Title
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Publication Date
1985-06-01

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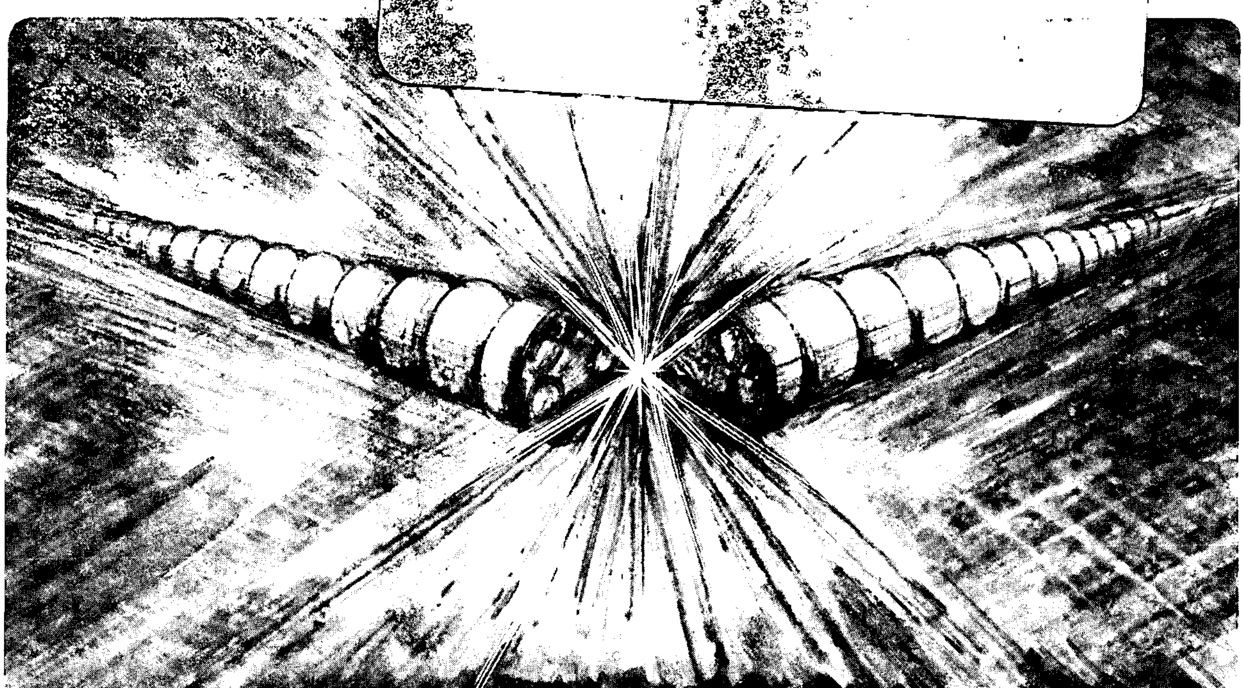

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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HI-FAN-290
LBL-19796

HEAVY-ION FUSION SYSTEM ASSESSMENT PROJECT

Quarterly Status Report, Jan.-Mar. 1985

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June 1985

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Berkeley Laboratory under contract DE-AC03-76SF00098. Funded by the Office of Program Analysis.

ACCELERATOR SYSTEM MODELING

1. The Cost Optimization Code LIACEP

1.1 Description

A computer model of an accelerator system is a necessary ingredient in estimating the cost of construction and operation of an ion-driven ICF power plant. The LBL computer program LIACEP[1,2] (Linear Induction Accelerator Cost Evaluation Program) is used to estimate the cost and efficiency of a heavy ion induction linear accelerator as a function of the ion mass, charge and energy for a specified beam output energy, power and pulse repetition frequency. In addition to estimating the accelerator system cost and efficiency, LIACEP can be used to identify the components and materials that have a high leverage on the cost and efficiency of the accelerator system. These high leverage items are logical areas for research and technology development to reduce the cost and increase the efficiency of the accelerator system.

In using LIACEP, the ion mass and charge, the normalized transverse emittance, tune depression, number of beamlets and pulse repetition frequency are set. Also set is the charge per beamlet and the acceleration module core material. Then for a given voltage, current and focussing system packing fraction the required field at the beamlet edge, the maximum beamlet envelope radius and the half period of the transport lattice are determined. These are used as input into a focussing system subroutine, which consists of a description of either pulsed quadrupoles or superconducting quadrupoles. From the focussing system subroutine, the quadrupole length and the accelerator inner radius are obtained, as well as focussing system costs and power consumption. The acceleration system subroutines are then used to determine the accelerator module dimensions, power requirements, and costs for each module design. A cost comparison subroutine selects the minimum cost alternative of the various acceleration module designs. The current is increased and the problem repeated for increased currents. The current is selected to give the minimum cost for a fixed voltage and packing fraction. The packing fraction is increased and the problem repeated. Then the voltage is increased and the problem repeated. The minimum cost packing fraction is determined for each voltage interval. Finally, the total cost, length, power, efficiency, etc. are determined for this minimum cost accelerator system.

A problem was run to determine the current state of LIACEP. This exercise reproduced the results presented by Faltens et al.[3] for a 200 amu, unity charge state ion (Hg^{+}) using 4 beamlets of 75 μ coulombs per beamlet and a total output energy of 3 MJ. The accelerator input voltage is 50 MV and the output voltage is 10 GV. The normalized transverse emittance is 1.17×10^{-5} meter-radians per beamlet and the tune depression is from 60° to 24°. The pulse repetition frequency is 1 hertz, which is lower than will be used for a fusion power plant and results in a spuriously low efficiency. Increasing the pulse repetition frequency will increase substantially the accelerator system efficiency. The acceleration cores are of amorphous-iron, and the focussing is by superconducting quadrupoles.

1.2 Study of New Problems

The above Reference Case is used as a base for comparison with several other runs that changed some of the material properties used in the accelerator design. The flashover gradient as a function of pulse duration has a large effect on the system cost and efficiency. The design flashover gradient varies from 20 kV/cm at a pulse length of 3 ns as the logarithm of the inverse of the pulse duration to 5 kV/cm at a pulse length of 1 μs, and is maintained at 5 kV/cm for pulse duration longer than 1 μs. Increasing the 3 ns flashover gradient at by a factor of 2.5 will decrease the system cost by 13% and increase the efficiency by 7.5%. Doubling the 1 μs flashover gradient will reduce the cost by 14% and increase the efficiency by 13%. Doubling the 1 μs gradient and increasing the 3 ns gradient by a factor of 2.5 will reduce the cost by 24% and increase the efficiency by 11%. These changes in the flashover gradient will result in a 70% increase in the accelerating gradient at 5 GV.

Increasing the breakdown voltage across vacuum gaps does not effect the cost of the accelerator system. This is due to the high cost of the insulator which requires the insulator to be located between the acceleration core and the beam such that the regions between the acceleration cells in the module can be isolated by oil. However, if the cost of the insulators can be reduced such that the core costs prevail and the insulators must be placed outboard of the cores for a minimum cost acceleration module, the breakdown voltage across vacuum gaps will become important to the cost of the system.

The effect of the voltage breakdown of ceramic insulators in vacuum as a function of length on the cost and efficiency of the accelerator system was also investigated. The current design curves allow about 38% of the voltage holdoff properties of high-power microwave tubes presented by Staprans,[4] and is about 80% of the voltage breakdown gradient of porcelain. By using a design curve at 40% of Staprans holdoff properties and at the breakdown gradient for porcelain the cost of the accelerator can be decreased about 11%, and the efficiency increased about 14%. Re-X, a General Electric castable insulator, has about 80% of the voltage breakdown gradient of porcelain, such that it lies on the current design curve. However Faltens recommends operating at about half the voltage breakdown gradient,[5] which will change the cost of the accelerator system. But since the cost of the Re-X insulators is expected to be substantially cheaper than porcelain insulators, there may be a cost advantage to using the poorer performing Re-X insulators in the accelerator system. The cost of Re-X will be entered into the LIACEP data base and the effect of the cost and performance of Re-X on the cost and efficiency of the accelerator system will be investigated.

To date we have identified the surface vacuum flashover gradient as a function of pulse duration for short pulses as a potential high-leverage field of research for induction linacs to be used as inertial fusion drivers. An experimental program that identifies the variables that affect short pulse flashover and determines the effects of 10^8 pulses on flashover will be cost-effective.

In addition, further studies on voltage breakdown as a function of length for ceramic insulators in vacuum may be cost effective. Of special interest is the effect of size and configuration on the breakdown.

1.3 Current Activities

Currently, LIACEP is being adapted to the VAX computer to make it a more generally available tool. Also, the tune depression tables are being replaced by an analytic approximation formulated by Lee.[6]

A defect of LIACEP is that it treats only the "80%" cost of the main part of the driver. To eliminate this defect, we are adding a low voltage section to the accelerator code that utilizes electrostatic focussing compares the costs to a superconducting quadrupole system, and selects the lowest cost option. Other efforts on LIACEP include reviewing old cost data and up-dating the data material and fabrication costs for new technology, adding an efficiency-maximization search to the program, and a total cost minimization search based on the capital and operating costs of the system. In addition, permanent magnets will be considered as an option to the super-conducting quadrupoles. Finally, an investigation of the beamlet losses as a function of background pressure which is determined by the vacuum system pumping power may be of some significance in determining the system efficiency.

LIACEP is being modified and expanded to better aid in guiding research and technology development to support the induction linac as a driver for inertial fusion.

CURRENT AND CHARGE NEUTRALIZATION OF THE HIF BEAM AFTER FINAL FOCUS

Elementary calculations show that propagation of an ion beam to a fusion pellet may require a high degree of neutralization. Here we give the solution for coinjecting electrons in such a way that the ion beam becomes charge-and-current neutralized without significantly heating up the ion beam. The required solution consists of an electron emitting cathode and a transparent grid anode placed at a separation $d = (\pi/2-1)\ 3\sqrt{2}/2\ d_{CL}$ and charged to a voltage $V = (m_e/m_i)\ V_i$, where d_{CL} is the separation given by the Child-Langmuir law which would be required to produce the neutralizing electron current density and velocity in the absence of the ion beam which would match the ions which have been accelerated to a voltage V_i.

BENDING A HIGH CURRENT BEAM

The focussing of multiple beams on target requires that individual beams be guided to their respective ports without signficant perturbations induced by the bends in the transport lines. While this is straightforward for low current beams, which may be treated by single particle optical methods, a high current beam is subject to uncontrolled forces from image charges in the vacuum pipes. In general, the combination of natural momentum and current variations occurring within a pulse produces a transverse perturbation which cannot be easily compensated. A preliminary study of this phenomenon has resulted in a design and operation procedure which minimizes the induced perturbations by a considerable factor (1-2 orders of magnitude improvement in deflection compared with naive design). The remaining perturbation is small enough that it should not affect spot size on target if reasonable criteria on current, energy, etc. are met. Work is continuing in this area to refine the design criteria and integrate them into the final focus model.

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