Basic Features of a Reactor Driver Concept for Indirect Drive

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Abstract

In 1985 a heavy-ion inertial-fusion reactor driver has been conceived (HIBALL II) for direct pellet drive (ablation after ion bombardment). Indirect drive by incoherent light generated by ion-heated converters requires about 100 times higher power concentration, but is regarded to be safer with respect to symmetry requirements. Out of the numerous concepts for so-called non-Liouvillean particle stacking, molecular ion dissociation by laser light was chosen for our design example. Final bunching of the ion beam is done with resonant metglass induction modules at low frequency in the buncher rings.

1 INTRODUCTION

A heavy-ion driven fusion (HIF) reactor driver using indirect-drive (drive by incoherent radiation) targets has been a focus of our work in the last two years, a replacement for HIBALL [1]. The specific deposition power in the target must be greater than in the HIBALL (direct drive) design by two orders of magnitude, in order to obtain high radiation conversion efficiency. Although a factor of 5 can be obtained by overlapping several beams in the same converter, it is also necessary to reduce the focal spot area and shorten the pulse length (15 ns effective length) to reach the required 10^4TW/g without increasing the required drive energy (5 MJ).

To obtain the required phase-space density, at least once a "non-Liouvillean" stacking process must be used, an in-flight manipulation of the ions' mass or charge connected with a transition from one storage ring into another [2]. A number of possible processes, most of them using laser light have been recognized (table I, [3]). We would prefer molecular ion dissociation for a number of reasons.

2 MOLECULAR IONS

Molecular ions useful in drivers need one havy ion (e.g., U) to give high stopping power, bound to one or two lighter atoms. Binding energy should be >5 eV to prevent dissociation by Lorentz forces while passing through bending and focusing magnets, and to minimize cross-sections for losses in ion-ion collisions in the storage rings. The mass ratio should not be too large between the heavy and the light constituents, otherwise the beam separation between the two rings becomes difficult; the example of IH^+ used in earlier studies [3] is not very practical. On the other hand, the masses should not be nearly equal, otherwise half of the ion energy is lost. A good compromise would be oxides, nitrides or fluorides of heavy metals. We choose as our nominal example UO^+ which dissociates into U^+ and neutral O. The binding and dissociation energies are known.

Multistep excitation, if efficient enough to dissociate the ion molecule completely within a flight path of several meters, would be an advantage over one-step excitation because powerful hard-ultraviolet lasers do not yet exist. By careful choice of a molecule (see, e.g., [4]), the hope is that all transitions can be excited with the same laser line. A power density level of 100 MW/cm^2 has been estimated to be sufficient, assuming a typical last-step photo-ionization cross-section of 10^{-17}cm^2. Further experiments on molecular ion spectroscopy are needed to make firmer estimates. The instantaneous power level is no problem with the state of the art, though lasers with the high repetition rate required have not yet been built.

3 BUNCHER SCHEME

At the targets the beam bunches must be compressed to an effective (rectangular-pulse-equivalent) lenth of 15 ns. This is done with RF voltages in the final, the "buncher" rings. Keeping them at this length for a longer travelling time would require an extremely high RF amplitude, even at high RF frequencies. However, "imploding" the bunches ballistically with a "time focus" just at the target, is much easier. To prepare the implosion, the bunches are tilted in longitudinal phase-space; the energy of leading particles is decreased, and late particles are accelerated. If the bunches are long during this process, the synchrotron frequency (of the longitudinal oscillations in the "tilting" bucket) is also low, and there is enough time to gradually change the particle energies: the implosion is prepared in a great number of turns (30 to 200) in which the RF cavity is passed repeatedly.

Low-frequency (<2 MHz) reentrant RF cavities of voltages of 1 to 10 MV, however, are not trivial. Vacuum cavities become extremely voluminous and present a vacuum quality problem to the ring whose vacuum pressure is required to be $< 10^{-10}$hPa. To make the cavities more compact, they must be loaded with magnetic material of high saturation induction density: tapewound mumetal, metglass [5] or permalloy powder cores; ferrites saturate at too low a field strength. High magnetic permeability is of less importance. The space of the magnet cores is separated from the machine vacuum by cylindrical ceramic windows. In order not to overstress them, and to minimize capacitive effects of the core material, the latter is

Table 1: Candidate Reactions For Non-Liouvillean Beam Manupulation

"In-Beam Chemistry"	Examples	Problems/Remarks/Status
Molecule Dissociation	$UO^+ + nh\nu \rightarrow U^+ + O$ (multi-step)	o.k.
	$I_2^+ + h\nu \rightarrow 2I^+ + e^-$	Unknown branching (I^0?)
Photo Ionization	$Bi^+ + \Sigma h\nu \rightarrow Bi^{++} + e^-$	Space-charge problem with Bi^{++}
Stimulated Recombination	$Bi^{++} + e^- + h\nu \rightarrow Bi^+ + 2h\nu$	To be studied; ideal candidate if it works
Multiple-Photon Ionization of Negative Ions	$Au^- + \Sigma h\nu$ $Au^+ + 2e^-$	Ideally good dispersion; best available data; best known overall case
Electron cooling	Ion+e^-	Dielectronic recombination?

subdivided into modules of a voltage of e.g. 10 kV each, and each module is tuned by lumped capacitors (ceramic) to the working frequency. A large number of modules is driven parallel as a common load to one power amplifier, if necessary with a cathode-follower as a final stage. It has been estimated that a module length of 10 cm is possible at 0.25 MHz; a voltage amplitude of 7 MV would require 700 modules per ring, occupying 10% of the total ring circumference.

4 DRIVER ARCHITECTURE

The linac is nearly identical to the HIBALL II linac. We use a transfer ring and conventional stacking ("wrapping") technique to store the beams in 24 storage rings (see fig. 1). In these rings the beam is slightly prebunched into 42 bunches each to facilitate the bunch transfer into the buncher rings. The non-Liouvillean transfer by molecular-ion dissociation condenses the bunches 21-fold.

We keep two bunches in each buncher ring. This helps to guarantee left/right symmetry in the irradiation of the two target radiators. The beam line lengths must be identical within ± 10cm. If equal filling of each storage ring could be guaranteed, a scenario with only one bunch per buncher ring could be an alternative.

Table 2 lists the design criteria. The full parameter list has to be omitted here for space reasons.

Compared with HIBALL II, the driver architecture has become much simpler. This demonstrates nicely some of the advantages in the adoption of non-Liouvillean stacking techniques.

5 REFERENCES

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Table 2: Storage Ring Constraints

	Transverse	Long.(LMI)	Magnet Tech.
TR	$-\Delta\nu < 0.25$	$(\Delta p/p)^2 U_\Sigma / I \gg \mid Z \mid$	normal cond.
SR	$-\Delta\nu < 0.25$	$(\Delta p/p)^2 U_\Sigma / I \gg 10\ \Omega$	supercond.
BR	$-\Delta\nu < 2$ before bunch. $-\Delta\nu < \nu/2$ before extr.	$(\Delta p/p)^2 U_\Sigma / I > 10\ \Omega$	supercond.
BL & reactor chamber	no limitations; SC compensation by actively ignited dilute plasma		

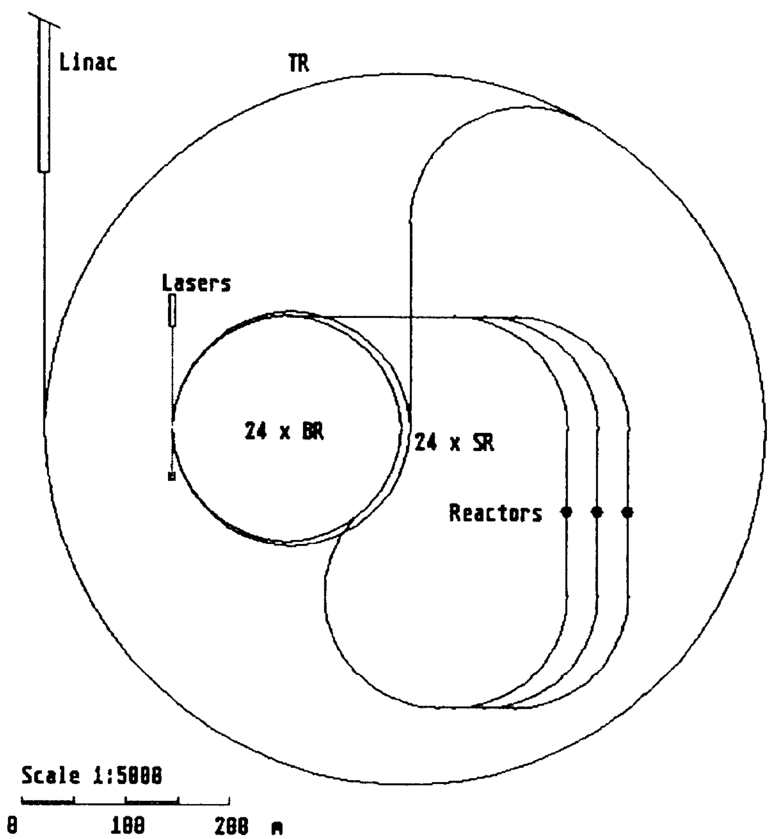

Figure 1: The driver architecture