FOCUSSING MAGNETS FOR DRIFT TUBE LINAC

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Abstract

A linear accelerator comprising of Radio frequency quadrupole (RFQ) and drift tube linac (DTL) is being developed at BARC. The Alvarez type CW DTL accelerates protons from energy of 3 MeV to 20 MeV. The drift tube linac is excited in TM_{010} mode, wherein the particles are accelerated by longitudinal electric fields at the gap crossings between drift tubes. The particles experience transverse defocusing forces at the gap crossings. The transverse defocusing correction is done by housing magnetic quadrupole focussing lenses inside the drift tubes. In a DTL at low energy, the strong space-charge defocusing requires high integrated quadrupole gradients, in constrained axial lengths of the drift tubes and in limited transverse volumes. The technical difficulties and costs of developing a high-gradient, high duty cycle electromagnet fitting in the small volume initial drift tubes, led to the choice of Permanent Magnet Quadrupoles (PMQ). The PMQs are placed inside the hermetically sealed drift tubes and provide a constant magnetic field gradient in the beam aperture.

The drift tubes are mounted concentrically inside the resonating DTL tank and are connected to the tank body with stems. Rare earth high energy permanent magnets have been used to achieve the required field gradients in the beam aperture. The drift tube body is subjected to RF heating and hence the sealed drift tubes are required to be cooled from inside. The temperature rise of the drift tube assemblies has to be limited to avoid degradation of permanent magnets and also to limit the thermal expansion of the tubes. This paper discusses various aspects of magnetic design, selection of magnetic materials and the engineering development as well as describes the prototypes developed in our laboratory. This paper further presents analysis of a novel approach of spilt-pole type focusing magnets and brings out its advantages compared to earlier designs.

ENGINEERING DEVELOPMENT

The drift tubes mounted concentrically inside the resonating DTL tank house the rare earth permanent magnets, to achieve the high focusing field gradients in the aperture of the drift tubes. The sealed drift tube body undergoes heating due to the conduction currents and hence the drift tubes have to be continuously cooled. Since the drift tubes are mounted inside a vacuum cavity, the heat removal can only take place by circulating the coolant around the internal periphery of the drift tubes. The thermal hydraulic analysis of the drift tube coolant channel circuit has been done and the theoretical results have been experimentally verified. The temperature rise has been limited to avoid reduction in magnetization of the permanent magnets and also to limit thermal expansion of the tubes. A prototype drift tube assembly has been made at BARC. The permanent magnet quadrupole assembly has been put inside a hermetically sealed cavity, which is laser beam welded at the equator and at the IRIS (Figure 1).

Figure 1: Laser Beam welded drift tube assembly with embedded PM Quadrupoles.

The magnetic design of the PMQs follow the well-known law of split-pole multi-pole lenses viz. the magnetization vector (as we move in the azimuth direction) rotates around the radial unit vector with twice the frequency. The electromagnetic design and analyses of the permanent magnet quadrupole was carried out using finite element analysis software Opera3D and COMSOL.

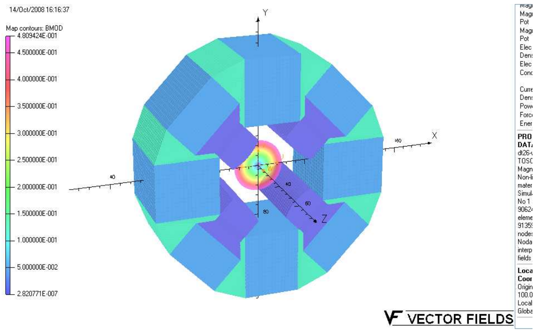

Figure 2: Arrangement of permanent magnets and soft iron poles inside drift tube. The magnetic flux density plot in the beam aperture is also shown.

Various magnets and pole configurations were analyzed to achieve requisite field gradient in the large beam aperture. The results of analysis are shown in figure 2 and figure 3. The final design of PMQ consists of eight NdFeB magnets and soft iron pole pieces as shown in figure 2. 3D representation of magnetic flux density, inside the bore of drift tube is shown in figure 3.

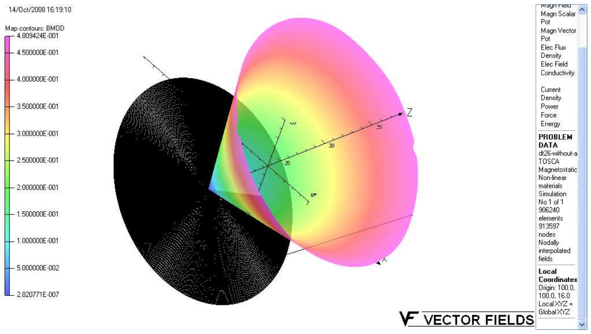

Figure 3: 3D contour of magnetic flux density inside the bore of drift tube.

SPLIT POLE TYPE DRIFT TUBE

The drift tubes need to be sealed hermetically. Laser welding is used for this purpose, since presence of high leakage magnetic field at welding joints precludes the use of electron beam welding. Also the spatial variation of leakage magnetic field at welding joint makes use of electron beam welding almost impossible. The leakage magnetic field density is of order of 100 mT. Laser welding on copper is difficult because of its high reflective coefficient in the molten state. Further the use of soft iron makes quality control an issue since large number of drift tubes need to be fabricated and used in drift tube tank. Another disadvantage of this design is the weight of the drift tube.

To address most of these issue, spilt-pole multi-pole magnetic lens based on cylindrical rare earth magnets has been analysed used FEM based COMSOL package. Two arrays of cylindrical permanent magnets are arranged in circular arrangement as shown in figure 4. Absolute magnetic flux density distribution is shown; the bore of drift tube has circular contours of magnetic flux density which is zero at the centre and increases linearly from centre to the circumference of the drift tube's bore. The main feature of the split-pole construction is the real possibility to reach high accuracy of magnetic field distribution with required harmonic contents [1].The maximum magnetic flux density gradient obtained by FEM simulations is 46.5 T/m. However integrated Gradient along the length of magnetic length is 50.6 T/m. The effective length of magnetic lens is 43 mm. These results are shown in figure 5.

The leakage magnetic field obtained at PCD of 120 mm is about 12 Gauss. However in order to facilitate electron beam welding this needs to be further reduced. High permeability soft magnetic materials like mu-metal can be used as an annulus ring around the magnets as shown in figure 4. Mu-metal of thickness 6 mm, at a PCD of 62 mm gives a leakage magnetic field of less than 1 gauss. This leakage magnetic field is of order of earth's magnetic field.

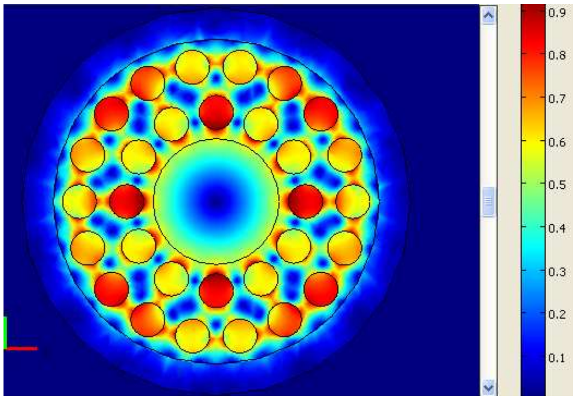

Figure 4: COMSOL simulation results for split pole PMQ. Annulus ring of mu-metal is used to reduce leakage magnetic field.

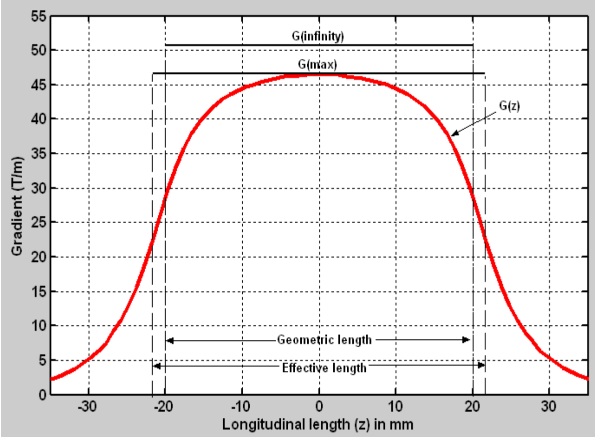

Figure 5: Magnetic flux density gradient (T/m) in longitudinal direction.

SUMMARY AND CONCLUSION

Drift tube PMQs using rectangular magnets have been prototyped. Magnetic measurement using hall sensors and rotating induction coil has been carried out. Results obtained are within requirements. New design based on cylindrical magnets is being carried out for which computer simulation results are encouraging. These drift tubes will be hermetically sealed by electron beam welding.

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