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Laboratoire
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FINAL FOCUS TEST BEAM
FOR THE NEXT LINEAR COLLIDER

Collaboration :
SLAC (Stanford, USA), KEK (Tsukuba, Japan), INP (Novosibirsk, USSR),
LAL (Orsay, France), and DESY (Hamburg, FRG)

presented

by **J. BUON**
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Abstract :

The Final Focus Test Beam, to be constructed at SLAC, will focus a 50 GeV electron beam to a 1 × .06 μm^2 spot size. The line optics, the magnets, their alignment and stabilization, and the instrumentation are described.

1. Introduction

A final Focus Test Beam (FFTB) will be constructed at SLAC by a large international collaboration[1]. It is a prototype of final focus for future electron-positron linear colliders. It aims to test concepts and hardware to realize submicronic spot sizes. Contrary to the Stanford Linear Collider (SLC), the FFTB involves one beam line only and no interactions at a crossing point.

In the FFTB line, a 50 GeV electron beam of the SLC type will be demagnified and focussed. The final goal is to obtain a 1 micron by 60 nm rms spot size at the focus, in an uncoupled mode of the damping ring operation.

Table I gives the FFTB beam parameters compared to those of the SLC beam and to those foreseen for a Next Linear Collider (NLC).

PARAMETER	NLC	SLC	FFTB
BEAM ENERGY : (TeV)	0.5 - 1.0	0.05	0.05
VERTICAL EMITTANCE : $\gamma\, \epsilon_y$ (rad-m)	3×10^{-8}	3×10^{-5}	3×10^{-6}
FOCUSING : β_y^* (μm)	100	7000	100
BEAM HEIGHT : σ_y (nm)	3 - 5	2000	60
ASPECT RATIO :	100 - 200	1	15
BUNCH LENGTH : σ_Z(μm)	50 - 100	500	500
BANDWIDTH : $\delta p/p$(%)	± 0.3	± 0.3	± 0.3
BUNCH POPULATION (10^{10}) :	1 - 2	3 - 5	1 - 2

Table 1 : Beam parameters at the focus of NLC, SLC and FFTB final focus systems.

In a uncoupled mode of operation, a 3×10^{-7} rad.m invariant vertical emittance has been experimentally obtained at the exit of the damping ring. But the emittance was degraded in the rest of the linac up to 1×10^{-5} rad.m at the end. Detailed studies of beam trajectories in the linac have lead to recent improvements in the alignement of the elements of the linac. Further emittance studies will soon be made using uncoupled beams in the linac. It is expected that our goal of $3. \times 10^{-6}$ rad.m will be achieved with low intensity beams ($1. \times 10^{10}$ particles).

The final design of the FFTB line is underway as well as the site preparation. Shielding will be installed during the next shutdown. It will allow construction work along the line during SLC runs.

The FFTB magnets will be fabricated in 1991 and installed in 1992. The first beam in the line is expected in the second part of 1992.

In section 2., the principles of the optical design are given as well as the sensitivity to errors and the tuning strategies.

In section 3., the magnet design and present ideas for their mechanical stabilization and alignment are briefly reported.

Finally, the instrumentation of the FFTB line is considered in section 4.

2. Optical design and tuning of the FFTB line

The FFTB line will be installed straight ahead at the end of the SLAC linac and will extend along a length of 170 m about.

The optics of the line follows an initial design by K. Oide[2].

The beam first enters a β-matching section. It is followed by two sections of chromatic correction, one to correct the horizontal plane, the other the vertical plane. In each one the correction is achieved by using two 7 mrad horizontal bendings and two sextupoles. The two sextupoles are 180 deg apart in betatron phase to cancel their geometric aberrations. A final transformer using a strong quadrupole doublet at the end will focus the beam 40 cm downstream of the exit face of the final quadrupole. Fig. 1 shows the variation of the beam enveloppe functions and the dispersion along the FFTB line.

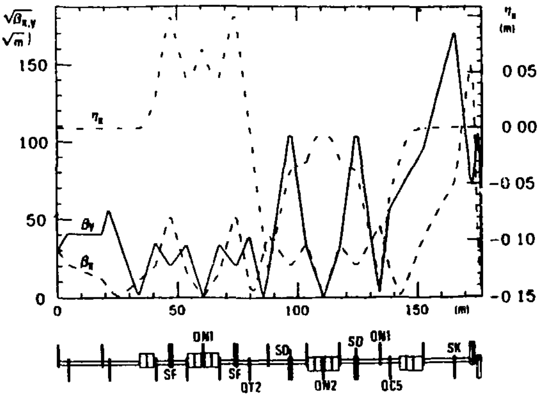

Fig.1 : The horizontal $\sqrt{\beta_x}$, vertical $\sqrt{\beta_y}$, beam enveloppe functions and the horizontal dispersion η_x along the FFTB line, that is schematically drawn below the horizontal axis. The values correspond to the optical design FFTB70D with $\beta_x^* = 9.0$ mm and $\beta_y^* = 0.1$ mm at the focus.

At the focus the dispersion vanishes and the β-functions are lowered to 3 mm horizontally and 0.1 mm vertically to obtain the designed dimensions. By varying the coupling in the damping rings and the vertical focusing of the final transformer, the vertical rms dimension can be varied from 1 micron (i.e. round beam) to 60 nm (i.e. flat beam with an aspect ratio of 16), keeping the horizontal 1 micron rms dimension constant. Third order aberrations would prevent reduction of the vertical dimension by a further decrease of the vertical β-function.

Magnet errors imply spot displacement and spot size increase at the focus. To control the vertical spot motion at a level of the order of its vertical size, the last quadrupoles must be controlled in position at the same level. (see Fig. 2).

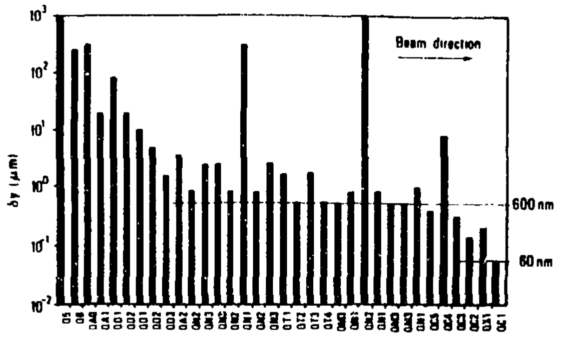

Fig.2 : The vertical displacement δy, that leads to 60 nm vertical displacement of the beam spot at the focus, as function of the displaced quadrupole in the FFTB line.

A spot size increase mainly results from two effects : the dispersion generated by quadrupole misalignments and the coupling generated by orbit errors in the sextupoles. Fig.3a shows that the main dispersion error at the focus would be due to the quadrupoles (particularly QC5) that are located $\pi/2 + n\pi$ in betatron phase apart from the last and strong quadrupoles in which their misalignment produces an orbit error. Fig.3b shows that the coupling in the sextupoles would be mainly due to the quadrupoles (particularly QN2) that are located $\pi/2$ before the second sextupole of a pair.

It has been shown[2] that a local correction using a steering algorithm to correct orbit errors in the sextupoles and orbit bumps to compensate dispersion errors would allow tuning the line to the design values of the final spot size. The starting point of the simulated tuning procedure was random alignment errors of each magnet : 30μm rms in vertical, 100μm in horizontal and 0.5 mrad in roll. A 10^{-3} random focusing error was added to each quadrupole. A global correction of the residual dispersion and coupling, with a few correctors, can tune the line as well.

3. Magnets, alignment and stabilization

The 30 some quadrupoles of the FFTB line are conventional magnets about 0.5 m long and 1 cm half-aperture. The final doublet is more difficult. To reduce the constraints, the last quadrupole is split into : a short (30 cm), large aperture (2 cm), quadrupole QX1 and a long (1.1 m), small aperture (1.3 cm), quadrupole QC1. The field on their pole tips reaches 14-12 KGauss and will require the use of Permendur to prevent severe saturation of the material at the pole tips. Harmonic tolerances are of the order of a few times 10^{-4} at 70% of full aperture. Permanent magnets are also studied for the last quadrupole doublet QC2, QX1-QC1.

Magnet movers will allow translation of all magnetic lenses in both tranverse directions with micron resolution. The last three quadrupoles of the final transformer will lie on a single girder that will be isolated against ground vibrations. The girder will be supported by three piers poured in the rock. Recent measurements of pier motion have shown that the site should be stabilized against temperature changes.

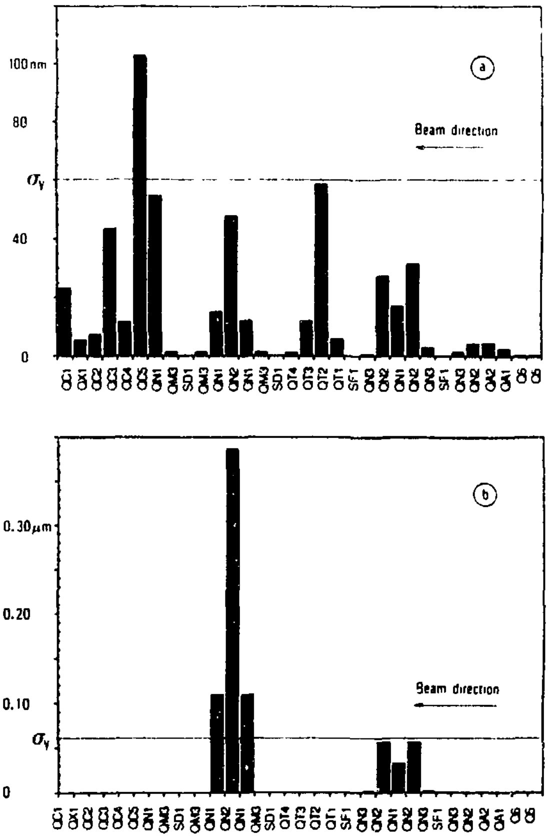

Fig.3 · The increase of the vertical rms dimension at the focus as function of the quadrupole that, by a 10 μm vertical misalignment, generates .

a) dispersion error at the focus for a ± 0.4 momentum spread
b) orbit error in sextupoles

In order to reach the alignment errors, quoted in the tuning simulation (see section 2.), two solutions are under study : either to extend the alignment laser beam system, used on the linac, or to install reference wires stretched on both sides of the magnetic lenses. The vertical reference will be provided by a hydrostatic levelling system with micronic resolution. Roll and pitch will be measured by inclinometers.

Vibration frequencies above one hertz will lead to incoherent jitter of the magnetic lenses. Measurements show that vibration signal is negligible above 50 Hz in the vertical direction and 100 Hz in the horizontal one. In the 1-50 Hz range vibration isolation systems would reduce the amplitude below 50 nm for the most sensitive last quadrupoles.

4. Instrumentation of the FFTB line

The FFTB line will be instrumented with beam position monitors (BPM) in all quadrupoles. They are of the type already used in the SLC final focus system. They will be incorporated in the vacuum chamber wall rigidly locked to each quadrupole. It is expected to reduce the BPM offsets to less than 30μm with respect to magnetic quadrupole centres. Wire scanners will also be installed along the line to precisely measure the profile of the beam spot.

A beam size monitor at the focal point is essential to tune the FFTB line. Conventional methods do not work for submicronic dimensions. The new method, presently under study[3,4], is based on the kick given to ions by the space charge field of the beam. The ions would be produced by ionization of a gas jet at the focus.

On one hand, heavy Argon ions receive a kick proportional to the electric field. The maximum velocity of such ions is proportional to the maximum field that is inversely proportional to the beam dimensions. The time of flight of the ions to reach a detector has a minimum value that scales linearly with the radius of a round beam (see Fig. 4). For a flat beam, this quantity is not very sensitive to the beam aspect ratio, and will mainly allow to measure the horizontal dimension.

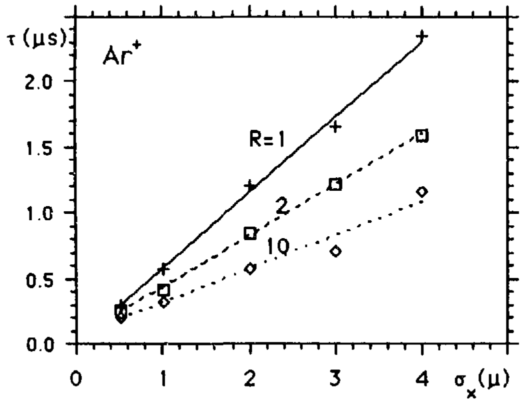

Fig 4 The time of flight of Ar^+ ions, for a 6 cm path from the beam to the detector, as function of the r m s. horizontal dimension σ_x and of beam aspect ratio R.

On the other hand, light Helium ions are trapped and oscillate in the space charge field. In the case of a flat horizontal beam, the ions mainly oscillate in the horizontal plane. After passage of the beam they are emitted with an angular distribution peaked along the horizontal transverse axis. The beam aspect ratio can be derived from the anisotropy of the angular distribution (Fig. 5).

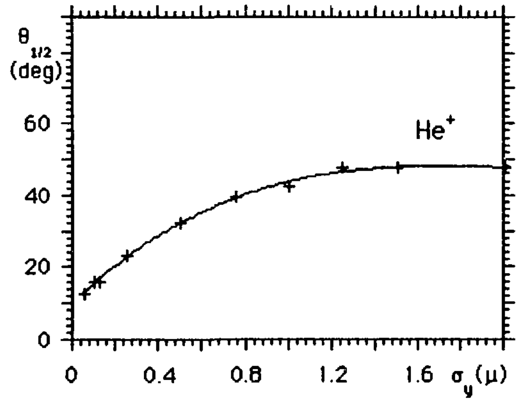

Fig.5 : The angular anisotropy $\theta_{1/2}$ of emitted ions vs. the r.m.s. vertical dimension σ_z with a constant r.m.s. horizontal dimension $\sigma_x = 1\ \mu m$

$\theta_{1/2}$ is the angle that divides $(0, \pi/2)$ in two equally populated intervals ($\theta_{1/2} = \pi/4$ for an isotropic distribution).

A beam size monitor based on this method would consist of a gas jet pulsed successively with Argon and Helium and an ion detector. The measurement of the angular distribution and of the time of flight will give the two beam dimensions.

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