THE BROOKHAVEN SUPERCONDUCTING X-RAY LITHOGRAPHY SOURCE (SXLS)

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1. Abstract

Synchrotron radiation from dipole magnets in electron storage rings has emerged as a useful source of x-rays for lithography[1]. The goal of the SXLS Project at BNL is to design and construct a compact storage ring of circumference, C = 8.503 meters. It will use superconducting dipoles with a field of B_0 = 3.87 Tesla and a bending radius of ρ = .6037 meters along with 700 MeV electrons to produce 10 angstrom x-rays for lithography. The project is proceeding in two phases: in Phase I low field iron dipoles are being used; in Phase II the low field dipoles will be replaced with superconducting dipoles. An overview of the design and a status report are presented.

2. Introduction

In March 1988 the Superconducting X-Ray Lithography Source (SXLS) project at the National Synchrotron Light Source at Brookhaven was initiated with funding from the Defense Advanced Research Projects Agency (DARPA). The goals of the project are to design and construct a superconducting magnet based storage ring as an x-ray lithography source and to transfer the technology of how to build the machine to US industry. The Grumman Aerospace Corporation and General Dynamics have been selected as the industrial participants.

As the design and fabrication of the complex superconducting dipoles requires considerable time and effort, the project is being executed in two phases. In Phase I the machine is being constructed with low field iron dipole magnets, B_{max} = 1.1 Tesla, with the same bending radius as the superconducting magnets. With this low field dipole the energy of the machine will be limited to E_{max} = 200 MeV. For Phase II, the low field dipoles will be replaced with superconducting magnets to enable the ring to reach E = 700 MeV and generate 10 angstrom photons for lithography.

3. Storage Ring Lattice

To achieve a small footprint and small electron beam sizes (σ_x,σ_y < 1 mm) the storage ring design is based on two 180° combined function bending magnets.[2,3] In such a small machine the dipoles have to serve many functions: bending, focusing, chromaticity correction and act as a source of radiation. An interesting feature of this particular lattice, which has a field index less than unity (n < 1), is that in the horizontal plane there are no defocusing elements, both the quadrupoles and the dipoles are focusing elements. The vertical plane is like a traditional FODO cell with alternating defocusing (quads) and focusing (combined function dipoles) elements. The main parameters of the ring are listed in Table 1 and a schematic drawing of the Phase I storage ring is shown in Figure 1. The Twiss parameters for the ring are displayed in Figure 2.

Machine Phase	Phase I	Phase II
Energy, E [MeV]	200	700
Dipole Magnet Type	EM	SC
Dipole Field, B_0 [T]	1.1	3.87
Bending Radius, ρ [m]	.6037	.6037
Field Index, n	.1759	.1759
Superperiods, N_s	2	2
Circumference, C [m]	8.503	8.503
Critical Wavelength, λ_c [A]	423	10
Horizontal Betatron Tune, ν_x	1.415	1.415
Vertical Betatron Tune, ν_y	.415	.415
Energy Loss Per Turn, U_0 [KeV]	.234	34.4
Uncorrected Chromaticity, ξ_x,ξ_y	-.49, -1.32	-.49, -1.32
Momentum Compaction, α	.32	.32
Natural Emittance, ε [m-rad]	5.92×10^{-8}	7.17×10^{-7}

Table 1: Storage Ring Parameters

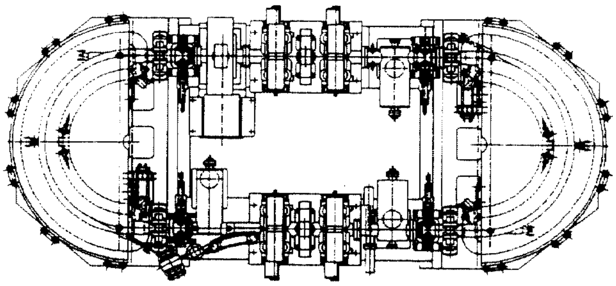

Figure 1: SXLS Phase I Storage Ring

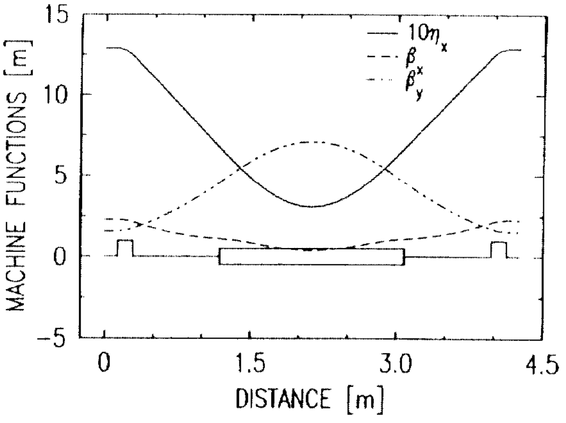

Figure 2: SXLS Twiss Parameters

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Although the photons from the Phase I ring (λ_c = 423 Å) are not suitable for proximity printing lithography which requires 6-10 Å photons, a slight variation of such a ring could serve as source of 130 Å photons for projection x-ray lithography.[4]

4. Phase I Storage Ring Magnets

The 180° dipoles for the Phase I ring are H-type magnets with a solid yoke made of AISI 1001 low carbon steel. The field is limited to 1.1 Tesla to limit the power consumption. Poleface windings have been included on the dipoles to allow for trimming of the gradient and sextupole components.

The quadrupole and sextupole magnets have laminated yokes as they will carry over to the Phase II machine where ramping (200 → 700 MeV) is required. Also included in the ring are four short 12-pole magnets to serve as trims.

All of the magnets have been measured and mounted on girders for installation. Field mapping of the 180° dipoles was a challenging task and necessitated the design of a novel apparatus consisting of a hooked arm on to which Hall probes are mounted.

5. Vacuum System

The vacuum chamber straight sections are fabricated from stainless steel type 304L and the dipole chambers from INCONEL 625. The system is designed for an operating pressure of 1×10^{-9} Torr or better with 500 ma of stored beam. An in-situ bakeout system is required to initially reach a low pressure. For 200 MeV and 500 ma operation, the power deposited on the chamber walls from synchrotron radiation is 0.3 watts/cm, therefore no water cooling of the Phase I chamber is necessary.

Pumping is due to a combination of pumps. Sputter ion pumps (SIP), titanium sublimation pumps (TSP), and nonevaporable getter pumps (NEG) have been used, thus taking advantage of each pump's optimum operating characteristics. A NEG strip pump built into the dipole chamber provides uniform pumping in this area of high gas desorption of more than 100 liter/sec/meter at 1×10^{-9} Torr. In the straight sections and on the RF cavity SIP, TSP and NEG pump assemblies will be used.

To facilitate low energy injection, both the straight sections and the dipole chambers in the Phase I ring have ion clearing electrodes installed.[5] The clearing electrodes are terminated with lossy coax cable of the same characteristic impedance, Z_0.

All of the vacuum system components have been completed, leak checked and installed in the magnets for final assembly of the storage ring.

6. RF System

The frequency selected for SXLS RF system is 211.54 MHz providing for up to six bunches in the ring. To conserve space, a single gap, capacitively load accelerating cavity driven in the TEM/TM01 mode has been built. A summary of the parameters of the Phase I cavity is given in Table 2.

The cavity has been put on frequency, higher order longitudinal and transverse modes have been measured and suppression antennae have been installed. Titanium nitride was applied to the inside of the cavity to reduce multipactoring effects and as a result gap voltages as low as 2 KV can be achieved. A 15 KW transmitter system has been assembled and it has delivered 8 KW into the accelerating cavity to produce a gap voltage of 50 KV. For Phase II of the project a new RF system is scheduled for delivery in February 1991.

RF Frequency, f_{rf} [MHz]	211.54
Quality Factor, Q	12,814
Shunt Impedance, R_s [MΩ/m]	1.87
Total Power Dissipation [KW]	169
Material	OFHC Cu
Δf_{rf} with gap [KHz/mm]	5,000
Δf_{rf} with temp [KHz/°C]	3.6
Δf_{rf} with tuner ins. [KHz/mm]	8
Harmonic Number, h	6

Table 2: Phase I RF Parameters

7. Injection Hardware

The injection process for SXLS requires two pulsed magnets, a 1 Tesla injection septum with a relatively long half sine-wave pulse excitation (≈ 50 ns), and a fast kicker (rise & fall times of 10 ns and a flat top of 50 ns) to bump the closed orbit toward the septum. Both pieces of hardware have been assembled and tested.

8. Control System

A control system has been developed for the SXLS machine which can at present provide all the controls necessary for the Phase I machine and will form the basis for a more fully automated system for Phase II. The control system consists of a distributed cluster of workstations which physically and functionally distribute the control system tasks. The workstations presently consist of 4 Hewlett Packard UNIX workstations which communicate over an ethernet local area network. One workstation acts as the system supervisor which provides the source of instructions to all other nodes in the system.

The control system software was developed at CEBAF of Newport News, Virginia. This control system provides a graphic interface for the rapid development of operator displays and control logic. The software includes features such as save/restore of system setpoints and the detection and logging of hardware faults. The control system software is written in the C language.

The control system interface to the SXLS hardware is through CAMAC modules. The modules communicate to the workstations through CAMAC crate controllers over an HPIB bus. Diagnostic instrumentation can be controlled by the computer system through an HPIB bus. A network/spectrum analyzer and a Lecroy 7200 storage oscilloscope are presently controlled through the computer system.

9. Status of Phase I

All of the major subsystems (magnets, RF, injection hardware, vacuum, controls & diagnostics) have been tested individually on the bench and at present the ring is being assembled in a shielded cave inside the NSLS building (see Figure 3). The existing NSLS linac and booster will serve as the injector for the ring. The 200 MeV transport line, which branches off the existing 750 MeV line for the 2.5 GeV NSLS X-Ray Ring, has been installed and is undergoing commissioning. Commissioning of the completed Phase I ring is scheduled to begin in August 1990. A primary goal of the Phase I project is to study how low of an injection energy ($E \leq 200$ MeV) is feasible.

10. Superconducting Dipole Magnets

In Phase II of the SXLS project the two 180 degree bending magnets are to be replaced by air-core superconducting dipoles. The nominal vertical field of the dipoles is 3.87 Tesla which is achieved by three pairs of superconducting coils (see Figure 4). Detailed magnetic field calculations were carried out with the

TOSCA and ANSYS computer programs to optimize the coil configurations to obtain the specified multipole components of the field while satisfying various mechanical design constraints. Several trim coils have been included in the design for independent adjustment of the field components.

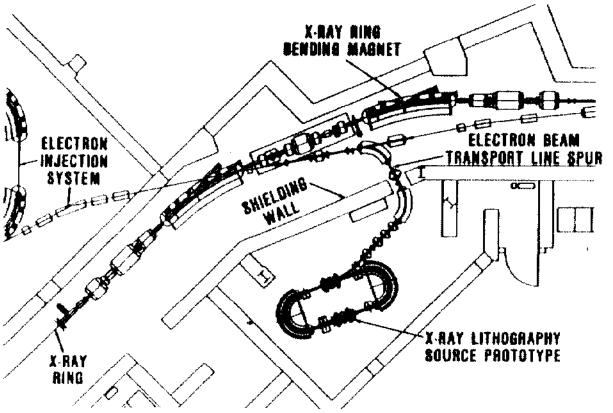

Figure 3: Location of the Phase I Ring at NSLS

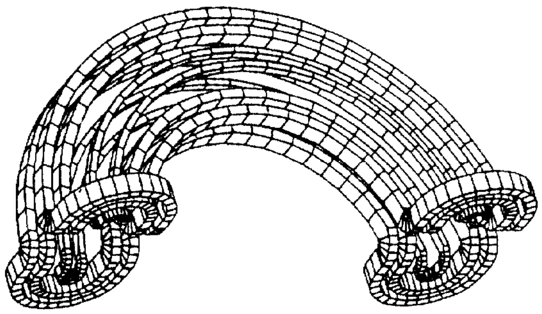

Figure 4: Superconducting Dipole Coils

The superconducting cables are supported and pre-stressed in stainless steel blocks. The vacuum chamber inside the dipole is maintained at room temperature by several layers of superinsulation between the chamber and the cold mass of the support structure. The chamber is designed to house NEG and DIP pumps, clearing electrodes and a water-cooled photon absorber. The photon absorber is required to shield those angular segments of the vacuum chamber that are not used for exit ports.

The design of the superconducting magnets is a joint effort between BNL and Grumman/General Dynamics. The fabrication will be carried out by General Dynamics in San Diego. Commissioning of the Phase II machine is planned for 1993. A dedicated 200 MeV linac will serve as the injector for the Phase II machine.

11. References

[1] J.B. Murphy, "Electron Storage Rings As X-Ray Lithography Sources: An Overview", SPIE Proc. of Electron Beam, X-Ray and Ion Beam Technology: Submicrometer Lithographies IX, Vol 1263, p.116, 1990.

[2] G. Vignola, unpublished work, 1987.

[3] R.P. Walker, M.W. Poole, V.P. Suller and S.L. Thomson, "General Design Principles For Compact Low Emittance Synchrotron Radiation Sources", Proc. 1987 IEEE Part. Acc. Conf., p. 494, 1987.

[4] T.E. Jewell, et. al., "20:1 Projection Soft X-Ray Lithography Using Tri-level Resist", SPIE Proc. of Electron Beam, X-Ray and Ion Beam Technology: Submicrometer Lithographies IX, Vol 1263, p.90, 1990.

[5] E. Bozoki and H. Halama, "Ion Clearing In the XLS-Ring", this proceedings, 1990.