DEVELOPMENT OF PERMANENT MAGNET FOCUSING FOR KLYSTRONS

Y. Iwashita, Kyoto University, Uji, Kyoto, JAPAN
S. Fukuda, KEK, Ibaraki, JAPAN

Abstract

Applying permanent magnet technology to beam focusing in klystrons can reduce their power consumption and increase reliability. These features benefit a variety of applications especially for large facilities that use a number of klystrons such as ILC. The low magnetic field needed for the purpose allows us to apply inexpensive ferrite magnets instead of magnets using rare earth material. In order to evaluate the feasibility of such a focusing system for magnets, a half scaled model is under construction. The results will be used to fabricate a full scaled model for a real klystron during power test.

INTRODUCTION

In the Distributed RF System (DRFS) for ILC, 4000 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 the lifetime of the klystrons longer. On the other hand, 4000 units of electromagnets for beam focusing would make maintenance problems. Replacing the electromagnets by permanent magnets can eliminate their 4000 power supplies and cooling system. Hence the down time of the RF system can be expected to be small[1].

Although there have been precedents for electron beam focusing in klystrons with permanent magnets such as ALNICO or rare earth (RE) magnet, none of them seem widely applied to large klystrons. ALNICO magnets, which have high remanence, shows less coercivity and demagnetization around the cathode and collector areas are anticipated. It is not easy for a permanent magnet system to generate a long magnetic 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 strong, but the cost is rather high and the supply of the RE material has been limited for these years. The anisotropic ferrite magnets have less remanence but higher coercivity than ALNICO, hence there is less anticipation of demagnetization. Figure 1 shows the B-H curves for these magnet materials. The required magnetic field less than 1 kGauss can be generated by the anisotropic ferrite magnets.

The magnetic field distributions at both ends are important in either case of electromagnets and permanent magnets. The cathode area has to be carefully designed so that the efficiency and the output power are optimum for the klystron operations. The used beam has to be well spread out on the collector surface especially with no input RF power; otherwise the surface wall of the collector would be destroyed by the intense beam with the original low emittance conserved. The magnetic field distributions on the axis between the cathode area and the collector area have to hold the axi-symmetry in order to transport the beam without hitting the cavity walls.

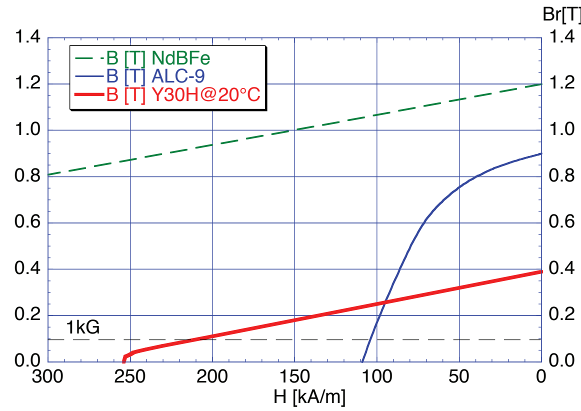

Figure 1: B-H curves of RE, ALNICO, and Ferrite magnets. RE magnets are strong but expensive. Historically well-known ALNICO magnets have high remanence but less coercivity. Anisotropic ferrite magnets have less remanence but stronger coercivity than ALNICO.

ALNICO DESIGN

In the 1960's, ALNICO had been used as the magnet material at SLAC (see Figure 2)[2]. ALNICO magnets, developed around 1940, are alloys, comprising mainly of the metals, Al, Ni and Co, and are mainly manufactured by the casting process. Although they have small temperature coefficient and large remanence, the small

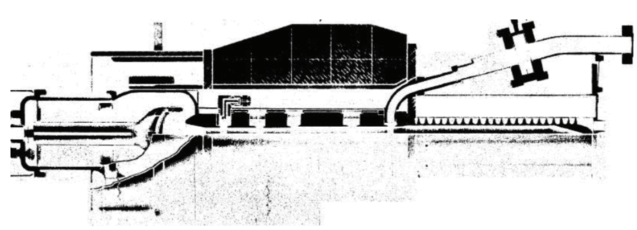

Figure. 2: SLAC 2422 Klystron. The black shaded area is the magnet part.

coercivity can result their partial demagnetization. This makes the design of the magnet system difficult.

Another development using ALNICO performed in the 1980's in KEK has a different outer shape than that of SLAC as shown in Fig. 3 [3]. The outer diameter of the SLAC type varied along the axis to adjust the magnetic field distribution, while that of KEK was just straight. In the design, ø25 mm x 50mm long rod magnets were stacked, where some of the magnets were partially demagnetized to adjust the magnetic field distribution.

As stated before, the magnetic field distribution at the cathode area has to be carefully adjusted for optimum efficiency and output power, which may be different for each klystron.

In a permanent magnet system, an integrated value of magnetic field vector along an axis (closed curve, in general) is zero, because of the Ampere's law. Therefore the magnetic field switches its sign somewhere along the axis. If there are no protruding objects such as the high voltage ceramic insulator or output wave guide, a longer permanent magnet system can easily push out such a reversal area from the klystron area. The protruding objects inflates the inner bore radius of the magnet system and the cost problem arises (see Fig. 4).

PPM (Periodic Permanent Magnet) focusing scheme had been developed recently. Although the alternating magnetic field can be easily generated by permanent magnets, the periodicity results stopbands. For pulse operations, the operating point always crosses such region and the beam loss caused by the stop band has to be minimized in design. The phase space mismatch of the beam, however, cannot be avoided around the stop band, hence it becomes serious for a short pulse operation, where the rise time and the pulse width are comparable. The beam loss causes wall heating and prevents stable operation[4].

ANISOTROPIC FERRITE DESIGN

For safe operation, a unidirectional magnetic field seems desirable rather than the PPM scheme. It 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 just iron oxide widely available, while RE material has resource problem. No supply problem would arise even for the 4000 units (8000 in HCS) for ILC.

Because the former designs using permanent magnets keeps compatibility with electromagnets, it generates large amount of unnecessary magnetic flux in the bore. Although the minimum area for the magnetic flux to fill is just around the area that electron beam occupies, the existence of cavities and their walls increases the radius up to above the outer radius of the klystron body. As can be seen in Fig. 4, this radius is fairly small compared with

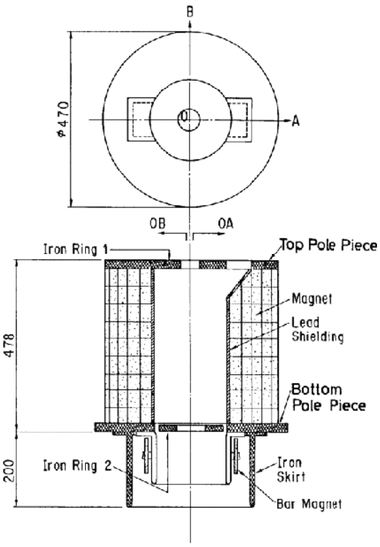

Figure 3: Permanent magnet for beam focusing in klystron at KEK (1987).

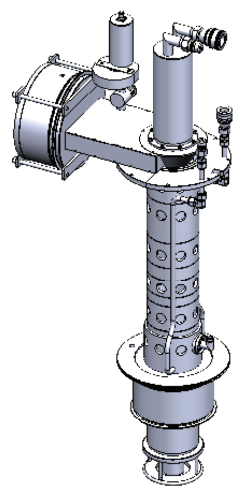

Figure 4: The klystron for DRFS.

the high voltage ceramic insulator. A solenoid electromagnet has to be designed not to conflict with all the 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 high voltage ceramic insulator. The bottom pole plate above the insulator of the klystron is designed larger than the insulator to hold the klystron weight.

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 50 mm. The magnet system can be divided into two sections that can open the aperture at the installation of the klystron in order for the fat cathode part to get through and the magnets can be pushed in closer to the klystron body after the klystron insertion. This reduces the required magnet volume significantly. Each section can be further divided into several blocks to move separately for the magnetic field adjustment.

RADIA4.29[5,6] is used for the magnetic field design. The current design is shown in Fig. 5. Many magnets are used, which are categorized into two groups. The one group iconsists 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 insertion step. They are designed so as not to interfere with the klystron parts such as cooling pipe or input RF connector. The hexagon shape at the middle area can evade the cooling pipes on the klystron body surface (see Fig. 4). The upper and lower parts in this group have many magnets because of the big protruding parts in this area. We can use the retracting mechanism for the magnetic field adjustment.

The other group iconsists of the bottom and the top large magnet bricks to form the magnetic field around the cathode and the collector area. Their easy axis is 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 part is covered by an iron cylinder as a magnetic shield in order to have less reversal magnetic field. The bottom four bricks can be also retracted to adjust the magnetic field around the cathode area. The resulted magnetic field distribution and the target value are shown in Fig. 6. Since it was designed to match the cathode and the output cavity area, the middle are has some discrepancy from the target value. The fine tuning will be performed through magnetic field measurement on a half scale model, which is under fabrication. Feasibility on the scheme and the mechanical structure will be checked on the model.

REFERENCES

[1] S. Fukuda, Distributed RF Scheme (DRFS) - Newly Proposed HLRF Scheme for ILC, LINAC2010, Tsukuba, pp.112-114, 2010

[2] Jean V. Lebacqz, Status Report on Klystron Improvements, IEEE, Trans., NS-22, 3, pp.1324-1327, June 1975

[3] Fukuda, S., Shidara, T., Saito, Y., Hanaki, H., Nakao, K., Homma, H., Anami, S., Tanaka, J., PERFORMANCE OF HIGH POWER S BAND KLYSTRONS FOCUSED WITH PERMANENT MAGNET, 198624009 KEK-86-9, Feb 1987

[4] S.Matsumoto, et al., STUDY OF PPM-FOCUSED X-BAND PULSE KLYSTRON, Proc. of LINAC 2006, Knoxville, pp.628-630

[5] P. Elleaume, O. Chubar, J. Chavanne, Computing 3D Magnetic Field from Insertion Devices, proc. of the PAC97, May 1997, p.3509-3511.

[6] O. Chubar, P. Elleaume, J. Chavanne, A 3D Magnetostatics Computer Code for Insertion devices, SRI97 Conf. Aug. 1997, J. Synchrotron Rad. (1998). 5, 481-484

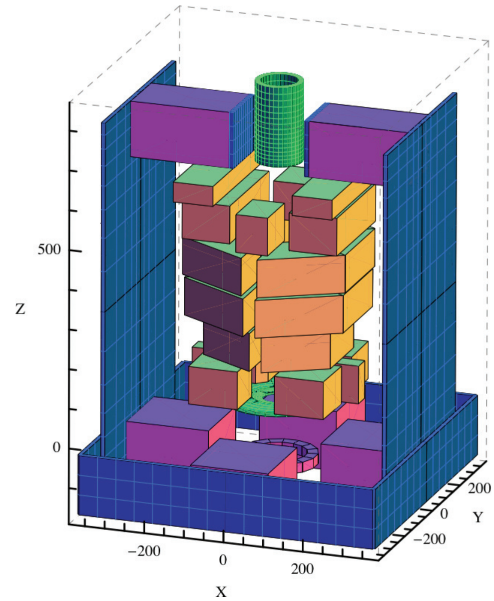

Figure 5: Permanent magnet focusing system designed with RADIA4.29

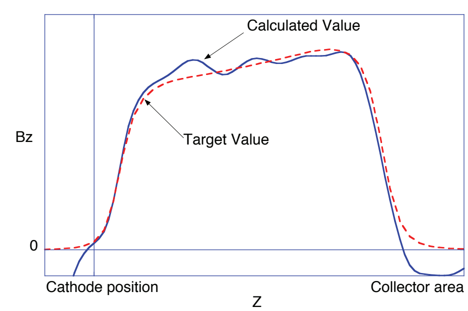

Figure 6: Designed magnetic field distribution and the target distribution (smooth curve).

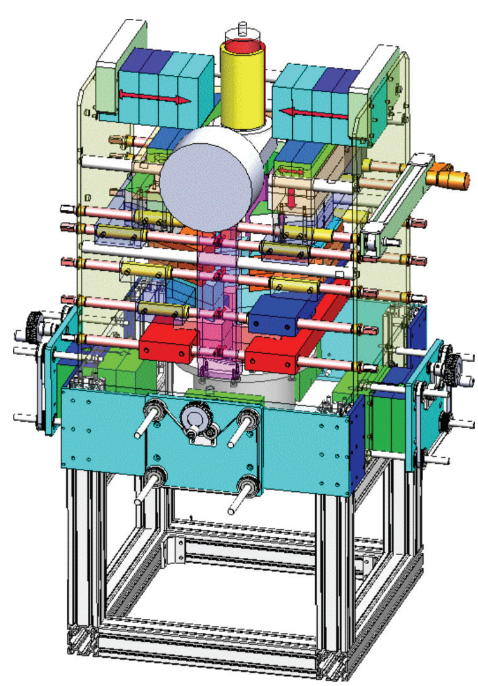

Figure 7: Mechanical design of a half scaled model.