ANISOTROPIC FERRITE MAGNET FOCUSING SYSTEM FOR KLYSTRONS

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Abstract

An anisotropic ferrite magnet focusing system for klystron beam is developed 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 L-band klystron with this focusing magnet is carried out. 94 % of the nominal output power has been achieved at a power test.

INTRODUCTION

Distributed RF Scheme (DRFS) 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 were 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 water systems. Hence the failure rate of the RF supply system can be reduced and cut down the operation cost. A klystron beam focusing system with anisotropic ferrite magnets is described in this paper.

FABRICATION OF FOCUSING MAGNET

Magnetic Materials

There have been precedents for electron beam focusing in klystrons with permanent magnets such as ALNICO and 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, show less coercivity and are easily demagnetized. 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 high enough. And the material costs are not expensive, because anisotropic ferrite magnets are composed of iron oxide.

Magnet Field Distribution

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 a closed curve or an infinitely-long axis is zero by the Ampere's law. However, the periodicity generates 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 operations, unidirectional magnetic field distribution is favorable and applied. RADIA 4.29[5,6] is used for the magnetic field design. Applied design is shown in Fig. 2. Magnets shown in Fig. 2 are categorized

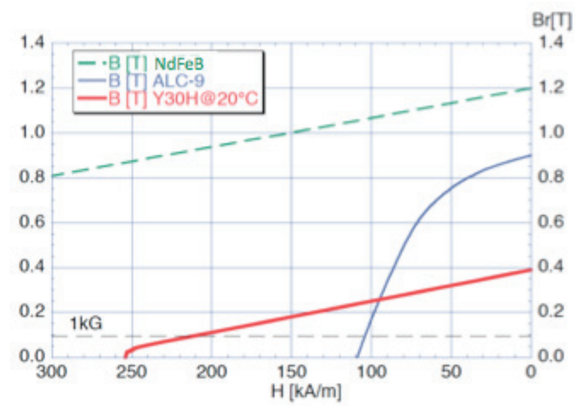

Figure 1: B-H curves of rare earth, ALNICO and ferrite magnets.

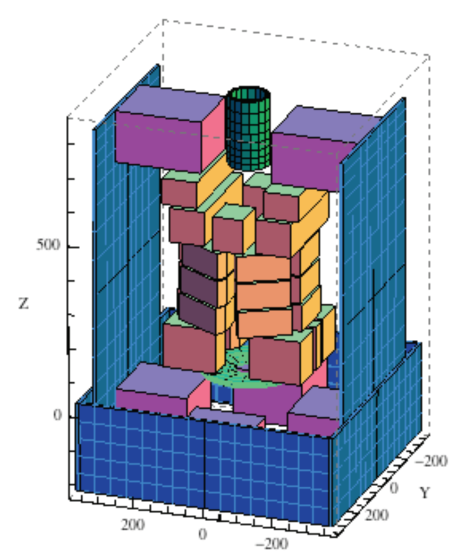

Figure 2: Layout of magnet and iron yoke.

into two groups. The one group consists of magnets surrounding the klystron body (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 Fig. 3). This retracting mechanism can also be used for the magnetic field adjustment.

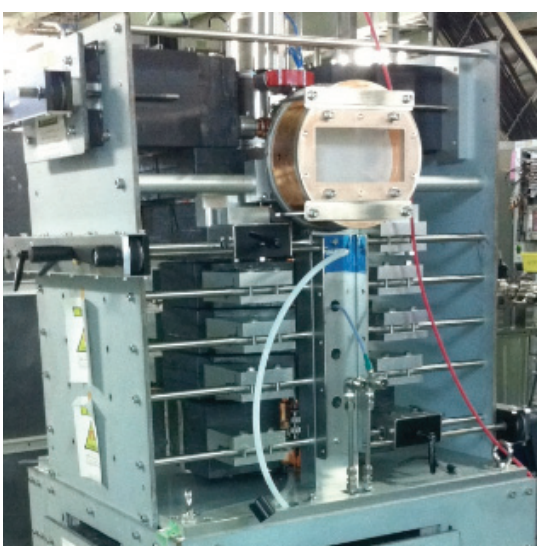

Figure 3: The magnets have larger aperture than the klystron body before the klystron installation (top). After the klystron installation, the magnets are brought close to the klystron (bottom)

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. Figure 5 shows the relative value of the longitudinal magnetic field used in the power test. 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 as input. The result of the simulation shows that the beam can pass through the klystron body without any loss in the DC operation (see Figure 6). 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 first power test is plotted in Figure 7 (red line). In the figure, blue plots are the output power with an electromagnet. The preliminary result of our magnet was lower than that of electromagnet. These low discrepancies were supposed to be caused by the not optimized magnetic field in the cathode area. Figure 8 shows the calculated magnetic field in the cathode area. Although the magnetic field near the axis looks good, that in the surrounding area was not axisymmetric and showed discrepancies, which may have resulted in beam mismatch.

Figure 4: The klystron used for 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

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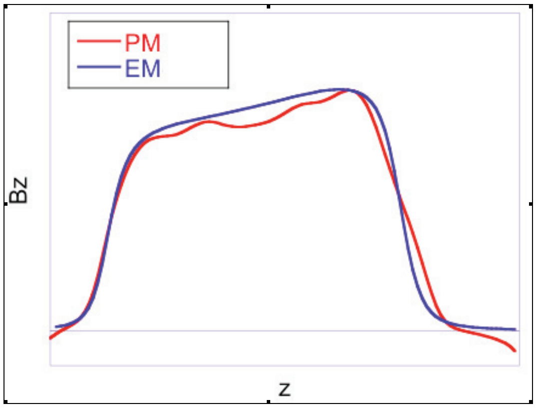

Figure 5: The longitudinal magnetic fields.

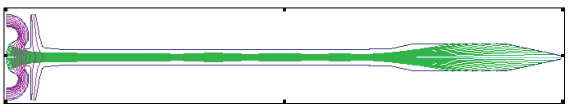
Figure 6: The result of DGUN simulation with the measured longitudinal magnetic field.

The magnetic field on the cathode area was improved replacing the oil tank material by iron (in the first power test, the oil tank was made copper). The Improved magnetic field is shown in Fig. 8 (bottom). In the last power test, 595 kW output power has been achieved with the iron oil tank. This output power is equivalent to 94 % power with electromagnet focusing. Taking Joule heat in the focusing coil into consideration, the electric power efficiency of our permanent magnet focusing magnet is better than that of the electromagnet.

REFERENCES

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

[2] Jane V. Lebacqz, Status Report on Klystron Improvements, IEEE, Trans., NS-22, 3 pp.1324-1327, June1975.

[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. Masumoto, et al., STUDY OF PPM-FOCUSED X-BAND PLUSE KLYSTRON, Proc. of LINAC 2006, Knoxville, pp.628-630.

[5] P. Elleaume, O. Chubar, J. Chavanne, Computing 3D Magnetic Field from Inserted 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.

[7] A. Larionov, K. Ouglekov, "DGUN-code for simulation of intensive axial-symmetric electron beams", 6th ICAP, TU Darmstadt, Germany, 2000, p. 17.

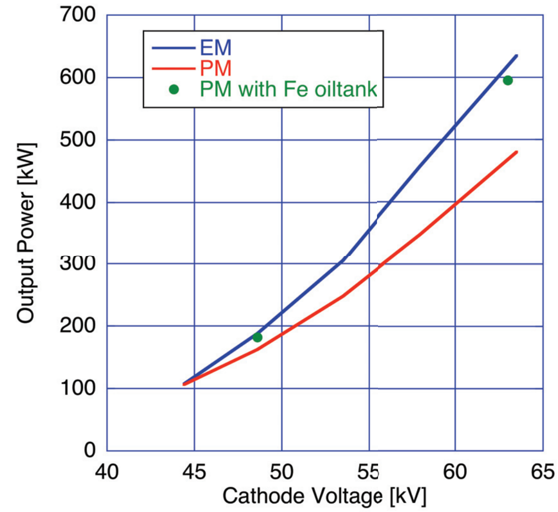

Figure 7: The result of the klystron power test.

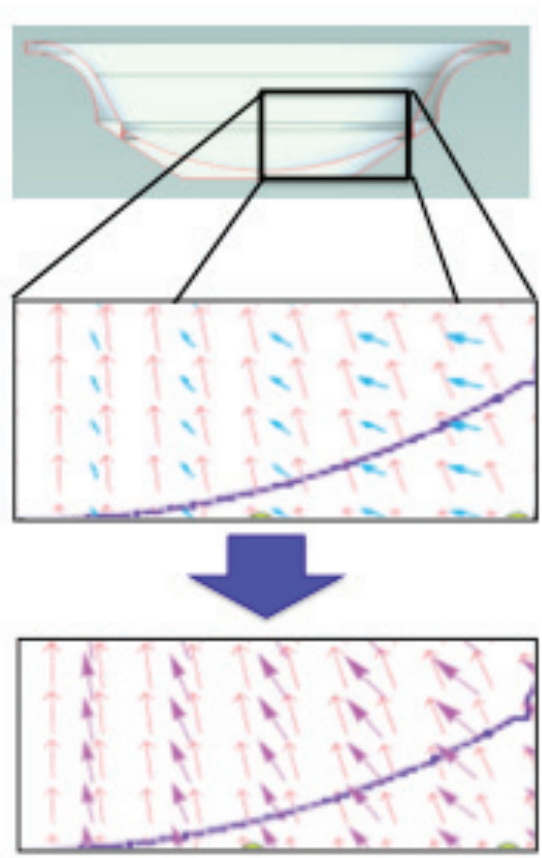
Figure 8: The cathode outline of the klystron used in the power test (top). The blue arrows are the calculated magnetic field on the cathode at the first power test The red arrows are the calculated magnetic field generated by electromagnet (middle). The purple arrows are the calculated magnetic field on the cathode after the Fe oil tank is introduced (bottom).