2.5 *An Accumulator/Compressor Ring for Ne^+ Ions*

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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.

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 as realistic as possible.

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

Rather than using an RF linac with 16 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 in 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 neutralization and drift compression to about 1 ns in beam length. A straw man's ring parameters are listed in Table 1.

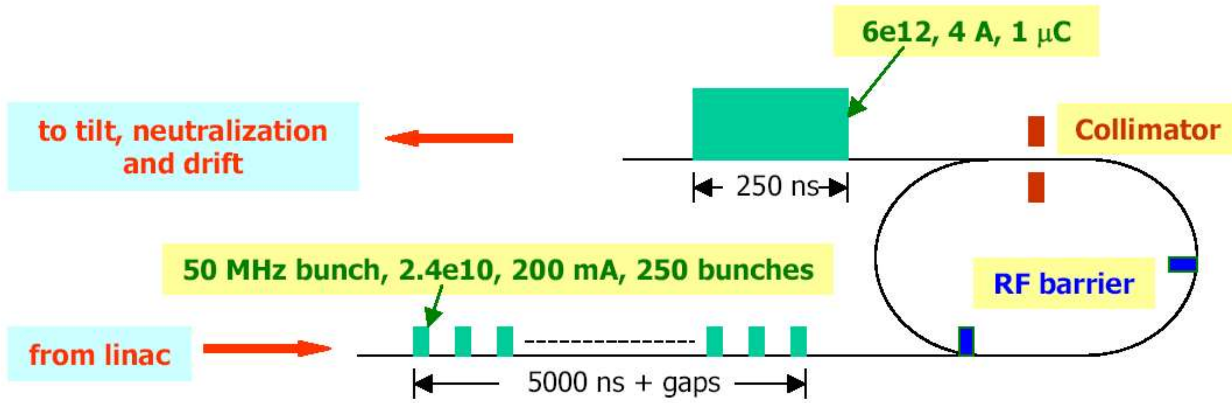

Figure 1. Layout of the accumulator/compressor ring

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
Beam occupancy	3.45 m (250 ns)
Momentum spread	$\pm$ 0.2%
Debunching rate	$\pm$ 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}

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 Fig. 1) for beam loss control.

3) Space charge:
The Laslett tune shift 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)	$6\,\pi$	$3\,\pi$
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.