

A MODIFICATION PLAN OF THE KEK 500MEV BOOSTER TO AN ALL-ION ACCELERATORS (AN INJECTOR-FREE SYNCHROTRON)*

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Abstract

A medium-energy synchrotron capable of accelerating all ion species based on a novel technology of the induction synchrotron has been proposed as an all-ion accelerator (AIA). The AIA without any specific injector employs a strong focusing lattice for ion-beam guiding and induction acceleration cells for acceleration and longitudinal capture, which are driven by a novel switching power supply. All ions, including cluster ions in their possible and arbitrary charge state, are accelerated in a single accelerator. A plan to modify the existing KEK 500MeV Booster synchrotron to the AIA is under consideration. Important aspects in a 200 kV ion source, and specific features in the orbit correction associated with the low-field injection and induction acceleration, are described.

INTRODUCTION

A modification plan of the KEK 500MeV Booster synchrotron (BS) has been proposed for the experiments to realize the AIA [1], where the BS used as the injector for the KEK 12GeV-PS is reformed as shown in Fig.1. The PoP-experiment of the AIA is divided into three phases: the first (phase-I) is a low intensity and a low energy operation to confirm the induction acceleration [2, 3] in the wide energy regime from 90 keV/u to 20 MeV/u, the second (phase-II) is for higher energy acceleration, and the last (phase-III) is with more species of ion. Beam parameters at each phase are summarized in Table 1. The phase-I experiment for argon is scheduled to start at the beginning of 2008.

The BS is a 20 Hz rapid cycle synchrotron with combined function magnets, excited by a resonant power supply. The required acceleration voltage, $V_{acc} = \rho C_0 dB/dt$, is a crucial parameter in a rapid cycle synchrotron. In the phase-I, the AC current amplitude is reduced so as

to allow the low acceleration voltage operation without any change in the existing magnet power supply (MPS). In the phase-II, the operation frequency is changed from 20 Hz to 10 Hz by increasing the capacitance of the MPS by a factor of four. A maximum energy of 3-4 GeV/ion is expected, keeping the same magnet ramping rate as in the phase-I. A large modification, such as replacement of the MPS by the patterned power supply, will be required in the last phase. This slow cycle operation allows the slow extraction of ions. Operation parameters are summarized in Table 2, and its overview of waveforms of a main magnetic field are shown in Fig.2. To increase a beam intensity for the latter phases, a multi-turn injection will be employed.

The modification plan of the BS, especially on its hardware, for PoP-experiment phase-I is described here.

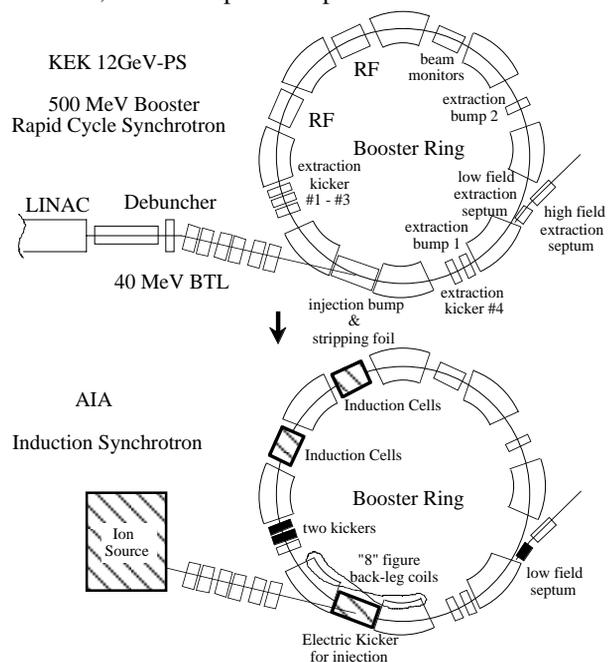


Figure 1: Overview of a modification plan from BS to a PoP-AIA. Hatched boxes indicate devices to be replaced to new ones, and black boxes to be removed.

* Work supported by a Grant-In-Aid for Creative Scientific Research (KAKENHI 15GS0217).

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Table 1: Target parameters for PoP-experiments of AIA.

PoP-exp. phase		I	II	III
Ion species		Ar	Ar, C, (Au)	(all)
Particle numbers	[ppp]	1E10	1E10	(*)
Repetition	[pps]	20	10	0.25-20
Top energy	[MeV/u]	20	70-90	70
Beam current	[eμA]	0.6	0.3	0.6
Beam power	[kW]	0.5	0.9-1.2	(*)

“(*)” indicates a parameter which depends on ion species.

Table 2: Operation parameters for PoP-experiments.

PoP-exp. phase		BS	I	II	III
Bmin.	[T]	0.28	0.029	0.028	(*)
Bmax.	[T]	1.1	0.44	0.85	< 1.1
Repetition	[pps]	20	20	10	0.25-20
(V _{acc.}) _{max.}	[kV]	6	3	3	(*)
T ₀ at injection	[μs]	0.44	9	9	(*)
T ₀ at extraction	[μs]	0.17	0.6	0.3	(*)

“(V_{acc.})_{max.}” is a maximum voltage for acceleration. “T₀” is a revolution time period. “(*)” indicates a parameter which depends on ion species.

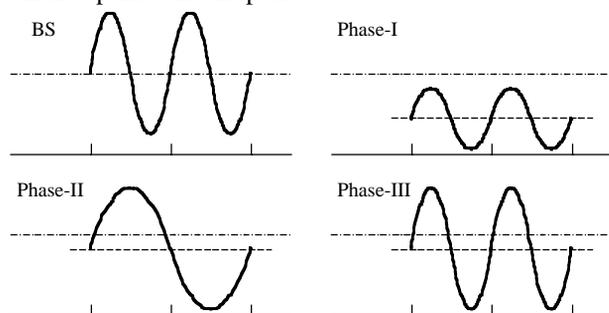


Figure 2: Field pattern of the main magnet for each phase.

ACCELERATOR COMPLEX FOR POP-EXPERIMENT: PHASE-I

Key issues to achieve the phase-I, such as an ion source, low-energy beam transport, low-energy injection, main magnets, acceleration, and extraction, are described below. Details of the induction acceleration including its control and acceleration scenario will be given in the companion paper [4] and the extraction line for applications will be discussed in another companion paper [5].

Ion Source

A new ion source will be installed, which is based on an electron cyclotron resonance (ECR) method [6]. A small prototype of the ECR ion source is now under construction for the phase-I. A travelling wave tube (TWT) with an output of 500 W at 9.4 GHz is used as a power source. In order to increase the μ-wave power density in the interaction region, a horn antenna is used. A mirror-type magnetic field configuration produced by permanent magnets confines a plasma. The magnetic flux

density is 0.336 T at resonance, and its maximum value is 0.6 T. All devices are electrically floated at 200 kV, for DC acceleration. Ions are extracted with an electric potential of -30 kV from the plasma chamber, a specific charge state is separated, and accelerated up to 200 kV finally. The ion source is set at 12 m upstream from the injection point. Transverse emittances from an ion source will be measured and optimised with this small prototype this year.

It seems to be difficult to produce higher charge state of ions, and this problem is now under consideration. It is necessary to improve its performance, because a momentum difference between charge states, $Z = n+$ and $(n - 1)+$ is very small in the order of 1% for heavy ions and there is a possibility to capture such different beams at the same time.

Low Energy Beam Transport (LEBT)

A part of the existing 40 MeV beam transport is used for the LEBT. A length of the LEBT is 12 m. Six quadrupole magnets are used to transport a beam core with 5 mm mrad transverse emittances and a momentum acceptance of 1%. Fig.3 shows twiss-parameters. A maximum beam width is 46 mm in horizontal, which is acceptable for the existing beam transport line. Each excitation current for quadrupole and dipole magnets is 10 times smaller, due to the difference in momentum.

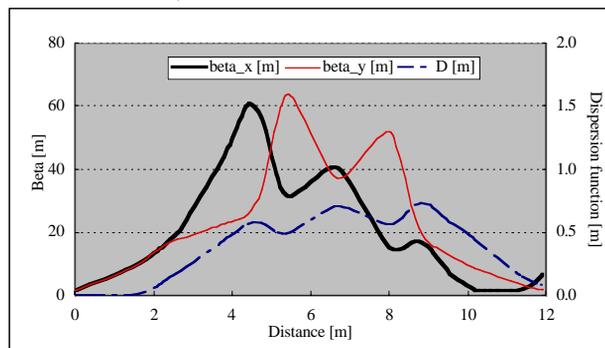


Figure 3: Twiss-parameters of LEBT. A black line, a thin red line and a blue dotted line indicate a horizontal beta-function, a vertical beta-function and a dispersion function, respectively.

Injection

An injection method of a H⁻ beam into the BS for proton acceleration was multi-turn injection by the charge state conversion method with a stripping foil. In the PoP-experiment, one-turn injection by an electric kicker system is applied for phase-I. One of power supplies for the extraction kicker magnet system is with a slightly modification. An equivalent circuit is shown in Fig.4. A deflection angle of 11.25 degrees and a mechanical aperture of W200mm x H40mm are required, then the potential of an electrode is 16 kV for 1m-long. Fig.5 shows its potential at the electrode, operated at 31 kV for one hour. The electric field must be vanished just after an injection. A turn-off time is required to be less than 5 μs

for phase-I. A fall-time is $1.4 \mu\text{s}$ including a spike due to an inductive reflection at connectors, so this electric kicker system satisfies the above demand for the phase-I.

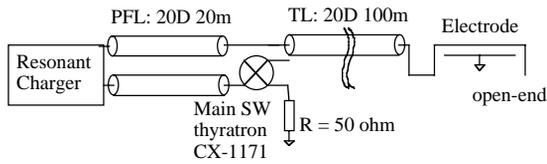


Figure 4: Equivalent circuit of an injection kicker.

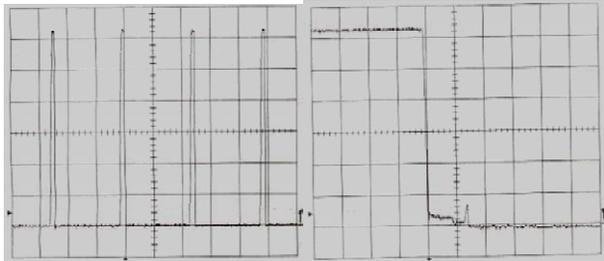


Figure 5: Potential wave forms of an injection kicker at 31 kV operation. Units of the horizontal axis are 20 ms/div. for a left figure and $1 \mu\text{s}/\text{div}$. for a right. Unit of the vertical axis is 5 kV/div. The black elliptic circle above a right figure indicates an injected beam and the open one indicates a circulating beam.

Main Magnets and Power Supply

A main magnet system is available without a large modification for the phase-I. The present 0.1% stability in the excitation current at 0.29 T reduces to the order of 1% at the 0.029 T operation. This must be solved in a way of real time ΔR feed-back system [6]. In addition, remanent fields of 10 Gauss are issues for the COD correction. We prepare a correction system by using back-leg coils of main magnets, excited by additional DC power supplies which feed several amperes and are effective during an injection period. These coils are wound around two nearby main magnets, as are making like "8" figure to cancel out a large voltage, induced from main magnets.

Acceleration

Four induction acceleration cells of the induction system are used for acceleration and another four for confinement. An acceleration pulse longer than $2 \mu\text{s}$ with a tolerable level of the droop is required. To meet this demand, the existing induction cell with 1 turn primary, which had been used in the induction synchrotron experiment [7], was modified. Two turns winding increased the core inductance by a factor of four. Consequently, a flat voltage pulse was realized [4]. To get the induction acceleration system more reliable, various tests and improvements are under way [8,9].

Extraction

A beam length at the top field is controlled by a pulse-duration between barrier voltages. Then, the beam can be extracted by the same systems of the BS. The existing extraction system is composed of two bump, four kicker

and two septum magnets. Each magnetic field can be reduced to 40% for phase-I. All extraction magnets are installed in vacuum chambers and those magnetic materials become sources of outgas, which may deteriorate an acceleration efficiency by recombination with electrons. We are considering to remove several magnets; for example, two kickers and a low-field septum.

In the case of a long bunch, more than 100 ns, it is necessary to modify the existing power supply for the extraction kicker magnet system. It is required several times electric power to produce a long pulse, but the existing system does not have enough capacity. The combined method with an excitation using a reflection and a parallel drive of two resonant chargers is applicable and capable to extract by only one kicker magnet for phase-I (Fig.6). The other pulse generator of the fast extraction kicker system from KEK 12GeV-PS will be applicable for more than 600 ns pulse at phase-II and -III.

The other extraction magnets have no large problem to the extent of $1 \mu\text{s}$.

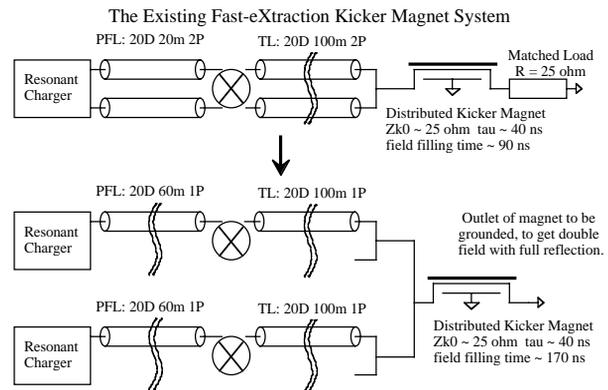


Figure 6: A modification of the kicker magnet system to extract a long bunch.

SUMMARY

A modification plan for the PoP-experiment phase-I is described here. New ion source, two induction acceleration devices, an electric injection kicker and correction devices are main hardware to be replaced. The PoP-experiment will be started at the beginning of 2008.

ACKNOWLEDGEMENTS

We are greatly indebted to Dr. Eiki Tojyo for a lot of advises on the ECR ion source. We wish to thank to staffs of KEK 12GeV-PS accelerator for a lot of supports.

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