ERROR ANALYSIS AND FABRICATION OF THE PROTOTYPE BENDING MAGNET FOR THE FANTRON-I

Min-joon Park, Han-sung Kim, Moon-sung Chun, Kie-hyung Chung,
Hyeok-jung Kwon[1], Kang-ok Lee[1]
Dept. of Nuclear Engineering, Seoul National University, Seoul 151-742, Korea
[1]Korea Accelerator and Plasma Research Association, Chonan 330-825, Korea

Abstract

A 10 MeV, 100 kW CW electron accelerator for irradiation purpose, named FANTRON-I, is under development by KAPRA(Korea Accelerator and Plasma Research Association). To investigate the error effects of the accelerating and focusing elements of the FANTRON-I, computer simulations for the cases with errors in beam line length, magnet pole face rotation angle and the accelerating field of the cavity were performed. A prototype bending magnet that was composed of a main and a supplementary bending magnet for effective transverse focusing was designed, fabricated and tested. In this paper, the results of the error analysis of the beam transport system and the test results of the prototype bending magnet are presented.

1 INTRODUCTION

A 10 MeV, 100 kW CW electron accelerator FANTRON-I whose purposes are to sterilize the agricultural and forest products, foods and so on, is under development by KAPRA. The FANTRON-I uses two nonagon shape coaxial cavities whose frequencies are 159.41 MHz and seventeen bending magnets each of which consists of main and supplementary magnet for transverse focusing. As presented earlier [1], the reference particle trajectory of the FANTRON-I is three dimension. Therefore the error effect of the beam transport elements on the beam should be analysed carefully. As a first step, the error effects of the beam line length, magnet pole face rotation angles, amplitude and phase of the accelerating field in the cavities were calculated and analysed. With the results of the magnet pole face rotation error calculated above, a prototype bending magnet for low energy acceleration system whose purpose is to validate the acceleration principle was designed, fabricated and tested.

2 ERROR ANALYSIS OF THE BEAM TRANSPORT SYSTEM

2.1 Model

The errors which influence the beam dynamics can be divided into three groups which are beam related errors, time-independent(slow) errors and time-dependent(fast) errors[2]. The characteristics of the FANTRON-I beam dynamics which are 3-D motion of the reference particle, relatively long accelerating section and non-negligible space charge force demand careful estimation of the error effects of the beam transport system. The schematic of the FANTRON-I bending magnet is presented in Figure 1. The bending magnet consists of three bending sections (one for main and two for supplementary magnet) and four straight sections.

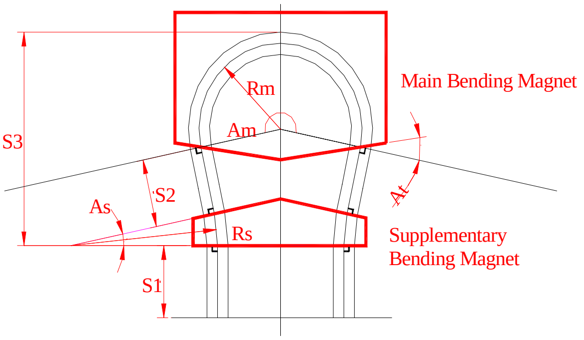


Figure 1. Schematic of the bending magnet

As a first step of the error analysis, the error effects of the beam line length of the straight sections (S1, S2), magnet pole face rotation angles of the main and supplementary magnet (for example “At” for main bending magnet), amplitude and phase of the accelerating field were investigated respectively and combined error effects of those were analysed. The limits for all simulated errors are presented in Table 1.

Table 1: Error types and their limits

Error types	**Error limits**
Beam line length (Case I)	
S1	± 1 mm
S2	± 1 mm
Magnet pole face rotation angle (Case II)	
Main magnet	± 0.28 °
Suppl. magnet	± 0.28 °
Accelerating field (Case III)	
Amplitude	± 1 %
Phase	± 1 °

2.2 Probability Analysis

Two hundred sets of random error samples within the limits in Table 1 were used to evaluate the error effects. The particle transport probabilities with respect to the error types are presented in Figure 2. As can be shown in Figure 2, the magnet pole face rotation angle error and beam line length error have relatively negligible effect on the beam transport probability, but the amplitude and phase errors of the accelerating field have great effects on the beam transport probability. Detailed analysis showed that energy spread due to accelerating field errors had a larger value than those due to the other two cases, and almost the particle losses occurred in the low energy bending region. The above two facts show that the designed beam transport system is more sensitive to the longitudinal beam dynamics rather the transverse one. The combined effects of the above three cases are shown in Figure 3. The Figure 3 has a similar tendency to particle transport probability curve due to the accelerating field error in Figure 2.

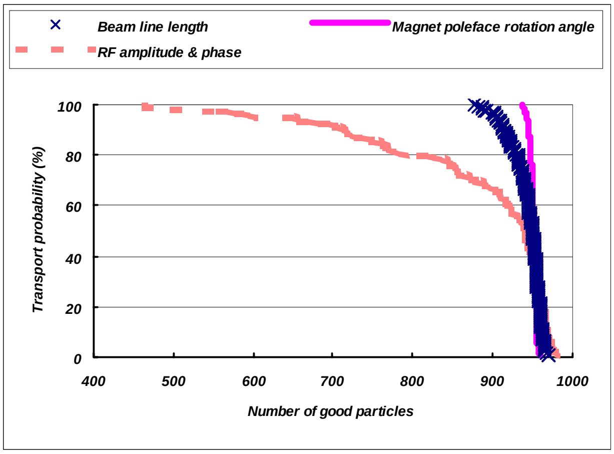


Figure 2. Beam transport probability with respect to beam line length, magnet pole face rotation angle, RF amplitude and phase errors

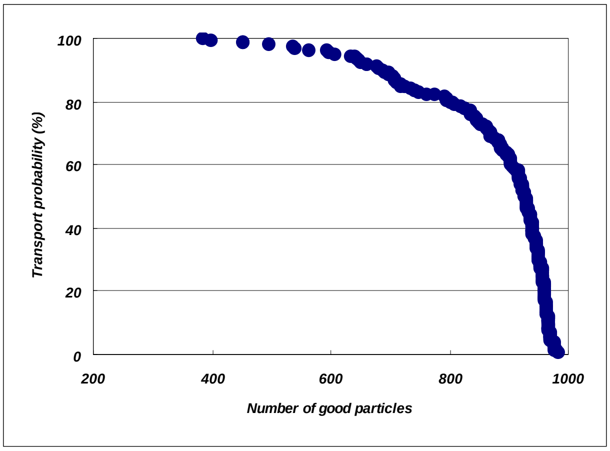


Figure 3. Beam transport probability with respect to combined effect

3 MAGNET FOR LOW ENERGY ACCELERATION SYSTEM

The low energy acceleration system whose purpose is to validate the FANTRON-I acceleration scheme was designed and fabricated. The system consists of one nonagon shape coaxial cavity, one bending magnet and other parts such as electron gun, RF system, vacuum system and so on as shown in Figure 4[3].

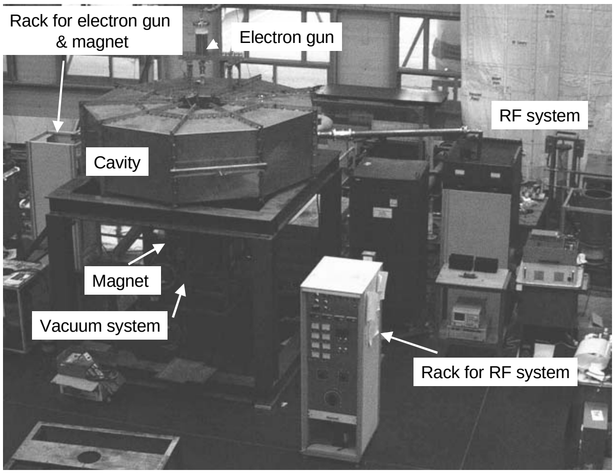


Figure 4. Low energy acceleration system

The design parameters of the bending magnet for the low energy acceleration system are shown in Table 2, and the simulation results of the magnetic flux density distribution using OPERA3D code are presented in Figure 5.

Table 2. Design Parameters of the bending magnet

Parameters	Main Magnet	Supple. magnet
Bending angle of the beam	200 °	10 °
Pole face angle	178 °	10 °
Pole face rotation angle	11 °	0 °
Air gap size	50 mm	50 mm
Magnetic flux density	36.1 gauss	21.5 gauss
Magnetomotive force	161 AT	97 AT

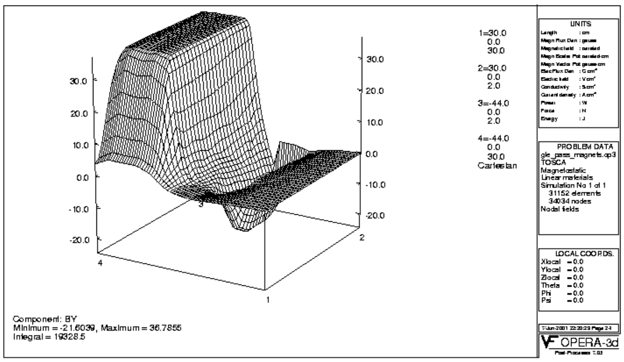


Figure 5. Magnetic flux density distribution

The fabricated bending magnet is shown in Figure 6. The main and supplementary bending magnets were joined together by stainless steel 304 plate for easy alignment and assembly. The coil was cooled by natural convection cooling and molded by epoxy resin (Ciba, Araldite, AW106, HV953K). The magnetic flux density distribution was measured using 3D gaussmeter (Lakeshore, 460) and the results about the main bending magnet are shown in Figure 7. The differences between the calculated and measured values were within 3 % and the differences were concentrated at the edge region. As for the supplementary magnet, the differences were more pronounced because of the relatively large gap size and non-symmetry of the reluctance of the magnetic circuits.

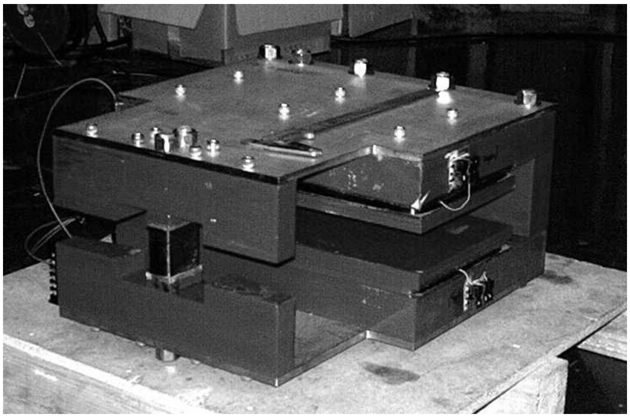
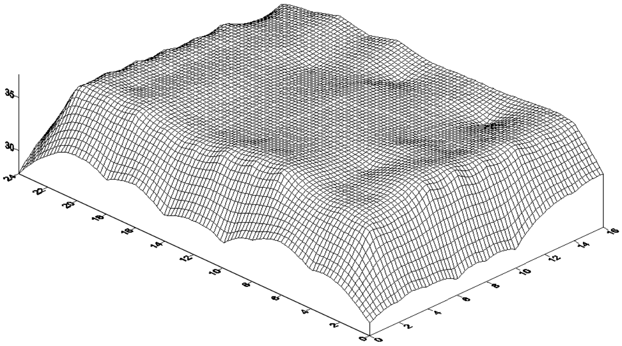
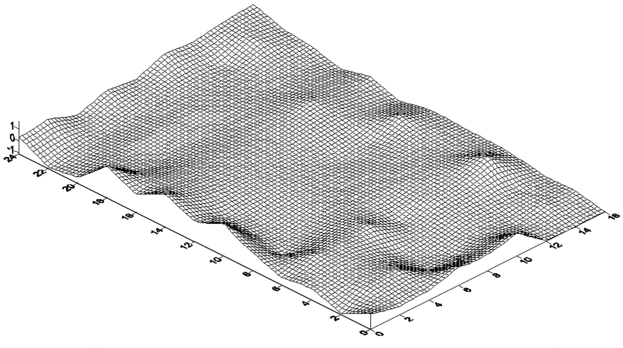


Figure 6. Bending magnet



(a) Measured B field distribution of the main magnet



(b) Difference between measured & calculated B field
Figure 7. B field distribution of the main magnet

5 CONCLUSIONS & FUTURE WORKS

Two hundred error sets about the beam line length, magnet pole face rotation angle and amplitude and phase of the accelerating field were used to evaluate the error effects on the beam transport probability of the FANTRON-I. The results showed that the beam line length and the magnet pole face rotation errors had negligible effects on the beam transport probability, whereas the amplitude and phase errors of the accelerating field had non-negligible effects on the transport probability. Those results explain that the designed beam transport system is more sensitive to the longitudinal beam dynamics rather than the transverse one. A bending magnet for low energy acceleration system was designed, fabricated and tested. The differences between the calculated and the measured magnetic flux density of the main magnet were within 3 % and the differences were concentrated at the edge region. Because the air gap size of the magnet is relatively large, the edge field effects on the beam should be analysed carefully.

REFERENCES

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