2.2 *Multiple-beam RF Linac Scenario*

John Staples, LBNL

Generating amperes of Ne^{+1} in an RF linac exceeds the capability of any RF-based linac now in existence An important new idea introduced at the workshop by P. Ostroumov is to use very-high-field superconducting solenoids as focusing elements, separated physically from the accelerating cavities. Calculations showed that for a 50 MHz frequency that currents of 300-500 mA of Ne^{+1} could be accelerated.

The beam conditions on target selected to provide a point of reference are:

Ion	Ne^{+1}	
Total kinetic energy	20	MeV
Total charge	1	microcoulomb
Pulse length at target	1	nanosecond
Beam radius at target	1	mm

To generate amperes, required to produce 1 microcoulomb of charge in a few hundred nanoseconds, requires multiple parallel beam to be accelerated and combined at the target. The energy spread of the linac after debunching limits the longitudinal ballistic compression attainable to meet the 1 nanosecond target requirement to 100 or so to 1.

The frequency of 50 MHz is selected but not optimized. It is characteristic of the low-frequency superconducting cavities on ATLAS and proposed for RIA, although the cavities proposed here are normal conducting, not superconducting.

The use of high-field superconducting solenoids extends significantly the focusing strength needed in the first part of conventional drift tube linacs. With quadrupole focusing located in the drift tubes, the entrance drift tubes are the shortest, with gap-to-gap center spacing $\beta\lambda$, limiting the length of the quadrupole and its integrated strength. The technological limit of quadrupole strength in the range of 2T/cm establishes the injection energy and was typically 750 keV in 200 MHz proton linacs of the last generation.

Superconducting solenoids operating in the 15 T range provide significantly larger focusing strengths, needed for ion with low charge-to-mass, such as Ne^{+1} than quadrupoles can, and have the added benefit of significantly reduced envelope flutter for better aperture utilization and wider momentum bandwidth.

A linac lattice was assembled (see section 2.4 for more details) comprising approximately 25 cm long accelerating cavities interspersed with 15 cm long 15 T superconducting solenoids with a 2 cm bore radius. Each cavity, modeled on a three-gap interdigital H-mode (IH) structure, provides an energy gain of approximately 1 MV. Twenty cavities accelerate the 2 MeV Ne^{+1} beam to 20 MeV total energy.

The space charge limit of this arrangement is estimated at several hundred mA per beam, and therefore approximately 16 beams at 300 mA per beam are required to produce a 200 nanosecond pulse at the end of the linac, 4.8 amperes total, to be ballistically compressed by introducing an energy ramp over the 200 nsec with an induction linac core.

The 16 parallel beams may be arranged either in a circle or in a linear array, constraining the shape of the drift tube. (The voltage distribution on the drift tube, a not insignificant fraction of a wavelength, must be compensated for in the cavity design so not to increase the energy spread of the accelerated beam.)

The large area of the drift tubes will result in a rather low cavity shunt impedance due to the high displacement current in the drift tube stems, but the high inter-gap capacitance will also allow a high stored energy in the cavity, as 16 parallel beams will remove nearly 1 joule of stored energy from each accelerating cavity, which stores 10-20 Joules.

More detailed calculations (see section 2.4a) indicate that at 300 mA, the 1-times normalized rms transverse emittance at the exit is on the order of 0.9 pi mm-mrad. With an input emittance of the same order, the transverse emittance growth is essentially zero, but remains almost constant as the input emittance is reduced, due to space charge.

The 1-rms longitudinal output emittance is on the order of 1 pi MeV-degree, about a factor of three larger than an optimized, idealized longitudinal input emittance (waterbag, not what a realistic prebuncher will produce). A debuncher cavity following the linac reduces the 1-rms energy spread from 350 keV to about 55 keV, a factor of six.

The center-to-center spacing of the multiple beams is dictated by the superconducting solenoids. Commercial 15 T units can be packed with a 12 cm center-to-center spacing of the bores, which would result in the beams, if arranged in a circle, to have a radius of 30 cm. Arrangements of 1 by 16 or 2 by 8 are also possible. The even number of beams is associated with alternating field polarities of the superconducting solenoids, which will tend to reduce the extent of the fringe field, as field clamping is not feasible at the 15 T level. Some fringe field penetrating the normal-mode cavities may be a benefit, reducing tendency of multipactoring.

As the linac itself is fundamentally a constant-velocity device, but it is possible to vary the output energy continuously by turning off cavities, starting from the high-energy end, and adjusting the timing of the induction linac core following the linac, used to impose the energy ramp needed for ballistic compression. The energy ramp required of the induction core is more than the energy gain of one linac accelerating cavity.