Electromagnetic design and engineering development of Alvarez DTL

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Abstract. Drift Tube Linac (DTL) is used for acceleration of heavy charged particles in the energy range, corresponding to β ranging from 0.04 to 0.4. The DTL consists of a cylindrical vacuum cavity called drift tube tank, resonating in TM_{010} mode. The Drift tube tank consists of hermetically sealed cavities called drift tubes arranged longitudinally in a periodic array (cell length βλ) and are concentric to the drift tube tank. The drift tube cavity shields the accelerating particle from the negative RF phase and also houses magnetic lenses for transverse focusing of the beam. The magnetic lenses are permanent magnet quadrupoles (PMQs). The drift tube design involves magnetic, thermal, mechanical and CFD engineering challenges. High magnetic energy density is needed for achieving required magnetic flux density gradient in the beam aperture. The RF currents flowing on the cavity surface cause heat dissipation of the order of 3.5 kW in each drift tube. This heat is removed by cooling water flow in the channels of the drift tubes. Hermitically sealing the drift tube cavity is another crucial issue in DT fabrication as the sealing has to be carried out in the presence of permanent magnets. This precludes the use of electron beam welding .Laser welding on copper is difficult due to its high heat reflectivity of the order of 90% at 1064 nm. The cooling circuit ensures uniform heat transfer from the cavity surface. This paper discusses various design and engineering challenges in the drift tubes design, fabrication and qualification. Two prototype drift tubes, housing PMQs have been designed and fabricated at Control Instrumentation Division, BARC. Design of prototype Drift Tube Tank is being carried out at CnID. Various aspects of Drift Tube tank design are brought out in the paper. The paper also discusses the results obtained from rotating coil magnetometer designed and developed for magnetic qualification of PMQs.

Keywords: Alvarez Linac, RF electromagnetic, focusing lenses, Permanent magnets

INTRODUCTION

Alvarez DTL is a subcomponent of LEHIPA (Low Energy High Intensity Proton Accelerator) which accelerates proton beam of 30 mA intensity from 3 MeV to about 20 MeV. LEHIPA is the front-end injector of the 1 GeV accelerators for the Indian ADS program [1]. Drift Tube Linac (DTL) is a 12-meter long electromagnetic cylindrical cavity resonating in TM_{010} mode. For ease of fabrication, metrology and RF power source availability, DTL is being envisaged to be built in four tanks, each of which will have two sections. The third and fourth DTL tanks along with the Drift Tubes, housing Permanent magnet Quadrupoles (PMQs), for all tanks are being developed at Control Instrumentation Division of Bhabha Atomic Research Center, Trombay. This paper discusses development of prototype DTs and DTL tank corresponding to the third DTL tank. Electromagnetic, cooling and thermal design of the DTs is brought out in detail along with the undergoing fabrication of DTL tank section.

ALVAREZ DTL FOR LEHIPA

Alvarez DTL named after *Luis Alvarez* of University of California is a cylindrical resonating cavity excited in TM_{010} mode with Electric field aligned along the beam axis and the magnetic field in azimuthal direction. The electric and magnetic field in adjacent gaps are in phase. This structure is used for acceleration of proton and heavy ions in β ranging from 0.04 to 0.4. A typical Alvarez DTL is shown in figure 1 below.

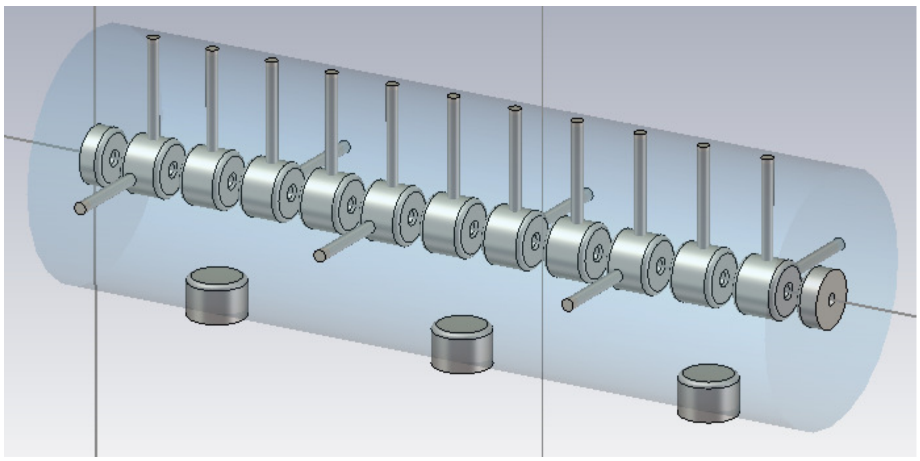

FIGURE 1: Typical Alvarez DTL (perspective view)

The DTL tank shown in semitransparent consists of an array of DTs with their apertures concentric to the tank axis. This structure ensures that fields in adjacent gaps are in the same phase, the electric field vanishes inside the bore of the DT as shown in figure 2. The accelerating particle is shielded from the decelerating phase of the RF as particle travels inside the DT during the decelerating phase. Figure 2 shows E-filed along the axis of the tank; the effect of tuners on the E-field profile is to reduce the E-field in region where tuners are placed.

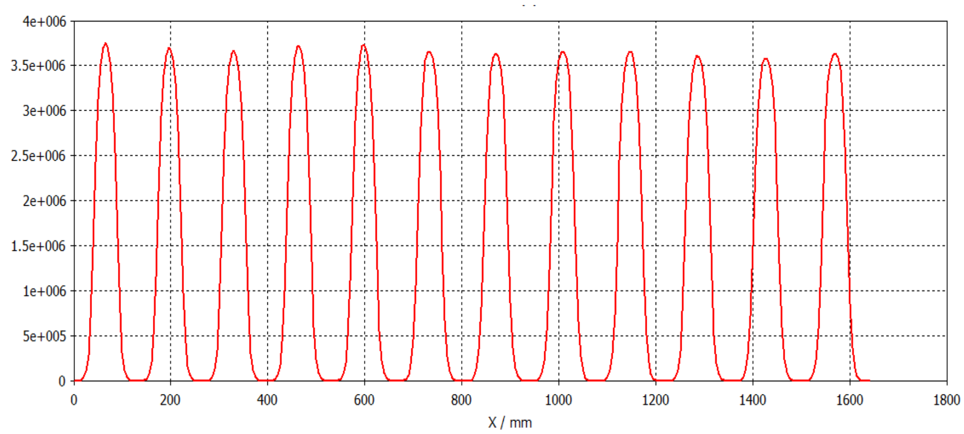

FIGURE 2: Electric field profile along axis

Among the various advantages of Linear Accelerators is its capability of producing high-intensity charged particles beams of high beam quality [2]. This is made possible with the help of magnetic lenses (Magnetic quadruples) placed inside the hermetically sealed DTs. The design of DTs is in the next section. The additional RF components seen in figure-1 are tuners and post couplers. Tuners (three numbers in each section at an azimuthal angle of 180º from DT stem axis) are used to achieve the required field flatness and for tuning the structure to the desired resonating frequency. As seen in figure 2, the electric field profile changes due to presence of tuner. This feature is used for achieving the required E-field flatness. The resonant frequency of the structure increases with removal of volume from magnetic field region of the DTL. The tuners are located in the magnetic field region; hence the introduction of tuners increases the resonant frequency. Frequency budget of each tuner is about 400 KHz. Post couplers (at 90º and 270º with respect to the DT stem axis, depending on design) are used for field stabilization and for giving immunity to the structure against mechanical perturbations resulting from fabrication errors and thermal deformation during the operation of the Linac.

The microwave induced surface currents in the structure causes large quantum of heat dissipation in the DTL components. On the DTL tank surface it is about 20,000 Watts/m^2. In the DTs it increases from the initial drift tubes to later ones. Heat removal from the structures (Tank, DTs, Tuners and Post couplers) is a challenging engineering problem. First DT of first tank has heat dissipation of about 2.5 kW, whilst for the last DT of last tank it is about 4.5 kW. Losses in end flanges(with half DTs integrated) is about 7 kW for first flange of first tank and 8.4 kW for last end-flange of last tank. Table1 summarizes the heat load in DTs and flanges. Nomenclature for table 1 is: D/F XX-YY; XX stands for tank number and YY stands for component number in that tank starting from low energy side.

TABLE1. Heat load in DTs and end flanges

Drift Tube	**Heat Dissipation (Watts)**	**Flange**	**Heat Dissipation (Watts)**
D01-01	2500	F01-02	6958
D01-36	3048	F02-01	7321
D02-14	3308	F03-01	7782
D03-11	3838	F04-01	8018
D04-20	4537	F04-02	8406

A prototype DTL corresponding to first section of the third tank is under fabrication. This prototype DTL section will be used for validating the RF design, including performance of tuners and post couplers, vacuum testing, and for copper plating trials on inner tank surface to a desired surface finish. Poor surface finish increases heat dissipation from the structure. The girder based design will also settle DT alignment issues with alignment mechanism being developed at CnID. The DT alignment ensuring the concentricity of their magnetic centre within ± 100 microns will be carried out using laser based metrological systems.

DRIFT TUBE DESIGN, DEVELOPMENT AND ANALYSIS

Due to space limitation inside the low-β drift tube cavities, and the thermal challenges involved in Electromagnetic quadrupoles, Permanent Magnet Quadrupoles (PMQ) using high energy density rare earth magnets have been used to achieve high focusing magnetic field gradients inside the beam aperture. Two numbers of PMQ based DTs have been designed and developed at Control Instrumentation division [3, 4]. Magnetic measurements carried out on the magnetic profile measuring bench have confirmed the magnetic design. The permanent magnet quadrupole assembly has been placed inside a hermetically sealed cavity, which is laser beam welded at the equator and at the IRIS (Figure 3 (left)). The magnetic field profile in the bore of drift tube is shown in figure 3(right). The final design of PMQ consists of eight NdFeB magnets and soft iron pole pieces as shown in figure 3(right). Hyperbolic pole of soft iron helps in achieving quadrupole field in the bore. The magnetic measurements have been carried out on the prototype drift tube and the results are in close agreement with the design values.

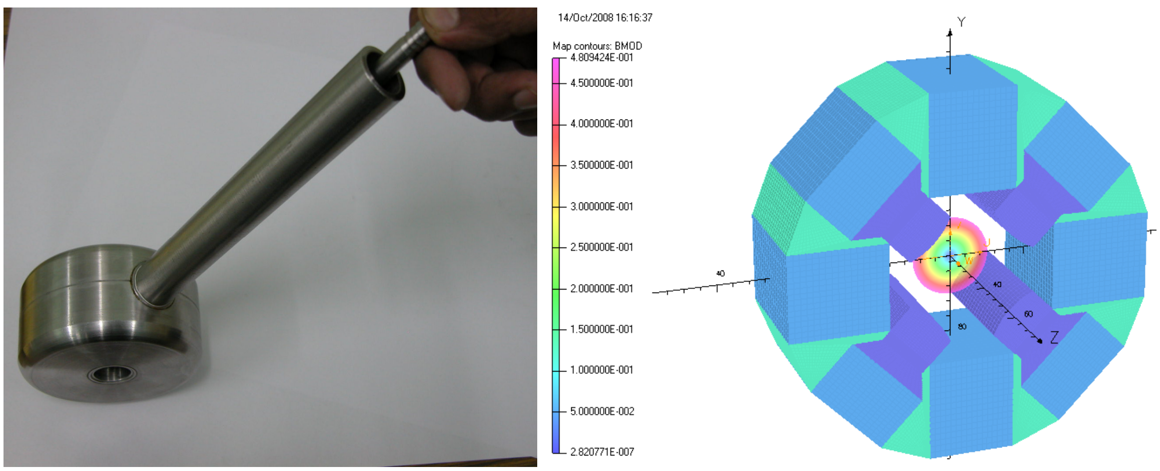

FIGURE 3: Prototype DT (left); magnet design simulation (right)

MAGNETIC MEASUREMENTS USING INDUCTION COILS

An Induction Coil Magnetometer (ICM) is designed and developed at CnID. ICM consists of induction coil rotated in bore of DT with help of motor. The DT is placed in x-y stages for measuring the magnetic field profile at different locations. The integral Gradient measured by ICM is 2.185 Tesla.

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