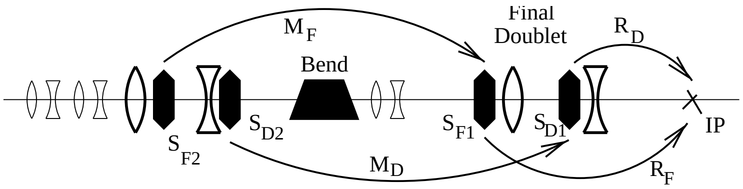

Fig. 7.1. Sketch of FFS with local chromaticity correction.

7.6 Focusing at interaction point

Andrei Seryi and Rogelio Tomás García

Final Focus design. The main task of a Final Focus is to focus the beams to the small sizes required at the interaction point (IP). To achieve this, the FF forms a large and almost parallel beam at the entrance to the final doublet (FD), which contains two or more strong quadrupole lenses. However, even for a beam with a minor energy spread of a fraction of a percent, the focused beam size will be diluted by the chromaticity of these strong lenses. The design of a FF is therefore driven primarily by the necessity of compensating the chromaticity of the FD.

There are two primary approaches for chromaticity compensation – the non-local scheme, implemented particularly at FFTB [1] and B-factories [2, 3] and the local compensation scheme [4] presently being implemented at ATF2 [5], which is used as a basis for the current FFS of proposed linear colliders.

In the non-local FF, the chromaticity is compensated in dedicated sections by sextupole magnets placed at maxima of dispersion and beta-functions. The geometric aberrations generated by the sextupoles are canceled when used in pairs with a minus identity transformation between them. The non-local FF is built from separated optics blocks with strictly defined functions, and its design and analysis is relatively simple. The major challenge of the non-local FF rests in its applicability to high energy colliders – the FF bend magnets have to be sufficiently long and weak to minimize the additional energy spread generated, thus lengthening the system to the range of several kilometers which makes it impractical to use it for TeV scale e^+/e^- colliders.

Local compensation of chromaticity is achieved by interleaving a pair of sextupole magnets with the quadrupoles of the final doublet, see Fig. 7.1. The dispersion throughout the FD is created by upstream bends, and is designed to be zero at the IP. Geometric aberrations, generated by FD sextupoles, are cancelled by two or more sextupoles located upstream. Sextupoles placed in FD generate second order dispersion – however, it can be compensated simultaneously with x and y chromaticity provided that half of the total horizontal chromaticity of the whole FF is generated upstream. The second order aberrations are cancelled when the x and y pairs of sextupoles are separated by transfer matrices M which have block-diagonal structure $\{A\ 0; 0\ B\}$ where $A = \{f\ 0; c\ -1/f\}$, where there is flexibility to modify the coefficients via a proper choice of optics that allows compensation of third and fourth order aberrations. The FF with local compensation requires fewer bends, and allows the design of a 3 TeV CM FF system with about half a kilometer length.

Final Focus optimization. The transfer map between the start of the FFS and the IP is given by $x_{IP} = X_{jklmn} x_0^j\, p_{x0}^k\, y_0^l\, p_{y0}^m\, \delta_0^n$, where X_{jklm} are the map coefficients that can be extracted from MAD-X [6] and PTC [7] and the sum over repeated indexes applies. The standard quadratic deviation of the particle distribution at the IP is expressed as a function of the X_{jklm} coefficients and the entry beam sigmas as given in [8]. This allows for a semi-analytical optimization of any lattice parameters (like the strength of non-linear elements) so as to minimize the IP beam size.

Final Focus tuning. The unavoidable misalignments and field errors of the different components of the FFS result in an emittance dilution at the IP. FFS tuning refers to the process of bringing the machine to nominal performance and maintaining it in the presence of dynamic errors. The initial set-up procedure involves steering the beam through the center of critical apertures and magnetic elements with known higher-order fields. Precomputed knobs use orbit bumps at the sextupoles to orthogonally control all the different IP particle distribution correlations. These knobs are iteratively scanned until the minimum IP beam size is reached. Finally either single magnets strengths or "Irwin knobs" [9] can be scanned to minimize the higher-order aberrations.

References for 7

[1] V. Balakin et al, Phys. Rev. Lett. **74**, 2479-2482 (1995).

[2] M. S. Zisman, "The PEP-II Project" LBL-34556 CBP Note-036.

[3] E. Kikutani et al, "KEKB Accelerator Papers", KEK Preprint 2001-157, December 2001.

[4] P. Raimondi and A. Seryi, Phys. Rev. Lett. **86**, 3779-3782.

[5] P. Bambade et al (ATF Collaboration), Phys. Rev. ST Accel. Beams **13**, 042801 (2010).

[6] `http://mad.web.cern.ch/mad/`

[7] E. Forest, F. Schmidt and E. McIntosh, KEK Report 2002-3.

[8] R. Tomás, Phys. Rev. ST Accel. Beams **9**, 081001 (2006).

[9] N.J. Walker, J. Irwin and M. Woodley, "Global tuning knobs for the SLC final focus", PAC 93 and "Third-Order Corrections to the SLC Final Focus", SLAC-PUB 6206, May 1993.