BEAM DYNAMICS STUDY OF THE FANTRON-I

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Abstract

Beam dynamics study of the 10 MeV, 100 kW CW electron accelerator (FANTRON-I) for industrial applications has been performed. The FANTRON-I is a recirculating accelerator using a pair of coaxial cavities in which electrons are accelerated repeatedly. The characteristics of the FANTRON-I are its long acceleration length in each cavity (70 cm) and the 3-dimensional motion of electrons. Beam dynamics calculations by PARMELA are performed and analysed. As a result, the locations and the physical parameters of the bending and the focusing magnets are determined. The results of calculations and the characteristics of the FANTRON-I beam dynamics are presented.

1 INTRODUCTION

A 10MeV, 100kW CW electron accelerator, FANTRON-I for industrial applications are now under development. FANRON-I uses a TM010 mode in a coaxial cavity as an accelerating mode and electrons are passed on the plane within the cavity on which electric field is maximum. After passing two successive cavities, electron beam is deflected into the cavity again by bending magnet. However, the motion of the electron beam is unusually 3 dimensional. All the focusing elements are one solenoidal magnetic lens and weak focusing of bending magnets. Operating principle of the FANTRON-I is illustrated in the Figure 1.

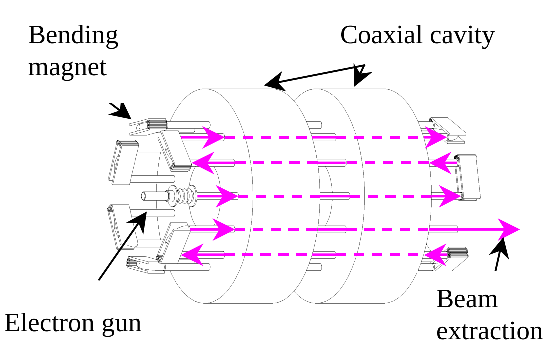


Figure 1: Operating principle of FANTRON-I

2 CHARACTERISTICS OF THE FANTRON-I BEAM DYNAMICS

Electric and magnetic field distributions seen by electron beam in the FANTRON-I cavity are not similar to those of the usual TM010 cavity. Figure 2 (a) shows the electric equipotential and magnetic field lines of the the FANTRON-I cavity and Figure 2 (b) for those of the usual TM010 pillbox cavity. It shows that electric field on the transverse plane in the FANTRON-I cavity has r- and θ -dependence, but that of the pillbox cavity, only r-dependence.

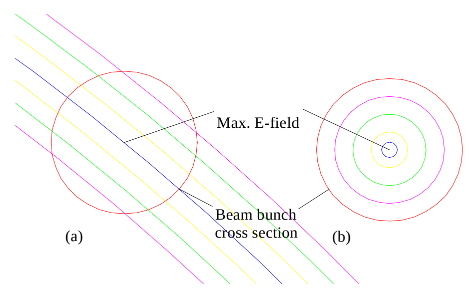


Figure 2: Field distribution seen by beam

As usual, beam motion is 2 dimensional on one plane, but 3 dimensional in the FANRON-I. Due to this 3 dimensional motion, it is more complicated and more difficult to analyse and handle the beam profile. But, as computer simulation result shows in the next section, beam profile is not so unstable when $\beta \rightarrow 1$.

Each FANTRON-I coaxial cavity length is 70cm, which is very long compared with those of other accelerators. Electric fields seen by particles are different depending on both transverse and longitudinal displacement from the reference particle. The larger cavity length is, the wider the energy spread becomes, which can cause serious particle loss when bended. Wide energy spread problem during acceleration in the long cavity can be dealt with by the injection phase angle into the 1st cavity and the good choice of this phase is very effective to the small energy spread.

3 PARMELA STUDY

PARMELA developed in the LANL(Los Alamos National Laboratory) was used as a main tool of the computer simulation of the FANTRON-I beam dynamics including space charge effect. The field seen by particles is unusual, as mentioned, but we made an assumption that the field seen by particles are not so much different as that of the modified pillbox cavity because dimension of the cavity is much larger than size of the beam profile.

3.1 Operating and initial conditions

The operating and initial conditions of physical parameters are as follows :

f_0(cavity resonant frequency) = 159.41MHz
E_0(maximum electric field in the cavity) = 0.594MV/m
L(cavity length including cavity material thickness)
= 70.4cm

x = y = 2mm, x' = y' = 5mrad
emittance = 10π mm mrad
beam phase length = 30 degrees (~6.5cm)
initial energy = 50keV
energy spread = 0.25keV
average beam current over 1 RF period = 10mA
initial number of particles = 1000

3.2 Focusing scheme with the bending magnets

For compact beam transport system, it is essential to achieve both x(horizontal) and y(vertical) focusing with the bending magnet. But it is difficult to achieve the both focusings with 180 degrees of bending angle and fringing field of bending magnet. Effective horizontal focusing needs the bending angle greater than 180 degrees. Therefore x focusing can be achieved by the bending angle greater than 180 degrees and y focusing by the fringing field through the pole face rotation. For bending angle greater than 180 degrees, it consists of the supplement bending plus main bending. The beam path through this method is shown in the Figure 3. Simulation shows that 15 degrees is suitable for supplement bending and 210 degrees for main bending. The pole face rotation angle to achieve y focusing is 15 degrees for the 1st main bending magnet and 11 degrees for others. Some PARMELA running shows that stable transport is very sensitive to the pole face rotation angle.

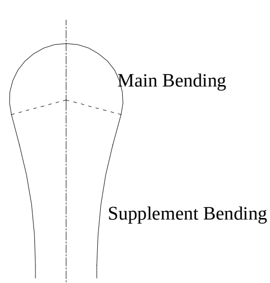


Figure 3: Beam path in the bending magnet

3.3 Simulation results

Unfortunately, it is necessary to install the solenoidal magnetic lens between the 1st cavity exit and the 2nd cavity entrance to transport the beam to the 1st bending magnet without loss. We expected the focusing effect due to the electric field distribution in the bores of the cavity, but it's not so effective. The length of the solenoid lens is 20cm and its magnetic field is 155G

Energy spread of particle is strongly related to the 1st cavity injection phase angle so the energy spread(dK(rms)/K) before the 1st bending and the number of "good" particles after the 1st bending versus the 1st cavity injection phase angle are plotted in the Figure 4 and, as a result, -20 degrees are selected as the 1st cavity injection phase angle.

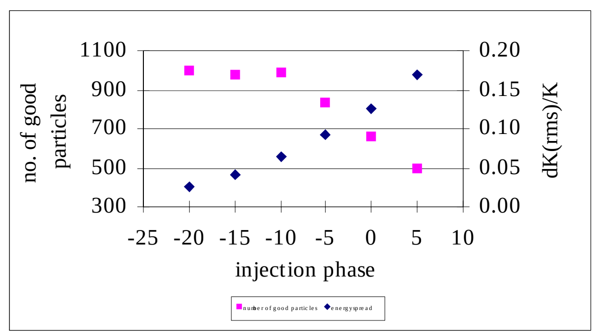


Figure 4: Determination of the 1st cavity injection phase angle

Total number of bendings is 16, final energy of the reference particle is 10.643MeV and the final number of the "good" particle is 875. The transverse phase diagrams(x-x', y-y'), beam profile(x-y) and longitudinal phase diagram(△w-△ϕ) before beam extraction are shown in Figure 5.

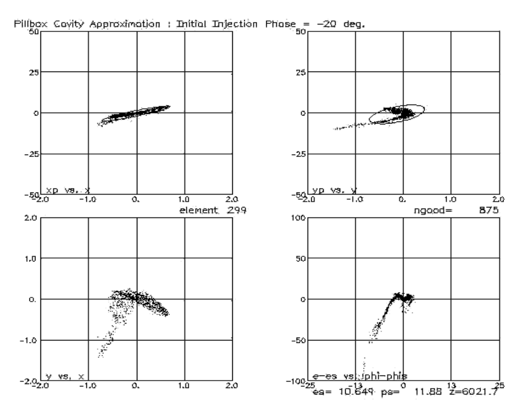
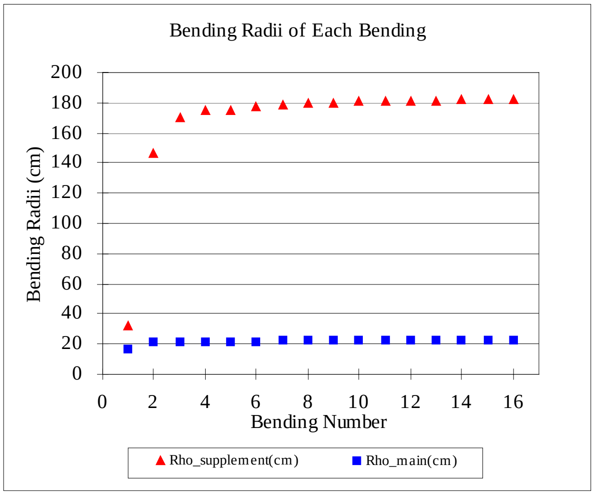


Figure 5: Phase diagram and beam profile before beam extraction

4 DETERMINATION OF THE MAGNETIC FIELD OF THE BENDING MAGNETS

From the calculated reference particle energy and the bending radii, supplement and main bending magnetic fields are determined. The results are plotted in the Figure 6.



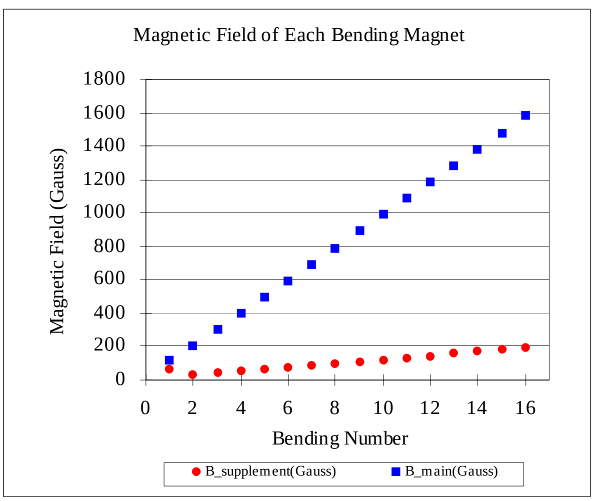


Figure 6: Bending radii and magnetic fields at each supplement and main bending magnets

5 CONCLUSION

For 10MeV acceleration of the 10mA electron beam, the transport system is studied with PARMELA. One solenoidal magnetic lens is required and no other extra focusing elements are needed because of the bending magnet focusing which uses 210 degrees of bending angle for horizontal focusing and fringing field by pole face rotation for vertical focusing. Initially total 1000 particles of 50keV are injected and 875 particles of 10.625MeV are survived in this computer simulation. Bending radii and required magnetic fields of each bending magnet are determined.

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