Transverse Kick by RF Cavities Observed in the SPring-8 Storage Ring

K. Soutome*, H. Ego, T. Ohshima, J. Schimizu†, M. Takao, H. Tanaka, H. Ohkuma
SPring-8, Hyogo 679-5198, Japan

Abstract

In the SPring-8 storage ring a stored electron beam is dumped by lowering the RF voltage and hence the RF bucket height. During this sequence an orbit distortion of the order of a few tens μm was observed. The harmonics of this distortion correspond to the horizontal and vertical betatron tunes. The kick source seemed to be at the RF section where the RF voltage was changed. We then carried out machine studies on this phenomenon, analyzed the measured orbit changes to deduce a transverse kick angle and finally found that a field distortion of the accelerating TM010 mode of RF cavities can generate such a transverse kick. The distortion is a result of the symmetry breaking of the RF cavities caused mainly by a coupler port and a frequency tuner attached to them. The magnitude and direction of the experimentally deduced kicks were found to be in good agreement with the calculations by MAFIA.

1 INTRODUCTION

In an 8GeV electron storage ring at SPring-8 the lattice has four-fold symmetry and correspondingly there are four RF accelerating sections (RF-A, B, C and D stations) in the ring. Each station has eight cavities and can give the maximum RF voltage of about 4.0-4.5MV. In usual beam operation the voltage of each station is set to be 4.0MV and the total value is 16.0MV. On the other hand, the one-turn loss of the beam energy is about 8.9MeV. We are then possible to store the beam with three RF stations at 12MV with enough beam lifetime, since the momentum compaction factor is small ($\sim$0.000146).

We sometimes change the RF voltage to dump the stored beam and in machine tuning. By comparing the closed orbit before and after this change, we found that a transverse kick is generated at the RF section. To understand this phenomenon, we performed machine studies and found that the magnitude of the transverse kick is proportional to the amount of change in the RF voltage and the direction of the kick is the same for all RF stations.

One might think that there can be a possibility that the direction of the electron beam passing through cavities is different from the axis of RF acceleration and has a crossing angle. However, by simple estimations, we see that the magnitude of a transverse kick by such a cause is much smaller than observed experimentally.

Another possible explanation will be the distortion of the accelerating TM010 mode. We then calculated the electro-magnetic fields in the RF cavity by using MAFIA and found that the order of magnitude and the direction of the experimentally observed kick can be explained by this field distortion effect.

In the following we present the results of field calculations and compare the kick angle with experimentally deduced one. We also discuss how the transverse kick contribution is extracted from measured closed orbit data. After subtracting the kick contribution we see that the residual orbit change in the horizontal direction agrees well with simulation results obtained by considering the energy loss at magnets and the energy gain at RF cavities.

2 FIELD CALCULATIONS

In each RF section of the storage ring eight bell-shaped single-cell cavities are installed[1, 2]. Each cavity has an RF input coupler, a frequency tuner for the accelerating TM010 mode (TM010-tuner), a tuner for higher-order mode (HOM-tuner) and a plunger with a fixed length. The position of the TM010-tuner is automatically adjusted in beam operation within a range of a few mm and the position of the HOM-tuner is usually fixed. The coupler port and the TM010-tuner are settled along one direction and the HOM-tuner and the plunger are settled along another direction perpendicular to the former. RF cavities with a horizontally directed RF input coupler and with a vertically directed RF input coupler are arranged alternately in the tunnel of the storage ring.

In order to simulate the field distortion in the cavity we used MAFIA and calculated a longitudinal shunt impedance R_L and a transverse shunt impedance R_T of TM010 mode. Since the cavity structure is complicated as explained above, it is difficult to perform a full model calculation with a huge number of mesh points. We then adopted a simple cavity model having the coupler port with a diameter of 110mm and the TM010-tuner. The HOM-tuner and the plunger were neglected, since the HOM-tuner position is fixed and its value is almost the same as the plunger position on the opposite side. This cavity model has a symmetrical structure and can be divided into four equivalent pieces. We then performed calculations by using one piece with four times larger number of mesh points[3].

In this model the field distortion of the TM010 mode occurs in the direction of the axes of the coupler port and the TM010 tuner. The transverse kick is also generated along this direction.

The transverse kick θ_T can be calculated from R_L and R_T as $\theta_T = V_T/E$, where $V_T = V_L\sqrt{2R_T/(kR_L)}$, E is the beam energy, V_L is the acceleration voltage and k is the

* Corresponding author; Email: soutome@spring8.or.jp
† Permanent address: The Japan Research Inst. Ltd., Osaka 550-0013

wave number of the TM010 mode. The results are shown in Fig. 1 for the case of V_L = 500kV.

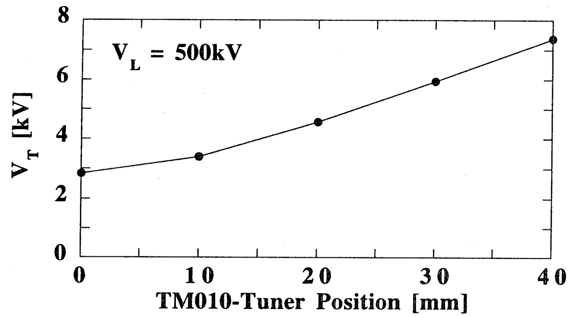

Figure 1: Voltage in the transverse direction due to field distortion of the TM010 mode (calculation by MAFIA).

In Fig. 1 V_T is plotted as a function of the TM010-tuner position. The acceleration voltage of 500kV per cavity corresponds to 4MV per one RF station. The kick voltage and the kick angle in the transverse directions of each RF station are summarized in Table1.

Table 1: Calculation results of the voltage and the kick in the transverse directions (H: horizontal, V: vertical) when the acceleration voltage V_L is 4MV at each RF station.

station	V_H[kV]	V_V[kV]	$\theta_H[\mu$ rad]	$\theta_V[\mu$ rad]
A	16.5	16.4	2.1	2.1
B	15.0	15.0	1.9	1.9
C	14.9	16.1	1.9	2.0
D	16.2	15.8	2.0	2.0

3 COMPARISON WITH EXPERIMENTS

As explained in the introduction, we carried out machine studies and changed the voltage of one RF station in the range between 0MV and 4MV. By comparing the closed orbit before and after this change we can estimate the magnitude and direction of the kick generated at the RF section.

In Fig. 2 we show the difference of measured closed orbits along the whole ring when the voltage of RF-A station is increased from 0MV to 4MV. The upper graph shows the horizontal orbit change and the lower shows the vertical one. We see that both horizontal and vertical orbit change become large as the voltage becomes high. We can obtain similar results as in Fig. 2 when a voltage of the other RF station is changed.

3.1 Energy Balance along the Ring

The horizontal orbit shift shown in Fig. 2 contains contributions from a change of the local energy balance along the ring. It is determined by the energy loss at magnets and the energy gain at RF cavities. In order to obtain a transverse kick by RF sections these contributions must be subtracted from measured orbit shifts.

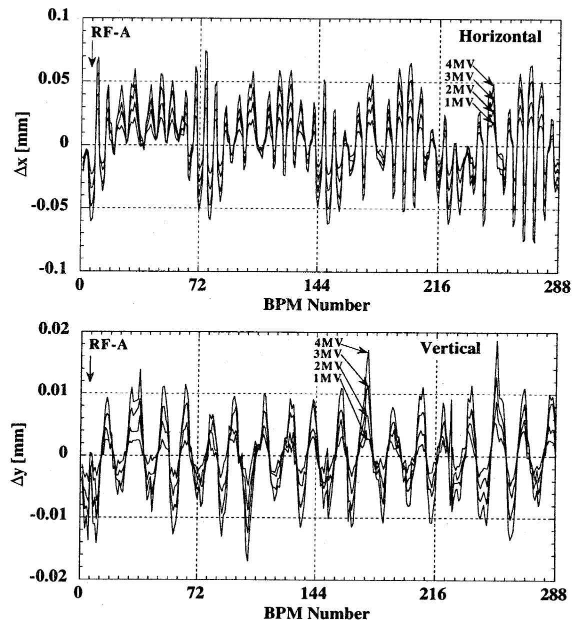

Figure 2: Orbit change when the voltage of the RF-A station is increased from 0MV to 4MV.

The effect of this local energy balance can be seen by computer simulations. Since we developed a 6-by-6 simulation code[4], we can calculate the local beam energy and the closed orbit when the RF voltage is varied.

We show in Fig. 3 the local beam energy for the two cases: an ideal ring with RF-A station on(A:4MV, total:16MV) and off(A:0MV, total:12MV). The energy difference between the two cases generates the horizontal orbit shift in dispersive sections. This shift is shown in Fig. 4 by the solid line.

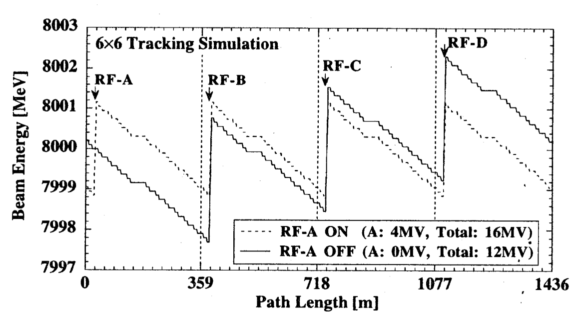

Figure 3: Local beam energy in an ideal ring with RF-A station on and off obtained by tracking simulations.

3.2 Transverse Kick at RF Cavities

Since a simple transverse kick cannot generate such a horizontal orbit shift as in Fig. 4, we can deduce a strength and a direction of the horizontal kick by assuming an amount of the kick at the RF section and fitting the measured orbit shift.

After subtracting the transverse kick contribution from

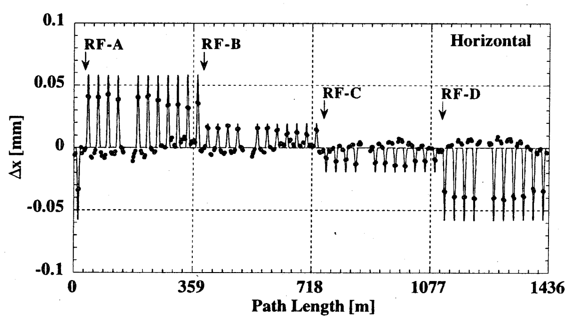

Figure 4: Horizontal orbit shift due to the local energy difference where the RF-A station is on. Calculation results are shown by the solid line. For comparison, experimental data at beam position monitors is also plotted by solid circles.

measured data there remains a contribution due to the local energy difference in the horizontal direction. Figure 5 shows the horizontal and vertical orbit changes after subtracting a transverse kick contribution.

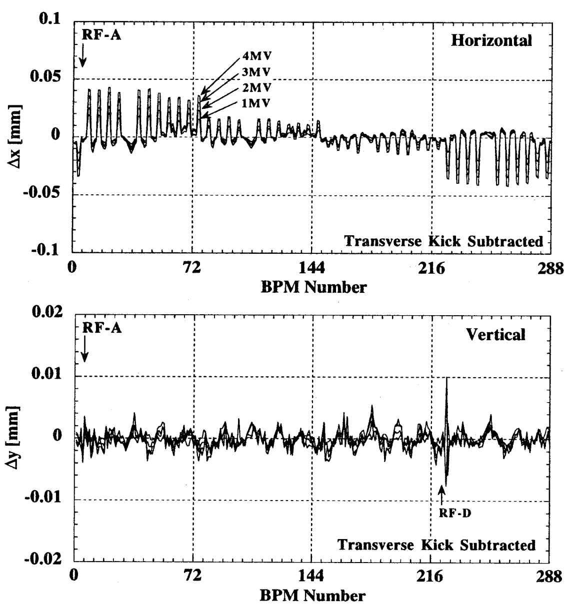

Figure 5: Orbit change after subtracting a transverse kick contribution from measured data shown in Fig. 2. A sharp spike seen in the lower graph at around the RF-D section is due to noise. Though hard to distinguish, there are four curves in the lower graph corresponding to the 1, 2, 3 and 4MV difference as in the upper graph.

The data for the 4MV difference in the horizontal direction is also plotted in Fig. 4 by solid circles. We see a good agreement between the calculation and the experimentally deduced data. This means that we could successfully separate a transverse kick contribution and the effect of the local energy difference. The obtained kick angle at each RF station is shown in Fig. 6.

The direction of the observed kick is the same as ex-

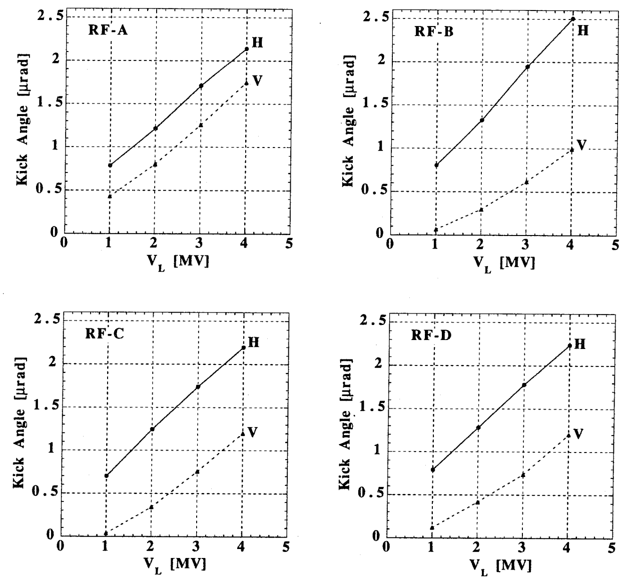

Figure 6: Transverse kick angle at each RF section deduced from measured orbit change.

pected from the calculations by MAFIA. We also see that the kick angle at V_L = 4MV is about 2μrad and close to the values listed in Table 1 especially in the horizontal direction. These facts suggest that the transverse kicks at RF cavities are generated by the field distortion of the TM010 mode.

It should be noted that the magnitude of the kick angle in the vertical direction θ_V is smaller than expected but the ratio of θ_V to V_L is not so far from the expected value of 2μrad/4MV. These values are listed in Table 2. At present the reason for this discrepancy is unknown but will be due to errors of fitting or an effect of HOM-tuners and plungers which we neglected in constructing our cavity model. If more precise calculations of the electro-magnetic field distortion become possible, this point will be clarified.

Table 2: The experimentally deduced kick angle in the transverse directions as a ratio to the acceleration voltage.

station	θ_H/V_L	θ_V/V_L
A	1.8 μrad/4MV	1.8 μrad/4MV
B	2.3 μrad/4MV	1.2 μrad/4MV
C	2.0 μrad/4MV	1.6 μrad/4MV
D	1.9 μrad/4MV	1.4 μrad/4MV

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