ACCELERATING STRUCTURE DESIGN IN COAXIAL CAVITY

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Abstract

The industrial electron accelerator named FANTRON-I whose merits are its low fabrication cost, high reliability and easy maintainability has been designed and its components tested at Physico-technology laboratory, KAPRA (Korea Accelerator and Plasma Research Association). Recently, several points were proposed to improve the performance of the accelerator, which are a) the coaxial cavity is situated in air, b) only beam path zones are evacuated and maintained in vacuum by ceramic tubes, c) the energy gain of electron beam is maximized by matching the length of each accelerating gap in the cavity with transit time of electron beam. To validate the newly proposed concepts, the effects of ceramic tubes and metal pipes in the cavity on the cavity parameters such as resonant frequency, quality factor and shunt impedance were analysed using 3-D electromagnetic code. On the basis of the above results, the accelerating structure was designed to maximize the energy gain. In this paper, the improvements of the FANTRON-I cavity are presented.

1 INTRODUCTION

An X-ray source using electron accelerator to sterilize the agricultural, forest and aquatic products has been developed by KAPRA [1][2]. The electron accelerator named FANTRON-I is one type of the so-called recirculating accelerators. It consists of coaxial cavities that accelerate the electron beam around the electric field maximum plane and bending magnets that redirect the electron beam into the cavity. For low fabrication cost and easy maintainability, the nonagon shape was chosen as a cavity geometry which has equivalent electrical properties to those of circular shape coaxial cavity [3]. The cold test of the real size nonagon shape cavity confirmed the TM_{010} like mode which could be used to accelerate the beam in the cavity. As presented earlier, the reference particle trajectory of the FANTRON-I is three dimensions. Therefore the error effects of the beam transport element 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. A low energy electron beam acceleration system to validate the acceleration scheme and understand the characteristics of the accelerator components was designed and fabricated [4]. During single path experiment period using low energy acceleration system, several methods to improve the performance of the cavity were proposed. All of which requires cavity modifications.

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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 [5]. 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 schematics 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.

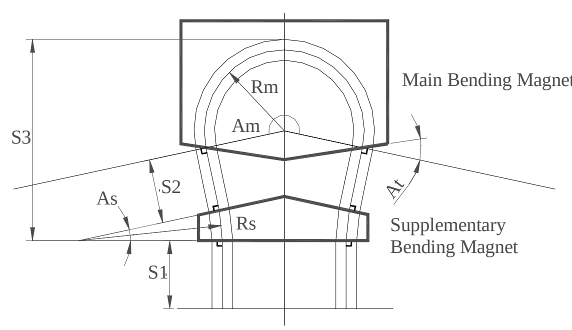

Figure 1. Schematics of FANTRON-I bending magnet

As a first step of the error analysis, the error effects of the beam line length of the straight line (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.

2.2 Error 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 than 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 in Figure 2 due to the accelerating field error.

Table 1. Error types and their limits

Error types		Error limits
Beam line length	S1	± 1 mm
	S2	± 1 mm
Magnet pole piece rotation angle		
	Main magnet	± 0.28 °
	Suppl. magnet	± 0.28 °
Accelerating field	Amplitude	± 1 %
	Phase	± 1 °

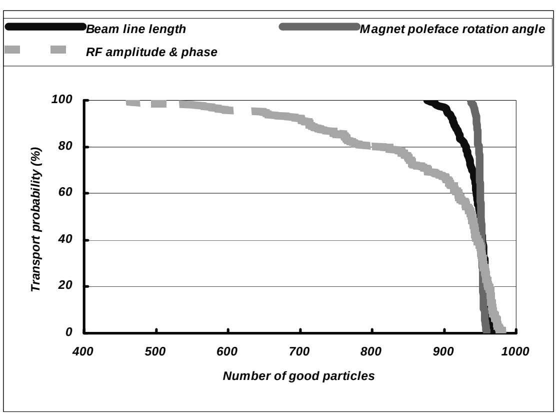

Figure 2. Beam transport probability with respect to various types of error

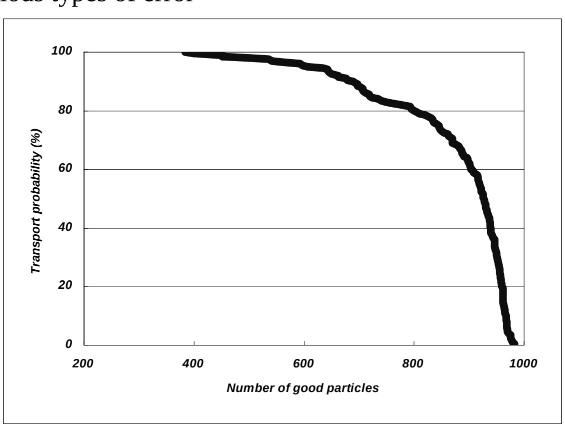

Figure 3. Beam transport probability with respect to the combined effect

3 CAVITY MODIFICATION ANALYSIS

As stated earlier, several methods to improve the performance of the cavity were proposed. Those are a) the coaxial cavity is situated in air, b) only beam path zones are evacuated and maintained in vacuum by ceramic tubes, c) the energy gain of electron beam is maximized by matching the length of each accelerating gap in the cavity with transit time of electron beam, - a) and b) are related with the low fabrication cost of the cavity, c) is related with the acceleration efficiency. All of which requires some modifications of the cavity. That is a) and b) requires insertion of ceramic pipe in the cavity beam holes and c) requires insertion of metal pipe in the cavity.

As a first case, cavity with ceramic tubes inserted into all beam holes was analysed using OPERA3D code and the results are presented in Table 2. At the Table 2, case I is the unperturbed cavity which has no ceramic pipe and case II, case III have ceramic pipes whose relative permittivity are 3 and 9 respectively. The dimension of the pipe was 30 mm inner diameter and 40 mm outer diameter. The results show that there is resonant frequency reduction in the cavity, which is evident because dielectric material is inserted in the cavity. But the quality factors and shunt impedances are almost same to those of the unperturbed cavity.

The effect of metal pipe insertion into the beam holes was calculated and the results are summarized as case IV in Table 2. The dimension of the metal pipe is same as that of ceramic pipe and the accelerating gap is 100 mm. The resonant frequency of the cavity with metal pipe was 108 MHz which is about 68 % that of the case I. Here the shunt impedance should be noted. Despite the uncorrected shunt impedance of the case IV which does not consider the transit time effect is lower than that of the case I, the corrected shunt impedance which takes into account the transit time effect is higher than that of case I by about 150 %.

Table 2. Calculation results of the modified cavity

Cavity Type	Resonant frequency	Quality factor	Shunt impedance
Case I	159.4 MHz	9820.4	468431 Ω
Case II	158.7 MHz	9820.1	462758 Ω
Case III	156.6 MHz	9821.0	473205 Ω
Case IV	108.4 MHz	8095.4	727296 Ω

4 CONCULSIONS AND FUTURE WORKS

An error analysis of the beam transport system has been carried out. The results showed that designed beam transport system was more sensitive to the longitudinal beam dynamics rather than the transverse one. This is because the accelerating sections are relatively long and several passes through the cavity are necessary to reach the relativistic velocity.

Several methods to improve the cavity performances were proposed. Two of which are related with the low fabrication cost of the cavity, and another is related with the acceleration efficiency of the cavity. The results of cavity analysis using OPERA-3D code showed that the operating frequency of the cavity with metal pipe was 108 MHz and corrected shunt impedance was 1.5 times that of the unperturbed nonagon cavity. This fact tells that the cavity crossing number can be reduced from 17 to 7 and the RF amplifier can be purchased easily because the frequency is within commonly used range. In addition to the above merits, another merits may be that the effects of the field amplitude and phase errors on the beam transport efficiency can be reduced because of the short accelerating gap. But to accept that cavity modifications, additional analysis should be done such as beam pipe cooling, higher order mode effects.

5 REFERENCES

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