EMITTANCE DILUTION AND MAGNET DESIGN FOR THE TTF FEL SECOND BUNCH COMPRESSOR

I.N.Ivanov , S.I.Kukarnikov, A.Yu.Molodozhentsev , V.A.Petrov, V.Ph.Shevtsov,
Laboratory of Particle Physics,
Joint Institute for Nuclear Research
Dubna, Moscow region, 141980 Russia and
T. Limberg, M. Marx,
DESY, Notkestrasse 85, 22603 Hamburg, Germany

Abstract

This paper presents results of investigation of the transverse emittance dilution in the TTF FEL bunch compression system. The requirements for the bending magnet field of the dipole magnets of the second bunch compressor are determined. The dipole magnet design for the bunch compression system is performed. The dipole magnets are optimised to obtain minimum transverse emittance dilution.

1 INTRODUCTION

The TTF FEL second bunch compressor consists of four identical bending magnets to change the longitudinal rms bunch size from 0.8 mm to 0.25 mm at the energy of 144 MeV [1]. Main parameters of the dipole magnet for the second bunch compression system should be the following [2] :

- C-type magnet with the aperture gap no less than 2 cm;
- the good field region should be no less than 20 cm in horizontal direction and ±1 mm in vertical direction;
- dipole magnetic field component should be variable from 2808.712 Gs till 3753.616 Gs for different values of the bending angle which should be between 17÷23 degrees [1];
- length of the bending magnet 50 cm.

The main peculiarity of the bunch compression system is the following. Each particle of the bunch moving in transverse magnet field spends time determined by own energy and bending magnet field value. The magnet field is not uniform in a working region caused by the magnet field errors which can be presented as some quadrupole and sextupole magnet field components. In this case calculation of the time should be made accurately to investigate longitudinal and transverse particle motions.

2 TRANSVERSE EMITTANCE DILUTION

Using the special algorithm [2] the special program is made to investigate emittance dilution due to quadrupole magnet field component in the bending magnets of the second TTF FEL bunch compression system. This results is checked by the PARMELA program. And as the next step, the transverse emittance dilution due to sextupole component of the bending magnet field is estimated by the PARMELA program.

2.1 Transverse emittance dilution due to the quadrupole component of the magnet field

To estimate transverse emittance dilution due to quadrupole component of the bending magnet field of the 2nd bunch compression system one can use the developed program. The particle bunch can be presented as some slices in the transverse direction. Each slice has the own energy. The energy of the slices are in the range 144±0.720 MeV (σ=0.005). The transverse coordinates and velocities of the particles in the slice are generated to get the microcanonical distribution.

The initial bunch parameters are the following:
σ_z=0.08 cm, σ_E=0.005; E_s=144 MeV;
ε_n=1 π.mm.mrad or 2 π.mm.mrad;
β_x=15.0 m, β_y=8.0 m, α_x=α_y=0, where σ_z are the rms longitudinal beam size, σ_E is the energy dispersion, ε_n is the normalized emittance.

Figure 1 presents the relative emittance dilution $D\varepsilon_x = (\varepsilon^{exit} - \varepsilon^{initial}) / \varepsilon^{initial}$ as a function of the average quadrupole component in the working region of the dipole magnet $\langle g \rangle = \left\langle \frac{1}{B_0} \frac{\partial B_y}{\partial x} \right\rangle$ for the dipole magnet field 2968.617 Gs for the different initial emittances.

The transverse emittance dilution may be estimated by the PARMELA program also. The emittance for the system with an ideal bending magnet field is constant before and after the bunch compressor for the developed program. Unfortunately, using the PARMELA program one can get this result with 1...2% accuracy.

Comparison of the obtained results with the data, obtained by the PARMELA code shows a good coincidence of the results. To analyse the transverse emittance dilution using the PARMELA program the particles of the bunch are generated randomly in a four dimensional transverse hyperspace with uniform phase and random energy (input6).

0-7803-4376-X/98/$10.00 © 1998 IEEE

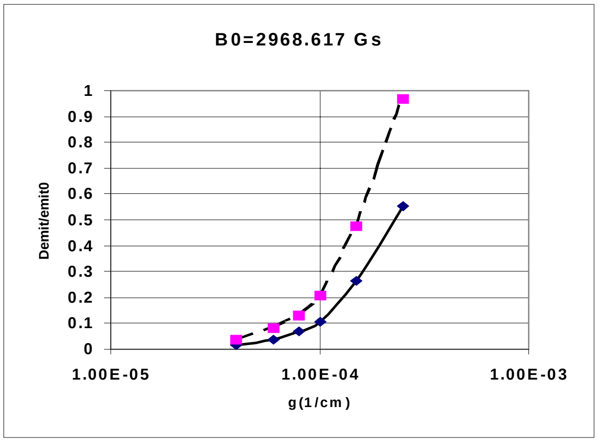

Figure 1: The relative emittance dilution as a function of the quadrupole component of the bending magnet field for different initial values of the normalized transverse emittance : 1pi mm.mrad- the dashed line, 2pi mm.mrad - the solid line. The dipole magnet field is 2968.617 Gs.

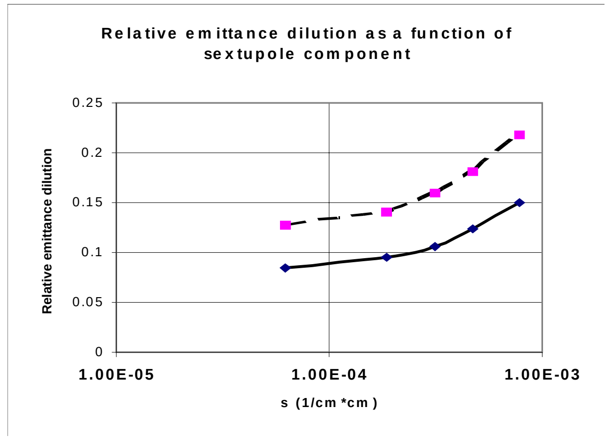

Figure 2: The relative emittance dilution as a function of the sextupole field component of the bending magnet for different initial values of the normalized transverse emittance : 1pi mm.mrad- the dashed line, 2pi mm.mrad - the solid line.

The initial parameters are the same as mentioned above. The obtained result corresponds to the emittance with the 90% of the particles. To present the bunch 1000 particles are used. To include the quadrupole field component in the bending magnet the magnet can be presented as "short" bending magnets. Between the "short" dipole magnets the quadrupole and sextupole lenses can be installed to model the "real" magnet field of the magnet with dipole, quadrupole and sextupole components. Length of the lenses should be small.

2.2 Transverse emittance dilution due to the sextupole component of the magnet field

To estimate the emittance dilution caused by the sextupole magnet field component in the bending magnet, the PARMELA program is used. In this case the quadrupole component is fixed and get from the previous calculations. Figure 2 presents the relative emittance dilution as a function of the sextupole field component of the bending magnet field for the dipole magnet field value of 3200 Gs. The quadrupole field component is g=5.0e-5 (1/cm) that corresponds to the 9.5% emittance growth of the 1 π.mm.mrad beam without the sextupole field component . To estimate the influence of the sextupole component for the another initial condition the extra calculation is made for the 2 π.mm.mrad beam with the quadrupole component g=7.5e-5 (1/cm) that corresponds to the 8.5% emittance growth. One can see from Figure 2 that to get the emittance growth about 15% in the 2nd bunch compression system the average sextupole field component should be about (2÷5)e-4 ($1/cm^2$).

3 DESIGN OF THE DIPOLE MAGNET

3.1 Definition of the main parameters of the magnet

For the 1 π.mm.mrad initial normalized emittance and the emittance dilution in the second bunch compression system about 15% the relative quadrupole component $g = \frac{1}{B_0}\frac{\partial B_y}{\partial x}$ of the magnetic field in the working region should be $4.0 \cdot 10^{-5}$ (1/cm) and the average sextupole component $5.0 \cdot 10^{-4}$ ($1/cm^2$). Then the dipole magnet design is performed to get the field quality in the working region for the emittance dilution less than 15%.

When the aperture of the magnet is much smaller than the length of the magnet and a radius of curvature is bigger than the magnet's length the ends of the magnets constitute only a small fraction of the investigated field seen by a beam and the fact that the fields in the ends are three-dimensional can be ignored. Magnet calculations are made by the POISSON and the OPERA-2D codes.

To simplify installation of the vacuum chamber and the magnetic field probes the C-type dipole magnet should be used [3]. These magnets will be installed vertically along the TTF accelerator. Unfortunately, this type of dipole magnet has some magnetic field gradient to the inner coil for the field in the 0.2÷0.4 T. The value of this gradient is constant in the working region for the range of the bending magnet field of the TTF bunch compression system. Magnetic field distribution is a function of permeability of the magnet material. To investigate the influence of the material on the magnetic field quality the different permeability tables are used which are the internal tables of the POISSON and the OPERA programs.

3.2 Optimization of the dipole magnet

To decrease the field gradient of the C-type dipole magnet in the working region one can use special trimming the poletips. For this the poles of the magnet should have some converging angle to the external coil to escape the quadrupole component of the field in the working region. Optimization of the pole shapes should be done after the magnet measurements. The correction angle of the magnet poles is a function of the type of the material. Figure 3 demonstrates the relative magnetic field distribution before (the solid line) and after (the dashed line) correction of the converging angle for permeability table that is the internal table of the OPERA-2D program.

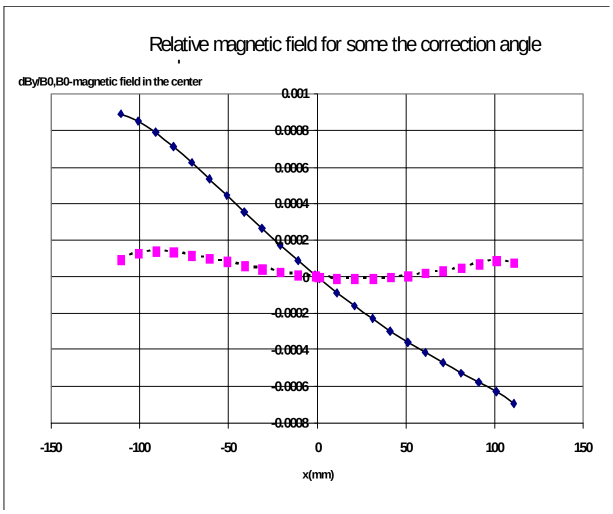

Figure 3: The relative magnetic field distribution before (the solid line) and after (the dashed line) correction of the converging angle of the poles.

3.3 Technical description of the dipole magnet

The steel 1010 with a carbon content less than 0.13% is planned to use for manufacturing of the magnet yoke. The yoke sizes have been optimized to provide the working region about 200 mm, sufficient durability of the yoke under influence of the magnetic field force and to reduce a quadrupole component of the magnetic field in the working region. To minimize the pole width and the power supply the gap height should be as small as possible. The gap size, determined by the beam tube dimensions, is equal to 20 mm. The poles should be made to separate from the yoke of the magnet, to install and swap of the magnet coils and to simplify the pole surface processing.

The final surface processing of the magnet poles should be carried out after the magnet measurement to minimize the quadrupole component in the working region.

After this processing the magnetic field accuracy has to be about 0.05% for the flux density 3753.62 Gs. To optimize the edge field the pole-end pieces are installed. The profile of the pole-end pieces should be determined after the magnetic field measurements. The correction coils will be used for the magnetic field tuning.

REFERENCES

[1] T. Limberg, H. Weise, A. Molodozhentsev, V. Petrov: The bunch compression system at the TESLA Test Facility FEL, DESY PRINT, September 1995, TESLA-FEL 95-04.

[2] I. Ivanov, A. Molodozhentsev, V. Petrov, V. Shevtsov: Emittance Dilution in the TESLA FEL Second Bunch Compression System, DESY PRINT, August 1996, TESLA-FEL 96-11.

[3] I. Ivanov, S. Kukarnikov, T. Limberg, M. Marx, A.Molodozhentsev, V. Petrov, V. Shevtsov: Magnet Design for the TESLA FEL Second Bunch Compression System, DESY PRINT, September 1996, TESLA-FEL 96-12.