PERMANENT MAGNET FOCUSING SYSTEM FOR KLYSTRONS

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Abstract

The Distributed Klystron Scheme for ILC requires thousands of klystrons. The failure rate of each klystron may be a critical issue for a stable operation of the ILC. In order to eliminate the power supplies and the cooling system for the solenoid focusing coils, a permanent magnet beam focusing system is under development. Since the required magnetic field is not high in this system, inexpensive anisotropic ferrite magnets can be used instead of magnets containing rare earth materials.

INTRODUCTION

In the Distributed Klystron Scheme (DKS) for the International Linear Collider (ILC), 8000 relatively small modulating-anode (MA) klystrons will be used to reduce the cost and the down time by raising the reliability. Because of the large number of units, the failure rate of every component has to be minimized. The low beam voltage owing to the moderate output power and the less stress to the RF window should make lifetime of the klystrons longer. On the other hand, 8000 units of electromagnets for beam focusing would cause maintenance problem. Replacing the electromagnets by permanent magnets can eliminate their 8000 power supplies and cooling system. Hence the down time of the RF system can be expected to be small [1]. In addition, the power consumption is expected to be small and the absence of the cooling system that belongs to the focusing solenoid coil suppresses the water leak faults.

There have been precedents for electron beam focusing in klystrons with permanent magnets such as ALNICO or rare earth (RE) magnet [2,3,4]. ALNICO magnets are alloys composed of Al, Ni and Co, and are mainly manufactured by the casting process. Although they have small temperature coefficient and large remanence, their coercivity is relatively small. This makes the design of the magnet system difficult, since some of the magnets were partially demagnetized in the process to adjust the magnetic field distribution.

It is not easy for a permanent magnet system to generate a long magnet field area along a straight flux line. Periodic Permanent Magnet (PPM) focused designs, where the magnetic field changes its direction along the axis alternatively, have been used in Traveling Wave Tube (TWT) and so on. Although the PPM configuration using RE magnet had been also tried for high power klystrons, it seems not widely adopted. Both the remanence and coercivity of RE magnets are high, but the cost is rather high and the supply of the RE material has been limited for these years. The anisotropic ferrite magnets have smaller remanence and higher coercivity than ALNICO, hence there is less anticipation of demagnetization. Fig. 1 shows the B-H curves for these magnet materials.

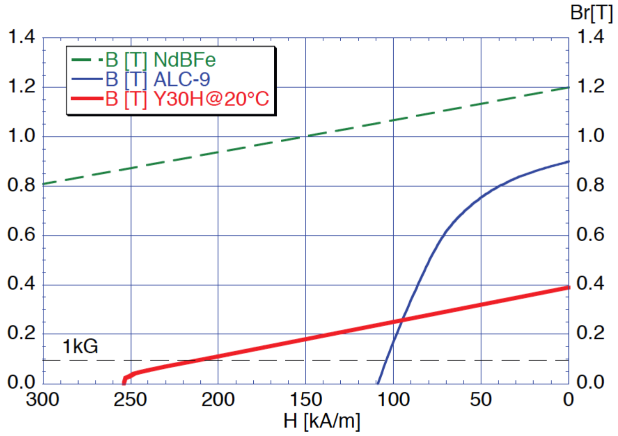

Figure 1: B-H curves of a RE permanent magnet (green), ALNICO (blue), and a ferrite magnet (red). RE magnets have high remanence and coercivity, but is expensive and their supply is not good. Although ALNICO magnets also have high remanence and high coercivity, which is adequate for generating relatively low and long magnetic field region.

FERRITE MAGNET DESIGN

For safe operation, a unidirectional magnetic field seems desirable rather than the PPM scheme. Although the alternating magnetic field can be easily generated by permanent magnets, the periodicity results stopbands of electron beam. For pulse operations, the operating point always crosses such region at rising and falling edges of the pulse and the beam loss causes wall heating and damage of the klystron body [4].

A unidirectional magnet field distribution has to be designed at moderate cost using our knowledge of anisotropic permanent magnet development. Because the required magnetic field is not high, inexpensive anisotropic ferrite magnets can be used. The raw material of the anisotropic ferrite is basically merely iron oxide widely available, while RE material has resource problem. No supply problem would arise even for the 8000 units in ILC.

Because the former designs using permanent magnets kept compatibility with electromagnets, it generates large amount of unnecessary magnetic flux in the bore. Although the minimum area where magnetic flux must be filled is just around the area that electron beam occupies, the existence of cavities and their walls increase the radius up to above the outer radius of the klystron body. This radius is fairly small compared with the high voltage ceramic insulator for cathode part. A solenoid electromagnet has to be designed not to conflict with any protruding objects at installation time. Klystrons are usually inserted from the top of the solenoid electromagnet and thus the minimum aperture of the magnet has to be larger than that of the cathode part. The bottom pole plate above the ceramic insulator of the klystron is designed larger than the insulator to hold the klystron weight (see Fig. 2).

This configuration requires very large volume for permanent magnets. The maximum magnet size, however, is limited by an ingot size and a big magnet has to be composed of small magnet pieces. A typical value for the maximum thickness along the easy axis is 25 mm. The magnet volume can be significantly reduced by splitting the magnet system into two parts that can open the aperture at the installation of the klystron in order for the fat cathode part to get through. The magnets can be pushed in closer to the klystron body after the klystron insertion. Each section can be further divided into several blocks to enable the magnetic field adjustment by adjusting the magnet block position.

RADIA 4.29[5,6] is used for the magnetic field design. The applied distribution of magnets and yokes is shown in Figure 3. Many magnets are used, which are categorized into two groups. The one group consists of magnets surrounding the klystron body whose easy axes are parallel to the klystron axis. These magnets can be retracted to make the space for the fat part of the klystron at installation step. They are designed so as not to interfere with the klystron parts such as cooling pipes or input RF connectors. The hexagon shape at the middle area can evade the cooling pipes on the klystron body surface. The upper and lower parts in this group have complex shapes because of the big protruding parts in this area. The retracting mechanism of the magnets works for the magnetic field distribution adjustment.

The other group consists of the bottom and the top large magnet bricks to form the magnetic field around the cathode and collector area. Their easy axes are perpendicular to the klystron axis. The top magnets and bottom magnets are supported by iron yoke plates that provide the flux return path between them. The collector area is covered by an iron cylinder as a magnetic shield in order to have less reversal magnetic field. This is important point for the electron beam not to injure the collector body by undesired focusing effect. The bottom four bricks can be also retracted to adjust the magnetic field around the cathode area.

Calculated magnet field distribution for the magnets described in Figure 3 is shown in Figure 4. The magnetic field distributions at both ends are especially important. The cathode area has to be carefully designed so that the efficiency and the output power are optimum for the klystron operations. The waste beam has to be well spread out on the collector surface especially in the case with no input RF power. The surface wall of the collector would be destroyed by the intense beam with the conserved original low emittance conserved. The magnetic field distributions on the axis between the cathode area and the collector area have to hold the axial symmetry in order to transport the beam without hitting the cavity walls. Since the magnetic field distribution was designed to match that in the cathode and the output cavity area, the middle area has some discrepancy from the target value.

The result of beam transport simulation with calculated magnet field distribution is also shown in Figure 4. DGUN[7] is used in this simulation. Although some modifications may be needed to reduce the beamsize oscillation, the result shows that all beam are transported from the cathode to the collector.

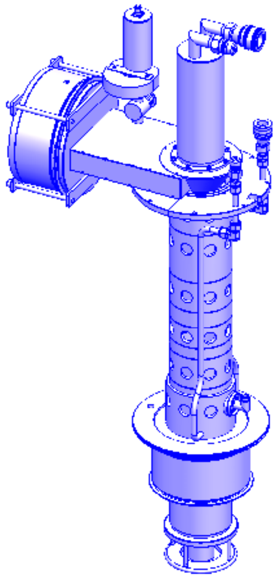

Figure 2: E37501 klystron for DKS.

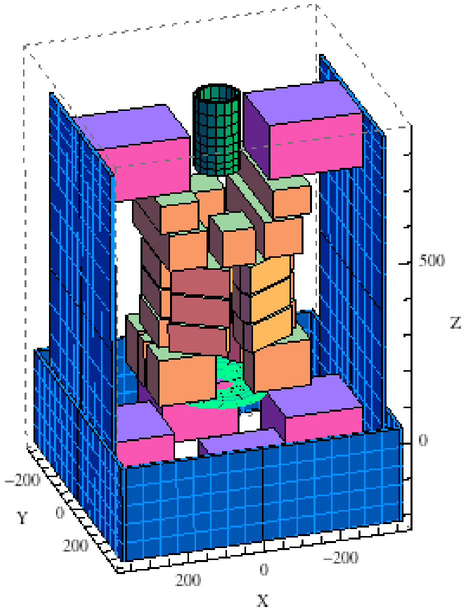

Figure 3: Layout of magnets and yokes.

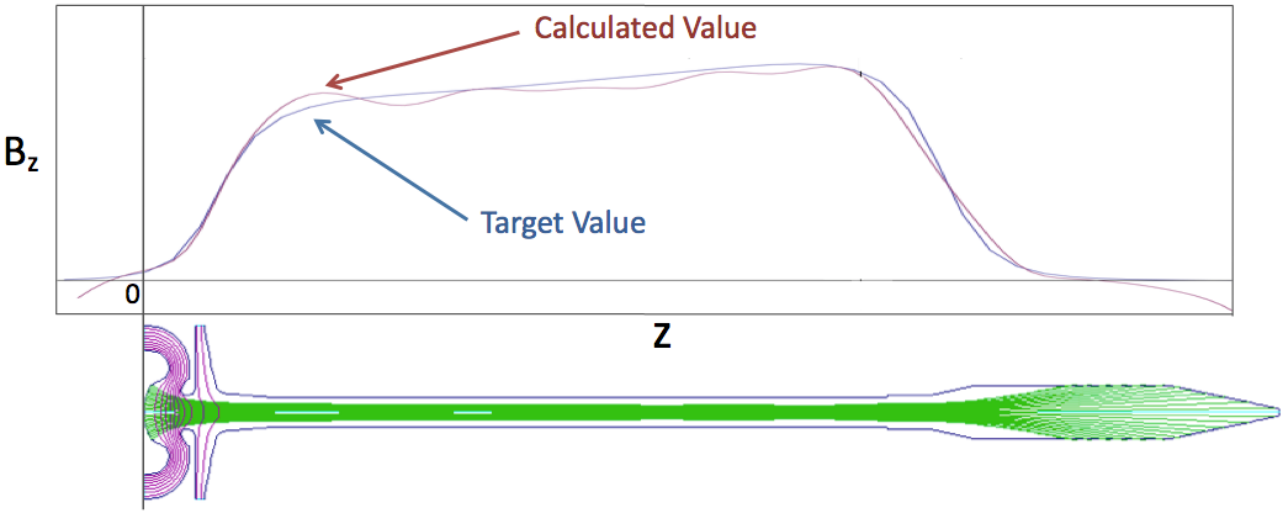

Figure 4: The designed magnetic field distribution and the result of DGUN simulation.

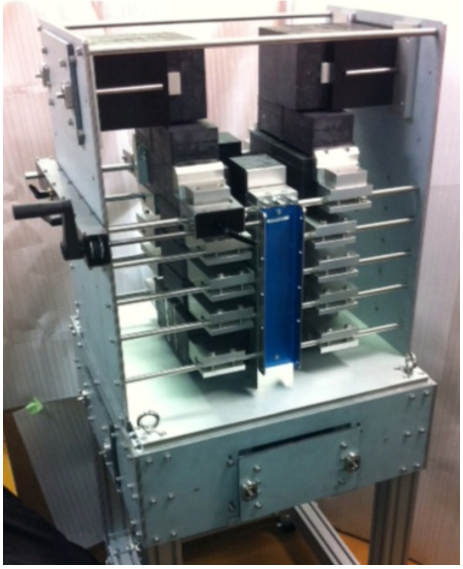

Figure 5: The full scale model of the focusing system.

In order to verify the design scheme and inevitable mechanical difficulties, a half scale model was fabricated. The maximum size of the available ferrite magnet was found to be 25.4x100x150, where the easy axis is along the 25.4mm direction. Only two largest area surfaces are mechanically finished, while other four surfaces have no treatment and their sizes fluctuate a few mm. Every block is assembled by stacking bare and/or machined from bare pieces and gluing together (HARDLOC G-55). We learned many aspects from the design and fabrication process of the half scale model. They are, mistakes in the calculation, necessity of more adjustment freedoms, insufficient jig capability, and so on.

The full scale model is designed and fabricated considering above mentioned aspects. We use as many bare magnet bricks to reduce the magnet fabrication cost (see Fig.5). This model is designed with mass production in mind.

After magnetic field measurement and adjustments, a power test of the klystron for DKS with this system will be performed.

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