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PROTOTYPING OF PERMANENT MAGNET BASED DRIFT TUBE FOR KOMAC 100-MeV DTL*

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Abstract

A high-power proton linac at KOMAC uses a drift tube linac structure to accelerate protons up to 100 MeV. Currently, a total of 148 drift tubes with electromagnetic quadrupoles are used in DTL sections for accelerating protons from 3 MeV to 20 MeV. A drift tube based on a permanent magnet quadrupole has been designed and prototyped to replace the EMQ-based drift tube to enhance the DTL reliability. A designed PMQ with an integrated field gradient of 1.6 T is assembled from 16 segments, which are made of Sm2Co17 magnetic material for its radiation hardness. Details of the prototyping study on the PMQ including design, fabrication, and test along with the beam dynamics effects are given in this presentation.

INTRODUCTION

A 100-MeV proton linear accelerator at KOMAC (Korea Multipurpose Accelerator Complex) uses drift tube linac (DTL) structure to accelerate proton beam from 3 MeV to 100 MeV. Total number of drift tubes used for acceleration up to 20 MeV is about 150 and every drift tube includes an electromagnetic quadrupole (EMQ) for the proton beam focusing. Because the space available for a magnet installation in the drift tube for 20-MeV sections is quite limited, it is very difficult to use a hollow conductor to make a winding for EMQ, while we used the hollow conductor for the EMQ in 100-MeV sections. Instead of using hollow conductor, we used simple enamel wire to fabricate the EMQ, which is typically used for making a transformer. The cooling of the EMQ is achieved by water flowing around the magnet winding. After several years of operation (over 15 years), some EMQs suffered from failure, especially due to electrical short between layers of magnet winding (see Fig. 1). It causes degradation of beam transmission along the linac. Moreover, it takes a lot of time and labour to replace the failed DT during maintenance period.

To enhance the DTL reliability, a prototype drift tube based on a permanent magnet quadrupole (PMQ) is designed and fabricated to replace the EMQ. In fact, most high-intensity proton linear accelerators, such as SNS in US, ESS in Europe and LINAC4 at CERN, took advantage of using PMQ based drift tube [1-5]. The designed PMQ is assembled from 16 segments, which are made of Sm2Co17 magnetic material for its radiation hardness, resulting in the integrated field gradient of about 1.6 T. We performed a design study on the PMQ to replace EMQ in 20-MeV DTL at KOMAC including magnetic analysis and beam dynamics effects. Parts of a prototype drift tube based on the permanent magnet were fabricated and magnetic field along the beam axis direction was measured before final electron beam welding.

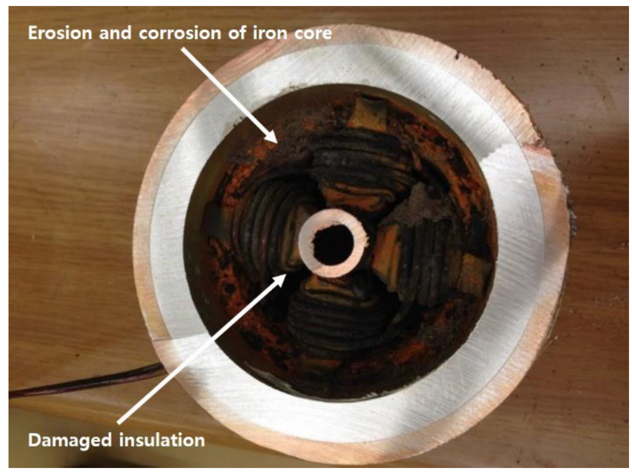

Figure 1: Cut-view of the failed drift tube, showing the damaged insulation and corroded iron core.

DESIGN STUDY

From the view point of beam dynamics, the integrated field gradient should be matched to successfully replace the EMQ with the PMQ. The iron yoke thickness of EMQ is 25 mm, while the permanent magnet used for the design is 30 mm. The 2D magnetic field analysis using POISSON code showed that contents of first allowed harmonics (dodeca-pole component) of PMQ is two-order of magnitude less than that of EMQ. This is mainly due to the lager distance from the axial center to pole magnet (inner radius of the PMQ is 20 mm, while the distance to the pole tip in EMQ is just 10 mm). The 2D harmonic analysis was performed along the circle with radius of 4 mm and the results are summarized in Table 1.

By using CST EMStudio and POISSON, we calculated the magnetic field distribution for both of EMQ and PMQ, as shown in Fig. 2. The magnetic field along the beam direction is compared in Fig. 3.

Table 1: Relative Field Amplitude of Allowed Harmonics

Harmonic index	EMQ	PMQ
n=6	5.05E-4	3.31E-6
n=10	5.87E-6	1.21E-5
n=14	2.05E-6	1.40E-5

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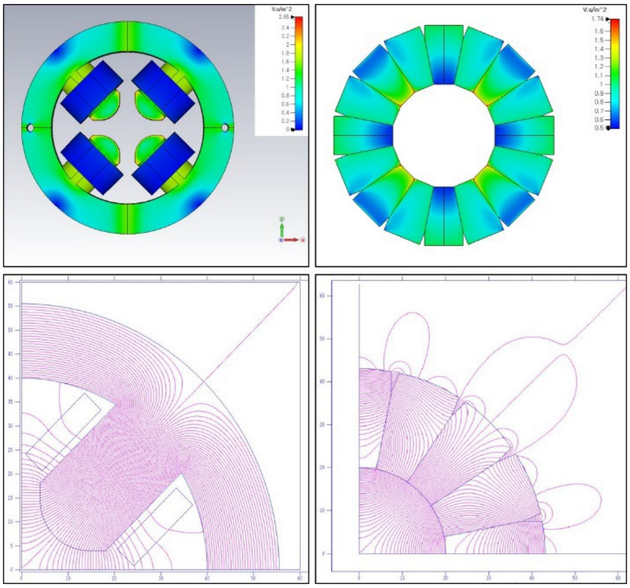
Figure 2: Comparison between the EMQ and PMQ (left column: magnetic field distribution in EMQ, right column: magnetic field distribution in PMQ).

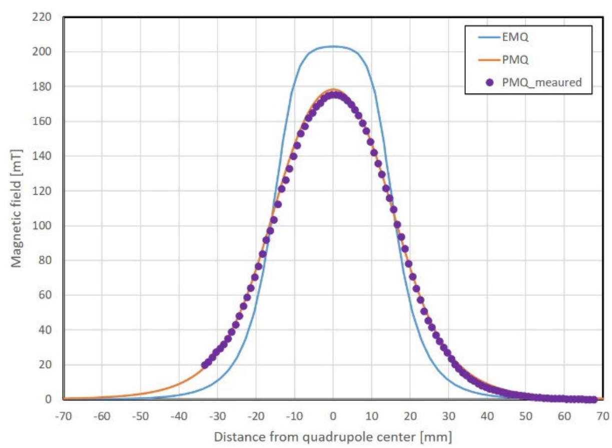

Figure 3: Magnetic field profile along the beam direction at 4.4 mm offset position in radiation direction.

The peak magnetic field of PMQ is about 10% less than that of EMQ but the effective length of EMQ is larger by same amount so that the integrated field gradient is same for both types of magnet. Same integrated field gradient means same beam behavior in the quadrupole channel at least in linear approximation, which was confirmed by TRACE3D calculation as shown in Fig. 4. EMQs are still needed in first DTL tank for beam matching purpose between RFQ and DTL.

FABRICATION STATUS

Based on the beam dynamics calculation and magnetic field analysis, we fabricated a prototype drift tube with PMQ. Overall design of the prototype drift tube can be seen in Fig. 5. Vacuum brazing is used to join the outer stem and DT cover. After installing the PMQ module in the drift tube, we use the electron beam welding for final assembly. Fine machining will be followed, resulting in right dimension.

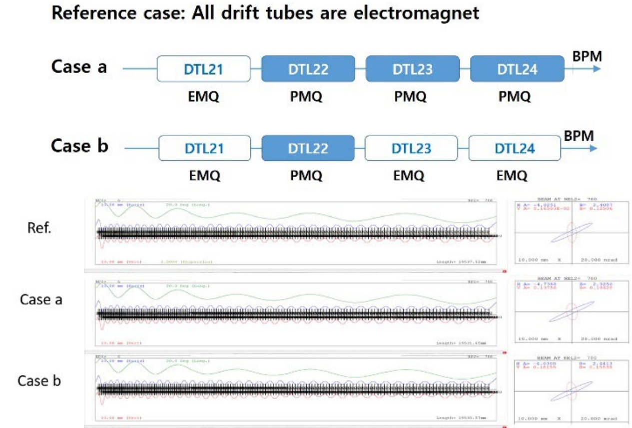

Figure 4: Beam dynamics effect by changing the EMQ to the PMQ (Reference case: all drift tubes are EMQ, Case a: all drift tubes except first DTL tanks are changed to PMQ, Case b: drift tubes in second DTL tank are changed to PMQ, while the others are EMQ). Both cases showed no noticeable change compared with reference case.

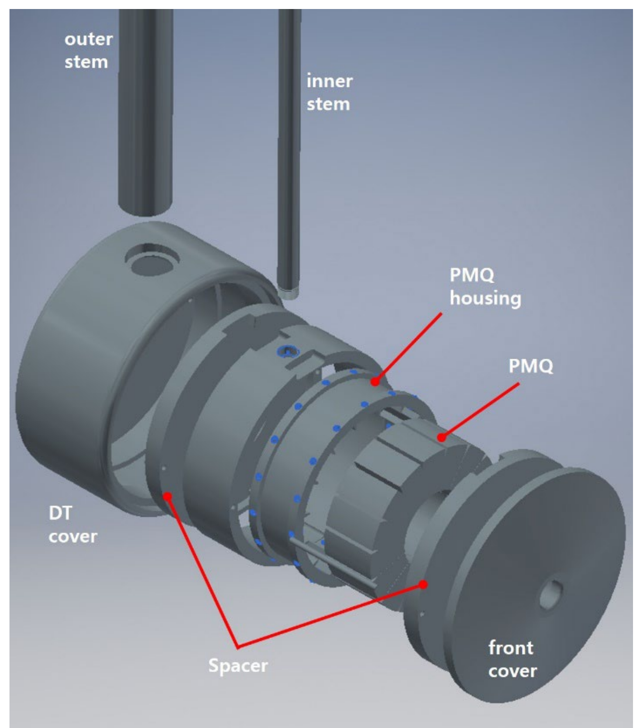

Figure 5: Overall design of the prototype drift tube.

We chose Sm2Co17 permanent magnet (Vacomax 225HR) with consideration of minimizing field strength loss due to neutron fluence. High strength aluminum alloy (7075-T6) was used as magnet housing material to minimize housing distortions due to set screw load on pole pieces. The fabricated PMQ and pre-assembled drift tube is shown in Fig. 6.

We measured the magnetic field profile before final assembly step by using electron beam welding (EBW) process. The measured results can be found in Fig. 3 (solid

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circle), which shows good agreement between the design profile and the measured one. After final assembly, we will measure the magnetic field again and we can check the EBW effect on the field quality.

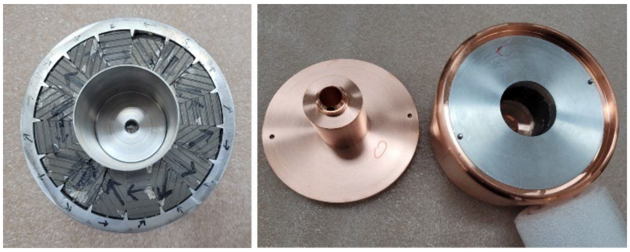

Figure 6: Fabricated PMQ and pre-assembled drift tube.

There is concern on the EBW process because the magnetic field from the PMQ may deflect the electron beam. The electron beam trajectory was calculated using CST Particle Studio, as shown in Fig. 7. From the Fig. 7, it is clear that we need to shield the PMQ with magnetic material during EBW process.

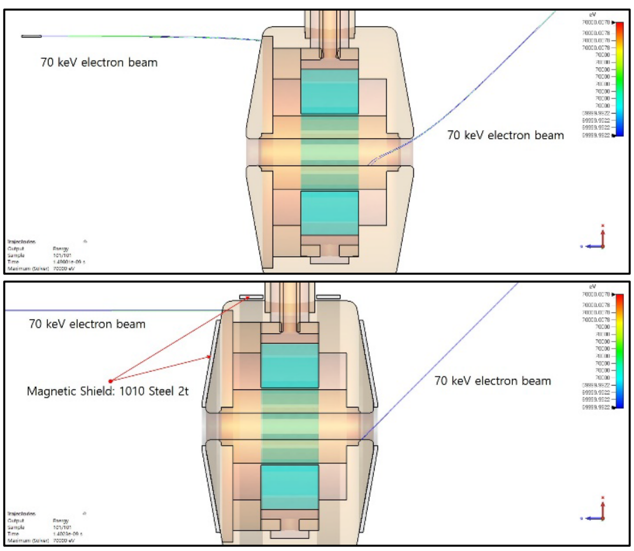

Figure 7: The electron beam trajectory simulation during EBW process (upper: without magnetic shield, the electron beam trajectory is severely deflected. lower: with magnetic shielding around the drift tube with 2-mm thickness 1010 steel, the electron beam is effectively shielded from the magnetic field of PMQ).

SUMMARY

A drift tube based on a permanent magnet quadrupole has been designed and prototyped to replace the EMQ-based drift tubes, which have frequent troubles mainly due to corrosion and insulation failure, to enhance the DTL reliability. A designed PMQ with an integrated field gradient of 1.6 T is assembled from 16 segments, which are made of Sm2Co17 magnetic material for its radiation hardness. The beam dynamic calculation shows effectively no difference between the EMQ-based system and the PMQ-based system. The measured magnetic field profile before EBW is well matched to the design value, which will be verified again after EBW. We are going to replace the EMQ-based drift tubes with the PMQ-based one in long-term maintenance period in coming year, tank by tank except the first DTL tank, where we have to reserve the capability of changing field gradient of the quadrupole for beam matching between the RFQ and DTL.

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