Estimation of Injected Beam Energy Based on Central Shift of First Turn Horizontal Trajectory

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At the first stage of storage ring commissioning, energy of injected electron beams must be checked, because the energy acceptance of Chasman Green (CG) lattice with sextupole magnets is small, about ± 1 % by $\Delta E/E_0$. The resolution of a few tenth % is thus necessary for the energy estimation.

Since the beams are deflected by bending magnets in the ring even on the reference orbit, the trajectory of each electron depends on its energy, which is called "energy dispersion". The linear part of this dispersion can be expressed by so called dispersion function with a periodicity corresponding to the number of super-period of the ring. In the SPring-8 case, a median plane is horizontal and the dispersion function is always positive in a horizontal plane. Here, we neglect the small contribution from magnetic errors. This distribution of the dispersion means an electron with larger energy circulates outside of a design orbit and one with smaller energy circulates inside. Provided that the effects of energy loss due to radiation and magnetic errors on the trajectory is small and the energy deviation is also small, the sum of horizontal displacements in the first turn X_{sum} is proportional to the averaged energy deviation of the injected beams $\Delta E/E_0$,

$$X_{sum} = \sum_{i=1}^{N} X_i \propto \frac{\Delta E}{E_0}\,, \qquad (1)$$

where X_i and N stand for respectively the horizontal displacement in the first turn at position s_i and the total number of position monitors.

To find the resolution of this method, we have simulated the first turn trajectory and investigated the behavior of X_{sum} by using the magnitude of magnet misalignment as a parameter. Here, we calculate the radiation at each magnet, U as the function of the trajectory by

$$U = \frac{2e^2 \cdot c^2 \cdot r_e}{3(m_0c^2)^3} \sum_{i=1}^{10} E(S_0+\Delta S_i)^2$$

$$\cdot \int_{S_0+\Delta S_{i-1}}^{S_0+\Delta S_i} \left(B_x(x,y,s)^2 + B_y(x,y,s)^2\right) ds, \qquad (2)$$

where e, c, r_e, m_0, B_x, and B_y stand for respectively charge of an electron, speed of light, the classical electron radius, electron rest mass, the horizontal and the vertical magnetic fields.

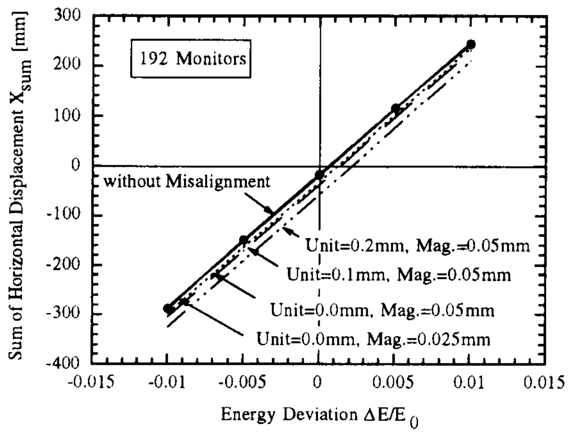

Fig. 1 Sum of horizontal displacements X_{sum} vs. $\Delta E/E_0$ by using the magnitude of magnet misalignment as a parameter. The symbols, Unit and Mag. represent respectively the misalignment of girders and magnets in each girder. Here, 192 position monitors are used to detect the trajectory.

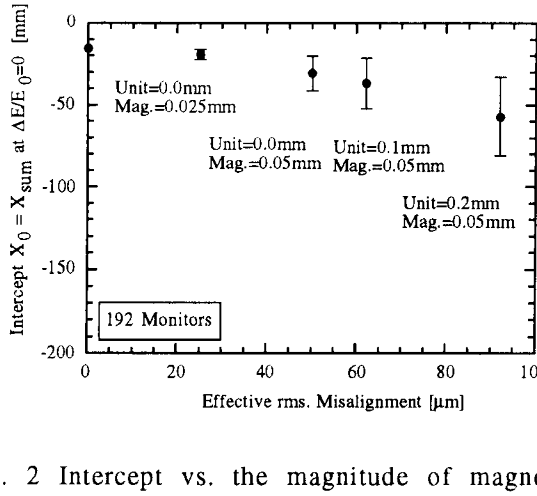

Fig. 2 Intercept vs. the magnitude of magnet misalignment. The error bar shows the standard deviation calculated by 20 rings with different error distribution. The effective rms. misalignment shows the misalignment by the unit of random magnet error.

Figure 1 shows X_{sum} vs. $\Delta E/E_0$. It's clear that X_{sum} is proportional to $\Delta E/E_0$ even with the misalignment. The value of X_{sum} at $\Delta E/E_0$=0, the intercept of the solid line for the case without the magnet misalignment isn't zero, because the radiation at all bending, quadrupole, and sextupole magnets is included in the simulation and this induces an oscillation of the trajectory. We also find that the ratio of $Xsum$ to $\Delta E/E_0$ is almost constant, but the intercept depends on the magnitude of magnet misalignment.

Figure 2 shows the intercept vs. the magnitude of magnet misalignment. At the tolerance, where rms. values of unit and magnet misalignment are respectively 0.2 mm and 0.05 mm, the average and the half width of intercepts are respectively about -60 and 20 mm. The shift of intercept (-80 mm) due to the error is equivalent to $\Delta E/E_0$ of -0.003 in case of no error. Consequently, the resolution of this method is ~0.003 at best.