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Displaced Bunch Synchrotron Oscillation Echo – 45 MeV IUCF Scenario

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In a previous note[1] we pointed out a recoherence echo phenomenon which may be elicited in longitudinal accelerator bunch dynamics, and suggested a plausible scenario for demonstrating it at the Indiana University Cyclotron Facility (IUCF) Cooler Ring. As space charge effects inhibit the initial decoherence which is a necessary prerequisite to a recoherence echo, it is essential to suppress the electron cooling normally used in this ring, so as to be able to attain a low proton density. At the 45 MeV injection energy, however, the absence of cooling severely impacts beam lifetime, so it was felt advisable to investigate the scenario where the 45 MeV injected beam is promptly accelerated to 400 MeV,[1] at which energy uncooled beam has a much longer lifetime. It then turns out that the combined decoherence and echo recoherence times amount to just a few tenths of a second.[1] As it is estimated that uncooled beam at 45 MeV would in fact survive at least about one second, we are led to reconsider the need for the acceleration step to 400 MeV, as the proposed echo experiment would be simplified, made capable of more frequent repetition, and made more reproducible by carrying it out at the 45 MeV injection energy. The purpose of this note is to present a technically plausible scenario for such a 45 MeV echo at IUCF.

Once again we use the longitudinal tracking code ESME[2] to simulate the echo, but now at 45 MeV, taking full account of the effects of space charge. Again we assume just a single bucket, which contains the lone bunch of 3×10^6 protons, the 0.5 μA of beam current being enough to permit the phase detector to satisfactorily track the synchrotron oscillations of the bunch centroid. Figure 1a shows the phase space portrait of this bunch, assumed to be a Gaussian of rms length 12°, which has just been displaced 40° in phase from the center of the bucket. Figure 1b shows the same bunch after 100 ms, at which point the spiral filamentation (decoherence) is well advanced, notwithstanding the remaining space charge effects of this low-density bunch. (The rms transverse beam size has been taken to be 3.4 mm within a beam pipe which averages about 51 mm in diameter, and the RF voltage has been taken to be 95 volts. Additional relevant parameters for the IUCF Cooler Ring are its transition gamma of 4.85 and its circumference of 86.82 m.) The RF voltage is now increased from 95 volts to 165 volts for 0.1 ms (about 103 turns), after which it is restored to its former 95 volt value, thus producing the RF voltage pulse which is supposed to initiate the echo. Figure 1c shows the elliptical deformation of the phase space spiral which results from this RF voltage pulse. Decoherence of this elliptically deformed spiral leads, by 200 ms after the phase displacement, to the characteristic confluence of phase reversal tips which comprises the echo peak, as seen in Figure 1d. Figure 2 displays the complete history of the echo in terms of the bunch centroid's synchrotron oscillation amplitude versus time. Again we see that the full time needed for the echo phenomenon is just a few tenths of a second, which ought to be comfortably compatible with the estimated

one-second lifetime of the uncooled 45 MeV beam. It is hoped that an echo experiment along these lines can be carried out during the summer of 1993 at the IUCF Cooler Ring.

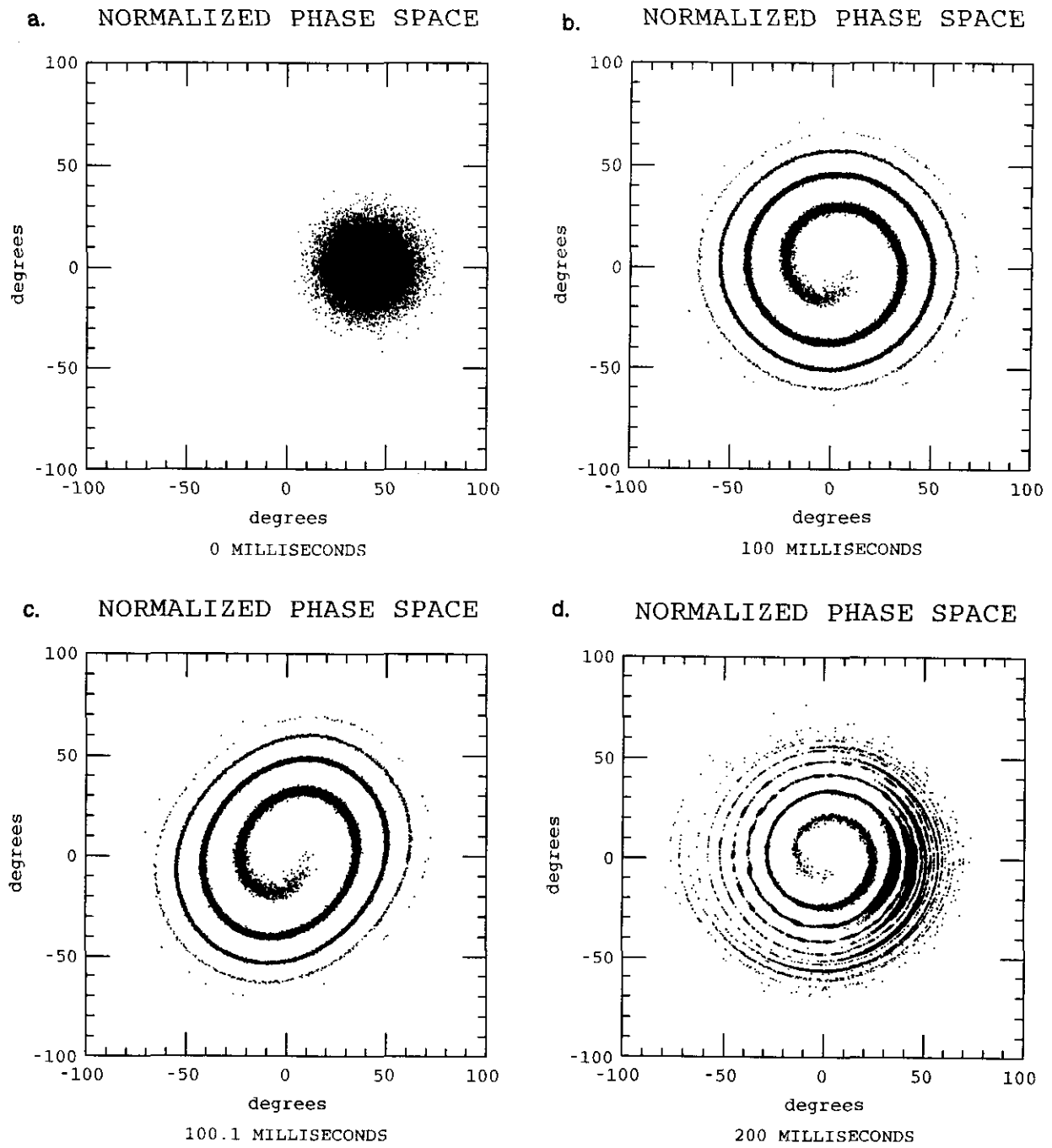

Figure 1. (a) Phase space portrait of 12° rms length Gaussian bunch at 0 ms, launched at 45 MeV with a 40° centroid displacement. (b) Same bunch after 100 ms, now decohered, notwithstanding the effects of space charge (3×10^6 protons in the bunch). (c) The decohered bunch elliptically deformed by the RF voltage pulse (RF voltage was increased from 95 volts to to 165 volts for 0.1 ms, and then restored to 95 volts). (d) Confluence of the phase reversal tips at 200 ms, near the peak of the echo phenomenon.

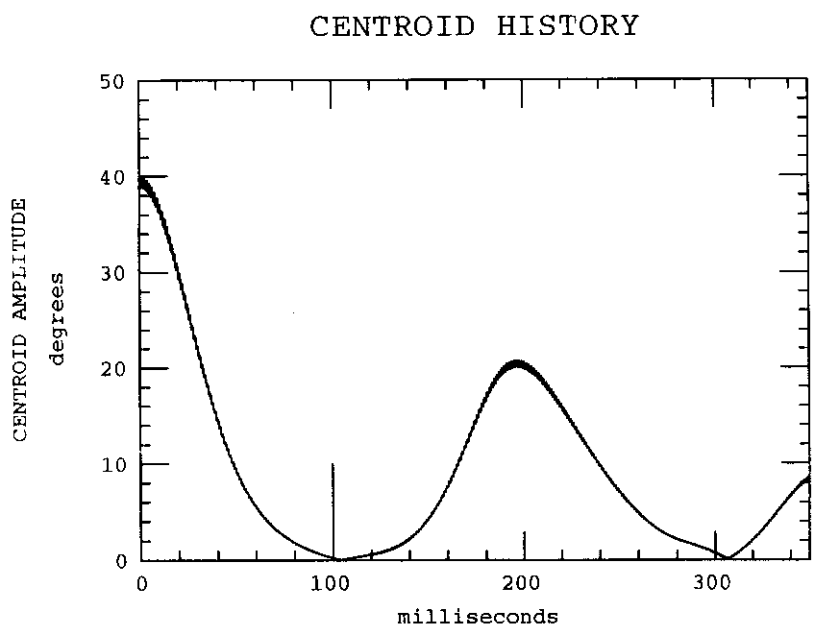

Figure 2. Centroid synchrotron oscillation amplitude history of the echo which has been depicted in Figure 1 by means of selected successive phase space snapshots. Long vertical bar locates the time (100 ms) of the RF voltage pulse.

REFERENCES

1. N. Mahale, J. Palkovic, S. Kauffmann, S. Dutt, and T. Ellison, "Displaced Bunch Synchrotron Oscillation Echoes in Accelerators", SSCL-N-817, June, 1993.
2. S. Stahl and J. MacLachlan, "User's Guide to ESME v. 7.1", Fermilab TM-1650, February, 1990.