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A LATTICE AND BYPASS DESIGN FOR A COHERENT XUV FACILITY*

A. Jackson and A.A. Garren
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

G. Vignola
Brookhaven National Laboratory
Upton, New York 11973

Abstract

The design of a magnet lattice and bypass for a coherent radiation facility is discussed. The lattice is the missing magnet FODO structure first proposed by Vignola [3] for a 6 GeV light source. This has been adapted for a 750-1300 MeV electron storage ring for use with both conventional insertion devices and a high gain FEL optimized for output at 400 Å. The latter device requires that the electron bunch be deflected into a small aperture bypass, then reinjected into the ring where the perturbing effects of the FEL are damped out.

1. Introduction

The storage ring described in this paper has been chosen from five candidates, all of which were optimized for operation with a single pass, high gain FEL.[1,2] The lattice utilizes gradient sector magnets similar to the design proposed by Vignola for a 6 GeV light source.[3] Here we discuss the tunability of the lattice, the dynamic aperture, and describe the bypass necessary for FEL operation. The main parameters of the r.f. and injector systems are also described.

2. Performance Goals

Optimization criteria in the design of a storage ring for operation with a single pass, high gain FEL are described in ref. [1]. In the examples discussed there the energy was selected to be 750 MeV, and the momentum spread was allowed to increase to $\sigma_p/p = 0.002$ under the influence of the microwave instability, so restricting the peak current, $\hat{I}_b$, in the electron bunch. For the lattice described here the limiting current is $\hat{I}_b = 200$ Amperes. The resulting intrabeam scattering blows up the emittance from its 'natural' value of 0.46×10^{-8} m-rad to 1.0×10^{-8} m-rad.

A further requirement of the lattice is that it be capable of operating at a higher energy for use with conventional insertion devices, such as undulators. To this end all systems, including the injector, have been made compatible with operation at 1.3 GeV, where designs for insertion devices have already been optimized.[4]

In order to meet the requirement for high K-value and small period, the FEL undulator has to be built with a small gap ~ 3 mm,[1] which demands the use of a bypass scheme. The operating procedure is to switch the single electron bunch into the FEL bypass where an intense optical pulse is produced, then reinject the bunch back into the storage ring where the perturbing effects of the FEL are damped out. The process can be repeated after one damping time, i.e. at a rate $\gtrsim 10$ Hz.

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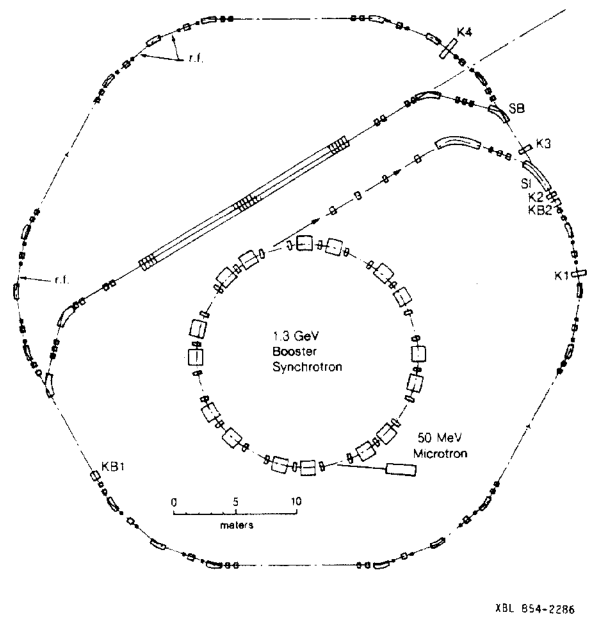


Fig. 1. Layout of the Coherent XUV Facility

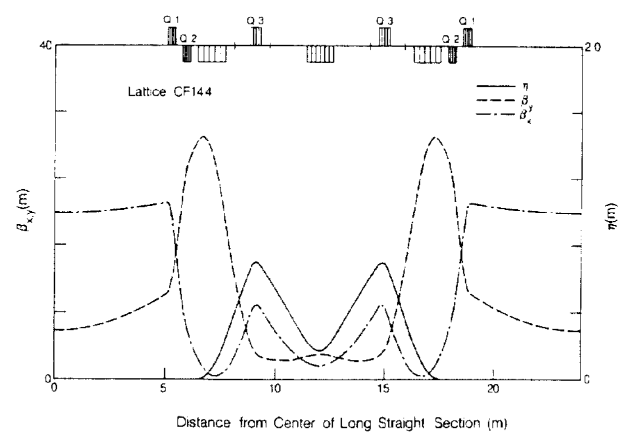
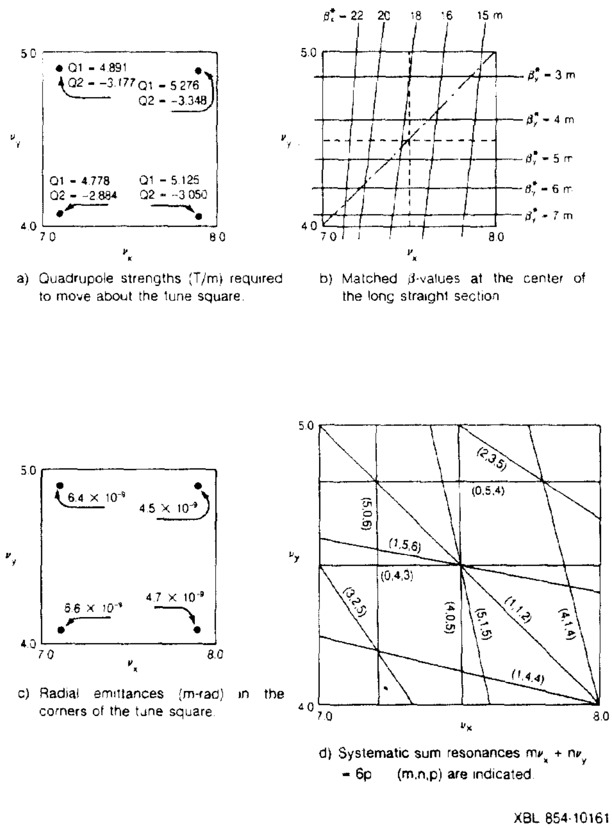


Fig. 2. Lattice Functions Through a Unit Cell

3. The Lattice

A layout drawing of the storage ring and its main systems are shown in Fig. 1. The lattice is constructed from six unit cells, each cell containing an achromat with three bending magnets and two quadrupoles, matched, into a 10 m long dispersion free straight section by quadrupole pairs. The bending magnets are all gradient sector magnets with $\ell_B = 1.22$ m, $\rho = 3.5$ m, $n = 5.0$. The structure of a unit cell together with the lattice functions β_x, β_y and η are shown in Fig. 2.



a) Quadrupole strengths (T/m) required to move about the tune square.

b) Matched β-values at the center of the long straight section.

c) Radial emittances (m-rad) in the corners of the tune square.

d) Systematic sum resonances $m\nu_x + n\nu_y = 6p$ (m,n,p) are indicated.

Fig. 3. Variation of Parameters in a Unit Tune Square

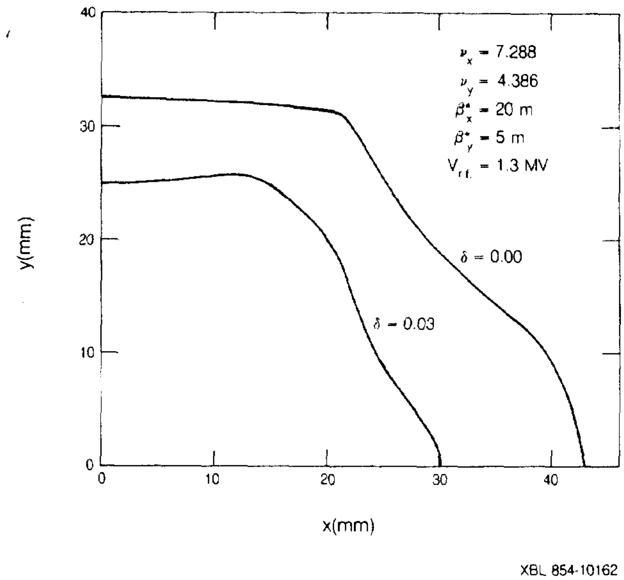


Fig. 4. Stability Measured at Center of Long Straight Section

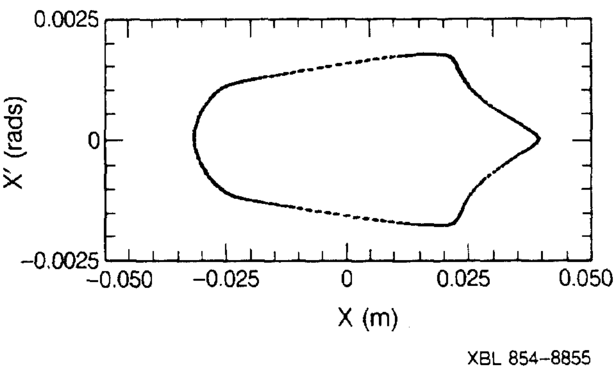


Fig. 5. Radial Phase Space Trajectory Close to the Stability Limit

Since quadrupole Q3 is used to match the dispersion bump, only Q1 and Q2 are available for lattice tuning. This gives a structure which is very easy to tune and, for a lattice with such low emittance, one which is relatively insensitive to errors. Functions of the lattice behavior within the integer tune square $7 < \nu_x < 8$; $4 < \nu_y < 5$, are shown in Fig. 3. The quadrupole strengths required to move about the tune square at 750 MeV, Fig. 3(a), are modest and not highly sensitive; $\Delta\nu/(\Delta G/G) \approx 12$. Variation of the matched β-functions at the center of the long straight sections, (denoted β*), are shown in Fig. 3(b). It can be seen that no dramatically large or small β*-values are encountered. Figure 3(c) shows how the radial emittance charges within the tune square and Fig. 3(d) shows the systematic sum resonances up to order 6.

The natural chromaticity of lattices designed for low emittance beams are usually quite high and this lattice is no exception: $\xi_x \approx -17$, $\xi_y \approx -14$. However excellent chromatic behavior of the corrected lattice is obtained using just two sextupole families, giving $\Delta\nu \lesssim 0.02$ over a momentum range of $\delta = \pm\ 0.03$, this despite the fact that strong correction strengths, $k_s \approx 5.0$, are required.

MARYLIE[5] has been used to track the dynamic aperture for two different momenta in the presence of synchrotron oscillations. The resulting stability limits, shown in Fig. 4, represent the largest dynamic aperture of the five sample lattices referred to in ref. [1]. The radial limit for $\delta = 0$ corresponds to $\sim 125\ \sigma_{x_0}$. A phase space trajectory corresponding to an electron close to the stability limit is shown in Fig. 5.

4. R.F. System

In order to sustain a reasonable Touschek lifetime at the high charge density required for this storage ring, a momentum acceptance of 3% is needed. This is achieved with a peak voltage of 1.3 MV at 500 MHz. Three single cell cavities, of a type already in use at other storage rings[6] are proposed with a separate r.f. transmitter for each cavity.

5. Injection System

A full energy (1.3 GeV) injector is proposed for the facility. The one shown in Fig. 1 represents an upgrade of the BESSY injector.[7] It consists of a 50 MeV racetrack microtron followed by a 10 Hz booster synchrotron with a circumference of 64 m. With a 20 mA beam from the microtron and 33% and 50% transfer efficiencies to the booster and storage ring respectively, it is calculated that the filling time to $\hat{I}_b = 200$ Amperes will take approximately 3.5 minutes.

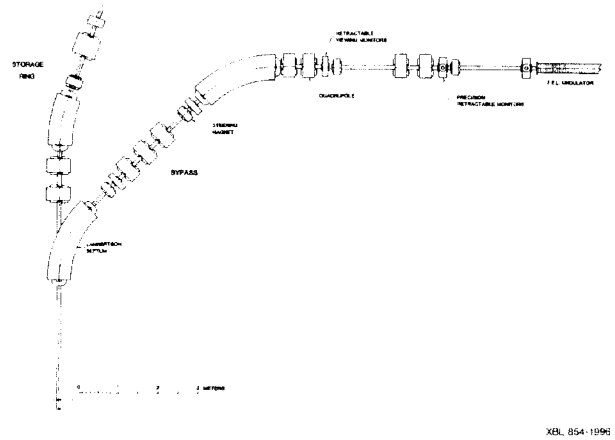


Fig. 6. The Extraction Side of the FEL Bypass

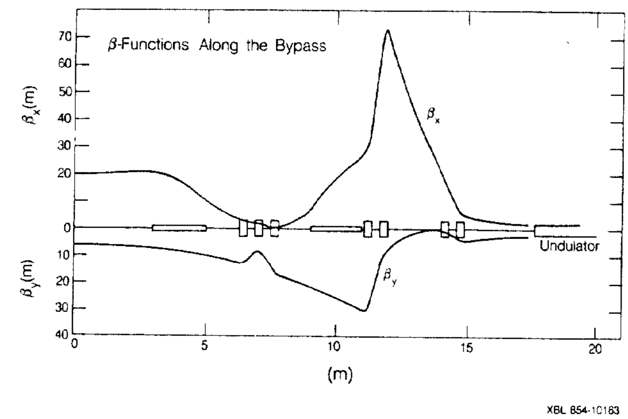


Fig. 7. Amplitude Function Through the Extraction Side of the Bypass

6. The FEL Bypass

The function of the bypass is to extract the electron bunch from the storage ring, to channel it with well defined properties through the FEL undulator, and to reinject it into the storage ring with high transfer efficiency. The layout can be seen in Fig. 1, and an expanded view of the extraction side of the bypass is shown in Fig. 6; the injection side is a mirror image. Extraction is by vertical deflection into a Lambertson septum magnet.

The optical properties of the undulator demand electron beam parameters of $\beta_x = \beta_y \approx 2\text{-}3$, $\alpha_x = \alpha_y = 0$, $\eta = 0$ at the entrance to the undulator. The functions of momentum matching and focussing are completely separated by utilizing an achromatic bend employing two bending magnets and three quadrupoles, and a focussing section comprising two quadrupole pairs. The evolution of the β-functions through the bypass are shown in Fig. 7.

In order to meet the very tight tolerances on beam stability through the FEL undulator it is necessary to power the two bending magnets in series and to maintain an extraction kicker stability of $\Delta\theta_k/\theta_k$ = few x 10^{-4}. Such tolerances are very stringent, but have been demonstrated in the SLC damping ring injection/extraction systems.[8]

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