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A COMPARISON OF THE DESIGN AND COSTS OF INDUCTION LINAC DRIVERS FOR INERTIAL FUSION USING IONS OF DIFFERING MASS

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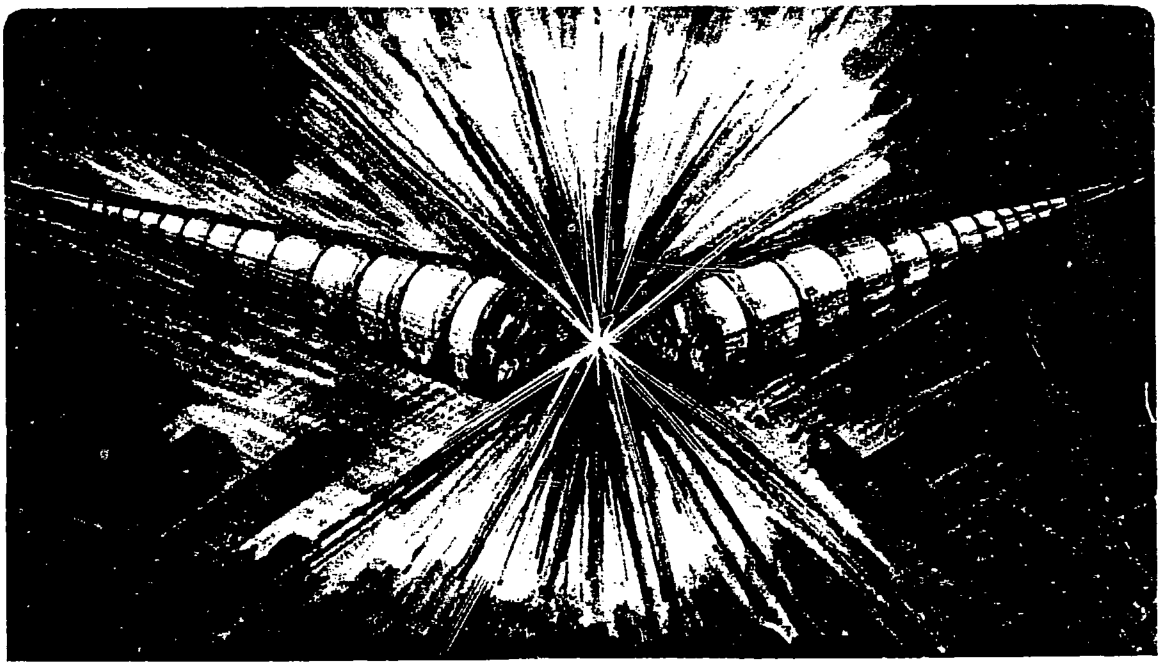

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An induction linear accelerator that produces an energetic (5 to 20 GeV) beam of heavy (130 to 238 amu) ions is a prime candidate as a driver for inertial fusion. The required accelerator output parameters for an ion species can be determined from the target requirements for a given fusion energy yield. The cost and efficiency of various accelerator configurations to produce the required output parameters can be determined to aid in the selection of the lowest cost accelerator design option. In this study, we compare the cost of various accelerator configurations that will produce various target yields and fusion powers using cesium 133 ions with those using mercury 200 ions, and report extensively on some 600 MJ target yield results.

The Lindl-Mark single shell target gain curves were used in this study.[1] For a given target yield, the accelerator output energy W is determined based on the upper bound of the Lindl-Mark "best estimate" gain curve. Also determined is the $r^{3/2}R$ parameter where R is the range of the ions in g/cm^2 in the target material and r is the target spot radius which must satisfy

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$$0.1\ W^{1/3} \leq r \leq 0.2\ W^{1/3}\ (W,\ MJ;\ r,\ cm) \quad .$$

From the $r^{3/2}R$ parameter and the target spot radius, the desired range can be determined. From this range for a given ion, the required ion kinetic energy can be specified. From the specified ion kinetic energy and the target spot radius for a given angle of convergence the normalized emittance of the accelerator beamlets can be determined assuming that this feature dominates the convergence beam dynamics. This completes the description of the required accelerator output. Also associated with the target gain and beam energy is a peak power requirement which is independently modulated by the drift lines between the accelerator and the reactor. The cost and performance of the accelerator can be determined using a modified LIACEP code[2] for various accelerator configurations.

We have investigated target yields between 300 and 1200 MJ and fusion powers between 1500 and 6000 MW for both the cesium and mercury ions with a range of charge states. Accelerator configurations accommodating 4, 8, and 16 simultaneous beamlets were studied, as well as various values of the initial and depressed tunes of the transport lattice.

For a 600 MJ yield, single shell target using the minimum target spot radius, the accelerator output requirements for cesium and mercury beams are given in Table I, based on an angle of convergence in the final focussing lenses of 0.015 radians and a spot radius due only to the beam emittance. The efficiency and normalized costs of the accelerators with an initial tune of 75° and a depressed tune of 24°, an ion charge state of +1, and a pulse repetition frequency of 5 hertz for a fusion power of 3000 MW are also given for accelerator configurations of 4, 8, and 16 beamlets. The normalized cost using the mercury ions is a minimum for 8 beamlets, while that for the cesium ions occurs at 16 or more beamlets. For both ion types, the efficiency is greater that 20%, resulting in a ratio of fusion power to accelerator input power greater that 28. As in previous designs, the minimum cost designs are also near the maximum efficiency designs.

The normalized costs can be reduced by increasing the charge state, increasing the initial tune and decreasing the depressed tune. For example, the normalized cost of the mercury ion accelerator can be reduced from 1.227 to 0.6393 by increasing the ion charge state to +3, increasing the number of beamlets to 16, increasing the initial tune to 85°, and decreasing the depressed tune to 10.5°. From considerations of the perveance in the final focussing system, this accelerator system will require at least 16 beams focussed on target. The perveance in the final focus scales as

$$K \propto \frac{WA}{N(\beta\gamma)^3 \varepsilon_i \tau_p} \left(\frac{q}{A}\right)^2$$

where W is the accelerator output energy, τ_p is the pulse length, N is number of beamlets, ε_i is the ion kinetic energy and q/A is the charge to mass ratio of the ions. Its value is a scale measure of the degree of space charge induced blowup of the spot radius. For a given accelerator output energy the charge state of the cesium ions cannot be increased as much as that of the mercury ions to reduce the normalized cost of the accelerator for a reasonable number of beamlets without the perveance exceeding an acceptable value consistent with a small focal spot.

In summary, very large cost reductions can be made on heavy ion induction linac drivers for inertial fusion. These reductions are possible by increasing the charge state, increasing the undepressed tune and optimizing the number of beamlets.

References

1. J.D. Lindl and J. W-K Mark, "Revised Gain Curves for Single Shell Ion-Beam Targets," 1982 Laser Program Annual Report, (C.D. Hendricks and G.R. Grow, editors), Lawrence Livermore Laboratory Report UCRL-50021-82, Livermore, CA, p. 3-19 (1983).
2. J. Hovingh, V.O. Brady, A. Faltens, E.Hoyer, and E.P. Lee," Cost/Performance Analysis of an Induction Linac Drive System for Inertial Fusion," Proc. 11th Symp. on Fusion Engineering, Austin, Texas (November, 1985) (to be published).

Table I. Accelerator Output Characteristics Efficiency and Normalized Costs for a 600 MJ Target Yield for Cesium and Mercury Ions

Ion		Cesium			Mercury	
Mass, (A) amu		133			200	
Energy, (W) MJ		4.25			4.25	
Gain (G)		141			141	
Spot Radius, (r) cm		0.162			0.162	
Range, (R) g/cm^2		0.160			0.160	
Un-normalized emittance, (ε) μm-radians		24.3			24.3	
$\beta\gamma$		.338			0.356	
Normalized emittance, (ε_N) μm-radians		8.21			8.65	
Ion kinetic energy, (ε_i) GeV		6.885			11.46	
Charge State (q)		+1			+1	
Initial Tune (σ_0)		75°			75°	
Depressed Tune (σ)		24°			24°	
Number of Beamlets	4	8	16	4	8	16
Normalized Cost	1.247	1.121	1.090	1.275	1.227	1.276
Efficiency, (η)%	24.9	25.9	29.2	21.5	24.6	23.0
ηG	35	35	41	30	35	32
Recirculatory Power Fraction			7%		9%	

*Initial voltage is 50 MV.