

BEAM TRACKING SIMULATIONS FOR A BPM-BASED ENERGY SPECTROMETER PROTOTYPE FOR ILC

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Abstract

T-474 at SLAC is a prototype BPM-based energy spectrometer for the ILC. A 4-dipole chicane is used with mid-chicane dispersion of 5-mm and magnetic fields of ~1 kGauss; these match the current ILC parameters. Better than 100 part-per-million (ppm) accuracy is needed for ILC energy measurements, requiring better than 50 ppm accuracy for magnetic field integral measurements.

Code for beam tracking through the spectrometer chicane was developed. Magnetic field maps for dipole magnets obtained from the measurements at SLAC are used. Different aspects of the magnetic field influence to the beam deflection value are discussed. Results of the beam dynamics study using the measured magnetic fields for T-474 chicane to estimate magnetic effects on capabilities for the energy measurements are also reported.

DESCRIPTION OF THE CODE

The developed program code is intended for tracking of charged particles through the different magnetic fields in Cartesian coordinate system taking into account synchrotron radiation. Code was written in the Mathematica environment working under the Windows platform.

Equations of Motion

Equation of charged particle's (electron's) motion in the magnetic and electrical field:

$$\frac{d}{dt}(m\dot{\vec{r}}) = e[\dot{\vec{r}}, \vec{B}] + e\vec{E},$$

where e is the charge of the particle (electron), B and E are strength of the magnetic and electric field and m is a relativistic mass of the electron:

$$m = \frac{m_0 c^2 + W}{c^2} = m_0 + \frac{W}{c^2} \quad (m_0 - \text{electron's rest mass,}$$

W - it's kinetic energy).

Equation of electron's motion in the magnetic and electrical field with presence of the synchrotron radiation:

$$\frac{d}{dt}(m\dot{\vec{r}}) = e[\dot{\vec{r}}, \vec{B}] + e\vec{E} - \frac{P}{c^2} \dot{\vec{r}},$$

where P -instantaneous power of the synchrotron radiation

$$P = \frac{2e^4 B^2 \gamma^2}{3m^2 c} [1] \quad (\gamma = W/E_0).$$

The projection of the equation of electron's motion to one of the Cartesian system's axis (x -axis):

$$\ddot{x} = -\frac{e}{m_0 + \frac{W}{c^2}} (\dot{y}B_z - \dot{z}B_y + E_x) - \frac{2e^4 B_x}{3(m_0 + \frac{W}{c^2})c^3} (1 + \frac{W}{E_0})^2 \frac{\dot{x}}{c^2}$$

Thus, the system of equations which describe electron's motion is given by:

$$\ddot{x} = a(\dot{y}B_z - \dot{z}B_y + E_x) - bB_x^2 \dot{x}$$

$$\ddot{y} = a(\dot{z}B_x - \dot{x}B_z + E_y) - bB_y^2 \dot{y},$$

$$\ddot{z} = a(\dot{x}B_y - \dot{y}B_x + E_z) - bB_z^2 \dot{z}$$

where $a = \frac{e}{m_0 + \frac{W}{c^2}}$, $b = \frac{2e^4(1 + \frac{W}{E_0})^2}{3(m_0 + \frac{W}{c^2})^3 c^3}$, point means

differentiation respect to time (time – independent variable).

These full differential equations of motion of electron in Cartesian coordinate system are integrated by Runge-Cutta method of the 4-th order. Z -coordinate is assumed to be aligned with longitudinal axis of the spectrometer chicane and beam direction, x – transverse to z -axis horizontal direction, y – transverse to z -axis vertical direction.

Magnetic Field

Magnetic field map $B_y(x,z)$ in $y=0$ plane (median plane of the dipole magnets) used inside the code. Map covers all the chicane length. It is possible to upload into total map the calculated magnetic field of dipoles as well as measured field map of each of four chicane magnets.

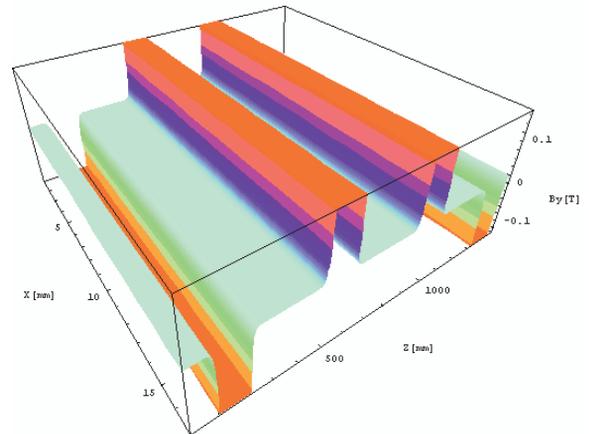


Figure 1: Magnetic field map of whole the spectrometer chicane.

Starting Bunch Data

The program is intended for tracking of a bunch of particles. It is possible to change its starting position along z-axis (longitudinal direction) as well as bunch initial transverse and longitudinal size and angular spread. Also one can vary starting energy value and the energy spread.

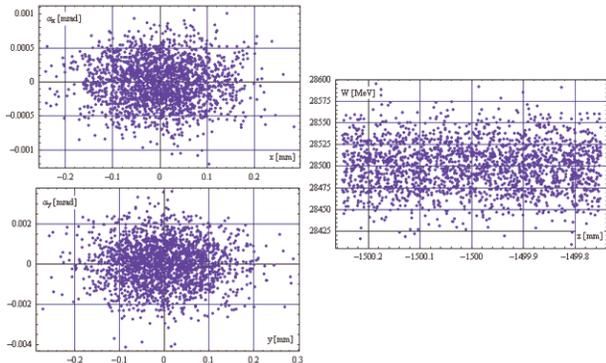


Figure 2: Generated bunch of 2000 particles with SLAC beam parameters: $\epsilon_x=1.1 \cdot 10^{-4} \pi$ mm-mrad, $\epsilon_y=3.5 \cdot 10^{-4} \pi$ mm-mrad [2], bunch length -500 μ m, average energy-28.5 GeV, energy spread -0.2%.

PRELIMINARY TRACKING TO DEFINE BEAM DEFLECTION RANGE

To define beam deflection range in the middle of the chicane (region of the BPM4) [3] the beam (with SLAC Linac parameters) tracking was carried out taking into account measured in SLAC Test Lab dipoles magnetic field (current equals 150A) (see Fig. 3).

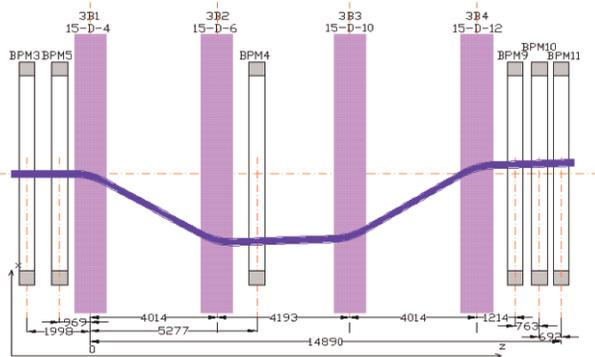


Figure 3: Beam tracking through the spectrometer. Plan view to the deflected trajectories.

Beam deflection value at the middle of the chicane (at the region of BPM4 location) is about 5mm (exact value equals 4.884mm – calculated by averaging of the x-coordinates of particles in BPM4). These calculations permit to define the range of the middle-BPM position shift in runs with changing of the dipole magnets’ polarity. This range equals ~10mm. The obtained value 4.884mm of the bunch mid-chicane deflection is in a good agreement with the experimental one measured in run-1699 (equals 4.781mm). The difference of a ~0.1mm

between the measured and calculated deflection value is due to a slightly different dipole’s magnetic field in ESA during this run and used in calculations one. Motion of the bunch center in the chicane is presented in Fig. 4.

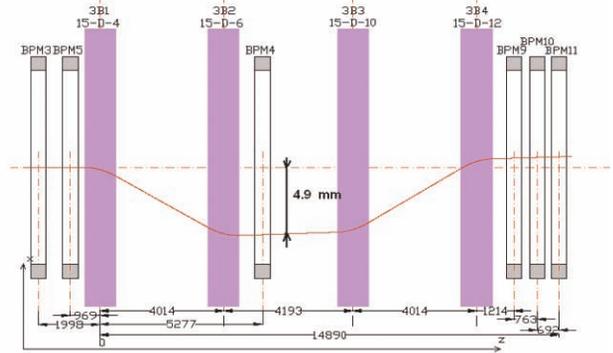


Figure 4: Track of the bunch center in the spectrometer chicane.

Deviation of the bunch from the chicane axis in this study is due to 0.0070 Tesla·m difference between the magnetic field integral in the 1st (3B1) and the 2nd (3B2) chicane dipoles. Magnetic field in the last magnets is the same as in 3B2 and 3B1 correspondingly.

BEAM TRACKING USING MEASURED ENERGY DATA

To understand the reliability of the created code the beam tracking calculations with the data obtained from one of the T-474 experiments (run-1699) of March-2007 run at SLAC were carried out.

The magnetic field map of dipoles was normalized such a way that *Bdl*-integral which beam “sees” when tracking through each magnet equals real magnetic field integral values which were obtained by control probes data [3]. Energy of the tracking particles equals measured bunches energy [3] in first part of the run-1699 during energy scan -200 → +200 MeV in five steps from nominal value.

In Fig. 5 there is a comparison of the experimentally measured value of the bunch deflection at mid-chicane region and the calculated one. Five steps of the deflection changing due to energy scan are clearly seen. Difference between the results is about 10 microns.

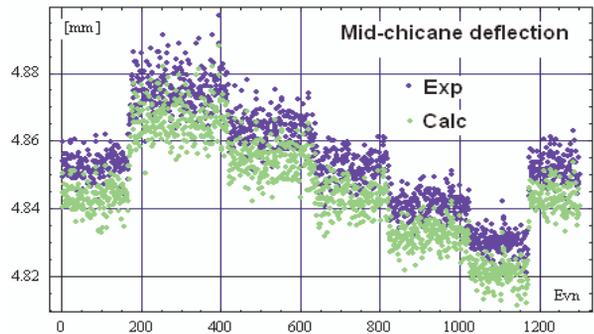


Figure 5: Experimentally measured and calculated mid-chicane beam deflection in energy scan in the run-1699.

INFLUENCE OF THE MAGNETIC FIELD INTEGRAL UNCERTAINTIES

A fluxgate magnetometer was used to measure the residual magnetic field in the T-474 chicane before installation of the dipoles for the March 2007 run (see fig. 6).

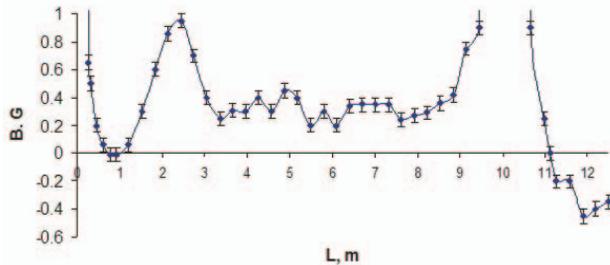


Figure 6: The residual magnetic field on the T-474 chicane length (vertical component).

The anomaly behavior of the magnetic field at some points is due to residual magnetization of rebar in the girder. Such a magnetic field may cause to the additional beam shift at the BPM region.

Additional tracking simulations were carried out to estimate the possible influence of the residual field to the beam deflection value in the mid-chicane region. If we suppose that magnetic field with strength of 2 Gauss exist at a range of 1m (see Fig. 6) it means that 0.0002 Tesla-m magnetic field integral value have to be added to the BdL -integral.

A set of the beam tracking simulations were carried out to estimate the additional beam shift at the region of BPM-4 (mid-chicane) due to such a residual field (see Fig. 7).

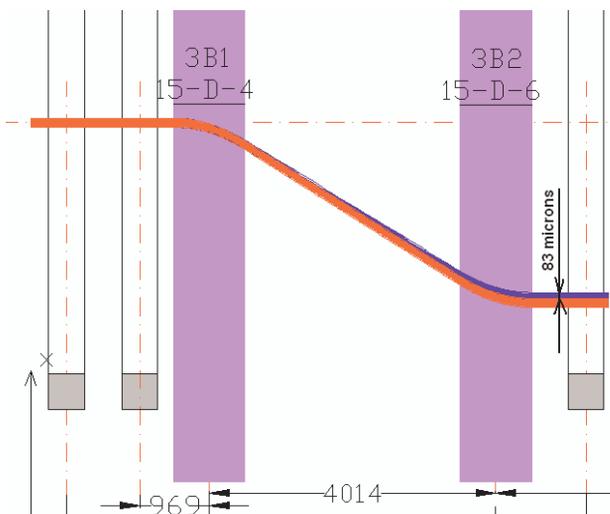


Figure 7: Plan view to the deflected beam.

The additional deflection of the bunch due to the magnetic field perturbation is 83 microns which is $17 \cdot 10^{-3}$ from the total deflection value.

CONCLUSIONS

Energy measurements technique was tested in joint research at T-474 at SLAC. Relative error of the energy definition is $2.3 \cdot 10^{-4}$ for this moment.

Code for beam tracking through the spectrometer chicane was developed. Magnetic field maps for dipole magnets obtained from the measurements at SLAC were used in the T-474 beam tracking simulations.

Beam deflection range ~ 10 mm in the middle of the chicane was calculated using measured in Test Lab dipoles magnetic field.

The obtained value 4.884mm of the bunch mid-chicane deflection is in a good agreement with the experimental one measured in run-1699 - 4.781mm.

The beam tracking calculations with the data obtained from one of the T-474 experiments (run-1699) of March-2007 run at SLAC were carried out. Differences between the experimentally measured and calculated deflection values are not more than 10 microns ($\sim 0.2\%$ from total value).

The residual magnetic field in the T-474 chicane before installation of the dipoles for the March 2007 run was measured. The anomaly behavior of the magnetic field at some points is due to residual magnetization of rebar in the girder.

Beam addition deflection due to the residual magnetic field in the T-474 chicane was estimated.

REFERENCES

- [1] A. A. Kolomensky “Physics principles of the particles acceleration methods”, 1980, p. 163.
- [2] F. Jackson, “ESA Optics Measurements and Tuning During April/May 2006 Beam Test”, ILC-SLACESA TN-2006-1
- [3] R. Arnold et al., “Magnetic Measurements and Simulations of a 4-magnet Dipole Chicane for International Linear Collider”, These proceedings.