RECORD CAPTURE AND ACCELERATION EFFICIENCY IN THE SURF-II 300 MeV CIRCULAR STORAGE RING

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Introduction

SURF-II is a 300-MeV, single-magnet, weak-focusing, circular storage ring. It is dedicated to the production of VUV and soft x-ray radiation for research and for absolute radiometry. The injector is a 10-MeV microtron. A single output pulse from the microtron is injected into the storage ring (SR) and accelerated to operating energy. A description of the SURF-II storage ring and the microtron injector was given at the IX Int. Conference on High Energy Accelerators [1]. Some additional improvements are described in references [2, 3 and 4]. The microtron is delivering 1-μsec long, 80-mA pulses. With multiturn capture, more than 300 mA have been accelerated to full energy. Last week (3/13/89) the average beam current was 262 mA and every beam was greater than 250 mA. This capture and acceleration efficiency is being achieved by improved transport line optics, kicker magnet pulse, the SR's magnetic field gradient and rf system.

Improved Capture

Electron capture is improved in several ways. The SR's magnetic field gradient is fine tuned. The radial betatron oscillation amplitude, at injection, is enlarged by about 60% over that used formerly. An optimum power level in the rf cavity has been found as well as better pulse shape and timing of the kicker magnet. Also the transport line optics are fine tuned for maximum capture. At injection energy, the magnetic field gradient which has led to maximum capture results in an index of .628 that is nearly constant over the radial zone occupied by the injected electrons. The inflector is positioned 3.4 cm out from the 83.82 cm equilibrium orbital radius. The betatron oscillation amplitude resulting from this position is nearly the maximum allowed by the internal dimensions of the rf cavity, the kicker magnet, the beam monitor electrode (BME) and other internal structures. The rf voltage in the cavity is set to ~1.7 kV at injection. Figure 1 shows the current pulse in the kicker magnet.

Figure 1. The kicker magnet current pulse. 1 volt corresponds to 95 amps.

As the peak current is increased to 250 A the electron capture increases. No change in capture is observed for peak current between 250-360 A. The peak current normally used is 320 A. The pulse shape is changed from the original by the addition of another capacitor and inductor in the pulse forming network. This results in a longer pulse decay time.

Figure 2 shows schematically the SR, the microtron and the transport line which connects them. There is an X Y steering magnet pair, a quadruple focusing doublet, an insertable target, a second quadruple doublet, a second XY steering pair, the inflector magnet (which bends the beam through 45 degrees) and a final insertable target.

For initial tuning the mid-beamline target is inserted and the beam is focused to a minimum size and positioned on the cross hair. The target is removed and the target following the inflector is inserted. The second quads and steering magnets as well as the inflector current pulse amplitude are adjusted to focus the beam and position it on the second target. The beam is thus entering the SR properly. The operator then removes the target and varies the SR.
magnet current until a signal, which is produced by electrons passing through the BME, is observed on an oscilloscope. This signal is maximized by tuning the inflector magnet pulse and the SR's magnet current. Next, the kicker magnet is started and its timing is adjusted until electrons are captured.

Figure 3: Beam monitor electrode signal

The waveform on the scope is shown in Figure 3. The beam is capacitively coupled to the BME and the signal is essentially the derivative of the current pulse. The operator then proceeds to maximize this BME signal by tuning the inflector current pulse amplitude, the SR magnet current, the kicker timing and all of the steering and focusing magnets in the transport line. As a final adjustment, it has been found very useful to make fine adjustments in the microtron's magnetron modulator voltage. Often we get a little more capture with slight changes in the modulator voltage. After tuning for maximum, the operator starts the ramp to operating energy. The microtron, the inflector and the kicker are fired one more time and then the storage ring's magnetic field starts ramping up at ~0.84 T per min. (300 MeV in SURF is 1 ZT).

As the magnetic field is increased the magnetic field index is changed. As seen in Figure 4 the average index drops from .628 at 10 MeV to just over .5 at 60 MeV. At energies below 60 MeV the index shows no radial variation in that portion of the zone occupied by the electrons which we are able to measure (82.2 - 87.3 cm).

Energy Ramp

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Figure 4: Magnetic field index vs. energy 10-60 MeV

Even though $\sigma_r$ is fairly large, we have found a means to increase it by about a factor of 2. A mechanical device has been built and installed in the rf power cable which can vary the length (phase angle) of the cable. The phase can be varied by as much as 180°. We have found a phase angle (a cable length) which allows self-stimulated radial and longitudinal oscillations that enlarge the beam and increase the lifetime. The phase angle which we found first for this effect worked fine at all energies, but as we began getting better capture efficiency and therefore more electrons during the energy ramp we began noticing small incremental, periodic losses during the ramp. It was found that these losses were avoided by increasing the phase angle by 8° during capture and most of the ramp. Since this phase angle gave a significantly poorer lifetime at high energies the phase angle was shifted back to the former "good" angle above about 200 MeV. We have since found an even better phase angle 6° larger yet, which is good for injection, ramping and full energy. It gives even better lifetime at full energy (300 to 150 mA takes almost 2 hours).

Figure 6 shows the beam monitor electrode signal processed by a spectrum analyzer. It shows the 114 MHz fundamental and the harmonics up to 1 GHz. The amount of beam current and the phase angle for each...
Figure 6. Harmonic spectra of beam monitor electrode signal showing harmonics up to 1 GHz. (a) 150 mA, $\theta = 144^\circ$, (b) 150 mA, $\theta = 138^\circ$, (c) 190 $\mu$A, $\theta = 144^\circ$, (d) 190 $\mu$A $\theta = 138^\circ$.

In many storage rings the beam current is increased by stacking. We have found that cycling from high energy to fairly low energy and back to high energy does not result in gross losses. We have started with 270 mA at 285 MeV and ramped to 93 MeV and back to 285 in 3 minutes. Fourteen percent of the beam was lost. Subsequent cycles over the same energy range resulted in 5% lost starting with 230 mA and a 2% loss when starting with 219 mA. These cycles were made with no attempt at optimizing index, rf voltage or anything else except the phase angle was shifted to $131^\circ$ (the former "good" angle) from $144^\circ$. Whereas $144^\circ$ seems to be best for the injection to full energy ramp, it results in bad losses when ramps back down.

**Lifetime**

We find that the coherent synchrotron-relaxation oscillation discussed by G. Rakowsky at the 1985 Particle Accelerator Conference [5] does not occur with the $144^\circ$ phase angle we are using. This oscillation is found by shifting the phase to $125^\circ$, i.e., shortening the rf cable by about 1/20 of a wavelength. The beam lifetime with the $125^\circ$ phase angle is not as good as it is with $144^\circ$. At the present time the beam current-lifetime product at SURF-II is about 500 mAHr.

**References**


