Heavy Ion, Recirculating Linac, Design Optimization

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Abstract

Cost optimization is important to the development of high-current, heavy-ion accelerators for power production based on inertial confinement fusion. Two heavy-ion, recirculating linac configurations are examined that eliminate the necessity to provide reset pulses for the cores used in the linac induction accelerating modules.

I. Introduction

A high-current, heavy-ion accelerator has emerged as a promising candidate for a driver for power production based on inertial confinement fusion (ICF). However, a major concern has been and will continue to be the cost of the system. A multi-beam recirculating induction linac introduces new complexities but may offer significant cost reduction due to reuse of expensive components.[1]

Many configurations or recirculators are possible. Optimization is required to find the lowest cost consistent with constraints that emerge from recirculation. While a recirculator will need fewer linac modules and quadrupoles, pulsed dipoles must be included that follow a carefully defined ramp that matches the acceleration schedule. In addition, consideration must be given to power losses in the dipoles as well as in the induction cores used in the linac modules. These losses may have a significant impact on system efficiency. In particular, we examine losses associated with the necessity to reset the induction cores. We consider configurations that use the reset pulse to accelerate beam bunches traveling in the reverse direction and thus potentially improve system efficiency and/or reduce cost.

II. Optimization

Parameter optimization is carried out using a fast desktop code RECIRC.[2] The code is used to develop and examine self-consistent conceptual designs and includes dipole losses. The same generic lattice is used throughout the accelerator. Every lattice contains a quadrupole and a short vacuum/diagnostic section, plus a dipole or a linac module. Occupations fractions are assigned, or calculated, for these components relative to the circumference. A series of lattices may contain dipole or linac modules, or any combination of the two. Self-consistency in the occupation fractions can be achieved independent of the external constraints on the location of these components.

Turn-by-turn integration determines the number of turns (typically 40 to 60) required to achieve the assumed final energy. Rerunning the program with different assumed dipole-rise times is the mechanism for adjusting the number of turns. Multiple beams ("beamlets") are assumed. In any recirculator design the principal assumption, and technical issue, is beam stability. Making the assumption that the beam is stable, RECIRC calculations are based on the transport formulas of Lee.[3] Further details concerning optional current amplification and dipole time dependence schemes that are in RECIRC can be found in ref. 2.

As the beam velocity increases the rotation time becomes rather short. For example, 10 GeV, mass 150, ions have a rotation time of 19 μsec for a 2 km circumference. When one considers the cost and complexity of providing a core reset pulse for every accelerating pulse, the question arises whether there is a way to convert the reset pulse into an additional accelerating pulse, for beams traveling in the opposite direction. The reset pulses would then, in effect, be automatically provided. The argument becomes even more compelling if the beam bunch expands to more than one-half of the circumference (as in some recent HIF recirculator schemes) so that more power is expended on reset than on the acceleration.

Among the number of possible configurations we singled out two for discussion. First, we consider the addition of a third linac to a conventional two-linac racetrack. This scheme offers a simple way to avoid the problem of opposing beam bunches meeting in the same channel, but adds considerable length to the dipole transport. Second, we consider a scheme that involves dividing the "beamlet" channels into two groups, one group for each direction of travel.

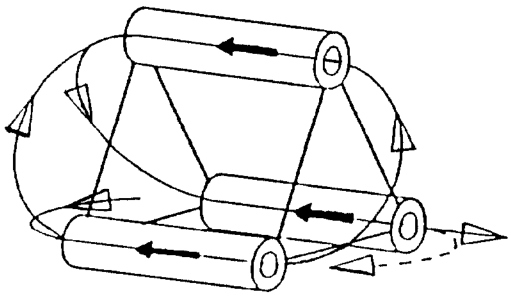

Figure 1

III. A Three-Linac Recirculator

Figure 1 shows an arrangement that allows beam bunches to be accelerated in three linacs in succession without interference. The acceleration schedule is arranged so that a beam pulse passes through each of the three linacs in opposite directions on successive passes. This allows the operation of the induction cores from saturation to saturation without the need for "resetting" the inductive cores. By using three beams in the system at once, we can arrange their relative positions so that all three (one in each linac) are moving in the same direction at the same time. When the beams reach the end of their respective linacs, each enters a bend that directs it back to the linac located 60 degrees clockwise (viewed from the end) from the linac from which it has just emerged. The dipole magnet that is required to deflect the beam direction at the end of each linac is constant in direction and must be ramped in time together with the other dipoles in the bends. The problem with injection and extraction remains but, again, it is no more complicated than the conventional racetrack and, with three beams moving in the same direction at the same time but displaced laterally, some efficiencies in final transport may be possible.

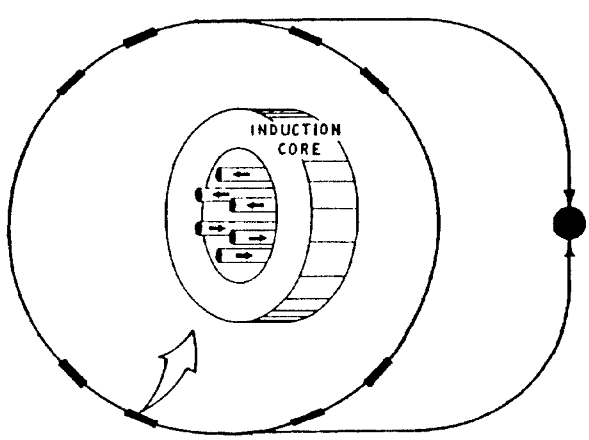

Figure 2

IV. A Bi-Directional Recirculator

Figure 2 shows an arrangement of the multiple beams in a conventional racetrack configuration that allows two groups of bunches to travel in opposite directions without interference. Six beamlets are shown, divided into two groups, three above and three below the median plane. The dipole fields for the first three are in the opposite direction from those of the second three. This grouping is chosen to allow easier injection and extraction. The pulse timing is arranged so that when one group is in the center of one linac, the other group is in the center of the other. The two groups of bunches pass each other in the center of the rings. The induction cores encircle all six beamlets.

This configuration requires the use of separate channels in the rings, the normal assumption. The effect of each group of beam bunches being physically offset from the central axis may need study. This would not appear to be a problem except perhaps in the case of heavy beam loading. The principal feature of this scheme is its simplicity. It is identical in structure and number of components with the basic arrangement in ref. 2.

V. Core Losses

The principal advantage of these concepts was first thought to be an increase in efficiency in that energy expended in resetting accelerator modules would be saved. We find the induction core losses per pulse (Courtesy of A. Faltens, M. Newton, J. Barnard) by the approximate formula, $\text{Loss(Joules/m}^3) = 100 + 140\Delta B^{1.8}/\Delta t^{.8}$ where ΔB is the flux swing in Tesla and Δt is the pulse duration in μsec. This formula applies to the Metglas most often assumed in recent conceptual designs. The first term represents hysteresis loss and the second is eddy current losses.

We have incorporated this loss formula into RECIRC. Initial results indicate that present conceptual HIF recirculator designs using Metglas linacs and acceleration schedules that maintain short bunch lengths relative to the circumference have little efficiency to gain from these new geometries. Still to be investigated are the potential advantages the geometries might offer in final transport. Ultimately these nonresetting recirculators are simply excursions into new geometries and parameters that enlarge the possibilities available not only to HIF but also to entirely new applications.

VI. Acknowledgements

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References

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