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HIF/HIFAR ACCOMPLISHMENTS: A SYNOPSIS (DECEMBER 1988)*

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The goal of the HIFAR program is to build a physics and technology data base for high-current induction linacs using multiple ion beams and current amplification. A central issue is maintaining a low enough 6-D emittance to allow focussing to a small focal spot. Accomplishments include the following:

1. High-current sources of heavy ions have more than adequate brightness:

A suitable injector for a driver should deliver a beam pulse of several amperes at a few MeV. At a time when we imagined a driver to use just one (big) beam starting with a few MeV at a few amperes, we built a 1-ampere, 1-MV cesium injector and determined that its emittance was 100 times smaller than needed in a driver. The surface-ionization source is 30 cm in diameter and is mounted on the high-voltage terminal of a Marx generator. The beam was further accelerated through three pulsed drift tubes to 2 MeV.

CBB 788-10358

Fig. 1: One-ampere cesium source

2. The Single-Beam Transport Experiment established linac transport limits:

Of key importance to driver design is understanding the beam space-charge limit in a strong-focusing linac. In a synchrotron, the Laslett tune-shift criterion allows space-charge defocussing to depress the betatron frequency, ω , by less than 10% of its low-current value, ω_0 . Some years into the HIF studies, the Single-Beam Experiment established in the laboratory that in a long AG transport system (87 electrostatic quadrupoles) very much larger space-charge effects can be tolerated, with the betatron frequency reduced by a factor of 10 from ω_0 . Down to this value both emittance and current are unaffected provided the betatron phase advance per lattice period is kept below 90° . Simulation shows that below this value image effects may be damaging if the beam is not centered properly.

CBB 831-845

Fig. 2: Two-inch bore quadrupoles in SBTE

These studies, which allowed us to consider drivers with ion charge-state > 1 , opened up the field of "space-charge dominated beams" in which the Debye length is a small fraction of the beam diameter.

3. The Multiple-Beam Experiment (MBE-4) amplifies current in four beams:

Ramping the voltage waveforms in the early accelerating gaps of an induction linac can halt (or indeed reverse) the natural distension of the current pulse thus leading to current amplification as the velocity increases. A driver (4.4 km long) relies on a factor of 200 gain in current with a corresponding reduction in pulse duration. MBE-4 accelerates Cs^+ ions from 0.2 MV to nearly 1 MV through 24 gaps which have shaped voltage pulses applied. Current amplification from 40 mA to 360 mA has been observed in this 15-m long experiment, although presently we are studying a less aggressive example (current amplification = 3). Four independently focussed beams thread the same accelerating structure; all are space-charge dominated.

XBB 8810-9680

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Fig. 3 (left): Current amplification ($\times 3$) in MBE-4

Fig. 4 (above): Four-beam ion linac, MBE-4

4. We are developing a high-voltage injector for 16 beams:

One reference driver example calls for 64 beams from a 3-MV injector. As a step in that direction, we are developing a 2-MV, 16-beam injector powered by a gas-insulated LC generator with a very flat voltage pulse ($< 0.1\%$ for several microseconds). The initial goal is to generate 0.5 amperes/beam of carbon ions (total current = 8 amps).

Fig. 5: Part of gas-insulated 2-MV injector

CBB 886-6385

5. The Induction Linac Systems Experiment (ILSE) will test many driver features:

Actually a cascaded set of six experiments, ILSE is designed to test, in a scaled way with space-charge-dominated beams, several important features and beam manipulations to be encountered in a driver. In many key parameters this is a one-tenth scale test. Electric-focussed acceleration of 16 beams is a scale-up from MBE-4. Combining these beams achromatically in sets of four to form four bigger beams involves new beam physics (collectively induced emittance growth). Magnetic-focussed acceleration can be studied for the first time; a light ion, carbon, was chosen to allow convenient magnetic elements at low kinetic energy. One of the emerging 10-MeV beams is selected to study space-charge effects in a large-angle bend, after which it is allowed to bunch in a drift-compression section. In this section, one relies on the collective self-fields at the beam head and tail to remove the velocity shear along the bunch thus avoiding chromatic problems in the final focus. The final focus arrangements allows a variety of experiments on beam propagation, gas and neutralization effects, two-stream instability, etc. A conceptual engineering design for ILSE has been completed and favorably reviewed; the program of experiments would take five years at an enhanced program level of about 13 M\$/years.

Fig. 6: ILSE schematic

Beyond ILSE, several steps of increasing scale are desirable along the road to a power plant driver. Experiments at 10 kJ, for example, can provide high target temperatures (> 100 eV), and allow new studies of final focussing as well as the control of high-current longitudinal effects in the accelerator.

6. The Heavy-Ion Fusion Systems Assessment (HIFSA) gave encouraging results:

DoE laboratories and industry have collaborated in a broad parametric study of a power plant with an induction linac driver (Fusion Technology, February 1988 issue). A surprisingly broad latitude is found in the choice of accelerator parameters, the projected cost of electricity is favorable (5.5 cents/kWh), and plant sizes down to 500 MWe look reasonable. Driver efficiencies typically lie in the 20-40% range.

Fig. 7: A cost-effective driver architecture (from HIFSA)