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MASTER

MEQALAC: A NEW APPROACH TO LOW BETA ACCELERATION

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ACCELERATOR DEPARTMENT
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ABSTRACT

An acceleration system is described which allows one to accelerate high currents of ions at very low velocities. The main principle is to utilize an array of electrostatic quadrupoles in an rf linac drift tube, rather than a single magnetic quadrupole, as is usually the case. Because electrostatic quads can be built with very small apertures, relatively high frequencies can be used. A number of examples are given.

MEQALAC is an acronym for a multiple-beam electrostatic-quadrupole-focusing linear accelerator. The principle of operation is very simple. It makes use of the fact that electrostatic quadrupoles focus more effectively at low velocities than conventional magnetic quadrupoles. Moreover, the "pole-tip" field of an electrostatic quadrupole is limited by field emission of electrons, and is not a function of the size of the quadrupole. Conventional magnetic quadrupoles, on the other hand, require increasingly high current densities if one attempts to scale to smaller size.

In designing an rf drift-tube linear accelerator, it is necessary to make shorter and shorter drift tubes as the velocity of the particle decreases, assuming the frequency is kept fixed. However, as the drift tube gets shorter, the hole in it must also decrease or the drift tube would cease to act as a shield to keep the particles from being deaccelerated when the field reverses.

By using electrostatic quadrupoles, the bore sizes can be made orders of magnitude smaller than for magnetic quads. Furthermore, they require no power and can be produced for very little cost.

The beam intensity that can be accelerated in a single beam diminishes as the velocity is decreased. An earlier report* described the longitudinal and transverse space-charge limits as a function of the linac parameters. The total MEQALAC current, however, is the sum of a large number of independent low current electrostatically focused channels. It is feasible to construct electrostatic-quadrupole arrays that contain thousands of separate channels.

The same physical principles that make the MEQALAC attractive also apply to ion source design. For years, very high current ion sources have been made with arrays of very small apertures. The MEQALAC is ideally suited to take the beam directly from a multiple-aperture ion source and accelerate it with rf directly from the extraction voltage (10 to 50 kV, typically). In some

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*Space-Charge Limits for Linear Accelerators, A. W. Maschke, BNL 51022, 1 May 1979.

cases it may be possible to actually run the extractors with rf and maintain the entire source body at ground potential.

There are numerous applications where MEQALAC's promise to make very large improvements. Virtually all existing Cockcroft-Walton pre-accelerators for linacs could be replaced by MEQALAC's. The MEQALAC, because it does not involve high voltage, allows one to produce "desk-top" ion accelerators in the few hundred kV to a few MV range.

The MEQALAC concept is directly applicable to the problem of producing intense D^- beams for plasma heating. The multiple-beamlet approach allows one to accelerate very large currents (tens of amperes), and to transport it arbitrarily long distances to the reactor, without space-charge neutralization. Furthermore, an array of thousands of small beamlets, in a quadrupole matrix, is a neutron barrier. Radioactivity, in the form of tritium, as well as neutrons, can be blocked by these arrays.

There are many applications for MEQALAC's. A few examples will be given, not necessarily optimized, to illustrate the very large impact this concept can have in some areas.

EXAMPLE I. High-Brightness Heavy-Ion Beams

Heavy-ion beams for inertial fusion are constrained by the pellet ignition requirements to have a very small six-dimensional phase-space area. All previous accelerator concepts have had difficulty obtaining a comfortable safety margin in this area. The best design,* in this regard, was the BNL conceptual design. A 2-MHz linac was used to accelerate 20 mA of U^{1+} injected at 500 kV. As pointed out in BNL 51022, the six-dimensional phase-space density of an optimally constructed linac is proportional to f^2/β^3. Now suppose we were to replace this with an 8-MHz linac, operating at a 30-kV injection energy. We have raised the frequency by a factor of 4, and lowered the injection velocity by a factor of 4 also. The result is a 1000-fold increase in the six dimensional phase-space density. In order to maintain the current, we require 64 beams.

This 8 x 8 array of quads would be contained in about 6 x 6 cm^2. The quadrupole bore is about 3.75 mm diameter, and the voltage is ± 3.3 kV. The gap voltage is 6.3 kV.

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*See HIF Workshop, ANL, 1978, report of the Reference Design Group (in press).

EXAMPLE II. D^- High Current Beam

We consider a 200-kV 10-A beam, of D^-. It might consist of 1000 10-mA beams, powered by a 200-MHz rf system. We assume 35-kV ion source extraction voltage. The gap voltage is 7.7 kV, and the quad voltage is ± 4.2 kV. The quad diameter is 1.8 mm, and the overall drift-tube diameter is ~12 cm. Total accelerator length is only about 25 cm.

EXAMPLE III. Deuteron Linac

A deuteron linac to produce 100 mA of 35-MeV particles is being built to produce an intense source of fusion-type (14-MeV) neutrons. The FMIT design, in order to overcome space-charge and focusing problems, has gone to an 80 MHz Alvarez structure. Using a MEQALAC injector, this linac could consist of twenty-five 4-mA beams at 50-kV injection energy into a 350-MHz Alvarez linac. Quad diameters are 2.5 mm, with the quadrupole voltage at $\pm$ 6 kV. The overall drift-tube diameter is at 2.5 cm. At $\beta = 0.0365$, the space charge has eased enough that we could switch to a conventional single-bore design. 350 MHz was chosen for the example because economical high power klystrons have been developed at this frequency for electron-positron storage rings.

There are many other applications which have not yet been fully explored. A pulsed drift-tube MEQALAC is a method for generating very high heavy-ion currents on a single-pulse basis. The technology associated with making very small quadrupoles, and hence very low emittance beams, also can be useful in a single-beam configuration. Proton microscopy is one example where a super-bright 1-MeV, say, beam of particles could be a valuable research tool. Because ion beams deposit their energies so abruptly, there are numerous micro-engraving applications that could be envisioned. This technology could also be applied to recording information, possibly at bit densities which are orders of magnitude greater than can be obtained with relatively long-wavelength optical techniques. Micro-ion beams might also be useful in producing microcircuits of smaller sizes than are now possible.