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An Accumulator/Compressor Ring for Ne^+ Ions*

Weiren Chou

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1. Observations

The primary goal of the High Energy Density Physics (HEDP) program is to create an extremely bright ion beam at low duty cycle. For example, a typical set of parameters is:

Particle type = Ne^+
Ion energy = 20.1 MeV
One ion pulse = 1 μC, 1 ns, 1 mm^2
Repetition rate = 1 Hz

This would give a volume density of ~10^{12} particles/mm^3, which is several orders of magnitude higher than any existing proton machines (typically 10^8 - 10^9 particles/ mm^3, see reference [1]). On the other hand, however, the beam power is very low. At 20.1 MeV, 1 μC and 1 Hz, one has:

Beam power = 20.1 W

This leads to the following observation: *In an HEDP machine, beam loss is a non-issue.* This has important implication in the machine design. The machine is fundamentally different from those high power (~ MW) proton machines such as PSR, ISIS, SNS, RIA, GSI and JPARC, of which the machine design is dominated by beam loss control.

A second observation is that, as it stands now, the HEDP program has limited funds (several $M). The hardware design needs to be as simple and realistic as possible.

2. An accumulator/compressor ring for Ne^+ ions

Rather than using an RF linac with 15 beam channels as suggested in an alternative design, we propose to use a ring that would require a linac with only one beam channel as the injector. It would accumulate a long linac beam pulse and compress it to a short pulse prior to extraction, just like a conventional accumulator ring. The layout is shown in Figure 1.

The linac is assumed to be 50 MHz and a beam current 200 mA. The beam intensity is 2.4×10^{10} per bunch, which is similar to that of existing proton linacs. The beam normalized rms emittance is 1 π mm-mrad. A train of 250 bunches for a total pulse length of 5000 ns (plus gaps) is injected into the ring in 20 turns. The beam is debunched and confined by two RF barriers. The beam length in the ring is 250 ns, corresponding to a compression ratio of 20:1. After 20 turns, the beam would accumulate 6×10^{12} particles or about 1 μC. The beam current is 4 A. It is then extracted from the ring and injected into an induction linac for an energy tilt, followed by

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neutralization and drift compression to about 1 ns in beam length. A straw man's ring parameters are listed in Table 1.

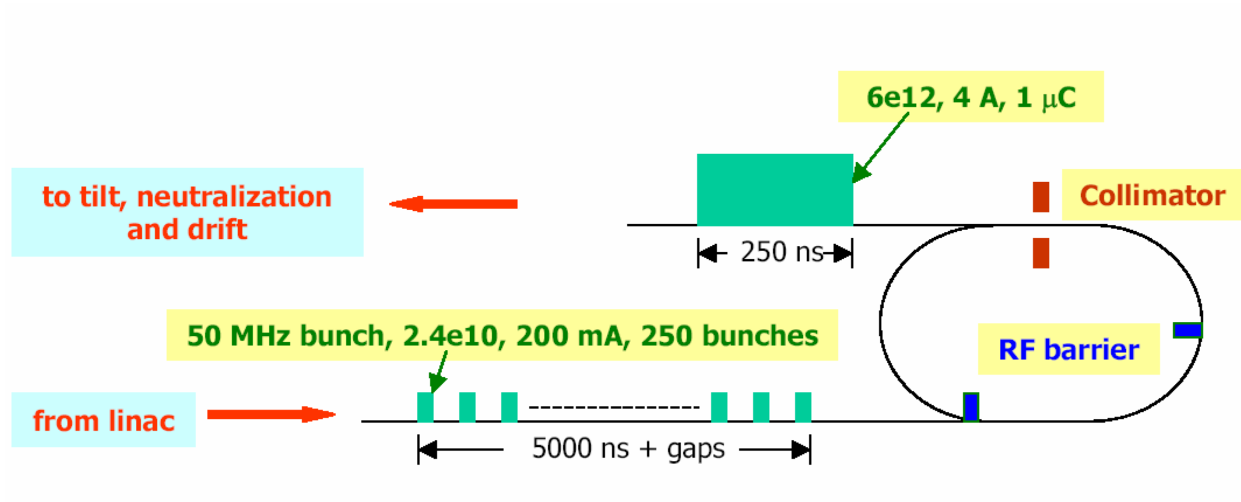

Figure 1. Layout of the accumulator/compressor ring

Table 1. Parameters of the accumulator/compressor ring

Particle	Ne^+
Mass number	20.17
Kinetic energy	20.1 MeV
Total energy	18.945 GeV
Momentum	0.872 GeV/c
β	0.046
γ	1.001
$B\rho$	2.91 T-m
Magnet	superconducting, combined-function
Bending field	4 T
Bending radius	0.73 m
Total magnet length	4.57 m
Ring circumference	8 m (580 ns)
Beam occupancy	3.45 m (250 ns)
Momentum spread	± 0.2%
Debunching rate	± 0.5 ns per turn
Injection turns	20
Injected beam emittance	1 π mm-mrad (normalized rms)
Accumulated beam emittance	6 π mm-mrad (normalized rms)
Total number of ions	6×10^{12}

The ring is partially filled. There are two ways to make a 250 ns beam in a 580 ns ring.

a) To create a macro structure in the linac beam by using a chopper at the ion source (similar to what was done in the SNS front end), i.e., to make a 330 ns gap after every 250 ns beam. The gap does not have to be clean because beam loss in the ring is not an issue. The injection would take 20 turns. In each turn the 250 ns long beam is injected into the portion of the ring bounded by the RF barriers. So the total linac pulse length would be (5000 ns + gaps = 11600 ns).

b) Another approach is to use RF barriers to compress the beam. A 5000 ns linac beam (without gaps) is continously injected into the ring in 8.6 turns. Then one would move the RF barriers to squeeze the beam from 580 ns to 250 ns. This has been done in the Fermilab Main Injector and is called "barrier RF stacking." This approach would take more turns (a couple hundreds). But this would not matter because the space charge effect is low (see below) and beam loss is not an issue. The final beam emittance would be determined by the collimator rather than by space charge dilution.

3. Discussions

The followings are a number of issues discussed at the workshop concerning the ring option:

1) Vacuum requirement:
Sessler and Yu estimated that a vacuum of 10^{-7} torr would be required for beam lifetime in the ring. This looks trivial when compared with the GSI storage ring, in which the vacuum reaches 10^{-11} torr.

2) Outgassing from lost ions:
Logan pointed out the lost ions could lead to outgassing from the pipe wall and shorten beam lifetime. This problem could be solved by installing a collimator (as shown in Figure 1) for beam loss control.

3) Space charge:
The Laslett tune shift for charge number Z = 1 particle can be expressed as:

$$\Delta \nu = -\frac{r_p}{4m\beta\gamma^2}\frac{N}{\varepsilon}B_f$$

in which r_p is the classical proton radius, m the particle mass relative to proton, β and γ the relativistic factors, N the total number of particles, ε the normalized rms emittance, B_f the bunching factor (peak current/average current). The tune shift is inversely proportional to the product of $m\beta\gamma^2$. For a 20.1 MeV Ne^+ ion β is low. But this is largely compensated by the value of m, which is 20 times higher than a proton. Table 2 is a comparison of 20.1 MeV Ne^+ ion and Fermilab Booster 400 MeV proton.

Table 2. Comparison of 20.1 MeV Ne^+ ion and Fermilab Booster 400 MeV proton

	Ne^+	Fermilab Booster Proton
Kinetic energy (MeV)	20.1	400
m	20.17	1
β	0.046	0.713
γ	1.001	1.426
$m\beta\gamma^2$	0.93	1.45
N	6×10^{12}	6×10^{12}
ε (mm-mrad, norm. rms)	6 π	3 π
B_f	2.3	2.5
$\Delta\nu$	–0.3	–0.4

It is seen the space charge effect in the Ne^+ ring is comparable to that in the Fermilab Booster. However, the duration of Ne^+ in the ring is much shorter (20 turns, or about 10 μs) than the protons in the Booster (19500 turns, or 33.3 ms). Therefore, the emittance dilution and beam loss should not be a problem.

4) Intrabeam scattering:
The emittance growth due to intrabeam scattering is slow and usually takes many turns. During a 20-turn circulation, this effect is negligible.

5) Energy tilt for drift compression:
To compress the beam longitudinally from 250 ns to 1 ns by drifting, the required energy tilt from the beam head to tail is ± 14%. This can be achieved by using an induction linac downstream from the ring.

References

1. W. Chou, O. Bruning, M. Giovannozzi and E. Metral, "*Summary Report of Session VI*," Proc. ECLOUD'02, CERN, Geneva, 15-18 April 2002, CERN-2002-001, p. 307.