This paper describes the electromagnetic design of the Drift Tube Linac (DTL). The 2D design of DTL cavities has been done, using SUPERFISH in order to tune them to the operating frequency of 352.21 MHz with maximum shunt impedance. In order to incorporate the features that break the 2D symmetry, the 3D electromagnetic field simulations have been done using CST Microwave Studio code. The tuner and vacuum port have been modeled and their effect on the resonant frequency has been studied.

Introduction

A 20 MeV, 30 mA proton linac, LEHIPA [1,2] is being built at BARC as part of our ADS programme. This system will consist of a 3 MeV RFQ, followed by an Alvarez Drift Tube Linac to accelerate the beam from 3-20 MeV. The operating frequency of the linac is 352.21 MHz. The electromagnetic design of the DTL has been done, using SUPERFISH [3] and CST Microwave Studio [4] codes. In the following sections, details of these studies are given.

Cavity Design

The DTL cavity was designed using SUPERFISH code with the aim to maximize the shunt impedance and to avoid voltage breakdown by keeping the peak surface electric field below 0.8 Kilpatrick. In addition to this, quadrupoles are housed inside the drift tubes in the DTL for focusing the beam. Hence the drift tubes must be large enough to have space for placing the quadrupoles inside. To design the DTL cavity first, the cavity diameter was optimized. The idea was to use the same tank diameter for all the DTL tanks i.e. in the entire energy range from 3-20 MeV for ease of fabrication. The effect of varying tank diameter on the various figure of merits of the cavity viz. effective shunt impedance, the peak surface electric field, power dissipation etc. at different energies was studied. As can be seen from Fig.1, the effective shunt impedance is maximum for a tank diameter of 52 cm for energies of 3-20 MeV. Hence, the optimum diameter is chosen to be 52 cm for the entire energy range. The other DTL parameters were also optimized using SUPERFISH.
The structure parameters of the DTL are listed in Table 1. The total length of the DTL is 12.5 m and it is planned to make it in four tanks. The focusing lattice is FFDD in all the four tanks as the quadrupole gradients required for focusing with FFDD is much smaller as compared to that with FD lattice [5]. The RF power dissipation is $-1.1 \text{ MW}$ and the beam power is $0.51 \text{ MW}$.

### Three-Dimensional (3-D) Cavity Design

In order to include features that break the 2D symmetry (tuners, vacuum ports, post couplers etc.) a 3D design of the DTL tank was done, using CST Microwave Studio. The first DTL tank consists of 36 cells and accelerates the beam from 3 MeV to 6.85 MeV. In order to simplify the simulation model, the geometry of the centre cell together with drift tube no. 18 was used. Three cells of this geometry have been modeled in CST Microwave Studio and the frequency of the accelerating mode ($T_{M_{010}}$) is 352.12 MHz. Fig. 3 shows the electric and magnetic fields in a DTL tank with 3 cells.

The peak surface electric fields were also calculated and are shown in Fig. 4. It is found, that the maximum surface electric fields were on the outer surface of the drift tubes.

### Tuner

Slug tuners are used, to provide frequency adjustment to the RF cavity. The tuners are cylindrical rods which when pushed inside the DTL cavity decrease the
magnetic volume of the cavity. This leads to a decrease in the inductance and hence an increase in the resonant frequency. According to Slater’s perturbation theorem [6] the frequency shift is given by,

$$\frac{\Delta f}{f} = \frac{\mu_0 \int \int \int V |H|^2 \, dV - \varepsilon_0 \int \int \int V |E|^2 \, dV}{\mu_0 \int \int \int V |H|^2 \, dV - \varepsilon_0 \int \int \int V |E|^2 \, dV}$$

where, dV is the change in cavity volume, V is the volume of the cavity without perturbation, E and H are the unperturbed electric and magnetic field amplitudes.

It is planned to put 6 slug tuners in each tank. In the simulation, one tuner is modeled and the frequency shift due to all the tuners is obtained, by multiplying the shift due to one tuner with the number of tuners. The CST MWS model of a tuner is shown in Fig. 5.

The effects of tuner depth and tuner diameter on the resonant frequency have been studied and are shown in Figs. 6 and 7 respectively. As the tuner is penetrated deeper into the cavity, the resonant frequency rises linearly, because the magnetic field is large at the location where the tuners are pushed in [7]. The rise becomes slow as the tuner is penetrated deeper, since they now start reducing the electric volume as well. If the tuner is pushed further down, the electric field starts dominating over the magnetic field and the net result is a drop in the resonant frequency. The tuning range using all the 6 tuners is estimated to be 2.28 MHz for a tuner diameter of 12 cm and a depth of 11 cm.
Vacuum Port

The operating pressure for the DTL will be in the range of $10^{-7}$ Torr. The primary requirement of DTL vacuum systems, is to provide sufficient pumping, to overcome the surface out gassing and maintain the operating pressure. In order to achieve this vacuum, pumping ports are provided on the tank walls. The apertures of the vacuum pumping ports are slotted [8] in order to attenuate the RF power leaking out of the port and also to reduce the surface currents at the port corners, thus reducing the heat dissipation at these locations. The slot orientation is in the same direction as the RF currents. Two pumping ports will be provided in one tank. A 5 slot configuration will be used for each port, with a slot dimension of 14 cm x 1.8 cm and the spacing between two slots will be 1 cm. The conductance of each port is about 1400 l/s. A vacuum port modeled in CST Microwave Studio is shown in Fig. 8. The frequency shift due to the port openings is found to be 13.39 kHz, which is negligible. This is expected because the ports provide very small openings on the tank, as compared to the tank volume.

Post Coupler

The DTL operates in the zero mode in which the electric field direction is the same in all the accelerating gaps. In this mode the electric field distribution is very sensitive to even small frequency perturbations in the cells. The $\pi/2$ mode on the other hand, is the most stable mode of operation for any cell-coupled accelerating structure. However as the $\pi/2$ mode is very inefficient for acceleration, we can try to change the slope of dispersion curve at the location of the zero mode, by introducing a 2nd resonator band which is then coupled to the TM01 band of the DTL. This can be done, by inserting short cylinders called post couplers in the horizontal plane, corresponding...
to the drift tube centres. The post couplers were modeled in CST Microwave Studio as shown in Fig. 9. In order to simplify the simulation model, the geometry of the centre cell along with drift tube 18 was used. Since it is too time consuming to simulate the entire tank, the model was limited to nine identical DTL cells with 4 post couplers representing almost one-fourth of the first tank.

To find the post coupler (TE) mode, the boundary condition at the left and right wall was set to ideal magnetic, in simulation. For optimum stabilization, the highest post coupler mode frequency should be as close to the resonant frequency of the DTL as possible. The post coupler stem represents an inductance while the gap between the post and the drift tube represents a capacitance. Both elements represent a resonant circuit whose frequency depends on the length and the radius of the post coupler. In order to achieve stabilization, the post coupler length and radius have to be chosen such that, the highest post coupler mode frequency is close to DTL resonant frequency of 352.21 MHz. The post coupler mode frequency as a function of post coupler length and radius is shown in Fig.10. From this figure, we can interpolate the post coupler length for different radii as summarized in Table 2.

Another technique will be used, to find the optimum radius for the posts, which gives the best stabilization against frequency errors in the cells. For this purpose, the tilt sensitivity technique is used, which is usually employed to study post coupler stabilization with mechanical models. These studies are in progress.

**Summary and Conclusions**

The cavity design for the DTL has been accomplished. The length of the DTL (3-20 MeV) is 12.5 m and it will be made in four tanks. There will be 6 tuners and 2 vacuum ports in each tank. One post coupler will
be provided at every third cell of the DTL tank for field stability. Based on these studies, a 3-D CAD model of a 1 m long DTL tank has been made (Fig.11). The fabrication of prototype DTL tank has been initiated, to validate these simulations.

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4. CST Microwave Studio software.


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