for different pulse charges.

5 CONCLUSION

A 4-cell PWT linac structure has been fabricated at CAT based on the simulations performed using SUPERFISH and GDFIDL codes. It is observed that the cold test results of the resonant frequency agree well with those predicted by GDFIDL simulations. Based on experience from two prototypes, we have made suitable modifications in the dimensions for the PWT structure to obtain a resonant frequency of 2856 MHz for the π mode.

6 ACKNOWLEDGEMENT

We thank W. Bruns for his support in providing us with the GDFIDL code. We also thank C. Pellegrini, R. Zhang and J. Rosenzweig for their help in providing initial sketches of PWT drawings.

7 REFERENCES

[1] R. Zhang, Development of a Novel RF Structure for Linacs and High Brightness Photoinjectors, Ph. D. Thesis, UCLA, 1997.
[2] Donald A. Swenson, Proc. EPAC (Rome, 1988), p. 1418.
[3] R. Zhang, P. Davis, G. Hairapetian, M. Hogan, C. Joshi, M. Lampel, S. Park, C. Pellegrini, J. Rosenzweig and G. Travish, 'Initial operation of the UCLA Plane Wave Transformer (PWT) Linac', Proc. of the 1995 Accelerator Conference, Dallas (TX), May 1995, p-1102.
[4] Arvind Kumar et al., CAT report, CAT/2000-14.
[5] Arvind Kumar et al., Phys. Rev. ST Accelerators and Beams, Vol. 5, 033501 (2002).