UPDATE ON ALADDIN*

Ednor M. Rowe
Synchrotron Radiation Center - University of Wisconsin-Madison
3731 Schneider Drive, Stoughton, WI 53589-3097

Abstract

Synchrotron Radiation from the 1 GeV electron storage ring, Aladdin, was first made available for research on a regularly scheduled basis in November, 1985, with beam currents in the 30 mA range. By May, 1986, achievable beam current had increased to 150 mA and funds for continued operation had been approved by the NSF. In this report, operational experience with Aladdin during the past year will be summarized and its present status described

Introduction

Aladdin is a 1 GeV electron storage ring designed and built to be a very high brightness source of synchrotron radiation over a spectral range extending from 2500 Å to 2.5 Å. It is now the principal instrument of the Synchrotron Radiation Center (SRC) of the University of Wisconsin-Madison, a national facility. Construction of Aladdin was begun in November, 1977, and first use of the machine as a synchrotron radiation source for research was in March, 1985. A plan view of the machine is given in Fig. I. Its parameters are given in Table I. The values shown for σ_x, σ_y, ε_x, and ε_y are calculated for 800 MeV, assuming 10% coupling.

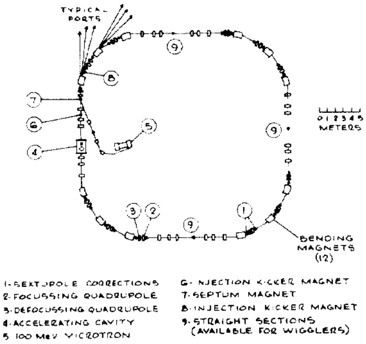

Fig. I Aladdin Plan View

Aladdin Parameters

Injection Energy		0.1 GeV
Maximum Energy		1 GeV
Average Radius		14.51 meters
Magnetic Radius		2.083 meters
Revolution Frequency		3.401 MHz
Harmonic Number		15
Energy Loss Per Turn at 1 GeV		42.5 KeV
λ_c		11.6Å
σ_x	at source points	0.52 mm
σ_y		0.075 mm
ε_x		0.1 mm·mr
ε_y		0.001 mm·mr
σ_s		66 mm
τ_x	at 0.1 GeV	13.6 sec
τ_y		14.0
τ_s		7.1
ν_x	nominal at 100 MeV	7.13
ν_y		7.10
ν_x	at 800 MeV	7.139
ν_y		7.229

Table 1

The lattice is asymmetric both optically and mechanically. This reflects performance goals at the time of its design. The first of these was to achieve high brightness with all source points in the bending magnets equivalent to each other, hence the doublet lattice. The second was to be able to extract as much of the 2π radians of radiation available from the bending magnets as possible, hence the crowding of the quadrupole doublets to the end of the short straight sections. Finally, the long straight sections were provided so as to be able to include insertion devices in the future development of the capabilities of the SRC. The resulting structure is extremely flexible: changing operating points within the quadrant of tune space $7<\nu_x, \nu_y<7.5$ with a stored beam at 800 MeV is rather trivial. This, to a great extent, is the result of the Meads[1] "transparent" straight sections which have fixed phase advances: $\Delta\phi_x=2\pi$, $\Delta\phi_y=\pi$. The injector for Aladdin is a 100 MeV race track microtron, an extremely economical and reliable electron source. Unfortunately, the very long damping times, at injection, imposed by the energy and circumference of the machine exaccerbated the injection and beam lifetime related problems encountered during the commissioning of the storage ring. These problems and their cures were discussed in a previous paper.[2]

Operational Experience: March 1986-February 1987

During this period, Aladdin was operated for eleven months on a four week cycle: stored beam for research twelve hours per day, five days per week, for three weeks followed by one week for development and maintenance. Operation was at 800 MeV, an energy that is near optimum for the vacuum ultra violet research programs now being carried out at the SRC. In addition, during this period, 15 eight hour shifts at 1 GeV were provided for exploratory experiments in x-ray lithography. The performance of the machine is summarized in Figs. II and III.

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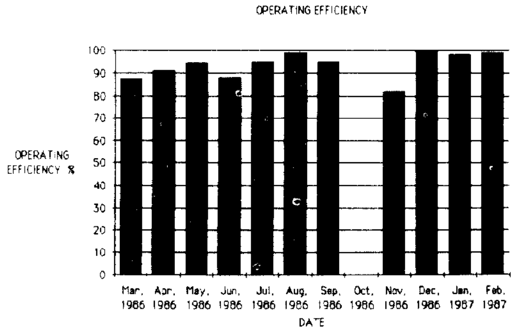

Fig. II

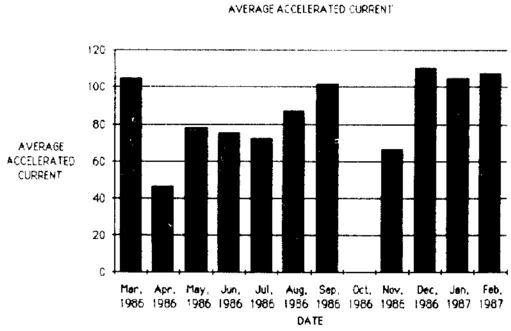

Fig. III

The twelfth month, October 1986, was used for a pre-scheduled shut-down for machine modification, the most important of which was the installation of a 30 period undulator.

As can be seen, the operating efficiency, here defined as the ratio of the beamtime delivered to the beamtime scheduled, was reasonably good: more than 93% overall. However, the average beam current fluctuated over quite a large range. The two largest fluctuations occurred immediately after major disruptions to the vacuum system. During the development week at the end of March, one quarter of the vacuum chamber was let up to atmospheric pressure to allow us to install a special section of vacuum chamber and to repair beamline valves. During November, the whole chamber was at atmospheric pressure for the installation of additional beamline front ends and the undulator. After such events, the increased partial pressure of high Z species, such as argon and carbon dioxide, in the vacuum chamber has a very deleterious effect on beam lifetime, particularly at injection energy. The smaller fluctuations were mainly caused by instability in the control system during acceleration. Even though good currents could usually be achieved at injection, there were, at times, large losses during acceleration because of miss-tracking of the various magnet systems. Recent improvements in the control system have greatly reduced this problem and now acceleration efficiencies of over 90% are generally the rule.

The maximum beam current accelerated to 800 MeV, so far, is 160 mA and the maximum current obtained at injection energy is over 240 mA. This was done before the improvements to the control system when the acceleration efficiency was unpredictable. Hence, there is good reason to believe that at least a factor of two increase in average beam current at 800 MeV is possible. However, increased beam current is not of high priority at present. The highest priorities at present are increasing the reliability of the storage ring and its subsystems and understanding some of the phenomena that we observe during its operation.

An example of the latter is the fact that we can inject and stack with good efficiency at a rate much higher than would be predicted by the beam damping time at 100 MeV. The beam damping time constant is about 10 seconds in all dimensions, but we find that we achieve the highest overall efficiency (~30%) at an injection repetition rate of 1.25 Hz. This phenomenon has been observed on two other machines: Tantalus I, the 240 MeV storage ring at the SRC, and MAX, the 500 MeV storage ring at the University of Lund, Sweden.[3] The reasons for this are not understood. Enhanced transverse damping has been reported in other electron storage rings in the past [4,5], but the proposed explanations do not appear to apply to the observations with Aladdin.

Control of the beam position in Aladdin has been extremely good during the past year in spite of the fact that the beam tends to come back to a slightly different orbit each time we accelerate. We have developed a very effective orbit optimization technique that brings the orbit back to the reference, or "golden", orbit to within 50 μ. This operation can be performed in less than 60 seconds and is now routinely carried out after each acceleration. This technique is described in two other papers[2,6]. Using the same technique we can place a bump in the orbit at almost any location with minimal disturbance to the orbit elsewhere. This allows us to steer the beam for special user requirements, and it can be a very useful diagnostic tool as well.

New Developments

The most important new developments have been the complete restructuring of the computer control system and the installation and commissioning of a 30 period undulator. The original control system,[7] which had served us well and was quite cost effective, had reached the end of its useful life because its capabilities could not be extended to meet the increased demands placed on it by operation for research and because of the obsolesence of some of its components. In the original system, a PDP 11-34 was the control computer which communicated with the various accelerator subsystems through three 6800 based front end processors. Three years ago, the 11-34 was replaced by a Vax 11-750. Thus, all of the intelligence in the system was concentrated in the Vax. In the new system, the front end processors have been replaced by VME crates with 68000 based CPU's. Communication between the control computer and the VME crates is by ETHERNET, a far more reliable method than the parallel communication links used originally. The new system is faster and is capable of considerable expansion. Because of the additional intelligence provided by the 68000 based CPU's in the VME crates, we are now able to use a Micro Vax in place of the 750. The 750 is now used for general computing and program development at the SRC. However, it can still be run in parallel with the Micro Vax if required.

The 30 period undulator was built originally at LBL for use on SPEAR.[8] After it was removed from that machine, it was made available to us through the good offices of Dr. Herman Winick, Associate Director of the SSRL. The installation of the undulator in one of Aladdin's 4 meter long straight sections was quite straight forward. A special section of vacuum chamber, which fits between the poles of the undulator, was constructed and installed in one of the long straight sections. This section of vacuum chamber was equipped with extra pumps because of its low conductance. It also has position monitoring electrodes at each end. This was the only modification to Aladdin. No modifications were made to the undulator itself. It was, however, equipped with a mount that allows it to be retracted during injection.

The first tests to verify the alignment of the undulator were performed in December, 1986, by operating the machine at 170 MeV so that the undulator radiation would be in the visible range. In late January, tests to verify the predicted undulator spectrum and brightness at 800 MeV were begun. Since no suitable monochromator was available, another, somewhat indirect, method was used. The calculated[9] spectrum of the undulator operated at K=1.55, driven by Aladdin at 800 MeV, is shown in Fig. IV. The fundamental appears at 45 eV and the third harmonic at 135 eV.

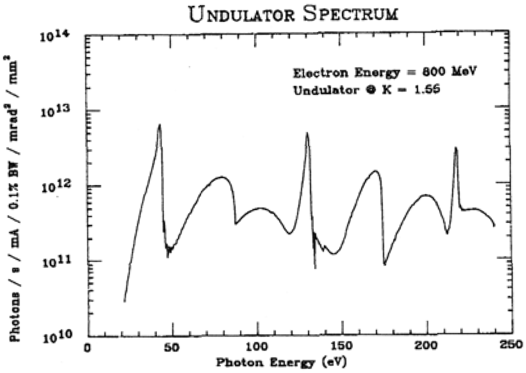

Fig IV

The arsenic 3d core level in galium arsenide is at 41.7 volts below the Fermi level, and the galium 3d core level is at 18.7 eV below the Fermi level. Thus, if one excited these core levels with 45 eV and 135 eV photons, one would expect to find photoelectrons from these core levels at energies given by

$$E_o = E_p - E_c - \phi \qquad (1)$$

where E_p is the photon energy, E_c is the core level energy and ϕ is the work function which is about 5 eV. If the undulator spectral peaks are as intense relative to the undulator continuum background as predicted, then the resultant 21.3, 88.3 and 111.3 eV peaks in the photoelectron spectrum should be quite prominent over the background photoelectrons. A scan of the photoelectron energy distribution from galium arsenide under these conditions is shown in Fig. V.

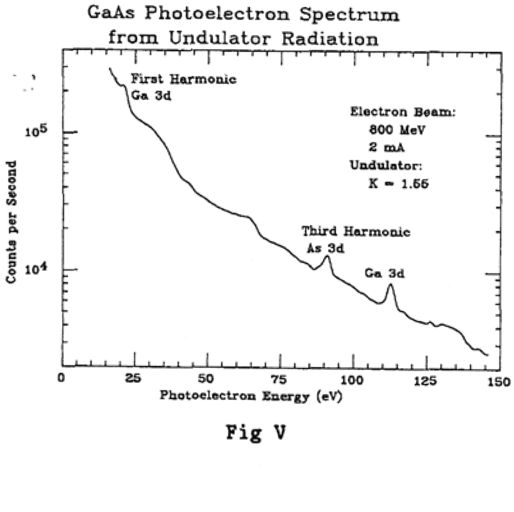

Fig V

Several comments are appropriate here. First, the scattered photoelectron background was caused not only by the undulator, which was 10.2 meters away from the GAs target, but also by synchrotron radiation from the up-stream bending magnet which is only 2.1 meters away from the target.

Second, the electron beam current circulating in Aladdin was only 2 mA at the time this data was gotten. Finally, the photon beam from the undulator was passing through a 200μ horizontal x 400μ vertical aperture, 9.8 meters from the undulator. There were no other optical elements in the beamline.

The results of this measurement support two conclusions. First, that the energy resolutions of these two undulator harmonics is no less than predicted and, second, that the brightness of the undulator at the fundamental is at least two orders of magnitude greater than that of the bending magnet sources. Indeed, when this measurement was repeated at higher beam current, ~60 mA, the contrast of the photoelectron peaks to the background was greatly degraded by heating effects in the target.

The undulator caused an almost unmeasurable tune shift and a very small orbit distortion. Both of these were easily compensated for. We have been operating the undulator during regular research shifts for several weeks with no complaints from our user groups. A 6 meter Toroidal grating monochromator is now being prepared for installation on the undulator beam port. Completion of this project is scheduled for early 1988. In the interim, several other experiments using the raw beam from the undulator are being prepared.

Future Plans

A number of projects aimed at improving the ring performance and reliability are now underway. Among these are operating program development to compensate for the lack of linearity, or even monotonicity, in the D to A converters in the magnet control system and the commissioning of an active orbit optimization system to make scanning the undulator more convenient. With the successful operation of the undulator, it has become attractive to replace the accelerating cavity which occupies one of the long straight sections with a short cavity designed to fit into one of the short straight sections. This may have another advantage: at the present cavity location, the η function is not only large, it is also negative. In the proposed location, the η function is much smaller and is positive.

As yet, no serious effort has been made to reduce the coupling in the machine. This is not a serious problem at the present. At the bending magnet source points, σ_y appears to be approximately 100 μ which is to be compared to the predicted 10% coupling value of 75μ. Aberations in the beamline optical systems currently installed at the ring would probably not allow a substantial increase in effective brightness at the monochromator entrance slits through a reduction of σ_y at this time. However, esthetics and the probability that optical systems will improve in the future make the reduction in coupling an interesting challenge.

Finally, there is still much to be learned about the technology and physics of low energy electron injection and about trapped ion effects. With the current interest in compact storage rings with low energy injection for industrial application, these studies will probably be of crucial importance.

Acknowledgements

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