AN ALTERNATIVE SCHEME FOR HEAVY ION DRIVEN INERTIAL FUSION

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Abstract

In order to achieve the required beam pulse length of about 5 ns necessary for ignition, present scenarios for Heavy Ion Driven Inertial Fusion (HIDIF) propose induction linacs for the final bunch compression. This, because final compression does not appear to be possible in the rings because of the huge velocity spread of the large bunches. In order to preserve a more economic in-ring, multi-pass buncher RF system, it is proposed to split these bunches into four families of sub-bunches, which are separated by gaps in energy. The target is located in the centre of the holding ring and the resulting scenario is far more compact and economic than the one presently discussed [1].

1 INTRODUCTION

HIDIF employs 10 GeV ion beams impinging simultaneously on the converters of a pellet target. A total energy of a 3-4 MJ is required for ignition, which has to be delivered at a rate of 700 TW, i.e. within about 5 ns. The short duration of the beam pulse is particularly hard to meet.

The difficulty resides mainly in the large velocity spread (2%) of the time-compressed bunch that limits the time available for the compression process to less than one revolution period. The ensuing RF voltages are far beyond present technology.

2 MAIN FEATURES OF THE ALTERNATIVE SCHEME

In this paper it is proposed to split these bunches into, say, four families of sub-bunches of height $dp/p = 0.29\%$ and separated by gaps of twice that height. The four families are accelerated in the injector rings to their respective energies, then transferred into RF holding buckets of the main ring and finally simultaneously rotated by a powerful RF system. The merging of the beams from the different injector rings takes advantage of the momentum gap between the families and is accomplished by double septa in a high-dispersion by-pass.

Major parts of the *Reference Scheme* [1] appear in the *Alternative Scheme*. For example, the complete 10 GeV injector linac remains unchanged, the storage

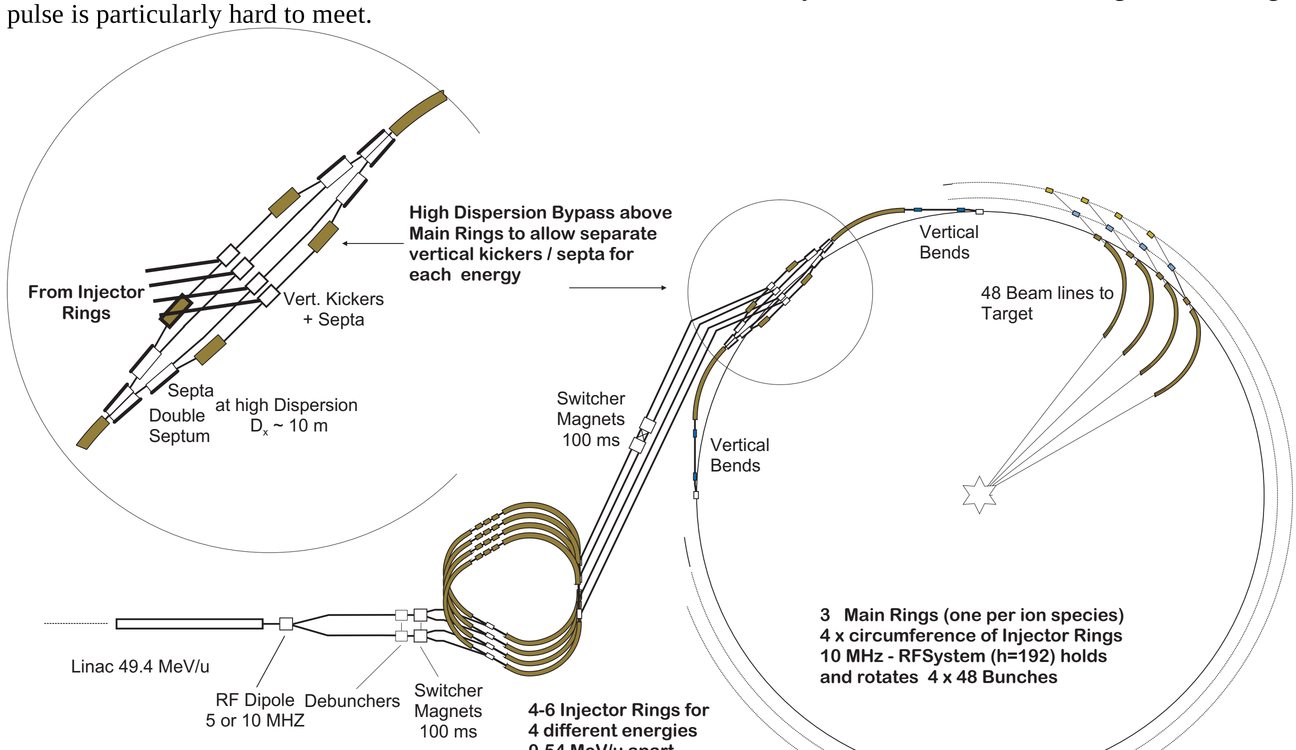

Figure 1: Alternative HIDIF scheme without external buncher induction linac

rings are the same but are now termed injector rings, as all storage is taking place in the main rings. The main rings, one per ion species, four times as large as the injector rings, are of nearly circular shape and feature a lattice of 48 superperiods. Each period holds an extraction system into one beam line towards the target at the centre of the ring. As can be seen in the scenario, Fig. 1, the regular shape of the ring and the radial final transport beam lines make sense only with a target of strong rotational symmetry.

The energy parameters of the Alternative Scheme are exactly those of the Reference Scheme. The filling time varies according to the number of injector rings: Doubling it (and halving the duty cycle of the linac) allows the filling of the main rings with only four injector rings. The maximum number of turns injected into the smaller rings without excessive losses appears to be about 20 [2]. An RF dipole 'unfunnels' at 5 MHz into two channels which in turn are swapped by switching magnets every 100 µs (corresponding to the possible maximum of 20 turns injected [2]) between pairs of rings. It is easy to show that with 6 injector rings and more switching magnets, the RF dipole then operating at 10 MHz, one can conserve the filling time and duty cycle of the Reference Scheme.

Table 1: Parameters of Alternative Scheme (Where different from Reference Scheme)

Scenario		**Altern.**	**Refer.**
Linac duty cycle		0.315	0.615
Filling time per ion	ms	0.9	0.45
Injector rings			
Number		4	12
Circumference	m	442.8	442.8
Number of bunches		12	12
RF harmonic number : (Acceleration)		48 (24)	12
RF freq. (fundamental)	MHz	10 (5)	2.5
RF volt. (fundamental)	MV	1 (11)	1
Main rings			
Circumference	m	1771.2	
Nr of machine periods		48	
Number of bunches		192	
RF harmonic number		192	
RF freq. (fundamental)	MHz	10	
RF volt. (fundamental)	MV	~25	

The main rings perform multiple operations: Holding the four bunch families while the injector rings continue to transfer batches to them until all 4 × 48 bunches have arrived, while accumulating the other ion species. Once the accumulation is finished, the simultaneous compression by bunch rotation of the four bunch families is performed. The latter is necessarily a fast process, to be accomplished within two machine turns. The bunches of the different energies are then phase-aligned (cf. Figs. 2 and 4), four bunches per machine period. At this moment they are kicked out such that they arrive simultaneously at the target. The outer of the concentric main rings for the three ions eject their beams through the extraction channels of the inner rings, which need injection septa for them. The kicker pulsers are already reset when the faster ions pass.

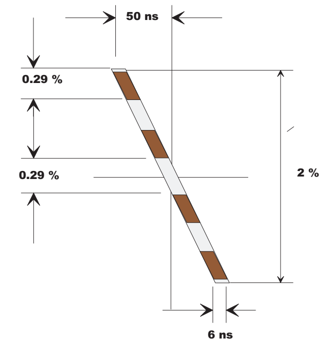

Figure 2: The four sub-bunches within the frame of the Reference bunch at the end of the final rotation.

An obvious complication arises from the fact, that each bunch family rotates at a different speed in the main ring. This means, that no kicker gap can be provided for consecutive injection of batches from the injector. The solution envisaged is a ¼ circumference overpass on top of the regular structure which provides a high-dispersion insertion (of normalised dispersion $D_x/\sqrt{\beta_x} \approx 4\ m^{1/2}$). The momentum gap of 0.58% between the energy levels allows separation of the orbits by 4 septa and the insertion of a separate vertical injection systems. Note that the by-pass (as well as the injector rings!) is common for all ion species.

3 IN-RING BUNCH ROTATION

The best way to avoid prohibitive bunch heights is to have a larger number of smaller bunches. However, the number of bunches is limited by the number of beamlines one is able to concentrate near the final focus – the present figure of 48 seems already to be an upper limit. For this reason it is proposed to split each of the 48 large bunches of the 2.5 MHz RF system of the Reference scheme into four small 10-MHz "Sub"-bunches circulating at slightly different energies. At a certain moment the four bunches are aligned in the same way as the large bunch of the Reference scheme at the exit of the buncher linac. Fig. 2 shows the four bunches in the frame of the reference bunch. It turned out that *simultaneous holding and rotation of the four families works only at revolution harmonics.* Accordingly, energy levels corresponding to RF frequency ratios of 191:192:193:194 were chosen. This fact allows the use of one single h=192 RF system if all cavities are properly phased. Even with the higher RF, the final phase of the rotation of the sub-bunches need to be performed in one main ring turn.

4 ACCSIM SIMULATION OF THE CRUCIAL RF MANIPULATIONS

The versatile ACCSIM code [3] used cannot yet simulate processes including more than one machine. For this reason, the two RF operations essential for the scenario have been studied separately:

- The 20-turn injection of the 200 MHz chopped linac beam into the waiting 10 MHz barrier buckets of the *Injector ring* and the subsequent acceleration to the energies of +0.54 MeV and +1.1 MeV within 20 or 40 turns, respectively.
- The final rotation of flat (barrier-held) bunches of the four energy levels within ~2 turns of the main ring. Only the results of this study are presented here

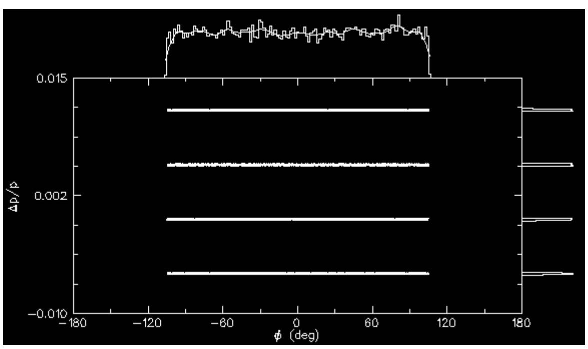

Figure 3: Barrier-held sub-bunches before rotation

Starting from a barrier bucket configuration (Fig.3), the RF is sharply raised to 12 MV (10 MHz) and 2 MV (20MHz). After nearly two turns the sub-bunches are rotated and aligned (Fig. 4; Note that the abscissa is in RF degrees). After a final drift of about 300 m the bunches coincide (not shown here). Their length is 22 degrees at 10 MHz or 6 ns, as in the Reference [1].

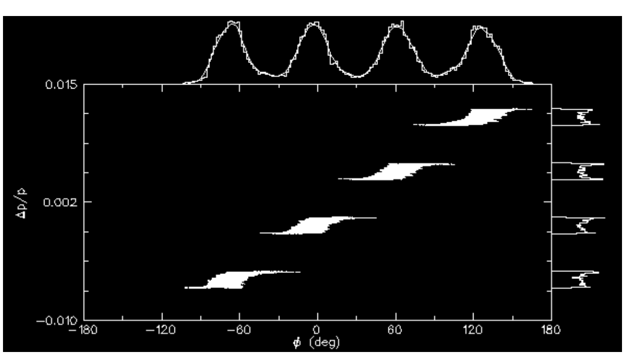

Figure 4: Rotated and aligned sub-bunches before extraction from the main ring.

5 CONCLUSION

As the proposed scheme is a variant of the Reference scheme, the first thing to look at is whether it could possibly be simpler and cheaper. For this purpose Table 2 records the quantities of basic hardware components of both scenarios.

Table 2: Comparison of Required Quantities of Major Components

Component	Quantity in Scheme	
	Alt	**Reference**
Beamlines (pipe length)		
Ring circumferences	7072 m	5304 m
Delay lines		23898 m
Bypass	880 m	
Final Transport	14400 m	14400 m
Buncher Linac (24-beamlines matrices!)		2640 m
Total	**23352 m**	**46246 m**
Magnetic Bending (angles)		
Rings	14 π	24 π
Delay lines		72 π
Final transport	24 π	24 π
Total	**38 π**	**120 π**
Kickers + Septa		
Bypass: Injection	10	
Rings: Extraction	148	144
Delay lines		132
Ion merging		96
Total	**158**	**372**

The savings suggested by the above figures are spectacular: Grosso modo the Alternative Scheme shrinks the Reference hardware (except the linac) to half size! Of course, this is to be weighed against the difficulties of producing practical designs for some of the concepts; a problem that is not absent in the Reference Scheme either..

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[3] F.W. Jones, G.H. Mackenzie, H. Schönauer, “ACCSIM – A Program to Simulate the Accumulation of Intense Proton Beams”, 14th Int. Conf. on High Energy Acc, p.[1409]/199, Tsukuba 1989.