Beam Induced Magnetic Field Effect on the Injected Low Energy Beam

SHUHEI NAKATA
Third Group, Advanced Electrotechnology Department, Central Research Laboratory
Mitsubishi Electric Corporation
8-1-1 Tsukaguchi-honmachi, Amagasaki, 661 *Japan*

abstract

A beam dynamic is studied including the effects of beam induced magnetic field at a C-type kicker magnet. The calculation shows that 90% of an injected beam is lost during the first 10000 turns and the current is limited to several tens of mA but also shows that the beam loss is strongly dependent on the beam position in the kicker magnet. Hence the induced field effects can be avoided and several hundreds of mA current can be accelerated by controlling the beam position at kicker magnet.

INTRODUCTION

When an electron is passing through a beam pipe of non-ferrite material, a magnet-static force and electro-static force on the relativistic electron are compensated eacn other. But in a circular machine there are some sections where a part of the boundary is made of ferrite material, kicker magnet section for example. In these section, the induced surface magnetic charges can produce strong non-uniform magnetic field and disturb the beam orbit.

To estimate these effects, beam tracking simulation is performed considering the induced magnetic field self-consistently.

In the following section, the method of beam induced field calculation and some simulation results are presented.

KICKER MAGNET

A kicker magnet used in this calculation is the same one which is installed in the synchrotron of MITSUBISHI ELECTRIC CORP.[1],[2] now. The cross-section of the magnet is shown in figure 1. The gap of the kicker is 15mm, yoke width is 30mm, and the length is 600mm. The magnet is made of ferrite.

The details of the kicker magnet and the beam extraction experiments by the magnet will be described in ref. [3].

MAGNETIC FIELD CALCULATION

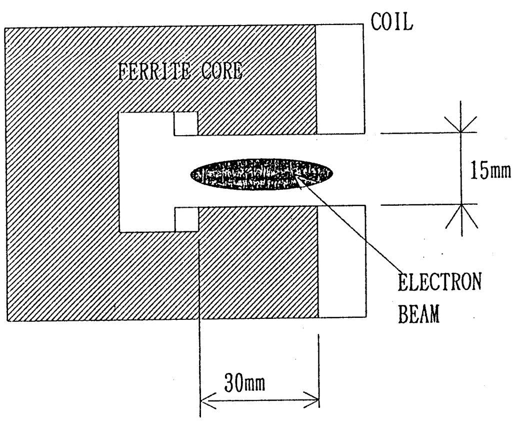


Figure 1: Kicker magnet cross-section

The induced magnetic field of the kicker is calculated by a 2-dimensional boundary element method. The variables used in this calculation are vector potentials and its normal derivatives. The relation of these variables can be written in the following equation.

$$C_p A_z = \int J(X,Y)dS - \sum_j \int \frac{\partial G}{\partial n} dS_j A_j + \sum_j \int \frac{\partial A_z}{\partial n} G dS_j, \quad (1)$$

where C_p is 1/2 when the observation point is just on the boundary and 1 when it is inside the boundary and G is defined as $1/r_{pj}, wherer_{pj}$ means a distance between the calculated point and the surface element, and J(X,Y)is an electron beam current density. By taking into account the beam distribution, which is obtained by beam tracking, the beam induced magnetic field can be calculated.

In this calculation, the normal derivatives of the vector potential at the surface are neglected because of the high permiability of the ferrite core.

BEAM TRACKING METHOD

The beam tracking is performed by an ordinary tracking method of using a 4×4 transfer matrix except a kicker section where the kicker is treated as a thin lens.

In this simulation, the lattice of MITSUBISHI's synchrotron [2] is used. The lattice has a FODO type , the circunference is 34m, and tune of the machine are 2.21,1.25 in x and y direction,respectively. The beta value at the kicker magnet is about β_x=2m and β_y=4m. The detail characteristics and its initial experimental results are given in ref. [2].

The effects of the induced field are estimated by two methods. One is to simulate a test particle behaviour under the kicker field which is induced by an externally fixed beam size and current. The other is to simulate multi-particles motion under the kicker field self-consistently.

For test particle's tracking initial position is x=0mm,x'=0mrad,y=2mm and y'=0mrad on the phase space which is close to the beam center.

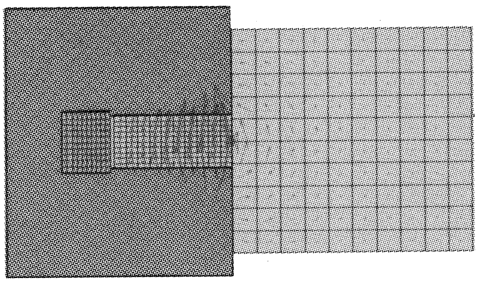
For self-consistent calculation, 100 particles are placed randamly in X-Y plane.

In both calculation, physical apperture is limited by the kicker cross section or artificially applied vertical apperture,$y \leq 10$mm, and the particle will not be lost at any other points through the synchrotron.

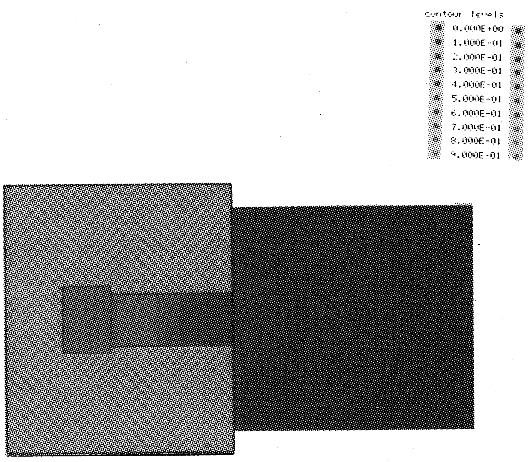
MAGNETIC FIELD DISRIBUTION

The calculated beam induced magnetic field is shown in figure 2, when the beam sizes are 40mm in horizontal and 4mm in vertical and the beam center is on the ideal beam orbit.

The figure 2 shows (a) **B** disutribution(vector) and (b) an equal vector potential painted contour.



: (A):MAGNETIC FIELD



(B):VECTOR POTENTIAL CONTOUR

Figure 2: BEAM INDUCED FIELD DISTRIBUTION, (A)MAGNETIC FIELD DIRECTION, (B)EQUAL POTENTIAL CONTOURE

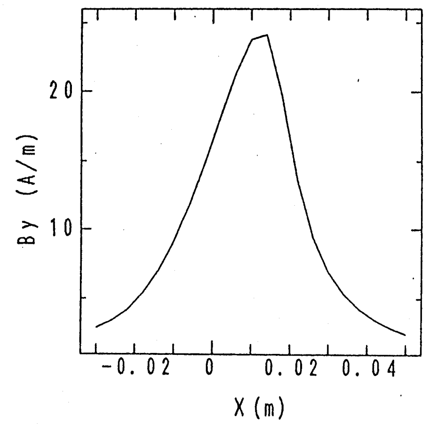


Figure 3: By PROFILE IN Y-PLANE

The induced magnetic field has sharp profile (see Fig. 3) and has a maximum value (~0.4G) at the yoke edge and hence a large non-linearlity is expected. In Fig. 3, the origin of the horizontal axis is kicker yoke center and the vertical axis represents a field intensity in A/m unit.

The magnetic field has characteristics that 1) field is concentrated and very strong at the yoke edge, 2)field intensity is about 0.4G.

To estimate the non-linearity, higher order components of the field are calculated by a least square method in $-35mm \leq x \leq 50mm, -7mm \leq y \leq 7mm$. From the calculation, it is found that a sextpole or octpole field have field gradients of about $0.8\mathrm{T}/m^2 \cdot m$ and $74\mathrm{T}/m^3 \cdot m$ respectively.

TEST PARTICLE SIMULATION

The test particle dymanics in X and Y phase space are shown in the figure 4. In the figure, (a) is in X-plane and (b) is in Y-plane phase space dynamics. Figure 4 is when the yoke of the kicker magnet is placed 20mm outside of beam center. The phase space diagram indicates that beam dynamics is storongly disturbed near the kicker edge (in this figure X=0mm is just under the kicker yoke edge).

Figure 5 is the time dependent beam oscillation amplitudes in X direction (a) and Y direction (b) in every 10 turns from injection to 10000 turns. The figure shows that a beam oscillation in Y direction is damped but the oscilation in X directions is excited.

SELF-CONSISTENT SIMULATION

From the above simulations, it is observed that the field intensity is enough to disturb a particle. To calculate the beam loss during the injection statge, self-consistent multi-particle simulation is performed with a parameter of kicker position. In this simulation initial beam current is set 500mA. The time dependence of the beam current when the kicker is placed on the beam center during the first 10000 turns are shown in figure 6 . This figure shows that about 90% of particles are lost in an early period and only 10% of the initial beam survives.

Calculated behaviour of particles is the same with a test particle's one. The betatron oscillation in y-direction is damped and the oscillation in x-direction is excited and then the beam is lost at the kicker yoke frame.

The figures 7 shows the survived beam current dependence on the kicker position. From this figure, it is clear that the beam

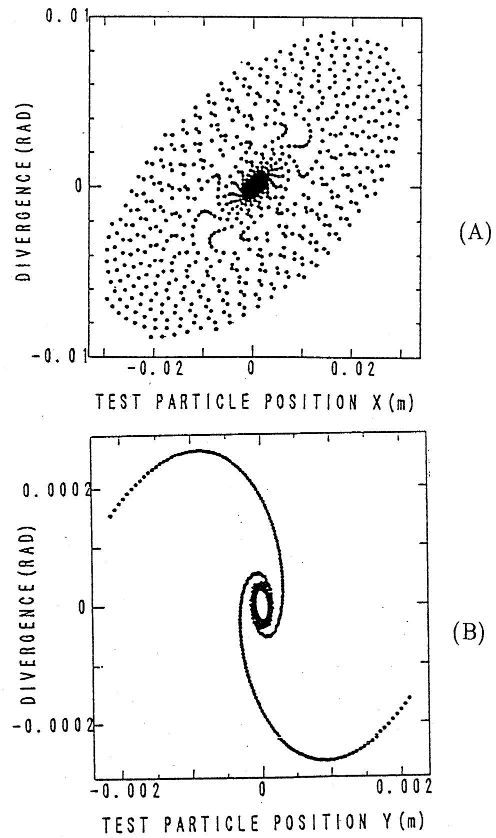


Figure 4: BEAM DYNAMICS IN (a) x AND (y) PHASE PLANE, WHEN THE KICKER MAGNET IS PLACED 20mm OUT OF THE BEAM ORBIT

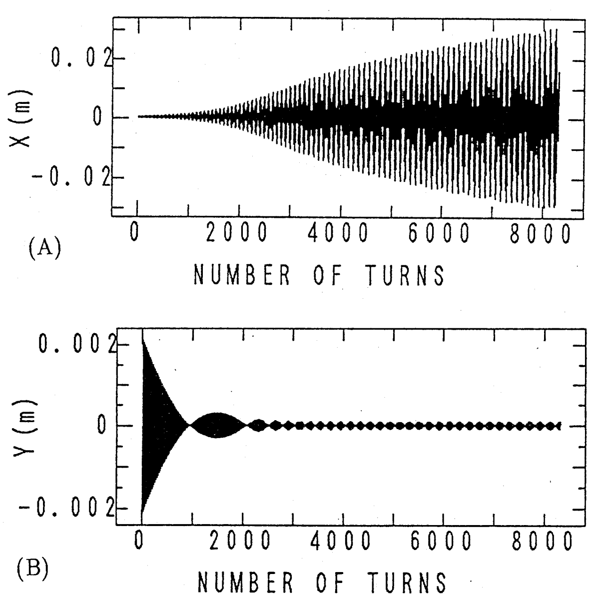


Figure 5: BEAM OSCILATION ENVELOPE IN (a) x AND (y) DIRECTION,WHEN THE KICKER IS PLACED 20mm OUT OF THE BEAM ORBIT

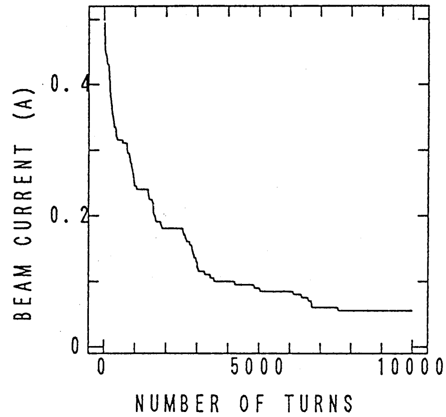


Figure 6: TIME DEPENDENCE ON THE BEAM CURRENT AFTER THE INJECTION

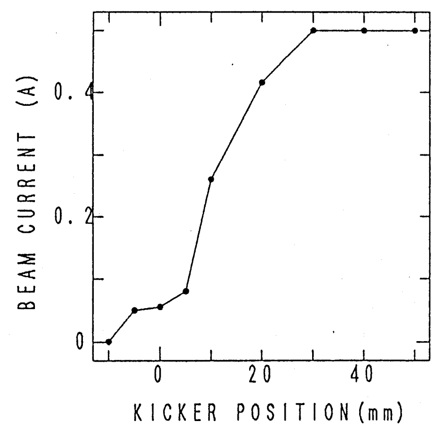


Figure 7: BEAM LOSS TIME DEPENDENCE ON THE KICKER POSITION

loss during the first 10000 turns are drastically changed by the kicker position. When the kicker is moved 20mm from the beam orbit, the beam loss is almost surpressed.

CONCLUSIONS

By beam tracking including an effect of beam induced magnetic field, the following conclusions are obtained. 1)The induced field intensity is $\sim$ 0.4G, has astrong non-linearity and is enough for the beam loss during the injection. 3)This beam loss is severly dependent on the kicker position and hence can be surpressed by beam position controll at the kicker magnet.

References

[1] S.NAKATA,Proc. of the PAC,1535-1534,1987

[2] S.OKUDA, et al, in Proc. of the PAC,TRA21,1991

[3] C.TSUKISHIMA and S.NAKATA :in Proc. of the 8-th Symp. on Acc. Sci. and Tech.