ARGONNE'S PROGRAM IN HEAVY-ION FUSION

MASTER

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Argonne is constructing the initial part of a xenon accelerator which could serve as the driver for an Inertial Confinement Fusion power plant. The project consists of a Xe source, a 1.5 Mv Dynamitron preaccelerator, independently phased rf cavities as a low β linac, and Wideroe linac at 12.5 and 25 MHz. The beam will be injected at 220 MeV into a circular ring to its space charge limit, transferred to a second ring for multiturn injection after an x-y rotation, extracted, compressed in time duration, transported and focussed onto foil targets. The project thus will demonstrate nearly all of the beam manipulations involved in a full scale ICF driver. The feasibility of accelerating in the accumulator ring to 10 GeV to achieve adequate beam energy to permit energy deposition experiments in hot plasma is being studied. The status and future plans of this project are discussed.

The Beam Development Facility shown in Fig. 1 would make extensive use of existing facilities and equipment made available by the decommissioning of the ZGS in October 1979. It would consist of a xenon source operating at 60 mA, 1.5 MeV Dynamitron pre-accelerator, independently phased cavities for initial rf acceleration to 3.1 MeV, and three sections of a Wideroe linac at 12.5 MHz for acceleration to 20 MeV. The beam would be stripped at 20 MeV to charge +8 followed by 25 MV of Wideroe linac at 25 MHz. The transition will include a vertical "dog-leg" to simulate the linear combination of a second 12.5 MHz linac beam into the 25 MHz linac. The linac beam energy would be 220 MeV. It would be debunched and multiturn injected into a stacking ring to its space charge limit. Several stacks from this ring would be transferred, with rotation from horizontal to vertical phase space, to a large aperture synchrotron. Acceleration to 10 GeV in 0.1 second, with extraction, longitudinal beam compression, transport, beam splitting, and final focussing to small spot sizes provides the beam necessary to do near term physics experiments.

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HEAVY ION FUSION BEAM DEVELOPMENT FACILITY RF ACCELERATION SYSTEMS

Figure 1

A first and second harmonic buncher should allow capture in the linac of 40 mA of the 60 mA Xe^{+1} beam from the preaccelerator with a normalized emittance of 0.1×10^{-6} m-rad. Numerical simulation indicates that a 20 mA, 1.0×10^{-6} m-rad beam will exit the first Wideroe tank at 8.8 MeV. It is expected that emittance growth in the linac will be small after this point. Considerably larger emittance growth could be tolerated and still satisfy the needs of the beam demonstration described here because injection is at relatively low energy with high beam current. For a power plant driver, however, the normalized transverse emittance from the linac should be $\leq 1.5 \times 10^{-6}$ m-rad. The study of emittance growth in the early sections of the linac is therefore an important part of the beam demonstration program. Potential for emittance growth, both transverse and longitudinal, also exists in stripping to different charge states, in linear combination of linac beams, and in frequency transitions in the linac.

The linac current of 40 mA at charge +8, however, is close to the space charge limit at 220 MeV for circulating current in a stacking ring with the aperture of the former Princeton-Penn 3 GeV synchrotron magnet (transferred to Argonne for this purpose). Therefore, in order to study multiturn injection, it will be necessary to collimate the linac beam to the desired current and emittance.

After the linac, the accelerator demonstrations would be carried out at relatively low intensity compared to the characteristics of a full scale power plant driver. Until the final acceleration to 10 GeV in the synchrotron, however, the ion energy is sufficiently low that space charge forces still play a dominant role and a great deal can be learned from beam manipulations under these conditions. Central issues in the circular machines are injection and beam loss due to charge changing collisions of beam ions among themselves and with residual gas atoms. Additional issues are the technology of 10^{-11} Torr vacuum systems in the presence of bombardment of the walls with beam ions, fast and efficient extraction of beams with large cross sections, and transfer between storage rings. The latter is likely the most practical approach to transverse stacking of 100 turns or more.

The growth time of the longitudinal microwave instability, identified at the 1979 HIF Workshop¹⁾ as a potential problem for a full scale power plant driver, will be much too long at the injection energy for its effects to be observed in the Beam Development Facility. A possibility of studying this particular phenomena might exist with coasting proton beams of 50 MeV in Argonne's Rapid Cycling Synchrotron (formerly called Booster II and presently in use as a pulsed neutron source). In particular, the difference in the phenomena between an unmodulated and a bunched beam might be of some interest.

The use of synchrotron acceleration to achieve relatively high ion energies appears to be the most economic method of reaching adequate total beam energies to make initial physics experiments possible. Preliminary estimates of beam loss due to charge exchange scattering indicate less than 10% loss will occur in an acceleration time of 0.1 second. The required B in the ring is much less than for the rapid cycling synchrotrons (60 Hz) initially investigated for the HIF application.²⁾ Nevertheless, the rapid acceleration will require multiple harmonic rf systems³⁾ in order to preserve the initial bunching factor of $\sim 1/2$ (to maximize the injection space charge limited current) and still maintain low enough momentum spread to allow final compression to the 10 nsec beam

duration desired.

After acceleration by a factor of 7 in momentum, the circulating current would be slightly in excess of 2 A with the same bunching factor. The space charge limited instantaneous beam current at 10 GeV, however, is > 20 A. The beam at full energy can be bunched to short time durations without exceeding the space charge limits and the effects of high instantaneous circulating currents (generating image currents and driving residual ions into the wall at high velocity), such as might exist in the storage rings of a full scale driver, can be studied.

Splitting of the beam extracted from the synchrotron into 16 beams for final focussing is to be accomplished by sets of septum magnets in both the horizontal and vertical planes. The final focussing is to be done by a nested set of triplet magnets. Fields up to 6 T are required to achieve final magnet to focal spot distances of 0.75 m and spot sizes of 0.5 mm radius. Computer calculations including space charge have been made of such focussing systems but no detailed design is yet produced.

2. EXPERIMENTAL PROGRAM

The ANL experimental program for the past two years has concentrated on developing the heavy-ion preaccelerator and low-beta linac. The preaccelerator and the initial linac cavities are operational. The preaccelerator has achieved pulsed 50 mA Xe^{+1} beams at 1.3 MeV.

A 100 MA low-emittance xenon (or mercury) source, a Penning discharge Pierce extraction source with a single 3 cm diameter aperture, was developed for this program by Hughes Research Laboratories.⁴⁾ Xenon currents of 100 mA have been extracted with no indication of plasma sheath instability. The high voltage power supply is a Radiation Dynamics, Inc. Dynacitron⁵⁾ which has been extensively modified for maximum pulsed current operation at 1.5 MV. The present oscillator will support more than 40 mA of beam-associated current with less than 0.25% voltage droop in 100 μs . A more complete description of the various elements of the preaccelerator has been published.⁶⁾

A high gradient accelerating column is used to accelerate this low-emittance space charge dominated xenon beam. The internal structure of the outer shell would not support voltages above 1.4 MV and experienced some damage to the internal rings and the ceramics. As a precaution, the preaccelerator voltage is being limited to 1.1 MV until a new modified shell is completed.

The 12.5 MHz low-beta linac begins 4.5 m downstream from the preaccelerator and is preceded by a buncher. The independently-phased cavities (IPC's) have a small number of gaps (2-8) to provide broad flexibility in injection energy and acceleration gradient. The first Wideroe tank will have 28 gaps excited by two stubs. The linac through IPC #3 will soon be operational. The first Wideroe tank is under construction.

At appropriate positions along the beam line, diagnostics are installed to determine accelerator performance and tune the beam transport. In addition to biased Faraday cups and toroidal current transformers, a non-destructive beam position and profile diagnostic system (PAPS) has been developed.⁷⁾ Two PAPS were used to determine the emittance of the preaccelerator beam at 1.0 MeV by measuring the waist at the buncher and the size after drifting 2.5 m. This gave a normalized transverse emittance,

$\epsilon_{nX} = \epsilon_{nY} = 0.019$ cm-mrad. The emittance is expected to drop to 0.01 cm-mrad at 1.5 MeV, but is already much brighter than other high current sources.

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