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Staff, Heavy Ion Fusion.

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**Heavy Ion Fusion Accelerator Research (HIFAR)
Year-End Report, April 1–September 30, 1988**

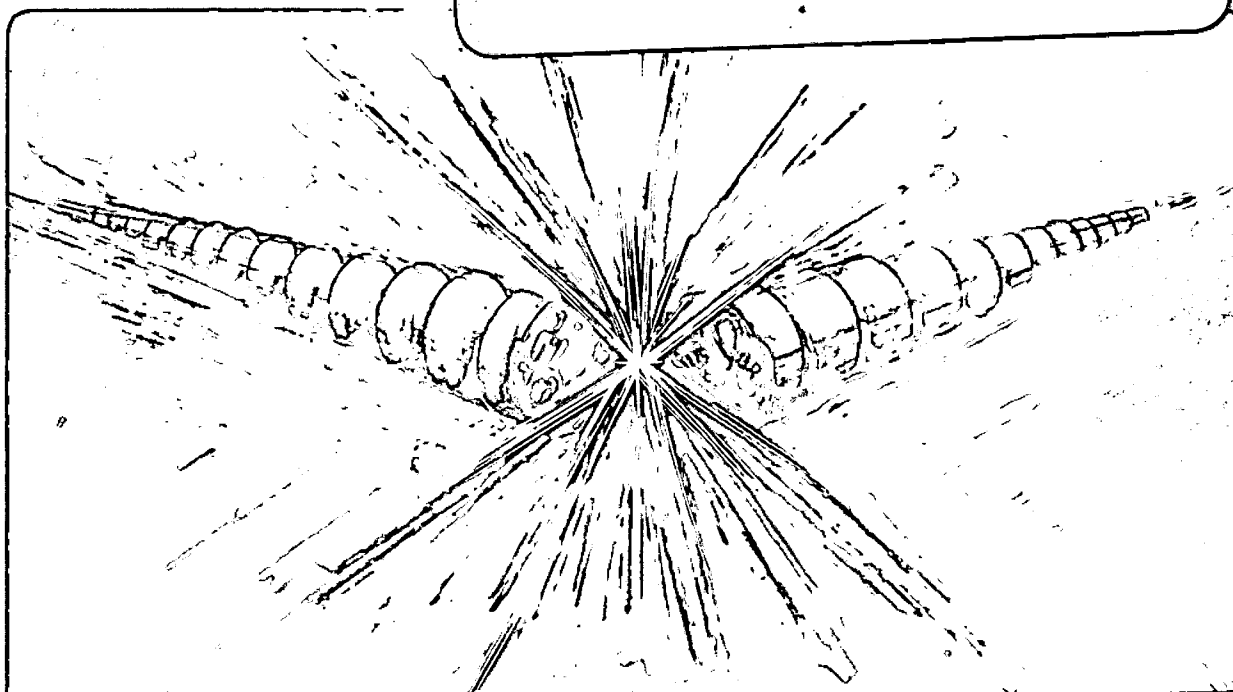
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HEAVY ION FUSION ACCELERATOR RESEARCH (HIFAR)

YEAR-END REPORT*

April 1 - September 30, 1988

Heavy Ion Fusion Staff
Accelerator and Fusion Research

Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

December 1988

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- * This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Advanced Energy Projects Division, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

FOREWORD

The basic objective of the Heavy Ion Fusion Accelerator Research (HIFAR) program is to assess the suitability of heavy ion accelerators as igniters for Inertial Confinement Fusion (ICF). A specific accelerator technology, the induction linac, has been studied at the Lawrence Berkeley Laboratory and has reached the point at which its viability for ICF applications can be assessed over the next few years.

The HIFAR program addresses the generation of high-power, high-brightness beams of heavy ions, the understanding of the scaling laws in this novel physics regime, and the validation of new accelerator strategies, to cut costs. Key elements to be addressed include: 1) Beam quality limits set by transverse and longitudinal beam physics; 2) Development of induction accelerating modules, and multiple-beam hardware, at affordable costs; 3) Acceleration of multiple beams with current amplification -- both new features in a linac -- without significant dilution of the optical quality of the beams; 4) Final bunching, transport, and accurate focussing on a small target.

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HIGHLIGHTS

D. Keefe

1. The biennial International Symposium on Heavy Ion Fusion, this time held at GSI in Darmstadt, West Germany, occurred in June, 1988. Six papers were presented by the LBL HIFAR group; the full texts will appear soon in the Symposium proceedings and are not included here.
2. A major new activity, the engineering design of the ILSE apparatus, continued at full speed throughout this reporting period. Participation by a number of LLNL engineers from the Beam Research Program was of especial help. ILSE is a sequence of seven experiments designed to address key driver issues. A conceptual engineering design is almost complete and a review by an outside panel of accelerator scientists is set for November 1988. Since a comprehensive report on this engineering design will be printed shortly (LBL PUB-5219, January, 1989) none of that material is described in this year-end report.
3. The physics design of ILSE described in the last half-year report has had to undergo some modifications as a result of practical engineering considerations. In the front end of an ion induction linac there is an intense competition for space among the accelerating, focussing, alignment, and vacuum systems. For ILSE, the trade-off among these requirements has led to an increase in the desired lattice-period length. A new parameter list is presented here.

Further studies with the POISSON code have revealed that the field quality in the electric quadrupoles in the rather crowded geometry of the combiner can be much improved by the addition of some small additional conductors.

4. First experiments with the complete MBE-4 apparatus succeeded in very ambitious current amplification by a factor of nine. This acceleration schedule reduces the physical length of the bunch by a factor of four — the same as in a full scale driver. A less extreme accelerator schedule which amplifies the current by a factor of three is now the subject of detailed study; again the physical length of the bunch is reduced but only by 30% which is more appropriate to the scale of MBE-4.
5. Lens misalignments in MBE-4 can cause the beam to deviate in position and angle from the axis. These deviations vary throughout the pulse because of the velocity tilt on the beam. Consequently, correction of the closed orbit requires time-dependent steering correction on a microsecond time-scale. An experiment in MBE-4 to explore this approach using two pulsed electric dipole correctors (placed $3/4 \lambda$ apart to correct both angle and position) succeeded in reducing the coherent betatron oscillations in the bunch to within 0.5 mm in position and to a negligible value in angle.
6. In support of the MBE-4 experiments, we have modified the SHIFTX code (due to Haber) to model the apparatus. Several experimental runs have given conflicting results on whether the normalized emittance grows or remains constant during current amplification. Observation of emittance growth could be intrinsic to the current-amplification process for reasons as yet undiscovered, or it could arise for many instrumental reasons such as poor matching conditions or lens misalignments. So far, the modified code has not revealed any significant intrinsic growth in emittance. Meanwhile, more diagnostic instruments are being built for MBE-4 to gain a better handle on the experimental situation.
7. The LBL SLID macro-particle code used in the design of ion induction linacs is proving to have limitations when used not as a design tool but rather as a diagnostic tool to understand

MBE-4 longitudinal dynamics. A new longitudinal code is now being written to circumvent the limitations of SLID.

8. Development of the 2-MV-injector voltage source included successful testing of a four-tray Marx configuration. When converted to an LC generator by addition of inductors and grading rings, the four-tray tests showed marginal performance because of unduly high electric field stresses. Re-design and testing of improved components is under way.
9. Problems with shot-to-shot variations in the carbon arc source were traced to the use of a mesh in the plasma switch that was somewhat too coarse (measured in terms of the plasma Debye length). Substitution of a finer mesh greatly improved reproducibility. As a check of the theory, a still coarser mesh gave much poorer performance.
10. A capacitor life test, begun nearly a year ago, has passed the one-million pulse mark without any capacitor failure. The test set-up uses an 85-psi enclosure specifically to check if recycling in pressure could cause deterioration in the capacitor. During this time, however, four of the Maxwell spark-gaps failed, indicating that they may need more preventative maintenance than anticipated.

The Physics Design of ILSE

T.J. Fessenden

The physics design of the Induction Linac Systems Experiment (ILSE) was finalized during this period and a sketch of the proposed facility is presented in figure 1. The accelerator consists of eight blocks of seven accelerating cells each of which is one-half lattice period long. The cell-blocks are separated by half-lattice periods that allow pumping and diagnostic access to the beams. A small magnetic core is also located in the inter-cell region to allow small corrections to be made to the total acceleration voltage supplied by each cell block.

In April we found that it was not possible to match the circular beams that the EGUN code predicted would be produced by the 2 MV injector to the electrostatic quadrupole channels at the beam spacings determined by the injector. Furthermore, the initial beamlet current of 0.5 Amp/beam,

which was the basis of the design reported in the last semi-annual report, required an initial lattice half-period in the electrostatically focused accelerator of 40 cm. This proved to be insufficient for both the accelerating cores and the alignment and support system. Also the beam size in the magnetically focused accelerator downstream of the combiner was larger than desired. These issues were satisfactorily resolved by a reduction of the beam current to 0.34 Amps/beamlet or a total current at injection of 5.4 Amps. The final ILSE design parameters are summarized in Table 1.

A peer review of the ILSE design is scheduled to occur in early November at LBL. A report is in preparation which details the physics and engineering concepts and design that went into this effort. We expect that the report will be printed in January 1989.

INDUCTION LINAC SYSTEMS EXPERIMENT

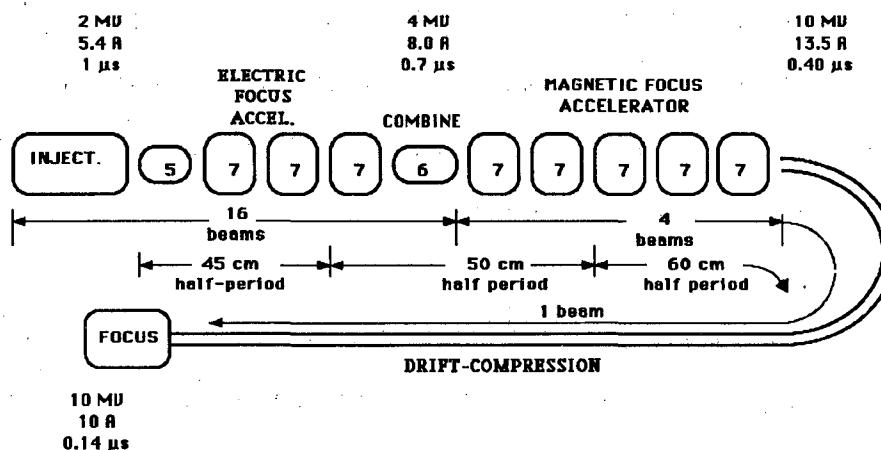


Table 1
Summary of the parameters of the final ILSE design

Mass number	=	12.00	
Initial Kinetic energy	=	2.00	MeV
Initial Current	=	5.44	Amp Total (Electrical)
Initial Current/Beam	=	0.34	Amp/beam (Electrical)
Initial pulse duration	=	1.00	microsecond
Initial pulse length	=	5.67	meters
Initial line density	=	0.06	microCoulomb/m/beam
Final Kinetic energy	=	10.2	MeV
Final Current	=	15.15	A Total (Electrical)
Final Current /beam	=	3.785	Amp/beam (Electrical)
Final pulse duration	=	0.355	microsecond
Final pulse length	=	4.39	meters
Final line density	=	0.31	microCoulomb/m/beam
Total energy			
end of linac	=	55	Joules
end of ILSE	=	13.9	Joules
Length of the Linac	=	37.5	meters
Total ILSE Length	=	96.1	meters
Final ILSE Current	=	10.2	Amps(1 beam)
# of accel. gaps	=	72	
# of ILSE half-periods	=	168	
Ideal Volt-Seconds	=	4.62	Volt-sec
Total Volt-Seconds	=	10.0	Volt-sec
Velocity tilt at Merge	=	18.2	%
Final Velocity tilt	=	7.7	%

Realization of Fields for Electrostatic Elements of the ILSE Combiner

Kenneth La Mon and David L. Judd

The ILSE combiner consists of an alternating sequence of dipole arrays and quadrupole arrays. Each array provides fields for sixteen beams, spaced in groups of four, in a dispersionless double-bend system calculated by E. Lee. Each array is characterized by the locations of the sixteen beam centers in a midplane normal to the system axis and by the approximately two-dimensional properties of the required fields. At the first dipole array, the beams are at the corners of a square with spacing $p = 7.03$ cm. Because the beams are to leave the combiner in the "stonehenge" configuration, half of them are to be bent through larger angles and half through smaller ones (called "large-step" and "small-step" beams, respectively). The desired fields can be produced by a set of rectangular electrodes having rounded corners. Because of the symmetries, only one rectangular module of a transversely periodic pattern need be calculated; the first such module is a square.

At subsequent dipoles and quads, the dimensions of such rectangular modules are found from the calculated displacements of the two classes of beams at the successive elements. Subtracting a large-step displacement from the side of the first (square) module, whose value is $2^{-1/2}p = 4.97$ cm, gives the short side of the corresponding module.

The variable shape of the rounded corners provides a degree of freedom with which to try to suppress unwanted harmonics. The computer program POISSON can generate solutions of the two-dimensional Laplace equation when conducting boundaries are specified, together with their potentials. Boundaries can be specified conveniently if they consist of segments of circles and straight lines. The program POISSON can also perform a Fourier analysis of such solutions in azimuthal angle, at a selected radial distance, about the beam center. These Fourier components determine the various electric multipole field harmonics (dipole, quadrupole, sextupole, octupole, etc.) present in the field. By changing the adjustable shape parameters and iterating this process, one strives to reduce the amplitudes of higher unwanted harmonics relative to the desired dipole or quadrupole component. If unwanted components are only a few percent of the wanted ones at the maximum radius of the beam, the search has ended.

The initially assumed ranges of electrode shapes proved adequate for the first dipole and the first quad, where beam-beam separations have not yet become very small, but for the following elements it was found necessary to add auxiliary electrodes in the form of small round rods whose positions and potentials provide additional adjustable parameters. By adjusting the voltage of an added electrode one may bring the lowest-order unwanted harmonic amplitude

to zero if the electrode is suitably positioned although this may tend to increase some harmonics of higher order. A compromise can be made, but the higher-order errors are less important because they vary as high powers of the radius.

At the right side of Figure 1, ten of the sixteen beams (shaded) and nine of the thirteen rounded-rectangle electrodes at the first dipole are shown. The longer arrows show forces on large-step beams while shorter arrows show forces on small-step beams. Adjacent electrodes have voltages of opposite signs; those marked C, the centers of four-beam groups, are negative. The heavily-outlined square is a symmetry module, shown greatly expanded on the left, where the K-V beam boundaries are circular arcs of radius 1.14 cm. With the optimized electrode shape shown, the sextupole and decupole fields are, respectively, 0.6% and 0.2% of the dipole field at the large-step (upper left) beam radius, and 1.6% and 0.4% at the small-step (lower right) radius.

Similarly, the right side of Figure 2 shows the complete sixteen-beam array (shaded) and the 36 oval electrodes at three of the quadrupole stations, where the rectangular modules and electrode shapes are the same. The beams, of maximum ellipticity at quadrupole centers, are shown in the D quads; their axes and the signs of electrode voltages are interchanged in F quads. The heavily outlined rectangle is a symmetry module, shown greatly expanded on the left, where the K-V beam boundaries are quarters of ellipses having major and minor semi-axes 1.44 and 0.89 cm, respectively. In addition to the two oval electrodes shown with opposite voltages, two round rods having diameter 0.3 cm with center-to-center spacing 0.6 cm are shown; their centers lie symmetrically along a diagonal. The lower left rod has voltage -0.25 V and the upper right one $+0.25$ V, where V denotes the magnitude of voltage on the principal electrodes. With this optimized set of electrodes, the unwanted field harmonics have the following amplitudes relative to the quadrupole at a radius of 1.4 cm: E_4 (octupole)/ $E_2 = 0.4\%$, E_6 (dodecapole)/ $E_2 = 1.1\%$, $E_8/E_2 = 6.5\%$, $E_{10}/E_2 = 2.1\%$.

In specifying the electrode shapes a minimum clearance between the closest electrode and a K-V beam boundary of 5 mm has been maintained, to allow for shoulders on beam shapes, dispersive displacements, and steering errors. If larger clearances are provided, the unwanted harmonics will in general be somewhat larger.

Electrode dimensions and shapes, multipole field amplitudes, and equipotential plots for all elements of the ILSE combiner are detailed in Report HIFAR-212.

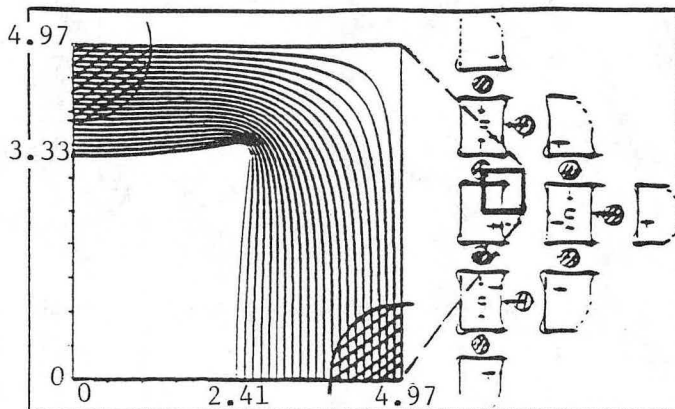


Figure 1: Dipole Array

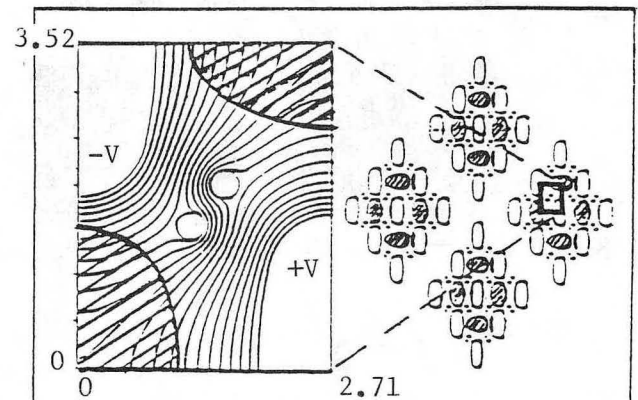


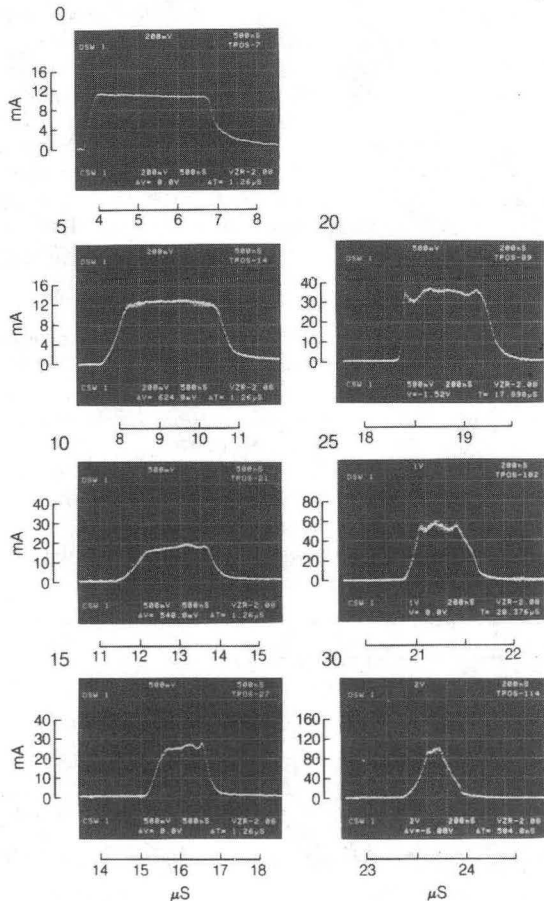
Figure 2: Quadrupole Array

A VIGOROUS ACCELERATION SCHEDULE IN MBE-4

A.I. Warwick and H. Meuth

Here we report on the measured longitudinal dynamics under a vigorous schedule of acceleration and current amplification in MBE-4. The current in each beam is increased from 10mA to 90mA and the kinetic energy increases from 200keV to 700keV in the middle of the bunch.

Figure 1 shows the current waveforms at each diagnostic station through the linac. Current fluctuations are apparent once the waves induced by acceleration errors have had time to oscillate one quarter period. It is particularly interesting to see how the ends of the bunch behave under the application of longitudinal focusing. The first longitudinal focus force is at gap 4. It is an extra pulser which acts to speed up the tail of the bunch. The results are seen at gap 15, the tail is steepened and a small spike appears where the focus pulser has affected the interior of the bunch. Subsequently the tail slows and spreads under the longitudinal space charge force. The focus forces on the head of the bunch are at gaps six and seven. Here we modify the main pulsers to refrain from accelerating the head of the bunch, causing the head to slow, and steepen at gap 20. Again a small spike appears where the focus force has intruded into the body of the bunch. Subsequently the head speeds up and spreads under the longitudinal space charge force. At gap 30 the bunch is ready for more longitudinal focusing.



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Figure 1. Current waveforms at each diagnostic gap.

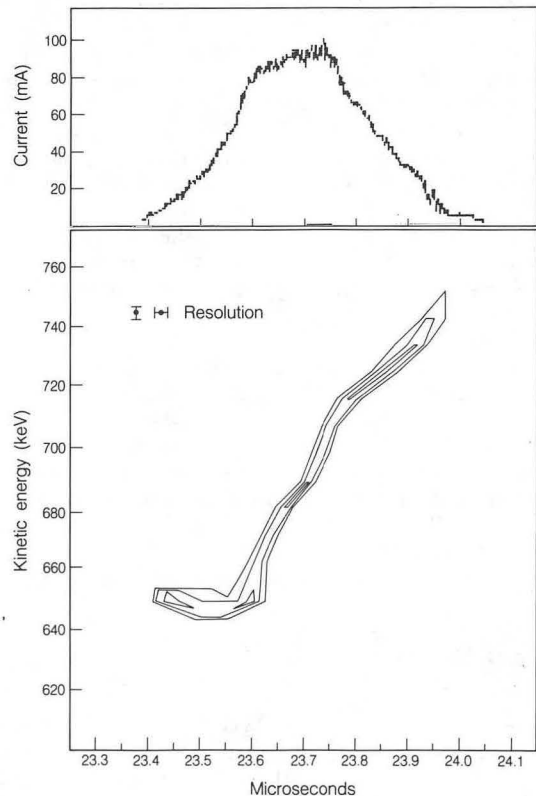
Figure 2 shows the measured longitudinal emittance, including shot-to-shot variations. The kinks in longitudinal phase space are systematic acceleration errors accumulated through the length of the linac. Particularly obvious is the poor control of the phase space distribution where the head of the bunch is longitudinally focussed by the leading edge of the accelerating waveform. The area of an enclosing ellipse is estimated to be:

$$\pi \epsilon_{\text{longitudinal}} = 4.0 \cdot 10^{-3} \pi \text{ eV s}$$

The higher beam velocity in a driver will reduce the contribution of a given error to the longitudinal emittance, in inverse proportion to the beam velocity. Current fluctuations at the beginning of a driver are further reduced by the square root of the line charge density, so that with acceleration errors the same size as in MBE-4 current fluctuations would be about 50 times smaller. Nevertheless the fluctuations observed here are unsatisfactorily large and more effort is planned to reduce acceleration errors through the linac before they oscillate into current fluctuations.

References:

"Performance of MBE-4, an experimental multiple beam induction linear accelerator for heavy ions". A.I. Warwick, T.J. Fessenden, D. Keefe, C.H. Kim and H. Meuth., Proc. 1st European Particle Accelerator Conf., Rome 1988.



XBL 885-8891

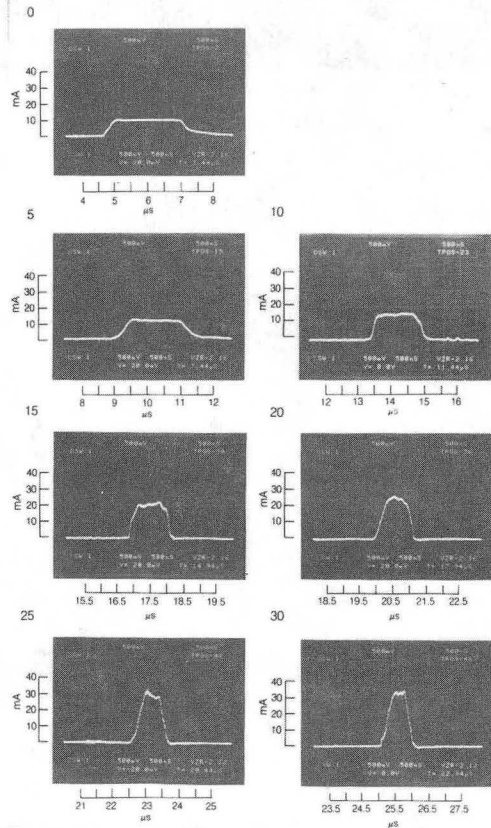
Figure 2. Measured longitudinal phase space distribution.

A GENTLE ACCELERATING SCHEDULE IN MBE-4

A.I. Warwick, D.E. Gough and H. Meuth

We report on a second schedule of acceleration and current amplification in MBE-4. We have devoted six of the 24 accelerating gaps exclusively to produce small correcting voltage pulses. These correcting stations are spaced down the linac so as to be able to modify the velocity profile of the bunch before errors have time to oscillate into current fluctuations. They also serve to hold the bunch ends together against the longitudinal space charge forces. The current amplification factor is reduced from 9 to 3.5. Figure 1 shows the results. Control of the current bunch is better than in the vigorous schedule and much easier to implement.

Figure 2 shows time-resolved measurements of the un-normalized transverse emittance at the end of MBE-4, a) for a drifting beam at 200 keV with no acceleration and b) for a beam accelerated through the gentle schedule to 620keV. These data are for a slice of 100ns duration at the detector, midway between head and tail of the bunch. Because of the increase in velocity, the un-normalized emittance in b) should be reduced by a factor of 1.75. Instead we observe emittance growth of approximately this magnitude so that the un-normalized emittance is little changed. Work is continuing to locate the source of this growth and to improve the performance of the accelerator in this respect.



XBB 880-9680

Figure 1. Current waveforms at each diagnostic gap through the linac under the gentle schedule.

The longitudinal emittance is measured at the end of the linac. We find:

$$\pi\epsilon_{\text{longitudinal}} = 3.0 \cdot 10^{-3} \pi \text{ eV s}$$

which is 75% of the value previously obtained in the first vigorous acceleration schedule. The head and tail of the bunch are well controlled.

When scaled to a fusion driver this is close to the maximum value of $1 \text{ to } 2 \times 10^{-4}$ that would be allowed under the constraints of the final focus onto the fusion target.

References:

"Acceleration, current amplification and emittance in MBE-4, an experimental multiple beam induction linear accelerator for heavy ions", Proc. Linear Accelerator Conf., Williamsburg, Oct. 1988.

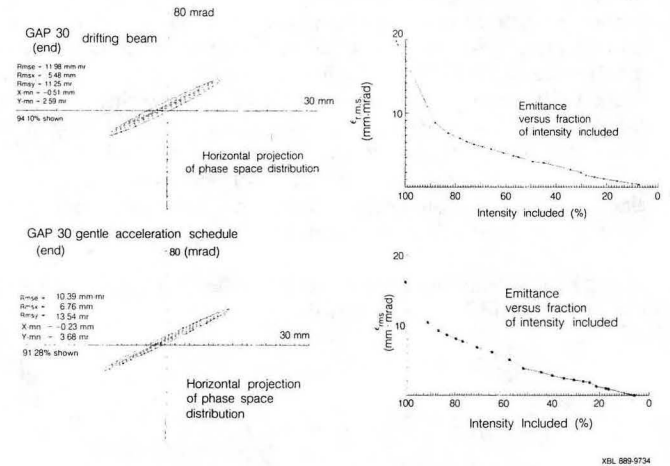


Figure 2. Measured transverse un-normalized emittance at the end of the accelerator in the longitudinal centre of the bunch for a drifting and an accelerated beam. Phase space plots are shown on the left. On the right the emittance is plotted against the fraction of the intensity included as a varying threshold is applied to the phase space density.

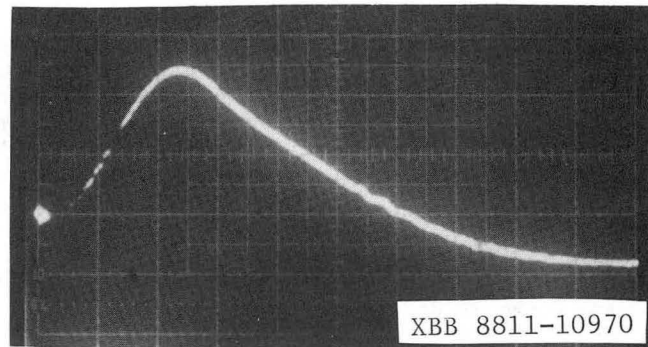
Pulsed Steering Corrections of Coherent Betatron Oscillations in MBE-4

S. Veitzer

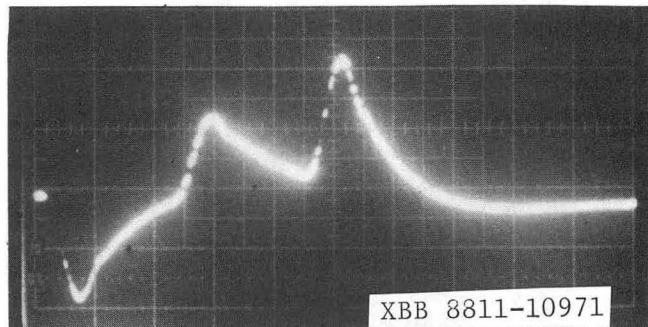
In the MBE-4 induction linac, an accelerated beam of charged ions has an energy (velocity) tilt. Coherent betatron oscillations about the beam axis in the linac arise because of small misalignments of quadrupole lattice elements. Since the energy of the bunch is not constant through the length of the bunch as it passes through a fixed quadrupole lens, the frequency of coherent betatron oscillation varies from the head of the bunch to the tail. A time varying pulsed dipole field is applied to the beam at two steering ports near the end of the linac. The two steering ports are separated by five quadrupole focusing and five acceleration sections. The quadrupoles are tuned so that an ion in the longitudinal middle of the bunch will have a phase advance of 270 degrees between the steering ports. The two deflections are nearly orthogonal in phase space, and the beam envelope remains small enough to avoid scraping on the conducting aperture.

The first deflection pulse is shaped so that the entire bunch is on axis with some transverse velocity at the second steering port. The second pulse delivers a momentum kick which exactly cancels the transverse momentum of the bunch at the second port. The bunch then travels on axis with nearly zero transverse velocity five more lattice sections where measurements confirm the success of the pulsed corrections. We were able to correct the coherent betatron oscillations to within 1/2 mm of the axis and to within the velocity uncertainty of our measuring diagnostics. Figures below show the actual voltage waveforms applied at gap 20 (first steering port) and at gap 25 (second steering port). In addition, the transverse mean position and mean velocity of the bunch as a function of time for the uncorrected (no steering) and the corrected beam are shown.

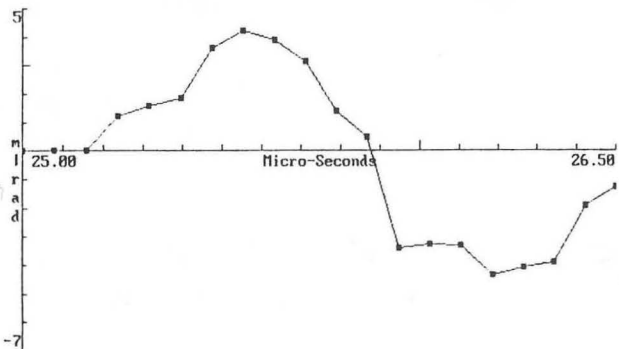
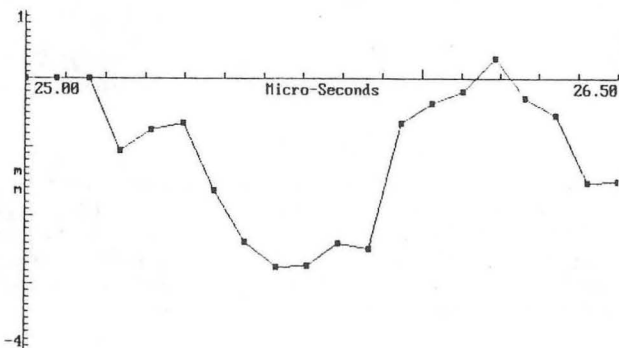
More information about the procedure and measurements can be found in HIFAR note-220.



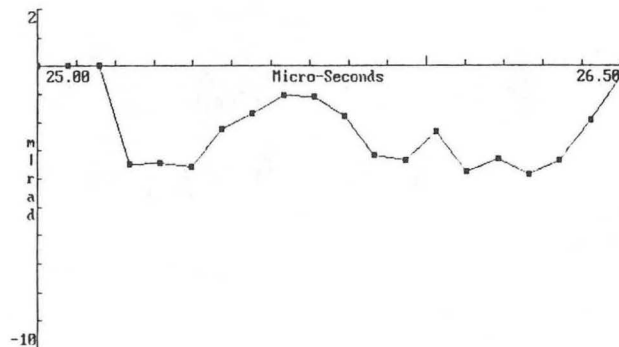
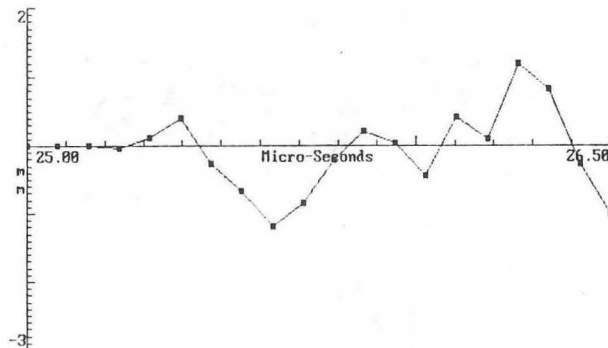
Gap 20 voltage waveform; 1 kV/cm, 200 nS/cm.



Gap 25 voltage waveform; 1 kV/cm, 200 nS/cm



Full emittance scan profile of "uncorrected" beam; both steerers at gap 20 and gap 25 off.



Full emittance scan profile of "corrected" beam; both steerers at gap 20 and gap 25 cm.

Upgrade of "SHIFTXY": Search for emittance changes

K. D. Hahn and L. Smith

Motivated by the recent MBE-4 experiments, in which the measured emittance is different with and without longitudinal acceleration and compression, several modifications to the 2-D PIC code, originally written by I. Haber, have been made to investigate these effects.

Acceleration is modeled by longitudinal δ -function kicks in the middle of the gaps between the quadrupoles, similar to the experimental setup. The slope of the each particle trajectory is reduced after each kick. The longitudinal particle energy is assumed to increase linearly with axial length, although other acceleration schedules can be easily incorporated.

The undepressed tune, σ_0 , is kept constant, as in the experiments, by increasing the quadrupole strength proportional to the beam energy. The effects of the longitudinal compression and acceleration on the space charge force are incorporated by setting only the macro particle charges to give the correct value of $Q \sim \frac{Nq^2}{mv^2}$ rather than the separate variations of v and N . Here N is the line number density, v the axial velocity, m the mass, and q represents the charge.

Several variations of the initial particle distribution, such as non-uniform density profile and position dependent local averaged velocity, as observed in the experiments, are also added to study their effects down stream. In addition, numerous diagnostics such as 3-D plots of the density and mode amplitude calculations have been added.

Figure 1 shows the time history of the emittance(ϵ) for the case where the initial velocity has been doubled and the line number density N has been quadrupled, which keeps Q constant, through the 30 down stream lattice periods of MBE-4. The initial density is assumed to be $n \sim r^2$ representing a hollow beam profile, where $r^2 = (\frac{x^2}{a^2} + \frac{y^2}{b^2})$ and a and b are the major and minor radii of the beam. An initial Gaussian velocity distribution is used. ϵ increases and oscillates rapidly for the first undepressed betatron period, corresponds to 6 lattice periods($\sigma_0=60^\circ$), due to the initial

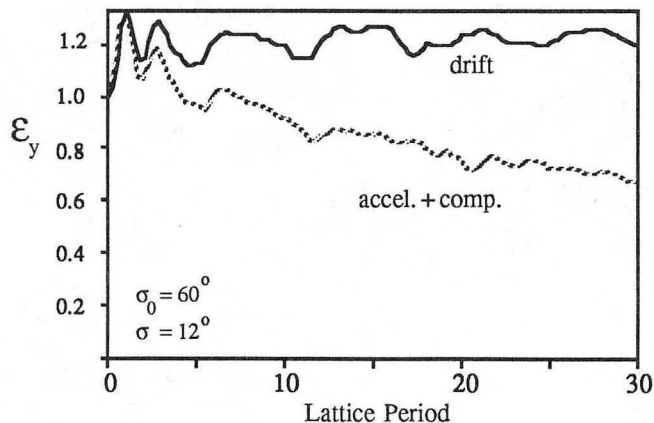


Figure 1. Time history of ϵ_y .

non-equilibrium density profile and settles down to a more quiet state with superimposed residual oscillations. The normalized emittance(ϵ_n) shows about 30% increase at the end. For comparison, ϵ of the drifting beam is also shown in Figure 1. The difference in the change of ϵ_n (22% increase) compared with the previous accelerated case is not significant probably because the rapid change of ϵ occurs before the beam is compressed significantly.

The effect of a position dependent velocity distribution is investigated for the case where $\langle v_x \rangle \sim \alpha(x^3 - \beta x)$ and $\beta=0.5$ in order to impose $\langle xv_x \rangle = 0$ at the center of the quadrupole. The amplitude α is chosen to give equal contributions to the rms ϵ from the temperature and the collective motion $\langle v_x \rangle$. The initial temperature has been reduced to give the same total observed ϵ . The distribution in the y direction is similar to x . The time history of the density profile integrated over y is shown in Figure 2; the initial uniform density profile evolves to a centrally peaked one, followed by a hollow shape and a gradual decay toward uniformity. The final emittance shows almost no change from the initial value and the beam remains rms matched even with the the strong compression and acceleration.

In summary, the effect of the non uniform space charge, created by previous external aberrations or velocity space non-linearity, propagating in a perfect quadrupole field is quantitatively not large enough to explain the MBE-4 experimental value of ϵ . However, some qualitative agreement is noticed, such as the decrease of ϵ at the head and tail of the drifting bunch where the decompression due to end erosion takes place and the increase of ϵ_n for the accelerated and compressed beam.

The effects of external non-linear fields from the quadrupole geometry and the surrounding conductor will be investigated in the future.

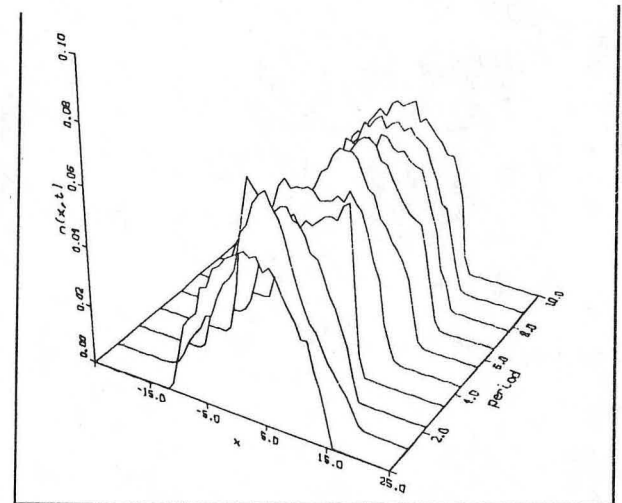


Figure 2. Density profile integrated over y as a function of distance along the channels given in lattice periods.

NUMERICAL SIMULATION OF LONGITUDINAL BEAM DYNAMICS

E. Henestroza

The SLID Code is a performance evaluation code that has been used to implement acceleration schedules for the MBE-4 and ILSE experiments.

INDEX is a code that generates a design of an ion-induction linac which includes acceleration and current amplification schedules, and a consistent electric and/or magnetic quadrupole transport channel. INDEX neglects longitudinal space-charge forces in its analysis.

From the design generated by INDEX, SLID follows the evolution of the longitudinal particle distribution for a set of accelerating voltage waveforms and under the influence of longitudinal space-charge forces.

There are several limitations built into the SLID code:

- i) SLID is a one-dimensional code.
- ii) Longitudinal space-charge forces are obtained by the long-wavelength approximation; that is, forces are assumed to be proportional to the derivative of the line-charge density.
- iii) The code does not allow particles to overtake.
- iv) There are no provisions for any longitudinal thermal velocity spread.

Work is underway to write a one-dimensional simulation code that will include a better approximation for the

longitudinal space-charge force, that will allow particles to overtake, and that will have an option to include a velocity spread.

The longitudinal space-charge force for a cylindrical beam inside a grounded beam pipe is given by

$$E(z) = \frac{4}{\pi} \int_0^\infty dk \int_{-\infty}^\infty dz_0 \frac{\lambda(z_0)}{a^2} \frac{1}{k} \cdot \left\{ 1 - \frac{2I_1(ka)}{kaI_0(ka)} + \left[\frac{K_0(ka)}{I_0(ka)} - \frac{K_0(kb)}{I_0(kb)} \right] 2I_1^2(ka) \right\} \sin k(z-z_0),$$

where λ is the line charge density, a is the radius of the beam, b is the radius of the pipe and I_m, K_m are Modified Bessel Functions of order m .

This expression can be integrated numerically using FFT methods, or be approximated as a single integral that can be calculated numerically.

In order to allow particles to overtake, the code is going to be a Particle-in-Cell (PIC) code.

A longitudinal thermal spread will handle some numerical instabilities always present in this type of code, as well as to allow the study of instabilities that arise from the inclusion of impedance in the system.

2-MV INJECTOR

H. L. Rutkowski

The generator subsection tests for the 2 MV system underwent a transition during this period. We stopped testing the pure Marx four tray assembly and moved on to the inductively graded Marx assembly. Weaknesses in the original design were discovered in the earlier tests. These problems were principally related to component underdesign and tray layout deficiencies. This circuit was not developed to a high level because the change to an inductively graded system was already underway.

The new inductive corona rings for the slow rise time inductively graded Marx were built and tested individually. Two types of windings were included; one with the original thick wires (.020" dia) coated in epoxy and another design with .010" wires without epoxy over them. The second design was of interest because of bubbles that formed in the epoxied coils. These bubbles over some long term use could be expected to destroy the insulative effectiveness of the epoxy. All four coils with their shielding spinnings were tested at 220 kV, or 10% above the normal expected impulse loading, for 50 to 60 shots each. No breakdown problems were observed in either design.

In late June, the first tests of the inductively graded four tray subsection occurred. Some breakdown problems occurred in the new trigger component arrangement and in the main gap between the coil spinnings. These latter breakdowns were attributed to defects in surface finish. Subsequent tests showed that this was not so. Attempts to radically increase the spinning separation on each coil resulted in even worse breakdown to the coils themselves and the unepoxied coils were abandoned. The spinnings were sprung out as much as possible and the system was operated satisfactorily at 80-85% of full charge voltage. The question of whether slits in the spinnings (to eliminate eddy currents) contributed to the spinning breakdown problem was investigated and shorting the spinnings did not improve the level to which the system could go. The latest change to the circuit was the addition of very large charging resistors which have 200W power dissipation that will allow operation at our 5 shot per minute repetition rate and with fast enough charging to fully charge all 18 trays of the final system at

that rate. The system worked without breakdown for a few shots at 94% charge voltage in 18 psig. of pure SF₆. This encouraging result is being pursued.

Considerable effort is being put into studying the options available for reaching the 2MV goal in the most efficient and reliable manner. Outside consultants have been brought in to review our experimental results thus far and to relate them to the final system design. As part of this effort there has been considerable calculational work done in the area of alternate circuits, pulse compensation and circuit variation techniques with the present circuit. Finally, alternate designs of the spinnings on the coils, which constitute the weak point at this time, are being studied. In this case we are looking for good performance not only at the subsection level, but also at the 2MV level when radial fields become a more serious problem.

The electrodes for the accelerating column have been fully designed and detailed with attention toward interfacing the injector with ILSE. Acquisition of these electrodes will begin at the start of the new fiscal year. The accelerating column design is shown in Fig. 1. Solid electrodes are being used for the "split end" elements to reduce the probability of temperature distortions in the lenses.

The electron trap provides a 980V on-axis potential barrier to prevent back-streaming electrons from entering the column. The final 500 mA beam radius is 20 mm and the aberrative emittance is $4 \times 10^{-8} \pi$ m-radius normalized compared to the $5 \times 10^{-7} \pi$ -radius specified for the injector total emittance. The optical beam divergence is 7 mradians. The electrodes will be made of titanium to reduce secondary electron generation inside the column. The solid plates will be laser welded to the spun conical pieces. The beam holes will be laser machined to reduce stresses in the flat plates. In addition to this major procurement, aluminum oxide bead blaster is being set up for cleaning the ceramic insulator modules and the water conductivity control system is being specified.

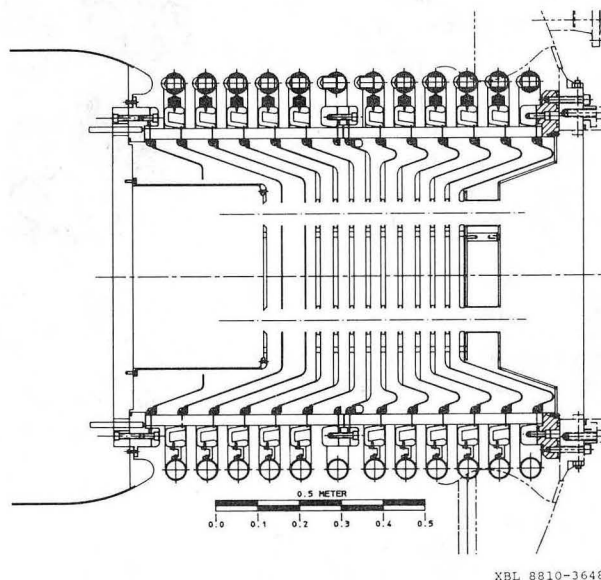


Fig. 1 2 MV Injector Acceleration Column.

CARBON ARC SOURCE DEVELOPMENT

H. L. Rutkowski and R. M. Johnson

The main area of difficulty in development of a suitable carbon arc source for the injection has been the reproducibility of the source with respect to both the extracted current density and emittance. In the previous half year report, many steps were discussed which, it was hoped, would lead to a more quiescent extraction plasma. In this report period, the source was made to act more reproducibly by changing the mesh used in the plasma switch. The source used for these tests was the three cathode internally triggered source that had been used earlier. Simultaneously, we have built a three cathode source which has three triggers. These sources are being tested in a new ion source test stand that includes some channel plate diagnostics developed by S. Humphries.

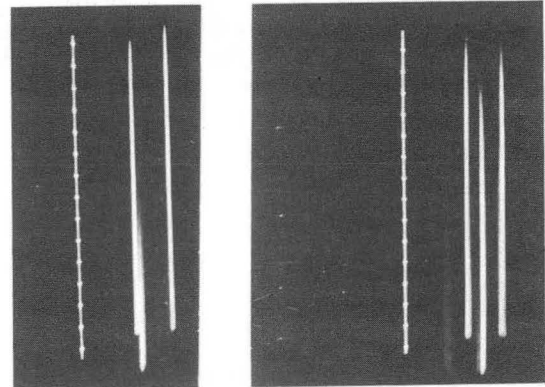
The reproducibility of the source was greatly improved by going to a more closely spaced plasma switch mesh. The general idea behind this approach is that as the source plasma becomes denser, the Debye shielding of the mesh wires becomes more effective and consequently the electric field from the wires becomes less effective in electrostatically shutting off plasma flow. Random leaks through the mesh would create randomness in the extracted beam. A 46% transmitting mesh with 3.4 mil wire separation was used to replace the 81% transmitting mesh with 9 mil wire separation. Plasma shut off was obtained at lower voltages and both the reproducibility and area of the emittance plots improved. We obtained a normalized emittance of $6.88 \times 10^{-7} \pi$ m-rad for a 1 inch diameter beam. This is an elliptical area value not an RMS emittance. A very open mesh with 19 mil wire separation produced very non-reproducible results much worse than those from the original mesh. These results were presented at the International Symposium on Heavy Ion Inertial Fusion in Darmstadt, FRG and at the Beams 88 conference in Karlsruhe, FRG and will be published in the proceedings of both conferences (Papers available as LBL 25101 and 25220, respectively).

Subsequently, the question of whether the three cathodes ignite simultaneously was addressed. A streak camera was obtained to take time resolved photos of the cathode spots on the cathodes. The cathodes reside in an envelope of about .5" diameter and they are coupled by plasma to each other. An electrical measurement of the separate currents to the cathode would be an unreliable indicator of cathode spot ignition because of the plasma coupling. Two ballast resistor circuits were involved in these tests. The one used in the source experiments discussed above was a single 4Ω resistor in series with three 3Ω resistors each going to one of the three cathodes. This circuit was dictated by the limited number of high voltage oil-vacuum feed throughs available on SBTE. The other circuit was three 16.7Ω resistors each going to a cathode. This circuit was to be used in the new test stand. The results with the two circuits are shown in fig. 1. The old ballast resistor system was used for the good emittance results described above. This circuit result in consistent late firing of one cathode which happens to be the top cathode of the triangular arrangement. The flashover trigger wire ends are arranged vertically. This top cathode is therefore collinear with the axis of the trigger discharge which indicates that the flashover trigger plasma expands preferentially to the side, igniting the other two cathodes more easily. The tests done with the new ballast circuit indicate that all three cathodes ignite in less than 10 μ sec. The normal delay from arc firing to the extraction

voltage pulse on the gun is 40 μ sec. We therefore expect the source to provide even more quiescent plasma in the new test stand.

The three-arc externally triggered source (known as ETMAS for Externally Triggered Multiple Arc Source) has been constructed and will be tested after the present Internally Triggered Multiple Arc Source (ITMAS). Both sources are designed to give a well behaved extraction plasma by combining the randomly varying plasmas from three or more independent arcs. The ETMAS is considerably larger and heavier than the ITMAS and it is hoped that the ITMAS will prove sufficient for the injector.

The new ion source test stand mentioned above is now operational and will allow the development of arc sources independently of the SBTE which is now free for its normal mission of doing beam transport experiments. The test stand has the standard extracted beam diagnostics for current and emittance measurement. It also has a new pepper pot-channel plate diagnostic for measuring emittance on a snap shot basis at a particular time in a pulse. This system was devised by Stanley Humphries of UNM under contract to this program. A deflection plate system directs the beamlets coming through the pepper pot holes to the side of the channel plate. At a pre-selected time in the pulse, a transmission line pulse is triggered which cancels the voltage on the plates and the beamlets proceed in a straight line to the channel plate. A film pack is used to obtain photos of the beamlet images for emittance measurement. A photometer operated by the SBTE-Test Stand control computer is now working and will be used to process the photos from the channel plate. Experiments will be carried on in the near future in the test stand using Langmuir probes to diagnose the source plasmas directly.



XBB 8810-10149

Fig. 1 Triple cathode streak photographs Left lumped ballast system, Right three discrete ballast resistor system time fiducials 5 μ sec apart.

INJECTOR MARX HIGH-VOLTAGE CAPACITOR LIFE TEST

J. Stoker

The injector Marx under development uses Maxwell Laboratory (Cat. No. 31445) high voltage energy storage capacitors and three electrode switch gaps. Maxwell's life test specification for the capacitors is that the capacitance and voltage value will remain stable for 100K shots with a maximum 20% reversal with a maximum discharge current of 50 kiloamps. The injector Marx design is critically damped and has no voltage reversal under normal operating conditions with a maximum discharge current of 50 amps (under these conditions). A capacitor life test was conducted.

The life test system was operated for one million pulses and terminated. The capacitor lasted for the entire test, while the spark gap was replaced four times during the test.

The capacitor that was tested is rated at 100 kVDC. 60 NF. The spark gap is a Maxwell catalog #77073-1 center electrode triggered gap.

The circuit is as shown in Fig. 1 which gave a pulse shape as in Fig. 2. The pulse has a risetime of 15 uS tailing off to near 0 volts in 300 uS. This closely approximates the injector waveform. The test vessel did not permit use of a H.V. trigger feedthrough so the gap was overvoltage and allowed to self-fire. The 100 KVDC charge source was an external 100 KVDC, 10 mA power supply.

The circuit was placed in a high pressure vessel and pressurized to 65 PSIG of SF6 after three flushings with pure nitrogen to 30 PSIG. During the course of the test, the vessel was opened for component replacement about 12 times at random intervals. The test capacitor was thus subjected to some pressure cycling during the test. The spark gap was fed

pure, dry instrument quality air form an in house air processing system. After black deposits were found in the spark gap, the air was tested and found to be hydrocarbon free. A second capacitor will be tested for more complete statistics.

The spark gap failure rate was surprisingly high. The first failed after 200K pulses, the second after 450K pulses, the third after 150K pulses and the fourth gap failed after only 70K pulses. The fifth gap worked to the end of the test (130K pulses). The gaps were considered unserviceable when they would not fire at 10 PSIG below the normal pressure versus voltage curve. The first four gaps were disassembled and inspected. They all had a bluish green deposit on the electrodes and on the lexan case around the electrodes. There were black track marks from the electrodes to the gas inlet ports. The black deposits were referred to in a report from Physics International Company.¹ In this report, gases were tested for breakdown characteristics. With a mixture of 90% argon and 10% SF6, this fouling was not apparent, but with pure nitrogen or air, it was. Maxwell Laboratories recommends use of synthetic air which is 79% nitrogen and 20% oxygen. The cause of the difference in gap failure rate is not clear.

(1) "Some Recent Advances in Three Electrode, Field Enhanced Trigger Gas Switches;" P D'A Champney, November 1974.

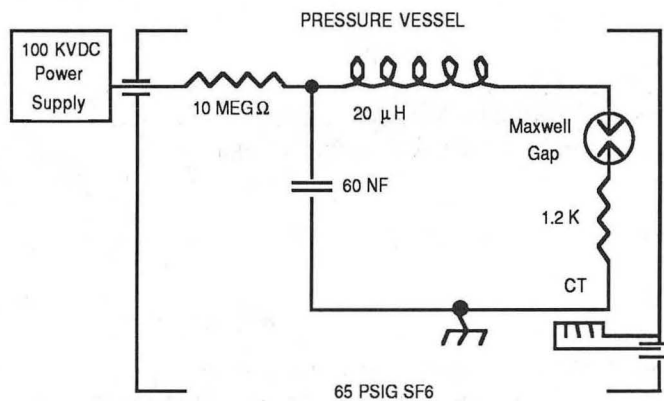


Figure 1

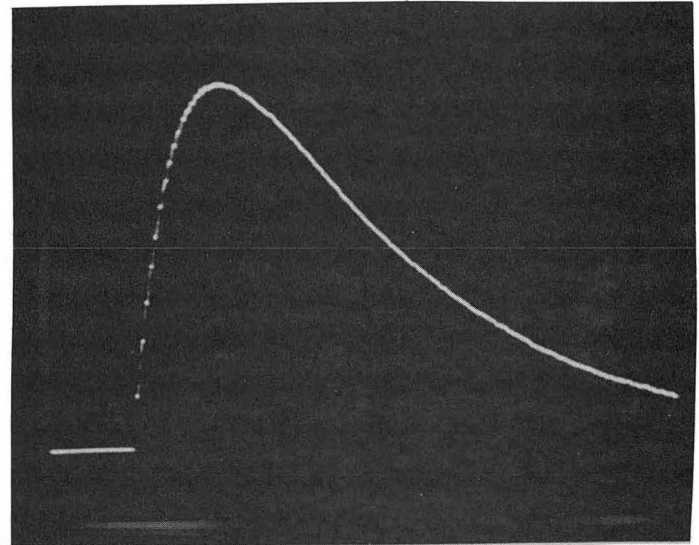


Figure 2

XBB 8810-9733

PUBLICATIONS AND INTERNAL NOTES

HIFAN-387
LBL-25096a
Fessenden

T. J. Fessenden
"Physics Design of the Induction Linac Systems Experiment"
Abstract submitted to the Spring Meeting of the American Physical Society,
Baltimore, Maryland, April 18-21, 1988.

HIFAN-389
LBL-25097
Fessenden

T. J. Fessenden
"Research on Ion Induction Linacs at Berkeley," Proceedings of the International
Symposium on Heavy Ion Inertial Fusion GSI Darmstadt, June 28-30, 1988 (to be
published).

HIFAN-390
LBL-26323
Keefe

D. Keefe
"Induction Linac Drivers: Prospects for the Future," Proceedings of the
International Symposium on Heavy Ion Inertial Fusion GSI Darmstadt, June 28-
30, 1988 (to be published).

HIFAN-391
LBL-25098
Meuth

H. Meuth, T.J. Fessenden, D. Keefe, A.I. Warwick
"Accelerator Research on MBE-4, An Experimental Multi-Beam Induction Linac,"
Proceedings of the International Symposium on Heavy Ion Inertial Fusion GSI
Darmstadt, June 28-30, 1988.

HIFAN-392
LBL-25099
Smith

L. Smith, K. Hahn
"Transverse Mis-Alignments in a Driver," Proceedings of the International
Symposium on Heavy Ion Inertial Fusion GSI Darmstadt, June 28-30, 1988 (to be
published).

HIFAN-393
LBL-25100
Lee

E. P. Lee
"Achromatic Beam Combiner and Bend System for ILSE," Proceedings of the
International Symposium on Heavy Ion Inertial Fusion GSI Darmstadt, June 28-
30, 1988 (to be published).

HIFAN-394
LBL-25101
Rutkowski

H.L. Rutkowski, A. Faltens, S. Humphries, D. Vanecek, C. Pike
"Progress on a 2-MV Injector for a Scaled HIF Accelerator Experiment,"
Proceedings of the International Symposium on Heavy Ion Inertial Fusion
GSI Darmstadt, June 28-30, 1988 (to be published).

HIFAN-395
LBL-25234
Warwick

A.I. Warwick, T.J. Fessenden, D. Keefe, C.H. Kim, H. Meuth
"Performance of MBE-4, an Experimental Multiple Beam Induction Linear
Accelerator for Heavy Ions," Proceedings of the European Particle Accelerator
Conference, Rome, Italy, June 7 - 11, 1988 (to be published).

HIFAN-396
LBL-25235
Warwick

A.I. Warwick, C. Celata, A. Faltens, T.J. Fessenden, D.L. Judd, D. Keefe, C.H.
Kim, H. Meuth
"Development of Heavy Ion Induction Linear Accelerators as Drivers for Inertial
Confinement Fusion," Proceedings of the European Particle Accelerator
Conference, Rome, Italy, June 7 - 11, 1988 (to be published).

HIFAN-397
LBL-25432
HIF Staff

HIF Staff
"Heavy Ion Fusion Accelerator Research (HIFAR) Year-End Report: October 1,
1987 - March 31, 1988," June 1988.

HIFAN-398
LBL-25220
Rutkowski

H. Rutkowski, A. Faltens, D. Vanecek, C. Pike, S. Humphries Jr., E.A. Meyer
"A 2-MV Multi-Beam Injector for Heavy Ion Fusion," presented at BEAM '88,
Proceedings of the 7th International Conference on High-Power Particle Beams,
Karlsruhe, West Germany, July 4-8, 1988 (to be published).

HIFAN-399
Laslett

L.J. Laslett
"The Quadrupole and Dodecapole Contributions to the Electric Field of an Infinite
Periodic Array of Fine-Wire Electrodes," June-July 1988.

HIFAN-403
LBID-1433
Fessenden

T. Fessenden, K. Hahn, D. Keefe, E. Lee, H. Meuth, H. Rutkowski,
"Trip Report to Darmstadt, Karlsruhe, CERN and Lausanne,"
June 26, 1988 - July 9, 1988.

HIFAN-405
LBL-25922
Keefe

D. Keefe
"Heavy Ion Driver Technology," lectures presented at the Inertial Confinement Fusion held in Varenna (Italy), September 6 to 16, 1988 (to be published).

HIFAN-413
Keefe

Denis Keefe
Trip Report, Varenna (Italy), Sept. 5-16, 1988.

HIFAN-417
LBL-26390a
Fessenden

T. Fessenden,
"Research on Multiple-Beam Induction Linacs for Heavy Ion Inertial Fusion,"
abstract submitted to the 1989 IEEE International Conference on Plasma Science,
May 22 - 24, 1988.

HIFAR NOTES (Internal and Informal)

HIFAR NOTE-192

Smith

L. Smith

"Transverse Mis-Alignments in a Driver," April 1, 1988.

HIFAR NOTE-193

Fessenden

T.J. Fessenden

"The Problems with ILSE--Tuesday, April 5, 1988/Summary and Recommendations," April 7, 1988.

HIFAR NOTE-194

Lee

E. P. Lee

"HIF Driver Issues/Presented at the Joint LLNL/LBL Seminar," April 29, 1988.

HIFAR NOTE-195

Pike

C. Pike and J. Stoker

"Injector Marx Inductive Corona Rings Electrical Parameter Tests," May 2, 1988.

HIFAR NOTE-196

Faltens

A. Faltens

"Injector Inductor Electric Fields," May 19, 1988.

HIFAR NOTE-197

Faltens

A. Faltens

"Tolerance Requirements for ILSE," May 31, 1988.

HIFAR NOTE-198

Celata

C. M. Celata

"Electrode Rod Sizes and the Dodecapole Field," May 26, 1988.

HIFAR NOTE-199

Warwick

A. I. Warwick

"Longitudinal Dynamics Measurement on MBE-4," June 6, 1988.

HIFAR NOTE-200

Fessenden

T. Fessenden

"Physics Design of ILSE (draft 1)," June 10, 1988.

HIFAR NOTE-201

Fessenden

T. Fessenden

"Diagnostics Plan for ILSE," June 16, 1988.

HIFAR NOTE-202

Faltens

A. Faltens, M. Gross, R. Hipple, R. Johnson, and H. Rutkowski,
"Carbon+ Ion Cross Section Measurements", June 6, 1988

HIFAR Note-203

La Mon

K. La Mon
"Multipole Fields in an Infinite Array of Round Rods," July 11, 1988.

HIFAR Note-204

La Mon

K. La Mon,
"Summary of Recent Work Done on the ILSE Combiner Electrodes," July 19,
1988

HIFAR NOTE-205

Fessenden

T. Fessenden
"Physics Design of ILSE/July 22, 1988"

HIFAR NOTE-206

Johnson

R. Johnson, J. Stoker, M. Gross, H. Rutkowski,
"Summary of Voltage Breakdown of Aluminum Over Hanging Gaps in Air,
Nitrogen & SF₆," August 9, 1988.

HIFAR NOTE-207

Hahn

K. Hahn
"Beam Dynamics in the Matching Section After The 4-Beam Combiner In ILSE,"
Aug. 11, 1988.

HIFAR NOTE-208

Brady

V. Brady
This report contains cross-sectional views of the first eight elements of the beam
combiner for a symmetric beam array as described in HIFAR NOTE-205,
Physics Design of ILSE (draft 2)". August 29, 1988.

HIFAR NOTE-209

Judd

D. Judd
"Final Ellipse Spacing in Last Combiner Element of ILSE," September 1988.

HIFAR NOTE-210

Judd

D. Judd
"Discrete-Wire Approximation of Linearly Varying Current Sheets," September
1988.

HIFAR NOTE-211

Judd

D. Judd

"Some Properties of the Last Combiner Element for ILSE," September 1988.

HIFAR NOTE-212

Judd

D. Judd

"Realization of Fields for Electrostatic Elements of ILSE Combiner," September 1988.

HIFAR NOTE-213

Judd

D. Judd.

"The "Golden Mean" of ILSE," September 1988.

HIFAR NOTE-214

Warwick

A. Warwick, E.P. Lee

"Acceleration Errors in MBE-4 and in a Driver," September 1988.

HIFAR NOTE-215

Faltens

A. Faltens

"Fine-tuning the Magnetic Quads for ILSE," September 1988.

HIFAR NOTE-216

Rutkowski

H. Rutkowski

"Status of the 2-MV Generator," September 1988.

HIFAR NOTE-217

Smith

L. Smith

"Resistive Instability Growth Rates," September 27, 1988.

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