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COMPUTER SIMULATION OF MULTIPLE-BEAM FINAL FOCUSING SYSTEMS FOR HEAVY ION FUSION*

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Summary

Heavy Ion Fusion ignition systems which employ multiple beams to achieve the required ignition energies on a target offer a number of advantages over systems with a small number of beams. In addition to the higher phase space densities which can be transported, the use of multiple lenses reduces the chromatic and geometric aberrations in the final focusing system. Computer simulations are described here which show that, at least for a modest number of beams, the transverse space charge interaction between adjacent beams does not appear to cause significant final spot aberrations for parameters consistent with pellet ignition requirements.

Introduction

The importance of space charge aberrations in limiting the current densities which can be focused onto a Heavy Ion Fusion target has been found to depend strongly on both the beam distribution entering the final reactor chamber[1] and the lens system used in the final focusing[2,3]. Because of the large number of free parameters in the design of such a final lens system, an exhaustive picture of the detailed relationship between beam phase space distribution and achievable spot size has not yet been obtained. However, lens systems appear to exist which can achieve ignition-level densities and which are not unduly sensitive to the details of beam current distribution.

In the absence of a significant body of experimental experience at the required beam intensities, it is attractive to exploit the large safety factor which results from the use of multiple beam systems to relax the phase space density required in each individual beam. In view of the tendency observed in simulations for space charge non-linearities to steepen during beam convergence, when a multi-beam ensemble is compared to a single beam with the same total angular divergence, it might be expected that the non-uniformities across such a system could cause significant space charge aberrations by the time the beam reaches the target. The work presented here seeks to demonstrate that, for a relevant set of parameters, the problems arising from such non-linearities can be substantially offset by the combination of the beam rigidity and the short interaction region in the final reactor chamber.

Simulation Results

In order to estimate the importance of the transverse beam-beam interactions during convergence onto the target, several computer simulations have been performed in which the orbits of several thousand particles are followed as they evolve in their self-consistent transverse electric fields. The computer code used is of the particle-in-cell kind utilizing for these simulations 16K particles on a 128 by 128 grid. However some runs were checked using a 256 by 256 grid with no significant differences observed. To facilitate the numerics, only a four beam system is considered. A Kapchinskij-Vladimiriskij distribution was used for each of the beams because the phase space occupied by such a beam will remain a hard-edged ellipse in the presence of linear forces and the effect of non-linearities is therefore easy to observe. Such a system also eliminates complications arising from any non-linearities caused by a non-uniform density across each beam individually. In addition, the hard edge of the distribution permits reduction of the inter-beam spacing to permit examination of the worst case of nearly parallel beams.

The numerical experiments were run by starting with the desired distribution at the spot and then allowing the beam to expand. The simulation is stopped when the system reaches the chamber wall and the macroscopic characteristics of the beam are then measured. The measured beam divergence, rms size, the locations of the beam centers and the average velocities are then used to define the focusing system parameters and to initialize a new distribution of particles with a K-V distribution so as to converge onto the spot. In practice because of statistical errors in measuring the beam parameters and because the adaptive regridding in the code is not exactly reversible, some tuning of the focusing system parameters of order 2%, particularly for the angle of individual beam convergence, can be necessary to refocus the beam at the desired spot.

Figure 1 shows four views of the desired four dimensional phase space distribution of the beam when initially at the spot. The beam parameters are chosen to correspond to the focused spot discussed by Garren, et al.[2] That is, the simulation is done in normalized units and corresponds to a family of solutions, but a typical member of that family corresponds to 830 A of 10 GeV singly ionized uranium and a 9.1 mm-mr emittance focused onto a 4 mm spot 10 m from the final lens. The beams are assumed to converge at an angle chosen so that the angular spread between beam centers is 1.5 times the angular spread within each of the beams. When the beam is allowed to expand self-consistently, the radius of each beam has expanded by 24 times and the distance between beam centers is 3 times the expanded individual beam radius when the beam has drifted the 10 m to the chamber wall.

Figure 2 is a set of phase space views of the four beams after they have expanded and been refocused. Some distortion is visible in the phase space plots but it is not of any substantial consequence to the spot density distribution. The rms spot radius is within 2% of the starting value. In addition, the focusing system does not appear to be sensitive to either current variation or magnet misalignment. For example, if the fourfold symmetry of the system is disturbed by translating one of the four beams by 1.5 mm at the start of convergence from the chamber wall, the resulting growth of the rms spot area by 5% is virtually the same as what would occur, because of the purely geometric result of misalignment, in a beam without space charge. Similarly, if the current is changed by 5% the spot area is changed by only 3%.

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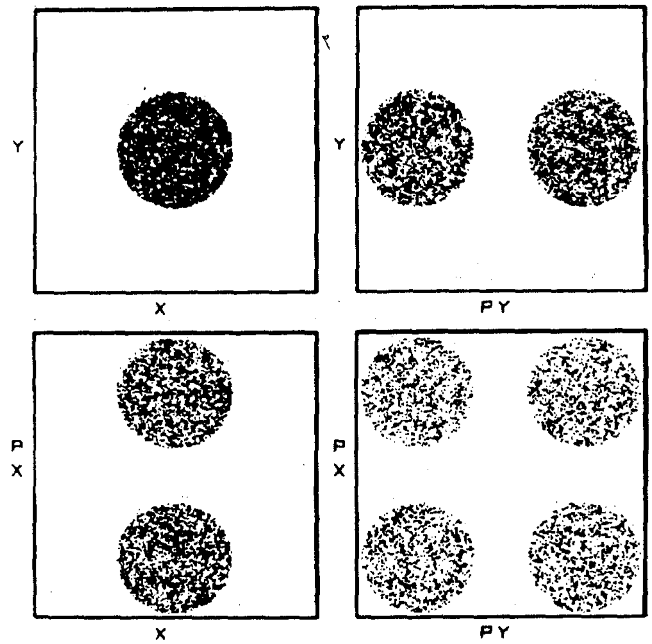

Fig. 1. Four views of the desired phase space distribution at the target spot.

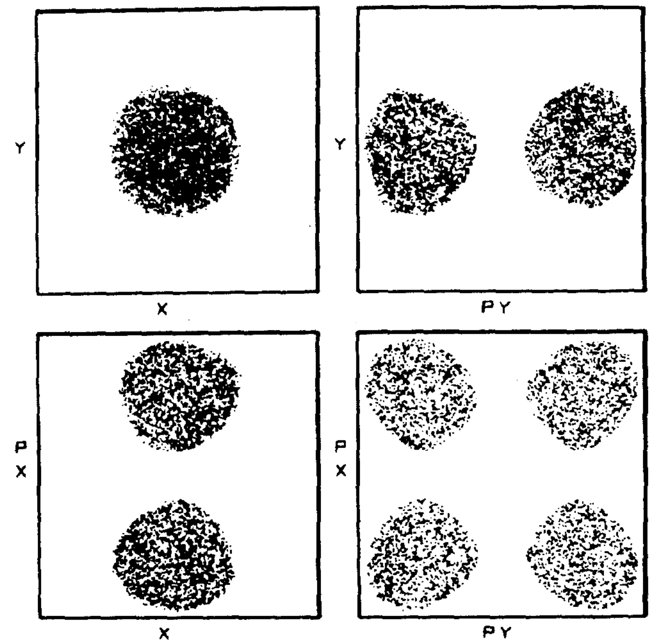

Fig. 2. Four views of the actual phase space distribution at the target of the focused beam.

Conclusion

The simulations described here concentrated on the transverse space charge interactions in a four beam system which can focus 3.3 kA at a 10 m distance from a final lens. The substantial currents and nearly parallel angles were chosen to give at least a representative estimate of what might occur in a realistic ignition system. The smallness of any effects observed reinforces the argument that multiple beam focusing systems, because of the advantages they offer, are a promising method of focusing the required power onto an inertial confinement fusion target.

References

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