FERMILAB
NOV 28 1994
LIBRARY
Fermilab Library
0 1160 0054040 5
UCLA-CAA0112-7/94

A Compact Hard X-ray Source for Medical Imaging and Biomolecular Studies

D.B. Cline[1], A.A. Garren[1,2], M.A. Green[3], J. Kolonko[1], and D. Madura[4]
[1] University of California Los Angeles, Center for Advanced Accelerators
Physics Department, 405 Hilgard Avenue, Los Angeles, CA 90024-1547
[2] Lawrence Berkeley Laboratory, Accelerator & Fusion Division
1 Cyclotron Road, Berkeley, CA 94720
[3] Lawrence Berkeley Laboratory, Mechanical Engineering Section
1 Cyclotron Road, Berkeley, CA 94720
[4] Martin Marietta, P.O. Box 85990, San Diego, CA 92186

UCLA–CAA0112–7/94

Abstract

There are a large number of synchrotron light sources in the world. However, these sources are designed for physics, chemistry, and engineering studies. To our knowledge, none have been optimized for either medical imaging or biomolecular studies. There are special needs for these applications. We present here a preliminary design of a very compact source, small enough for a hospital or a biomolecular laboratory, that is suitable for these applications.

1 Introduction

We believe there will be a strong commercial interest in a very hard x-ray source that is compact enough for hospitals and molecular biology laboratories. In the past there have been at least two generations of general purpose synchrotron radiation light sources and perhaps one generation of very compact light sources. These machines were mainly for soft x-ray lithography purposes and they illustrate two extremes.

The first light source was made for general users and has many beam lines and therefore is rather large. The other was developed for a specific

purpose (the utility of this machine is now questioned) and is not only very compact but generally is not designed for good beam optics.

In this brief report we describe a third type of light source: a compact hard x-ray source with good beam optics and a large range of practical applications. We believe such a machine must be designed partially by the experts who will use it and partially by a group of machine experts who's goal will be to insure a high beam quality. This machine will be compact so that it can fit into a hospital or into an x-ray crystallography laboratory. We propose to use high field superconducting magnets for the compact design and as the hard x-ray source, yielding an economy in the overall machine structure as well as cost, as shown in Figure 1. There are three potential applications for such a machine:

1. Protein Crystallography[1] :
   There is on going interest in drug designs based on an X-ray study of a crystallized virus, etc., and X-rays in the range $8-15$ KeV are needed.
2. Coronary Angiography:
   It has now been demonstrated that X-ray snap shots of the human heart can detect the build-up of dangerous substances in the arteries. For this use the X-ray energy should be ~ 33 KeV.
   A non-invasive screening procedure to study coronary circulation and heart disease is obtained using intense x-rays and a technique called digital subtraction angiography[2, 3], producing an intensity and quality of x-ray sources[4, 5]. There have been extensive studies of this technique over the past decade which have proved the technique to be very promising[2, 3]. This technique could, in principle, be performed on an out-patient basis, and could be extremely effective in screening for heart and other medical problems to identify them before they become potentially fatal. If a relatively inexpensive x-ray source can be developed with large patient throughput, it could be competitive with current models. While there are extensive tests of the concept at many SR facilities around the world, we are not aware of a current design study to attempt to optimize the x-ray source for this purpose[4]. Hard, intense x-rays are required (~ 33 KeV) and, we believe, a very compact storage right is required if it is to be placed in a hospital laboratory. The machine discussed here may be suitable for this purpose.
3. Monochromatic Mammography[7]:
   There is now evidence that 18 KeV x-rays provide a superior resolution to detect breast tumors.

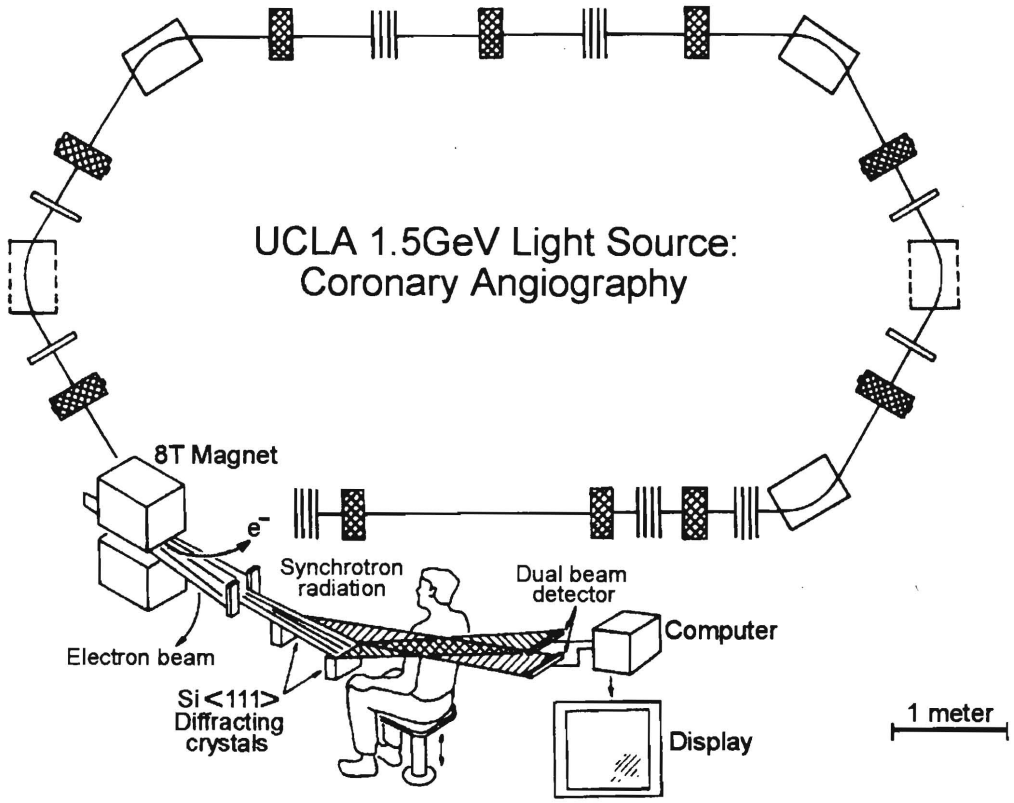

Figure 1: A very compact, hard x-ray source using an 8-Tesla superconducting magnet; used for coronary angiography. This source can also be used for mammography and biomolecular studies. (Adapted from Reference 6.)

Table 1: Parameters for the Hard X-ray Source

Electron Energy (GeV)	1.5
γ	3914
Circumference (m)	22.62
Tune ν_x	2.83
Tune ν_y	3.30
Horizontal Emittance*, (m-rad)	2.326×10^{-6}
Vertical Emittance**, (m-rad)	1.163×10^{-6}
Horizontal, β_{max} (m)	5.4
Horizontal, β_{min} (m)	0.63
Vertical, β_{max} (m)	6.2
Vertical, β_{min} (m)	0.09
RF Voltage (kV)	2000
FR Frequency (MHz)	499
Momentum Compaction	0.0985
Bunch Length, σ_l (cm)	2.2

*unnormalized
**fully coupled

We present here the preliminary design of a very compact hard X-ray source that is designed for industrial, medical and biotechnological uses. In Table 1 we give the parameters of the source. Note that the small size and the strong and efficient X-ray source emission at the 60° dipole bends make this machine a very effective X-ray source. Figure 2 shows the x-ray intensity vs wavelength for the machine described here. Figure 1 shows a possible use of the system for coronary angiography.

The most important components of this storage ring are the 8 Tesla superconducting magnets. We are working with the General Dynamics and LBL groups to propose the construction of a prototype magnet in the near future. Recently, funding has been obtained to start the design of this magnet.

2 Preliminary Design of the Compact Light Source

The ring has a racetrack shape, shown schematically in Figure 1. It has reflection symmetry about a vertical line through the center of the figure.

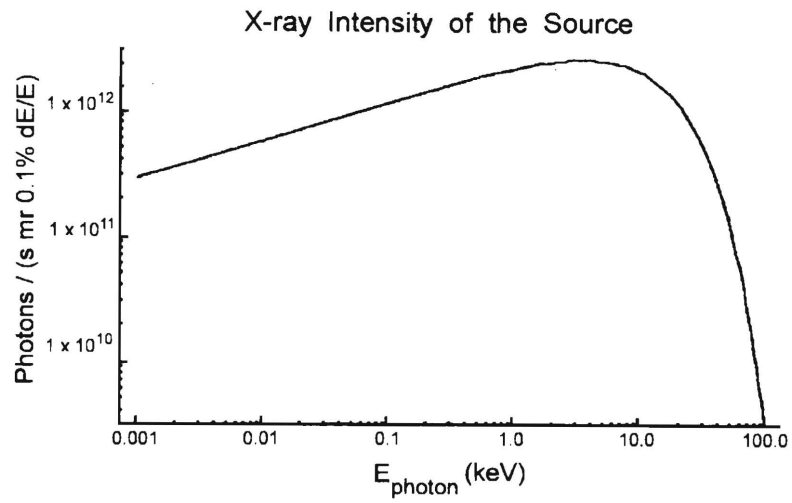

Figure 2: Photons/sec/mrad, theta/0.1%, $dE/E = 3.686$, 10^{12}gl (y) for 1.5GeV, 100mA, 7.9994 T.

It consists of two arcs and two straight sections: the straight sections have equal lengths but different beam optics. The magnet layout and orbit functions are shown in Figure 3. The origin is in the center of the insertion-device region. Quadrupoles are represented by rectangles shown above or below the axis, according to whether they are horizontally focussing or defocussing, respectively. Dipoles are shown as rectangles centered on the axis[8, 9].

Each arc consists of three cells with the following cell structure:

QF D B D QF

where QF is half of an F-quadrupole, D is a drift space, and B is a rectangular dipole. The cell closest to the insertion straight section in each arc is missing its first two elements. The cell at the center of each arc contains, in addition, two horizontally focussing sextupoles, SF, which are combined with the QF quadrupoles, and two vertically focussing sextupoles, SD, at the centers of the drift spaces, D.

3 Summary

We have made a preliminary design of a very compact x-ray source suitable for a hospital or biomolecular laboratory. We are starting a detailed design of the 8-T magnet and hope to fabricate one in the next 2 years. In order to

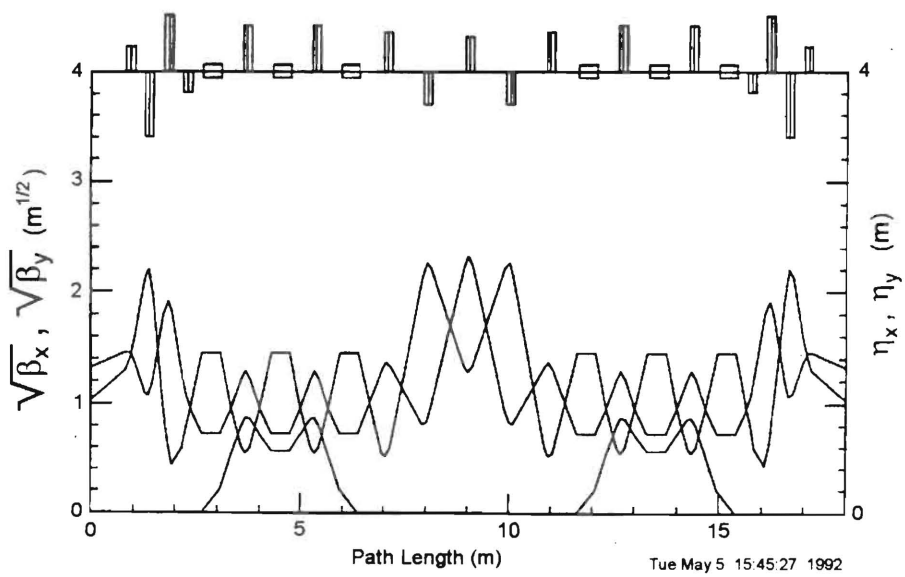

Figure 3: Lattice parameters for the 1.5GeV storage ring. The insertion device region is in the center of the straight section shown at the ends of the figure; the injection system is in the straight section shown in the center of the figure.

fully optimize this source we seek input from the UCLA and other medical imaging and biomolecular community.

References

[1] W. Smith, Private Communication, Agouron Corp, San Diego; D. Eisenberg, private communication.

[2] E. Rubenstein, et al., *Proceedings of the National Academy of Science, USA*, 9724 (86) 83.

[3] A.C. Thompson, et al., *Rev. Sci. Inst.*, 1674 (89) 60.

[4] T. Tomimasu, *Rev. Sci. Inst.*, 1622 (89) 60.

[5] See for example the report of dedicated Coronary Angiography Ring by the Japanese Group and reported to the Washington Particle Accelerator Conference, Y. Oku, et al (1993).

[6] A.C. Thompson, *Handbook of Synchrotron Radiation*, Elsevier Science Pub. BV., 1991, Vol. 4, 105.

[7] E. Burattini, et al., Rev. Sci. Inst.m 63, 638 (1992).

[8] D. Cline, et al, Design of a Compact Superconducting X-ray Source, UCLA-CAA-0084-2/92; we discuss the other important issues such as the vacuum pipe system in this report.

[9] M. Green (LBL), D. Madura and E. Leung (General Dynamics), Private Communication.