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SURF'S UP AT NBS: A PROGRESS REPORT

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Abstract

The NBS Synchrotron UV Radiation Facility (SURF-II) is a 250 MeV single-magnet, weak-focusing electron storage ring, with 10 MeV microtron injector. Circulating beams of up to 35 mA at energies up to 250 MeV have been achieved. Beam lifetime, limited by Touschek effect, is extended to several hours by resonant vertical rf excitation. At low energies bunch shape oscillations occur, involving coherent synchrotron oscillations, negative-mass-type blowup and loss of beam. Effective avoidance and suppression techniques are discussed. A new set of high current gradient correction coils and power supplies, plus additional pancakes for the main field coils are being obtained. These are expected to extend SURF operation to 280 MeV and provide useful light output to 0.4 keV photon energies.

Introduction

The NBS Synchrotron UV Radiation Facility (SURF-II) was converted in 1974 from a 60 Hz, 180 MeV synchrotron[1] and now serves as a precision light source for VUV radiometry, calibration of transfer standards and optical physics. This report describes some of the problems and progress since conversion and outlines plans for the immediate future.

Choice of Field Index

The heart of the SURF storage ring is its single magnet which provides an azimuthally symmetric guide field. Its tapered poles produce a field index $n \gtrsim 0.8$. For focusing and phase stability the field index must lie in the range $0 < n < 0.75$[2], except that a number of major betatron resonances must be avoided. The gradient correction coils, distributed over the upper and lower polefaces, trim the field to the desired field index.

The correction coil power supplies were first programmed to maintain a field index of about 0.7. It soon became apparent that, at this field index, beam could not be accelerated beyond about 180 MeV because it required more radial aperture and more RF voltage than was available. Fortunately, both limitations are eased if the field index is reduced further to about 0.6. However, this does require more field correction. With some strain on the correction coil power supplies, SURF reached 243 MeV on November 1, 1974.

Performance

Typical operating currents through 1975 were in the range of 1-5 mA. One problem was beam loss caused by transients inductively coupled into the correction coils at the start of the field ramp. To overcome this difficulty, fast regulators were added to the slow SCR-type supplies and by December 1976 beam currents of up to 14 mA had been achieved. In 1977 the RF cavity and power amplifier were redesigned and a record beam of nearly 35 mA was obtained in December of that year. Currents of at least twice this value should be achievable through improvements in the output of the microtron injector which is at present operating well below its design current.

Lifetime Improvement

Due to SURF's uniform magnetic field beam size is extremely small. The mechanism primarily responsible for beam decay is therefore Touschek effect[3]. The halflife of a 1 mA beam is less than 1 hour, while at 10 mA the halflife is only 20 minutes.

In the course of measuring betatron frequencies in SURF, using the resonant RF excitation technique[4], we noticed a dramatic improvement in lifetime. By applying a small RF voltage to a pair of vertical deflection electrodes at one of the RF excitation frequencies, such as $f_0(1-\nu_z)$, one induces vertical betatron oscillations which are essentially incoherent[8]. Vertically enlarging the beam reduces charge density, which in turn reduces Touschek scattering. An order of magnitude increase in lifetime was easily achieved. Beams in the 10-20 mA range now run routinely with a halflife of 3-4 hours. This technique has been in use at SURF since December 1975. Although extremely useful, it has some disadvantages:

1. Beam size tends to fluctuate;
2. The enlarged beam has less brightness than the normal beam;
3. The angular distributions of the synchrotron radiation may differ from those predicted for an ideally small beam.

Bunch Shape Oscillations

Large amplitude bunch shape oscillations are observed in the SURF storage ring at low and intermediate energies. These are characterized by a slow buildup of the bunch amplitude followed by a sudden collapse and spreading of the bunch, in phase as well as radially. The period of this oscillation ranges from several seconds near injection energy to milliseconds at 200 MeV (Figure 1). Above 200 MeV the oscillations usually disappear. The first cycles of these oscillations can be quite violent and account for large beam loss. At intermediate energies the oscillations occur with little or no loss, but they do cause fluctuations of the synchrotron light.

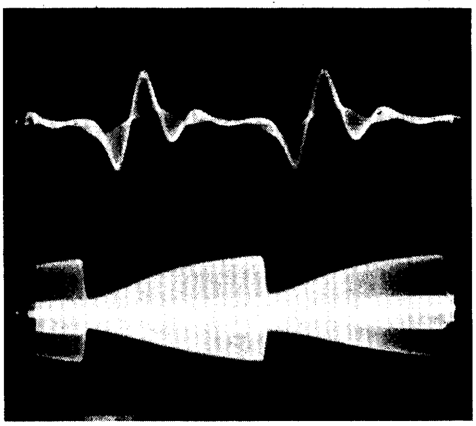

Fig. 1. Signal from capacitive beam monitoring electrode, showing bunch oscillations at 140 MeV. Upper trace shows the two bunches at 2 ns/div, with repetitive sweep. Lower trace displays the envelope at 20 ms/div, single sweep.

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The threshold of this oscillation depends on beam energy, beam current and RF voltage. One way to minimize beam loss is to keep the RF voltage below the threshold of oscillation during the early part of the ramp. This is now done at SURF. However, by reducing the RF voltage below threshold, the amount of current that can be accelerated is also limited. The observed behavior appears to be due to a combination of several effects:

1. Coupling Between the Beam and Surrounding Structures. We observe strong beam-induced ringing in the pulse bump coil at 455 MHz, the fourth harmonic of the RF. The bump coil (Figure 2) is about 30 cm long and happens to be near resonance at that frequency as a half-wave drift tube. A 1-nsec long bunch passing through such a structure couples to this parasitic mode very effectively.

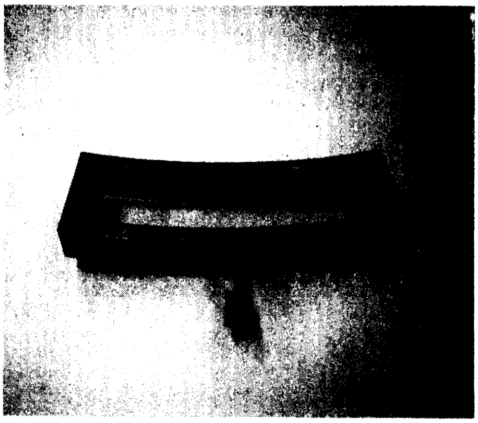

Fig. 2. Pulse bump coil, removed from ring.

2. Coherent Synchrotron Oscillations. Spectral analysis of the signal from the capacitive beam monitoring electrode reveals a sideband structure about each RF harmonic, similar to that observed in Tantalus I[5]. At 140 MeV, with RF voltage below the threshold of oscillation, sidebands are seen at 80 KHz intervals, with amplitudes of -40 db or less. At threshold a second set of sidebands appears at 200 KHz intervals. Above threshold the 80 KHz sidebands disappear, while the new set spreads out to 400 KHz intervals and amplitudes as high as -15 db (Figure 3).

The spectra suggest coherent synchrotron oscillations, 80 KHz being the dipole mode, while the 200-400 KHz sidebands may be due to quadrupole or higher modes. The quadrupole mode in particular is likely to couple most strongly to the half-wave drift tube mode of the bump coil.

3. RF Pumping. Increasing the RF voltage reduces bunch length, which in turn induces stronger ringing in parasitic circuits. This makes more energy available to drive a beam mode. Furthermore, shorter bunches mean higher charge density.

4. Radiation Damping of betatron motion also contributes to increasing charge density.

5. Coupling Between Bunches. Each bunch sees the fields induced in parasitic circuits by its predecessor, and by itself, cumulatively over many revolutions.

6. Negative-Mass Instability. The quadrupole mode of synchrotron oscillation, produced by coupling to a parasitic, can produce the classic conditions for negative-mass instability[6]. Combined with the buildup of charge density described above, radial blowup can occur, accompanied by elongation of the bunches. The force driving the parasitic then disappears. The surviving electrons regroup slowly under the influence of RF voltage and radiation damping, and the cycle repeats. The time it takes the betatron motion to decay is a function of beam energy, hence the variation of the oscillation frequency. Radiation also damps radial excursions. This allows the beam to oscillate with little or no loss of particles at intermediate energy.

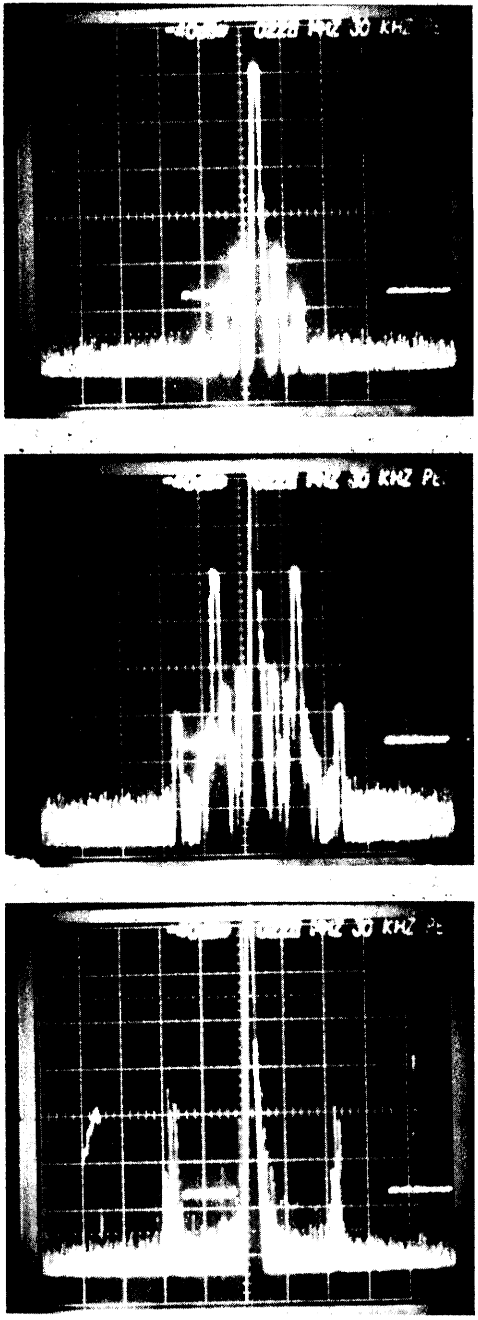

Fig. 3. Modulation sidebands about 2 f_{RF} (228 MHz) with beam of ~2.5 mA at 120 MeV.
Upper photo: below threshold (50 watts RF)
Middle photo: at threshold (100 watts RF)
Lower photo: above threshold (1750 watts RF)

The negative-mass instability can be either enhanced or suppressed by tuning the parasitic circuit. At SURF we disconnect the bump drive circuitry from the coil immediately after injection and switch in a suitable tuning circuit at the feedthroughs. Both a variable capacitor and a coaxial "trombone" have been used successfully to suppress the oscillation, or at least to raise its threshold.

Two other solutions are being considered. One is resistive damping of the ringing. Another is driving the bump coil at the fourth harmonic of the RF as a Landau cavity[7]. This should not only suppress the oscillations but improve lifetime as well.

New Correction Coils for 280 MeV Operation

Recent breakdowns in the gradient correction coils have led us to a complete redesign of the correction coil system. New high-current gradient coils plus additional windings for the main field coil are being procured. The new gradient coils will be capable of providing more than twice the ampere-turns of the present set. The auxiliary field windings will add 20% more turns to the main coils. Together they will not only improve machine reliability, but will, at very little additional cost, permit an increase in SURF operating energy to 280 MeV or more. Figure 4 shows the synchrotron radiation spectra for 250 and 280 MeV.

New power supplies for the gradient coils are already on hand. In the design stage are series regulators and a microprocessor-driven program generator. No changes are needed in the main supply as it has sufficient capacity to handle the additional windings. Installation is scheduled for fall, 1979.

Acknowledgments

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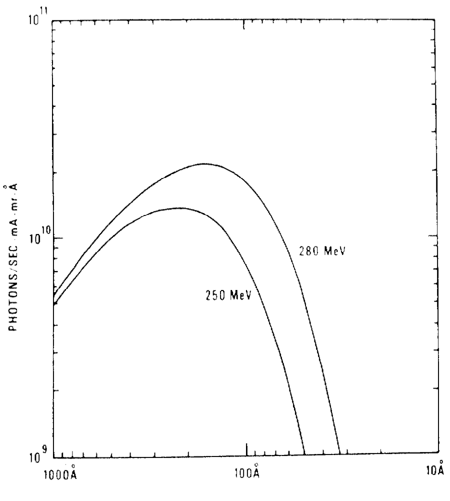

Fig. 4. Synchrotron radiation spectra for SURF II at 250 MeV and 280 MeV.

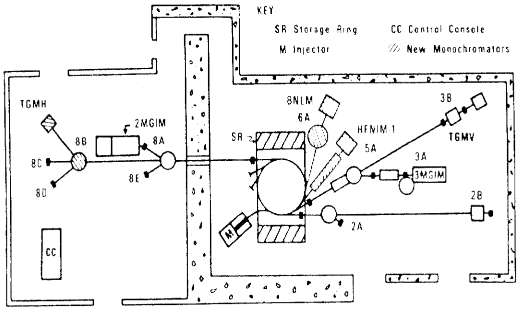

Fig. 5. Layout of NBS Synchrotron UV Radiation Facility.