The 1.2 GeV High Brightness Photon Source at the Stanford Photon Research Laboratory

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Abstract

The design of the 1.2 GeV low-emittance storage ring at the Stanford Photon Research Laboratory (SPRL) is described. This ring is currently under construction at Stanford University to serve as a high brightness XUV source and as a driver for free electron lasers (FEL) in the soft x ray regime. The design features and status of the project is being described.

Introduction

The design goals for the storage ring under construction are to provide high brightness synchrotron radiation in the XUV regime and in a different mode of operation to provide a particle beam with very high peak intensity as an efficient driver for free electron laser experimentation in the soft x-ray regime. For high brightness synchrotron radiation production a small beam emittance is required while for FEL experimentation a small beam emittance but also a short damping time is essential. Both design goals are competing since a short damping time can be achieved only by intense synchrotron radiation which in turn causes strong quantum excitation of the beam emittance. A compromise must be reached to satisfy both requirements.

Ring Lattice

Basically the lattice follows the design of the 1.2 GeV damping ring for the Stanford Linear Collider [1,2]. The storage ring has the shape of a long race track (Fig.1) with two about 25 m long "straight" sections between two tight arcs. One of the "straight" sections has the form of a chicane to provide four free sections for synchrotron radiation insertion devices aimed in different directions. The other straight section is available for the installation of a wiggler magnet for FEL experimentation. The strong damping for the FEL operation is achieved through the intense synchrotron radiation produced by strong bending magnets. The low emittance is a consequence of the short FODO cells resulting in small bending angles per cell and strong focusing of the arcs. Each arc is composed of 20 FODO cells each 1.72 m long. At the end of the arcs special matching sections are configured such as to provide a dispersion free straight section on the FEL side and two 2.5 m long dispersion free sections for the RF cavity and the injection elements. In Fig 2 the lattice functions for the complete ring are shown and in Table 1 the main parameter of the storage ring are compiled.

VUV Chicane: The straight sections for the four insertion devices are 3.1 m long and are separated by a combination of two bending magnets separated by a quadrupole triplet. The photon beamlines thus emerge from the ring at an angle of 9 degrees (Fig 1).

Table 1 Main Storage Ring Parameters

Nominal Beam Energy		1.0 GeV
Max. Beam Energy		1.2 GeV
Circumference		107.029 m
Beam Current avg.		1000 ma
Peak Beam Current		270 amp
tunes: nux, nuy =		7.74, 4.85
Beam Emittance		3.7×10^{-8} m-rad
Nat. Chromaticity, hor.,vert. :		-10.2, -8.7
Energy Spread		0.058%
Transv. Damping Time		15 ms
Beam Sizes in Insertions	inner two	outer two
sigmax =	.46 mm	.50 mm
sigmay =	.15 mm	.074 mm

Matching Sections: Four sections of the ring are used to match the lattice functions of the arcs to those in the FEL straight section and the VUV chicane. They consist of at least two FODO cells from the arcs plus five extra quadrupoles in the straight section or chicane. The matching section upstream of the VUV chicane include the free spaces required for two RF cavities while the one downstream include the spaces for three injection kickers and a septum magnet. In the straight section the betatron function are large due to the distance between quadrupoles. As a general rule, the betatron functions are kept as small as possible to reduce the effect of errors on the beam and of Coulomb scattering on the beam lifetime.

Chromatic Correction: Geometrical and chromatic aberrations are of great concern in low emittance storage rings. In the case of the SPRL ring a combination of electromagnetic sextupoles and sextupole fields incorporated into the bending magnets provide the means to control the aberration effects in of the lattice. A simple two sextupole family correction scheme was not sufficient to avoid strong coupling of the horizontal and vertical motion leading to large amplitudes and therefore to beam loss at the physical aperture. More sextupole families were required to control the coupled motion. The final correction scheme was developed using the program PATRICIA for tracking studies to achieve a dynamic aperture which is larger than the physical aperture. Figures 3 and 4 show the dynamic aperture as calculated at the position of the element QV5. Figure 3 indicates that the vertical amplitude exceeds the physical aperture at very small initial amplitude while figure 4 shows that the vertical amplitude remains relatively constant.

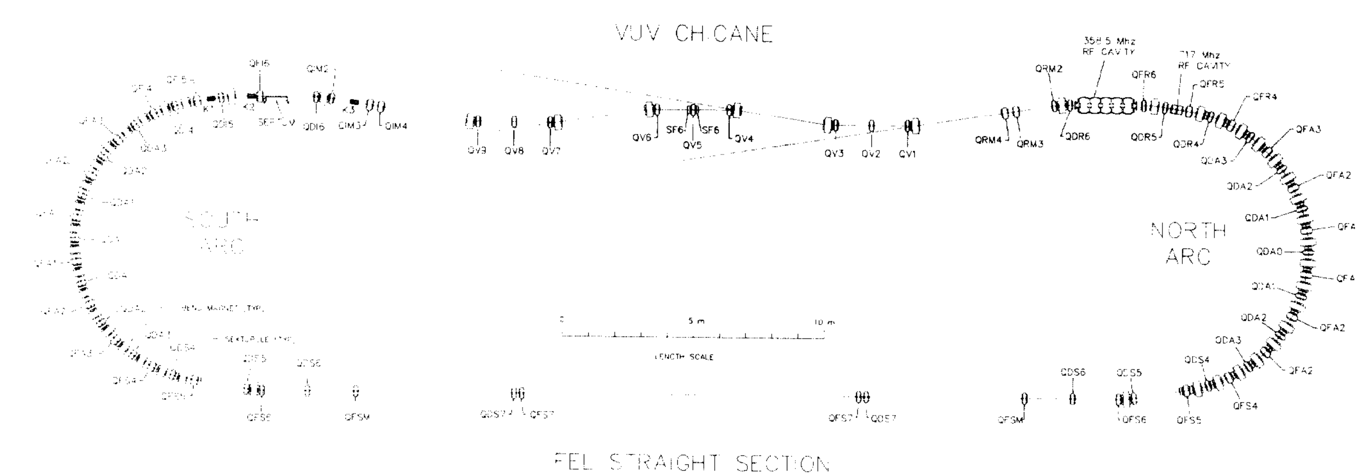

Figure 1. SPRL Storage Ring Layout Showing Magnetic Elements and Cavities.

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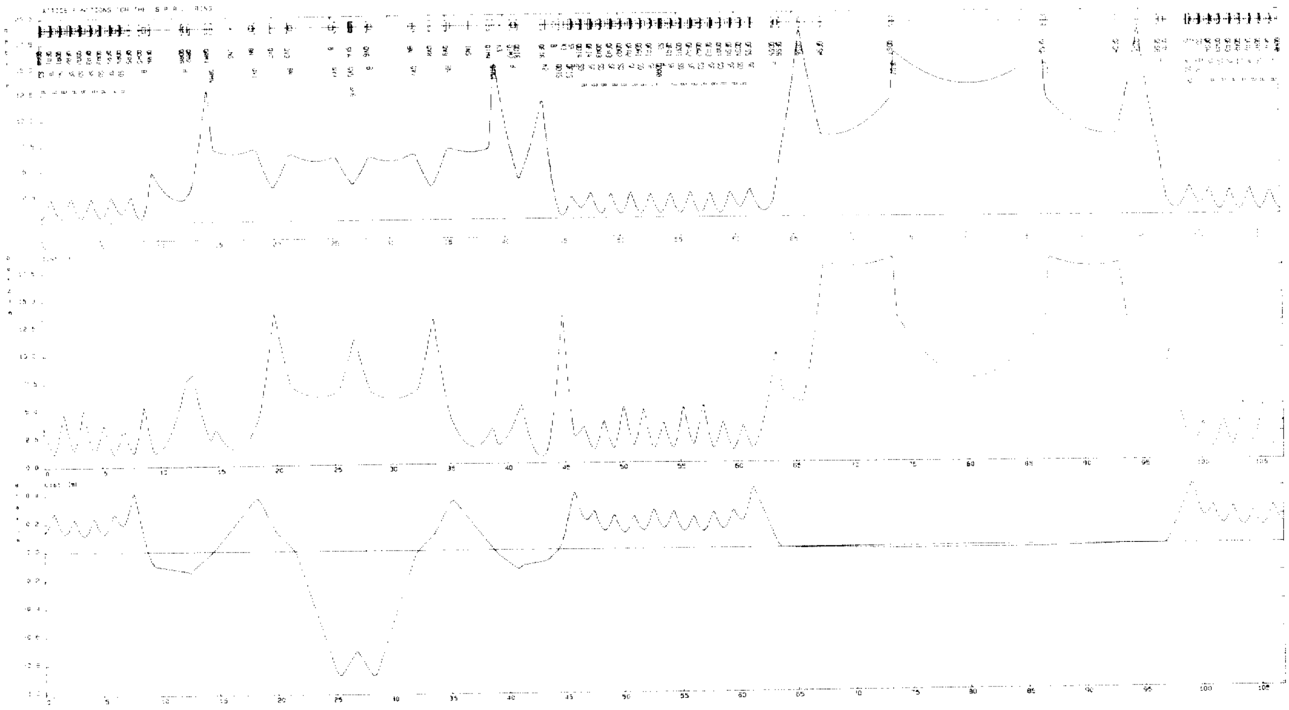

Figure 2. Plots of the Horizontal and Vertical Betatron Functions and the Dispersion Function.

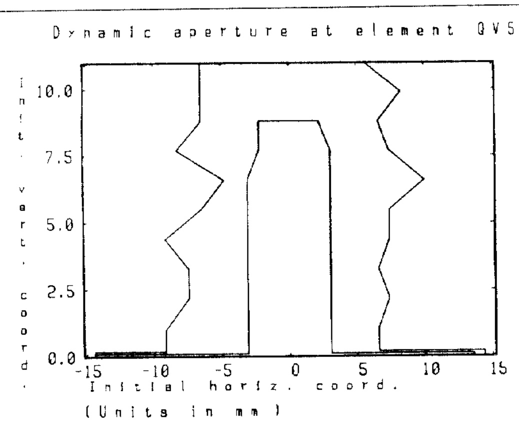

Figure 3. Two sextupole family configuration.

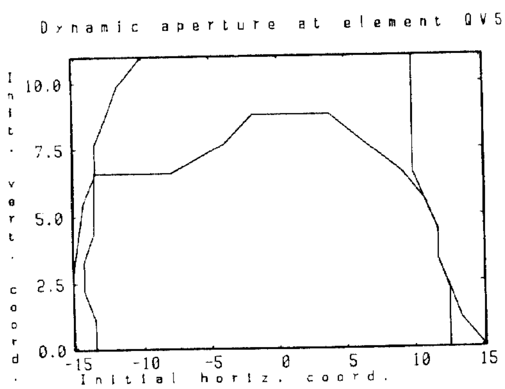

Figure 4. Many sextupole configuration.

Each pair of coordinates represent the initial amplitude of the particle motion starting at element QV5. Particles with initial coordinates inside the outer line undergo stable betatron oscillations while those with coordinates outside have unstable trajectories. The region inside the inner line represent particles that stay within the physical aperture defined by the vacuum chamber. In between the two lines the motion is stable but the amplitude is such that the particle hits the vacuum chamber wall and is lost.

RF System

The radio-frequency system is required to compensate for the energy lost to synchrotron radiation and to parasitic modes, as well as to provide a large energy acceptance. The ring is a low energy and high current storage ring and therefore special attention must be given to the Touschek lifetime and parasitic mode losses while specifying the RF system. Long Touschek lifetime during high peak current operation for free electron laser experimentation requires a large energy acceptance. The RF system is designed to provide a total energy acceptance of about 5% which is consistent with the chromatic acceptance of the lattice.

Main RF system: Two RF systems, the main RF system and a second harmonic RF system are used in this storage ring to achieve the desired beam characteristics. The main system provides the required gap voltage in a 5-cell cavity resonating at a frequency of 358.53 MHz. The cavity is one of the retired Aluminum cavities used in SPEAR, the 3.5 GeV storage ring at the Stanford Linear Accelerator Laboratory and the RF power will be supplied by a SPEAR type klystron.

Second harmonic system: The second harmonic RF system is used to control the single bunch and multibunch instabilities by modulating the bunch length or splitting the synchrotron oscillation frequency between bunches. It is composed of a 2-cell copper cavity and a 717 MHz transmitter with an RF power of 50 KW. The cavity's peak voltage is 0.65 MV. With this system the bunch length can be modulated between 0.6 cm when only the main system is used and 2.7 cm when both systems are operating.

FEL and VUV operation modes: There are two modes of operation, the VUV mode and the FEL mode. To produce high brightness synchrotron radiation in the VUV mode many bunches with low bunch currents are used to reach a high average beam current of up to 1 ampere. In this VUV mode,the second RF system is operated to stabilize the multibunch instabilities. The second mode of operation is the FEL mode to provide a powerful driver for FEL experimentation. Only one or few bunches are stored to reach the maximum possible peak current which is essential to sustain a free electron laser in the sift x-ray regime. The limiting effect on the peak current at 270 ampere is determined by a Touschek lifetime of one hour. The second RF system in this mode of operation is used to control the bunch length for maximum peak current and one hour beam lifetime. Some of the RF parameters for both modes are compiled in Table 2.

Table 2 RF Parameters using two RF System

	FEL Mode	VUV Mode
Cavity Coupling Coefficient	2	2
Synchrotron Radiation		
Loss per turn	44 keV	44 keV
Parasitic Mode Energy Loss	65 KeV	11 KeV
Energy Acceptance	± 2.4%	± 2.6%
Max. Beam Current per Bunch	150 mA	11 mA
Bunch Length	2.7 cm	0.6 cm
Synchronous Phase Angle	173.5 deg.	176.5 deg
Peak Cavity Voltage	1.3 MV	1.3 MV
Power Required from Klystron	110 KW	110 KW
Total Beam Current	500 mA	1000 mA

Injection system

The electron beam for storage ring injection is generated in a 1.0 GeV full energy linac and is transported to the inner side of the storage ring and finally deflected into the storage ring by a Lambertson septum magnet. Three kicker magnets provide the fast beam bump for electron accumulation. The septum magnet bends the beam vertically by 170 mrad and the maximum required kicker strength is 5 mrad which can give a beam bump of 11 mm at the septum which is sufficient for the injection process.

Magnets

All storage ring magnets are made from 1008 low carbon steel. For ease of vacuum chamber installation all magnets can be split in the midplane. For diagnostic purposes and flexibility all quadrupoles and sextupoles are connected to individual power supplies. All bending magnets are in series on one power supply. Trim coils in all magnets serve as the orbit correctors in the ring. A list of magnet parameters is given in table 3.

Table 3 Magnet Parameters

	Dipole	Quadrupole	Sextupole
Gap/Bore radius (mm)	24	20	25
Pole tip field (kG)	20.3	7.7	4.2
Magnetic length (cm)	33	14/20	10
Number of magnets	48	71	40

Magnetic Measurements

A Magnetic Measurements Laboratory has been set up for the magnetic characterization and experimental development of the storage ring magnets. The magnetic measurements are controlled by a microVaxI. Precision shunts provide accurate readings of the current delivered by the remotely controlled power supplies. The interlock system monitors pressure and temperature of the cooling water, as well as the current through the excitation coils. Harmonic Analysis of the field is performed with the use of a rotating coil which rotates about its central axis, carefully aligned with the magnet axis. Fourier analysis of the induced voltage furnishes the harmonic contents of the magnetic field. The path integral of the field in the bending magnets is determined by the signal from a Hall probe guided on a precision track along the curved particle trajectory in the magnet. For quadrupoles and sextupoles, the amplitude of the voltage induced in the rotating coil furnishes an alternative and more precise measurement of the integrated field strength.

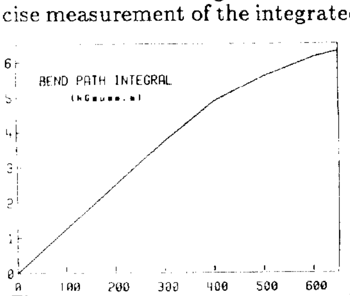

Figure 5

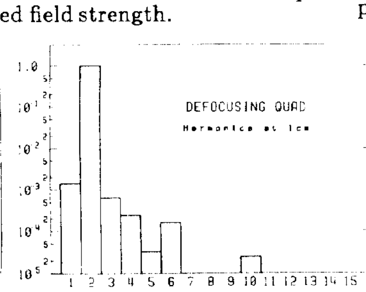

Figure 6

Figure 5 shows the experimental excitation curve of a prototype bending magnet. The maximum field achieved is 20.3 kGauss though only 19.0 kGauss is necessary for 1.2 GeV operation. Figure 6: Harmonic analysis of the field at 1 cm for a defocusing quadrupole magnet

Because of the relatively small bore of the quadrupoles it is necessary to machine the pole tips to a precision of one thousanth of an inch. The quality of the field is demonstrated in figure 6.

Vacuum System

The vacuum system is an all metal bakeable system with a base pressure measured at 0.1 nTorr and designed for an operating pressure of one nTorr at full beam current. 37.44 meters of the ring are assembled from 44 arc vacuum chambers (Fig. 7). The remaining 69.589 meters of the ring incorporates stainless steel straight sections, copper radiation masks, an aluminum and a copper RF cavity and ceramic kicker chambers. The arc chambers are all made of stainless steel with water cooled copper absorbers for a maximum synchrotron radiation heat load of up to 60 W/cm. The vacuum chamber is designed to give maximum pumping conductance limited only by the magnet apertures. A "smooth transition" perforated copper screen encloses the beam area to minimize higher mode losses. Each chamber incorporates one 60 l/sec ion pump mounted on a 15 cm plenum which provides good effective pumping speed for most of the chamber. Each chamber includes 900 cm2 of NEG (non evaporable getter) material mounted as a strip line adjacent to the beam area for added pumping. Ten 120 l/sec ion pump complete the pumping system in the ring straight sections.

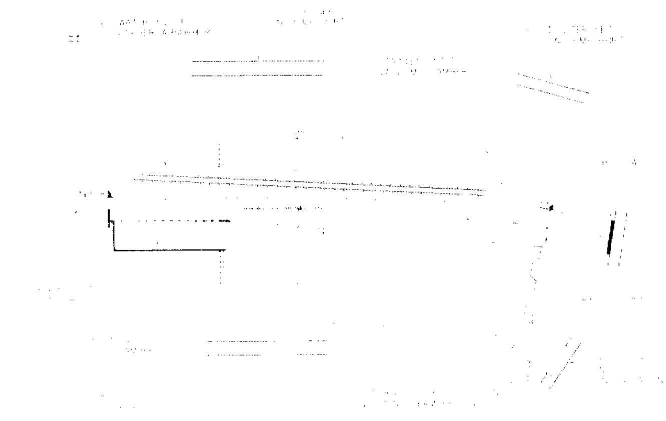

Figure 7. Typical arc vacuum chamber.

Control System

The control system must provide the monitoring and control functions to operate the ring as well as to provide for future control of the linac injector and of scientific experiments which interact with the storage ring. The system consists of loosely coupled computers which are organized in an hierarchical architecture. There will be approximately 900 signals interfaced to the control system. Further details are given in another paper at this conference.

Photon Beam Brightness

Two undulators of identical design are planned for two of the SR beamlines. With 35 periods of 7 cm they will give a maximum spectral brightness (brilliance) at 80 eV of 1.7×10^{17} and 6.3×10^{16} photons/sec/mm^2/mrad^2/.1% bandwidth. The two values are due to the different particle beamsizes at the undulator positions (Table 1).

References

[1] H.Wiedemann,"Scaling of Damping Ring for Colliding Linac Beam Sytems", 11th International Conference on High Energy Accelerators, 1980, Birkhäuser Verlag, Basel

[2] G.E.Fisher, W.Davies-White, T.Fieguth, H.Wiedemann, "A 1.2 GeV Damping Ring Complex for the Stanford Linear Collider", 12th International Conference on High Energy Accelrators, 1983, Batavia