X-ray Drought Ending at Brookhaven's NSLS

The flux from the x-ray ring at the National Synchrotron Light Source has reached a respectable level and experiments are finally under way

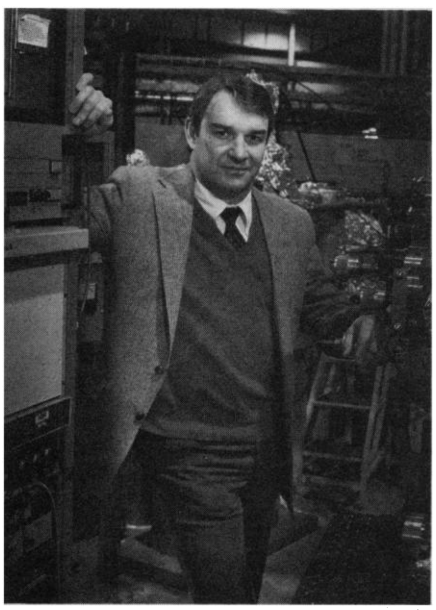
People are smiling again at the National Synchrotron Light Source (NSLS). After more than 3 years of waiting, sometimes not so patiently, experimenters now have as many x-rays as they can handle for the moment. As researchers tune up their equipment, however, they will want more. The prospects for meeting the demand and eventually attaining the full design specifications are encouraging, if not certain. "The emphasis now is on getting the science going," says Michael Knotek, who took over as NSLS chairman in April.

Located at Brookhaven National Laboratory, the NSLS comprises two electron storage rings and associated facilities for the production of synchtrotron radiation and once was scheduled to be open for business in late 1981 (*1*). The smaller ring of energy 0.75 billion electron volts (GeV) did not run well enough to be useful to users of vacuum ultraviolet (VUV) radiation until about 2 years ago. Now its performance has improved so greatly that NSLS officials boast it is the brightest VUV source in the world. Users are equally pleased with its reliability, which, according to Janos Kirz, the chairman of the NSLS users' committee, exceeds that of a rotating anode x-ray tube.

The larger ring of energy 2.5 GeV has been much harder to bring on line. Almost everyone has been extremely frustrated, and some users have been quite bitter. The experimental stations and the beamlines that guide radiation from the ring to the stations have price tags within sight of $1 million and take years to design and construct. Researchers who feel they have missed publications and promotions because of the lengthy delay have been understandably grumpy.

While it may take some time to heal all the bitterness, x-ray users are rather suddenly too busy to worry about anything other than getting their equipment commissioned to handle high radiation fluxes. One measure of performance is the electron beam current stored in the ring. The x-ray ring was designed to hold 500 milliamperes at 2.5 GeV. It now routinely stores 100 milliamperes at 2.4 GeV, which is already enough to make it the brightest x-ray synchrotron source anywhere.

At the moment, there are 18 beamlines and attached experimental stations in place around the x-ray ring. Half of these are taking data, while the other half are in various stages of commissioning. Knotek estimates that 25 beamlines will be running by the end of the year, and there are already plans for 17 more within the next 18 months. The numbers for the VUV ring are similar, except that all of the existing 18 beamlines are operational. Evidently, the NSLS will soon be living up to its name.



Michael Knotek

"The light source is open for business."

It is difficult to pinpoint precisely the reasons for the delays in a facility as complex as the NSLS, which in addition to the two storage rings has two smaller accelerators in sequence to feed electrons into the rings. All four machines had to be commissioned from scratch. The closest to a diagnosis came in June 1984 from an ad hoc review committee established by the Department of Energy, which funds the NSLS (*2*).

The committee, headed by Robert Jameson of the Los Alamos National Laboratory, turned in a report that declared, "While the NSLS has experienced long commissioning delays, the delays do not result from fundamental technical problems." Instead, "it appears that many of the problems now perceived result from underestimates of various types, by all parties, of the complexity of bringing this state-of-the-art facility into being."

Jameson's committee particularly criticized the practice in the United States, which is presumably driven by financial constraints and competition for project approval, of submitting proposals with budgets cut dangerously close to the bone. Cost cutting is not intrinsically bad, but it requires a realistic judgment and understanding by the institution, the funding agency, and the users of the risks involved, especially when one is designing a machine that is to have a performance level never achieved before. Ways to cut costs include omitting otherwise desirable components in the hope they will not be necessary, failing to observe careful quality control, and allowing insufficient staff to commission the machine. The NSLS has been paying the price for playing this game by, for the last 2 years, "doing it over."

The necessity of doing it over only gradually dawned on NSLS officials. This process began in earnest in late 1983 when Brookhaven deputy director Martin Blume assumed the role of acting NSLS chairman, following the departure of previous chairman John McTague to take a position with the Office of Science and Technology Policy. Blume broke the facility into functional blocks and detailed staff, including scientists and engineers he was able to acquire from other Brookhaven divisions, to bring the components in each block up to specifications. The idea was that, barring some fundamental flaw in the overall design, if each part of the system functioned individually, they would also work together.

How far the x-ray ring has come can be gauged from the situation in February 1984, just after Blume took charge. The ring stored a maximum of 20 milliamperes at 1.7 GeV with a beam lifetime (decay constant) of only 20 minutes and it was not getting any better. In its report that June, the Jameson review committee noted signs of improvement and foresaw the realistic possibility of storing 50 milliamperes at the full 2.5-GeV energy with a beam lifetime of 2 hours by the end of the year.

The NSLS chose to adopt a somewhat

different strategy from the one recommended by the review committee and, after a long shutdown, achieved these current and lifetime goals last May. The improvement since then has been spectacular. "It all came together about 2 months ago," says Samuel Krinsky, who is in charge of the x-ray ring.

No one is more pleasantly surprised than the users, not all of whom are ready to deal with their sudden good fortune. Says one researcher, "Because so many past predictions of beam availability had not held up, the users put their NSLS activities in a state of suspended animation and worked on other projects. Now the community is really awake." Researchers had planned on being able to align their optics and otherwise prepare their equipment during the commissioning process when the storage ring was not yet producing high intensities of x-rays. Later, as the intensity grew, they would deal with the problem of heating and distortion of optical elements due to high x-ray fluxes. Now they have to do both tasks at once.

There is no single cause for the dramatic improvement in x-ray ring performance, but NSLS officials cite several important developments. The first concerns the beam lifetime, which was 20 minutes and now is 4 hours at a current of 100 milliamperes. To achieve such lifetimes, the vacuum in the storage ring must be 10^{-9} torr or better. With a poor vacuum, electrons in the beam scatter off gas molecules and are lost.

Good vacuum pumps alone are not enough because contaminants, such as carbon monoxide and carbon dioxide, adsorbed on the inner surface of the vacuum chamber are gradually released and thereby raise the pressure. The synchrotron radiation itself exacerbates the problem by desorbing gas molecules from the walls. Eventually, if the radiation is intense enough, the vacuum problem solves itself, as the vacuum chamber walls are scrubbed clean. However, there is a kind of catch-22. A good vacuum is necessary to store the high beam current that generates the radiation needed for a good vacuum.

As explained by Mark Barton, a Brookhaven accelerator physicist tapped by Blume to be deputy chairman of the NSLS, one can reach a balance during the accumulation of current where the rate of scattering of electrons out of the beam matches the rate at which they are injected into it, and no further growth in beam current takes place. The two ways to beat this limitation are to have the initial vacuum as good as possible and to increase the injection rate.

The conventional method for removing contaminants is heating the vacuum system to a high enough temperature to thermally desorb them. For a system as big as the x-ray ring, which is 170 meters in circumference, this baking out procedure is tedious and time-consuming, but it was eventually carried out in April 1984 under the direction of Henry Halama, another one of Blume's recruits from elsewhere at Brookhaven.

Last fall, current could be injected into the x-ray ring at a rate of about 3 milliamperes per minute, which even with the improved vacuum after the bakeout was not enough to accumulate a large current. Since last January a group under the direction of Richard Heese, a former NSLS physicist who was lured back into the fold, has by careful attention to details in every part of the system raised the typical injection rate into the x-ray ring by over a factor of 3 to 10 milliamperes per minute and as high as 17 milliamperes per minute on occasion.

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With this injection rate, the stored current is high enough for the synchrotron radiation to begin effectively scrubbing the vacuum chamber walls. As a result, the beam lifetime has risen to its present value and should continue to increase with accumulated operating time until other lifetime-limiting effects become dominant.

One of these is called ion trapping. Positive ions in the vacuum chamber are drawn toward the electron beam orbit by the negative charge of the electrons, thereby increasing the effective pressure there. The higher pressure reduces the beam lifetime. At the moment, ion trapping does not limit the lifetime in the x-ray ring by this means, but it has been disrupting the beam in another way.

Until recently, the x-ray ring was plagued by sudden disappearances of the beam about 80 percent of the time as it gradually decayed from the injected value. Sometimes the beam would recover, sometimes not. Although ion trapping is too complicated to be modeled in detail, the experimental data leaves little doubt that it is the cause of the lost beam. In any case, by making the electron charge density around the ring asymmetric, a year-long development project, NSLS accelerator scientists have reduced the frequency of these occurrences to about 20 percent.

The one part of the x-ray ring system that prevents it from reaching higher beam currents is the set of two radio-frequency cavities that feed energy into the electron beam. While Krinsky admits there are "major problems," there are also both short- and long-term R&D programs to remedy them. Moreover, if one of the two operating cavities failed, a fear of some users, a spare on hand could be inserted into the ring in only 2 to 3 weeks.

One of the problems is that the NSLS radio-frequency system works at a relatively low frequency, about 53 megahertz. The low frequency makes the storage ring easier to operate, but cavity design is more difficult than at higher frequencies. Moreover, the cavities have vacuum leaks, so that the pressure in the storage ring vacuum chamber where the cavities sit is about 2×10^{-8} torr and may be where the ion trapping occurs.

Despite these difficulties, a group headed by John Keane has made considerable progress with the radio-frequency system. During the long shutdown that lasted from last September to January, for example, the group replaced the original cavity with two new ones, thereby providing the power for high-current, high-energy operation. The original cavity is now on a test stand, where it is being used to test further improvements that may solve the electrical and vacuum problems.

In conformance with NSLS chairman Knotek's emphasis on getting on with the science, the plans are to operate the x-ray ring 4 to 5 days a week for experiments and the remainder of the time for maintenance and machine development until fall 1986. At that time, there will be a lengthy shutdown of at least 5 months to add several ultrabright radiation sources called insertion devices and accompanying beam lines as part of the NSLS Phase II project. Phase II, whose construction cost, almost $20 million, is near that of the original NSLS, also involves additional experimental, laboratory, and office space. In between, there will be two shorter shutdowns, but long-frustrated users should be getting the x-rays they have been waiting for.

—ARTHUR L. ROBINSON

References

1. A. L. Robinson, *Science* **222**, 313 (1983).
2. *Report of the DOE Ad-hoc Committee on the Brookhaven National Laboratory National Synchrotron Light Source*, Los Alamos National Laboratory Document Number AT-DO: 84–157 (unpublished).