Nuclear Instruments and Methods in Physics Research A 768 (2014) 14–19

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Compact spreader schemes

M. Placidi, J.-Y. Jung, A. Ratti, C. Sun *

Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
2 September 2014
Accepted 7 September 2014
Available online 21 September 2014

Keywords:
Free electron lasers
Beam switch yard
Spreader
Septum
Charged particle optics

ABSTRACT

This paper describes beam distribution schemes adopting a novel implementation based on low amplitude vertical deflections combined with horizontal ones generated by Lambertson-type septum magnets. This scheme offers substantial compactness in the longitudinal layouts of the beam lines and increased flexibility for beam delivery of multiple beam lines on a shot-to-shot basis. Fast kickers (FK) or transverse electric field RF Deflectors (RFD) provide the low amplitude deflections. Initially proposed at the Stanford Linear Accelerator Center (SLAC) as tools for beam diagnostics and more recently adopted for multiline beam pattern schemes, RFDs offer repetition capabilities and a likely better amplitude reproducibility when compared to FKs, which, in turn, offer more modest financial involvements both in construction and operation. Both solutions represent an ideal approach for the design of compact beam distribution systems resulting in space and cost savings while preserving flexibility and beam quality.

Published by Elsevier B.V.

1. Introduction

Modern Linac-based Free Electron Laser (FEL) systems are often equipped with multiple beam lines which require a beam switchyard (BSY) to distribute electron bunches from the Linac to individual FELs. The BSY design is challenging, as it requires not only to preserve beam quality and provide flexible bunch repetition rate, but also to meet the physical constraint of the facility site. In this paper we present designs of compact Beam Switchyard (BSY) systems. Fast Switching Devices (FSD) like Fast Kickers (FK) or RF Deflectors (RFD) initiate a low-amplitude vertical splitting. Septum magnets installed downstream as the vertical separation between the trajectories matches the magnet apertures provide the first horizontal deflections. The resulting schemes represent an ideal solution for the design of compact beam distribution systems resulting in space and cost savings while preserving flexibility and beam quality in a variety of Beam Switch Yard topologies.

Transverse deflecting RF structures, originally proposed at the Stanford Linear Accelerator Center (SLAC) [1] and at the Thomas Jefferson National Accelerator Facility (TJNAF) [2] as tools for beam separation, space phase diagnostics and bunch length measurements [3,4], have subsequently found additional applications as fast switching devices in beam distribution systems for multiple beam lines layouts [5,6]. The adoption of transverse RF deflectors allows distributing electron bunches with on-demand repetition rates in each line, well above the few hundred kHz limit likely represented by fast kickers. In addition, the steady state nature of the CW transverse fields provides higher deflection stability and shot-to-shot reproducibility as compared to those achievable with fast kickers where the deflecting pulses are created at every bunch passage. Beam distribution schemes adopting cascading RF deflectors have been discussed in [7] and complement this paper.

Conversely, the technology associated with stripline- and ferrite-based Fast Kickers is well developed and their use represents a more attractive solution from the financial investment point of view.

Issues related to Machine Protection also play an important role in the choice between the two options.

2. The initial splitting module

Stability and reproducibility criteria require the deflections from the fast switching devices to be of the order of 1-mrad or less. A BSY layout based on reduced amplitude initial horizontal deflections would involve very long beam lines to provide clearance to the downstream deflecting and focusing elements.

Schemes involving an initial splitting in the vertical direction further combined with horizontal deflections provided by properly designed Lambertson-type septum magnets (LSM) located at a short distance downstream offer instead options for substantial reductions in the longitudinal extent of the beam lines. The LSM thin septum accepts a contained vertical separation between the trajectories allowing the magnet to be installed at a relatively short distance from the fast switching devices, resulting in a more compact longitudinal footprint of the BSY layout.

In the basic splitting module scheme shown in Figs. 1 and 2 an initial section produces three vertical trajectories selectively deflected

* Corresponding author.
E-mail address: csun@lbl.gov (C. Sun).

http://dx.doi.org/10.1016/j.nima.2014.09.017
0168-9002/Published by Elsevier B.V.

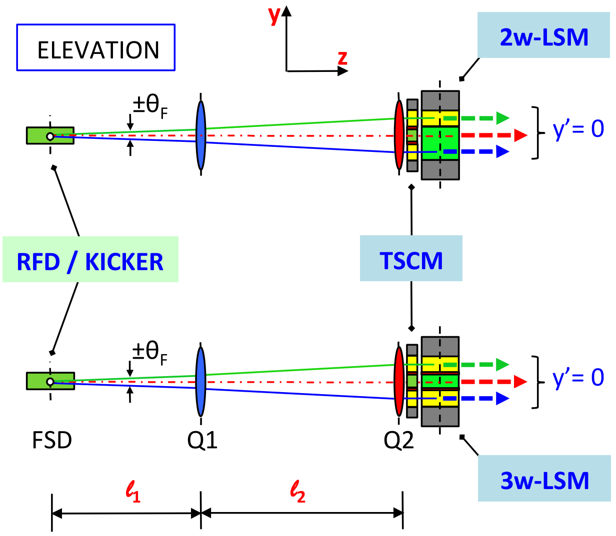

Fig. 1. Elevation of the basic module of the initial vertical splitting scheme. A Fast Switching Device (FSD) vertically splits an incoming bunch train into three trajectories with a small amplitude angle $\pm\theta_F$. The initial slopes, enhanced by the vertically defocusing quadrupole Q1, are compensated at the entrance of the LSM downstream.

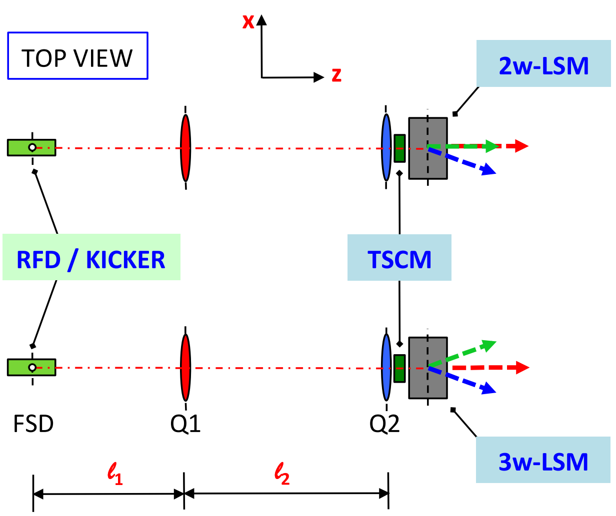

Fig. 2. Top view of the basic module of the initial vertical splitting scheme showing the role of two- or a three-way LSM installed at a relatively short distance from the FSD.

by the LSMs. Two-way and three-way Lambertson magnet options can be adopted depending on the chosen BSY topology.

2.1. Vertical splitting

A Fast Switching Device, either a bipolar kicker or an RFD, vertically splits an incoming bunch train into three trajectories, two deflected and one straight. The small amplitude deflections are enhanced by the vertically defocusing quadrupole Q_1 while the Q_2 location defines the trajectories separation Δy. A Twin Septum Corrector Magnet (TSCM) or Q_2 compensate[1] the slopes $\Delta y'$ at the LSM entrance.

The scheme consists of a telescopic arrangement of elements governed by the vertical transfer matrix from the FSD to the LSM with the constraints:

$$R^y_{12} = \Delta y/\theta_F, \quad R^y_{22} = 0. \tag{1}$$

[1] Arguments supporting slope compensations are developed in a subsection below.

Solving (1) with the compact arrangement condition

$$l_1 + l_2 = min \tag{2}$$

gives, in thin lens approximation:

$$l_{1,2} \equiv l = -f_1 + \sqrt{f_1(f_1 + R^y_{12})}\ , \ f_2 = l\left(\frac{2f_1 + l}{f_1 + l}\right) \tag{3}$$

where f_1 and f_2 are the Q_1 and Q_2 focal lengths.

A numerical example for $R^y_{12} = 15.0$-mm/mrad and a conservative $f_1 = 1.48$-m gives $l = 3.46$-m and $f_2 = 4.34$-m. The quoted focal lengths are consistent with a 0.6-T B_{TIP} value at 4-GeV beam energy for 0.15-m long standard quadrupoles with 20-mm and 60-mm respective bore diameters offering comfortable apertures for the local trajectory separation.

2.2. Horizontal deflection: dedicated magnets

LSM magnets provide the first horizontal deflections. A typical two-way LSM is shown in Fig. 3 in upright configuration. In this design, originally conceived for the three-way RFD deflecting scheme of the Next Generation Light Source (NGLS) project at the Lawrence Berkeley National Lab, the zero-field passage has a relatively large internal diameter to accommodate two un-deflected trajectories while the other one is right deflected to create the first branch of the spreader. A 2-mm thin septum separates the deflecting gap from the field-free region.

A Poisson simulation for the LSM of Fig. 3 anticipates (Fig. 4) a residual field in the field-free region with components

$$B_x^{res} = 0.74\ \text{G}, \quad B_y^{res} = 2.4\ \text{G}. \tag{4}$$

The 0.33-T design figure of the main deflecting field and the < 2.5-G residual B-field in the field-free region provide 25-mrad and about 20-μrad deflections respectively for a 4-GeV beam. A parameter list for the two-way LSM is given in Table 1.

In compact beam distribution schemes it is sometimes useful to concentrate two horizontal opposite deflections in a single LSM still leaving the option for an un-deflected trajectory. A design of a three-way LSM, with a central zero-field region separating two deflecting gaps, is shown in Fig. 5. The cylindrical vacuum pipe is installed in a rectangular cross section passage for easier yoke construction.

In a basic scheme the same amplitude opposite B-fields fully compensate the residual field in the central passage. A more flexible solution is proposed with the present "asymmetric deflection" design where different amplitude deflections are available. The 0.7-m long magnet provides up to 5- and 10-mrad opposite deflections to a 4-GeV beam. The Poisson-simulated magnet properties (Fig. 6) anticipate a ~ 0.6-G residual field in the central passage and a 0.7×10^{-3} radial non-homogeneity of the main deflecting fields. Table 2 gives a parameter list for the three-way LSM sketched in Fig. 5.

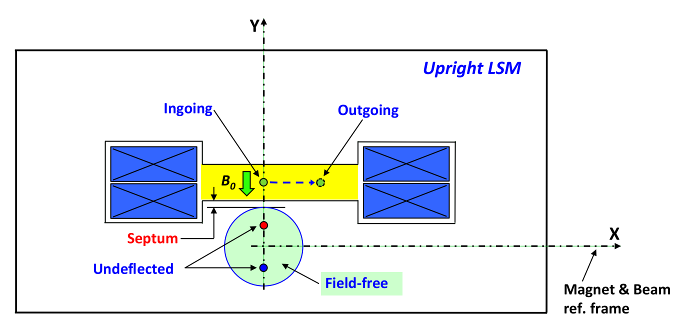

Fig. 3. Cross section of a two-way upright LSM magnet. The top trajectory (green) is deflected to the right while the two others travel un-deflected in the field-free channel. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)