DEVELOPMENT OF PERMANENT MAGNET FOCUSING SYSTEM FOR KLYSTRONS

Y. Fuwa, Y. Iwashita, H. Tongu, Institute for Chemical Research, Kyoto University, Kyoto, Japan
S. Fukuda, S. Michizono, High Energy Accelerator Research Organization, Ibaraki, Japan

Abstract

A permanent magnet focusing system for klystrons is under development to improve reliability of RF supply system and reduce power consumption. To save production cost, anisotropic ferrite magnets are used in this system. A test model has been fabricated and the power test of a 750 kW klystron with this focusing magnet is carried out. 60 % of the nominal output power has been achieved at a preliminary power test so far.

INTRODUCTION

Distributed Klystron Scheme (DKS) is proposed as one of the RF supply scheme for International Linear Collider (ILC) to reduce the cost and the down time by raising the reliability [1]. Because thousands of relatively small modulating anode (MA) klystrons ware required in DRFS scheme, the failure rate of each component must be reduced. Especially thousands units of electromagnet for klystron beam focusing would cause maintenance problems. Replacing the electromagnets by permanent magnets can eliminate their power supplies and cooling system. Hence the failure rate of the RF supply system can be reduced and cut down the operation cost. A klystron beam focusing system with ferrite magnets is under development is described.

FABRICATION OF FOCUSING MAGNET

Magnetic Materials

There have been precedents for electron beam focusing in klystrons with permanent magnets such as ALNICO, the rare earth (RE) [2,3,4]. Figure 1 shows the B-H curves for these magnet materials and anisotropic ferrite magnets. ALNICO magnets, which have high remanence, shows less coercivity and easily demagnetize. Although RE magnets such as NdFeB has high remanence and coercivity, they are rather expensive and have the resource problem. The anisotropic ferrite magnets have less remanence but higher coercivity than ALNICO. The required magnetic field for beam focusing in klystrons is less than 1 kGauss, therefore the remanence of the anisotropic ferrite magnets is enough high. And the material costs are not expensive, because anisotropic ferrite magnets are composed of iron oxide.

Magnet Field Distributions

Periodic Permanent Magnet (PPM) focusing scheme has relatively well-known magnetic field distribution. In a focusing system with permanent magnet, the alternating magnetic field can be easily generated because an integrated value of magnetic field vector along closed

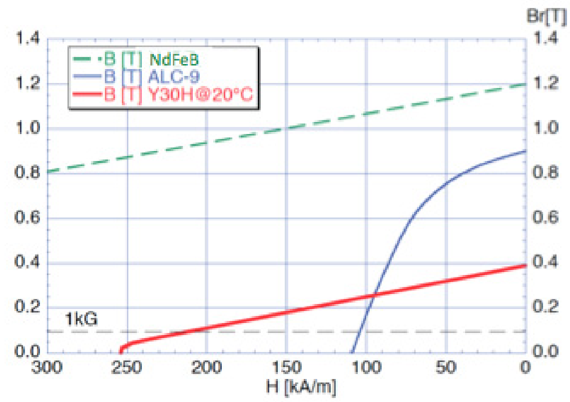

Figure 1: B-H curves of rare earth, ALNICO and ferrite magnets.

curve or infinitely-long axis is zero by the Ampere's law. However, periodicity cause stop bands. For pulse operations, the operating point always crosses such region during pulse rising time and the beam loss causes wall heating and prevents stable operation.

For safe operation, unidirectional magnetic field distribution is applied. Because the required magnet field is not high, anisotropic ferrite magnets can be used. RADIA 4.29[5,6] is used for the magnetic field design. Applied design is shown in Figure 2. Magnets shown in Figure 2 are categorized into two groups. The one group consists of magnets surrounding the klystron body

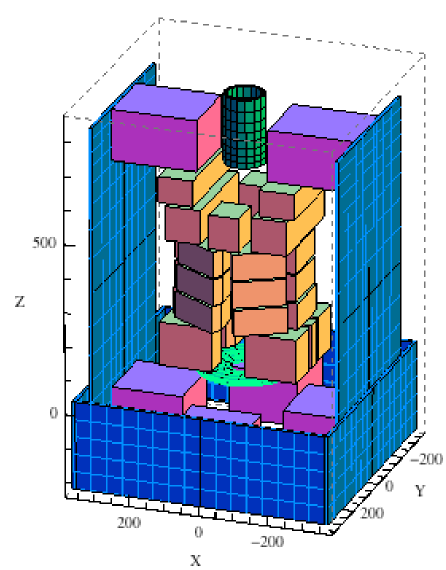

Figure 2: Layout of magnet and iron yoke.

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(yellowish ones in Fig. 2), whose easy axes are parallel to the klystron beam axis. The other group consists of the bottom and the top large magnet bricks (purplish ones in Fig. 2) to form the magnetic field around the cathode and the collector area. Their easy axis is perpendicular to the klystron axis. All magnets are retractable for the insertion of the klystron. Klystrons are usually inserted from the top of the focusing magnets and thus the minimum aperture of the magnets must be larger than most fat part of the klystron such as ceramic insulator. The retractable magnets can open their aperture at the klystron installation time and close at the operation. (see Figure 3). This retracting mechanism can also be used for the field adjustment.

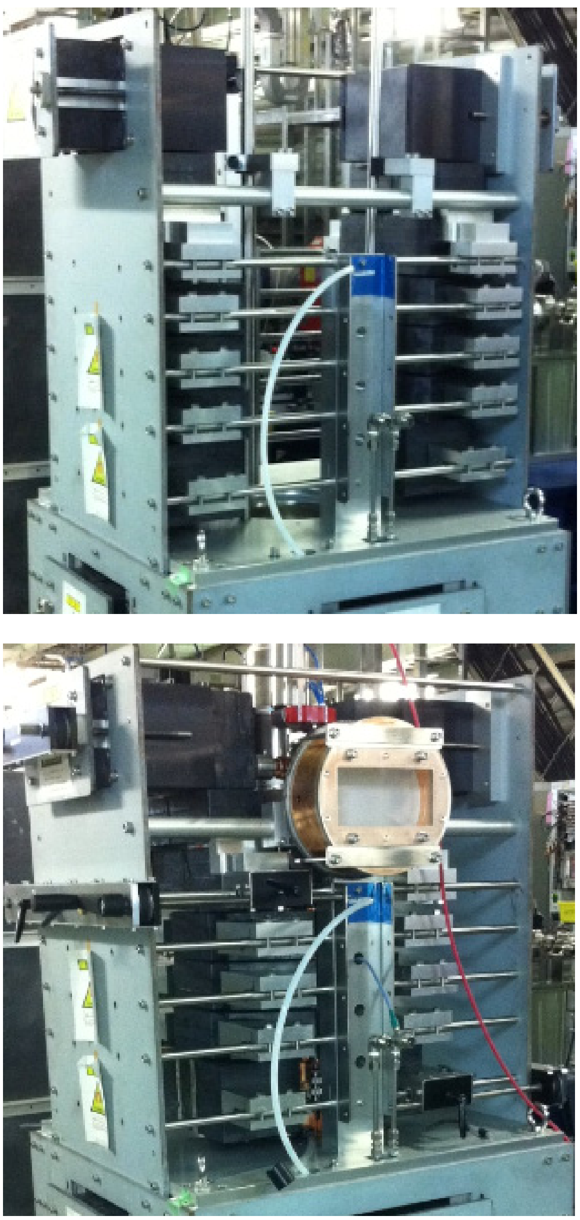

Figure 3: The magnets have larger aperture than the klystron body before the klystron installation (upper). After the klystron installation, the magnets are brought close to the klystron (lower).

KLYSTRON POWER TEST

To evaluate performance of the fabricated focusing magnet, a power test with real klystron (Toshiba E37501) is carried out. Figure 4 shows the E 37501 and Table 1 shows its nominal specification. The magnet field distribution, which is measured, adjusted is applied for power test. Figure 5 shows the longitudinal magnetic field. The blue line shows measured magnetic field generated by permanent magnets and the red line shows that by the electromagnet. The beam transport simulation has been performed by DGUN[7] using measured longitudinal magnetic field. The result of the simulation shows that the beam can pass through the klystron body without loss in the DC state (see Figure 6). Figure 7 shows transverse magnetic field components. The transverse magnetic field components are adjusted less than 10 Gauss by moving magnet's position. In the power test, the klystron was operated with 1 Hz repetition rate and the RF pulse duration was 1 ms so as not to damage the klystron body by unexpected beam loss. The result of the preliminary power test where the klystron cathode voltage is from 45 kV to 65 kV is shown in Figure 8. In Figure 8, red plots are the output maximum output power with our permanent magnets and blue plots are the max output power with an electromagnet measured by Toshiba. About sixty percent of the nominal output power at Toshiba is attained by the permanent

Figure 4: The klystron using in power test (Toshiba E37501).

Table 1: Specification of E37501

frequency	1.3 GHz
Max Output Power	750 kW
Max Efficiency	55 %
Max Gain	43 dB
Max Pulse Length	1.5 msec
Max Repetition Rate	5 Hz
Max Beam Voltage	66 kV
Max Beam Current	50 A

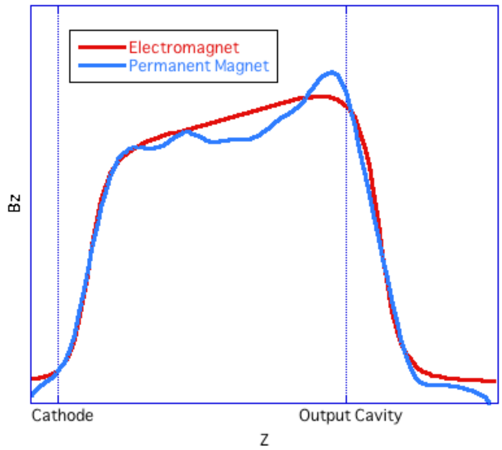

Figure 5: The longitudinal magnetic fields.

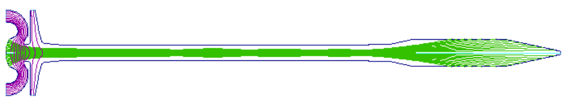

Figure 6: The result of DGUN simulation with the measured longitudinal magnetic field.

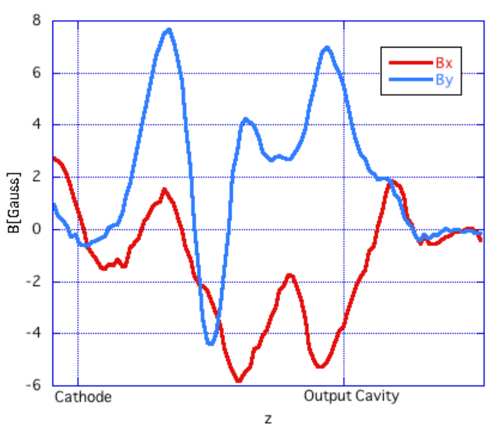

Figure 7: The measured transverse magnetic fields.

magnets in this early stage experiment. And the energy efficiency is about 33 % for our permanent magnets. This low output power and efficiency are supposed to be caused by the not optimized magnetic field in the cathode area. Figure 9 shows the calculated magnetic field in the cathode area. Although the magnetic field near the axis looks good, that on the outskirts may not be optimum, which results in beam mismatch.

Electric discharges occurred frequently in the operation and prevent stable operation. The electric discharges seem to be caused by the shape of the oil tank; the oil tank has a smaller diameter than that for the electromagnet focusing in order to reduce the distance from the magnets to the axis. This problem will be fixed by a remodeling of the tank. Further study will be continued for a better performance through magnetic field adjustment and so on.

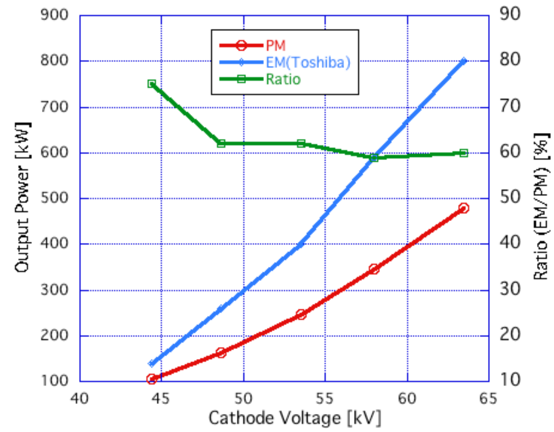

Figure 8: The preliminary result of the klystron power test.

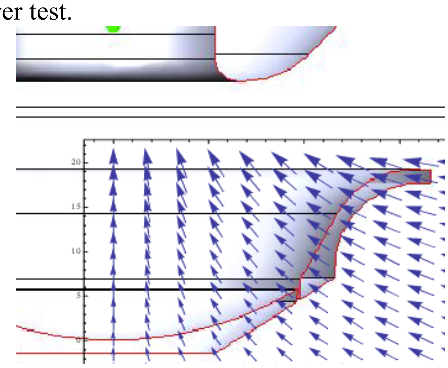

Figure 9: The calculated magnetic field in the cathode area

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