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POSSIBILITY OF ACCELERATING THE LIGHT NUCLEUS BY KEK PROTON SYNCHROTRON

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Summary

An accelerating method of the light nuclei with charge-mass ratio of 1/2 by use of the proton synchrotron system of KEK, is described. The description is mainly on the ring accelerator system and the ion source is excepted. The poor manpower and fund were large constraint conditions to find the acceleration method.

As the velocities of the extracted nuclear beam from the linac and from the booster synchrotron are half the present proton's in this method, wider range of accelerating frequency than the present one is necessary for the ordinary acceleration method in the main ring synchrotorn. To avoid much modification in r.f. system coming from the extension of frequency range, a method called multi-stage acceleration is applied.

Introduction

The search of the acceleration method was carried out under a principle that the introduction of huge equipment and new large investment to realize the plan must be suppressed strictly, because there is extreme lack of manpower and fund coming from our big project 'TRISTAN'. The underlying schemes of acceleration are as follows:

(A) The radio frequency of linac is left unchanged. The field gradient, however, must be modified slightly.

(B) The ranges of radio frequency of the booster and main ring remain unchanged. The frequency patterns must be changed a little.

(C) The magnetic field patterns are varied, though the high power equipment in the magnet system of both synchrotrons are not touched.

Acceleration in the Linac

Electrons bounded to nucleus injected to the linac are assumed to be fully stripped. Then the nuclear beam is accelerated by 4π-mode in RF phase and a slightly modified field gradient to be ejected with a half velocity of the present proton's. The rigidity is almost equal to the present proton's.

The result of the preliminary experiment on 4π-mode acceleration is reported in this conference.[1]

Acceleration in the Booster Synchrotron

The range of the accelerating frequency in the booster is kept in the present one (1.6 MHz - 6.0 MHz), because the extension of the frequency range brings the sharp modifications in the r.f. accelerating system and this offends against the principle stated in the opening. Therefore, the revolution frequency of the nuclear beam at the injection is half the accelerating frequency (harmonic number h = 1 at present), that is, the haromonic number h for the nuclear acceleration becomes 2.

A couple of bunches are accelerated to 75 MeV/nucleon, and the main parameters at the end of acceleration are;

the final accelerating frequency f_{acc} = 6.0 MHz ,
β_{max} = 0.38 (β; v/c) ,
the maximum magnetic guiding field B = 7.7 kG
(70 % of the present value) .

Calculation shows 80 % accelerating voltage of the present one is enough to accelerate the nuclear beam.

The procedure of the phase synchronization at beam transfer to the main ring needs no modification because the accelerating frequency at the extraction from the booster and the waiting frequency of the main ring are same as the present value (6.0 MHz). The pulse current of the extraction kicker magnets are made lower than now, but the pulse duration should be stretched longer than now because a couple of bunches are extracted instead of a single bunch in the present case. The injection porch of magnetic field of the main ring accumulates 9 bunches of 500 MeV proton beam for 450 ms at present. For nuclear beam, as the booster accelerates two bunches in a cylce, the main ring accumulates 18 (2 × 9) bunches in the injection porch for the same period.

Acceleration in the Main Ring Synchrotron

The range of the accelerating frequency in the main ring synchrotron is also kept in the present one (6 MHz - 8 MHz) for the same reason as the booster. The changing ratio of the accelerating frequency is 1.33. On the other hand, β_{max} of the nulcear beam corresponding to the maximum magnetic field is 0.989 and the minimum value β_{min} = 0.38 (= β_{max} in the booster synchrotron). So the necessary changing ratio of the frequency must be β_{max}/β_{min} = 2.6. As this ratio exceeds 1.33 by far, it is impossible to accelerate the beam to the maximum magnetic field by the ordinary way. Then the multi-stage acceleration method was thought out.

This method can accelerate the nuclear beam to the maximum magnetic field keeping the range of the accelerating frequency in the present value. The process of acceleration is as follows:

(1) The main ring accepts 18 bunches from the booster synchronously with the accelerating frequency of 6 MHz. They are accelerated to 8 MHz with the harmonic number of 18 in the first place. At the end of this first acceleration,

T = 150 MeV/nucleon (T; kinetic energy) ,
β = 0.5 ,
f_{rev} = 444 kHz (f_{rev}; revolution frequency) ,
B = 1.46 kG .

(2) A flat pass is formed in the magnetic field when the process (1) is finished and the 18 buches are debunched at the biginning of the flat pass. After debunching, the beam is rebunched by resetting the accelerating frequency to a value which is an integer multiple of the revolution frequency nearest the starting frequency (6 MHz). The integer is 13, which is the new harmonic numebr and the reset freqeuncy is 5.78 MHz.

(3) After rebunching in (2), the beam of 13 bunches are accelerated to 8 MHz again. At the end of the second acceleration,

T = 370 MeV/nucleon ,
β = 0.7 ,
f_{rev} = 615 kHz ,
B = 2.44 kG .

(4) The second flat pass is formed at the end of the process (3). Debunching and rebunching are

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carried out again. The accelerating frequency at rebunching is 5.54 MHz and the new harmonic number is 9.

(5) The final acceleration to the maximum energy 5.5 GeV/nucleon is carried out by swinging the accelerating freqeuncy from 5.54 MHz to 7.78 MHz after rebunching in the process (4).

The overall changing ratio of the accelerating frequency with the multi-stage acceleration is

$$(8/6)(8/5.78)(7.87/5.54) = 2.26 \quad ,$$

and equals to β_{max}/β_{min}.

As debunching is a technique being used in slow extraction of the beam and rebunching is equivalent to trapping of injected coasting beam from the linac, no new technique is necessary to develop for the process.

Fig. 1 shows an example of the pattern of the magnetic field of the main ring to accelerate the nuclear beam and some parameters on the way of acceleration.

Fig. 2 shows a result of a preliminary test on debunching and rebunching by use of the present proton beam. The picture is a mountain view display of the signals from a bunch monitor. The lower five traces show the bunch signals with h = 9, f_{acc} = 7.9148 MHz, the middle four lines show debunching of the beam and the upper seven traces show the rebunched signals with h = 7, f_{acc} = 6.1560 MHz. The test is carried out on the flat top of the magnetic field.

A problem is in the transition energy. It is 5.3 GeV/nucleon, and is just before the top energy unluckily. Some countermeasures for that are examined. For example, the transition energy is raised up over the top energy by adjustment of tune, or the extraction energy is reduced to little lower level than the transition energy.

Conclusion

The fundamental obstacle can not be found at present for the accelerating procedure above mentioned, that is, it is possible to accelerate the nuclear beam without addition of some huge equipment to the present synchrotorn system or sharp modification of the system.

Reference

1. E. Takasaki et al., "4π-mode Acceleration in KEK 20 MeV Proton Linac", paper presented at this conference.

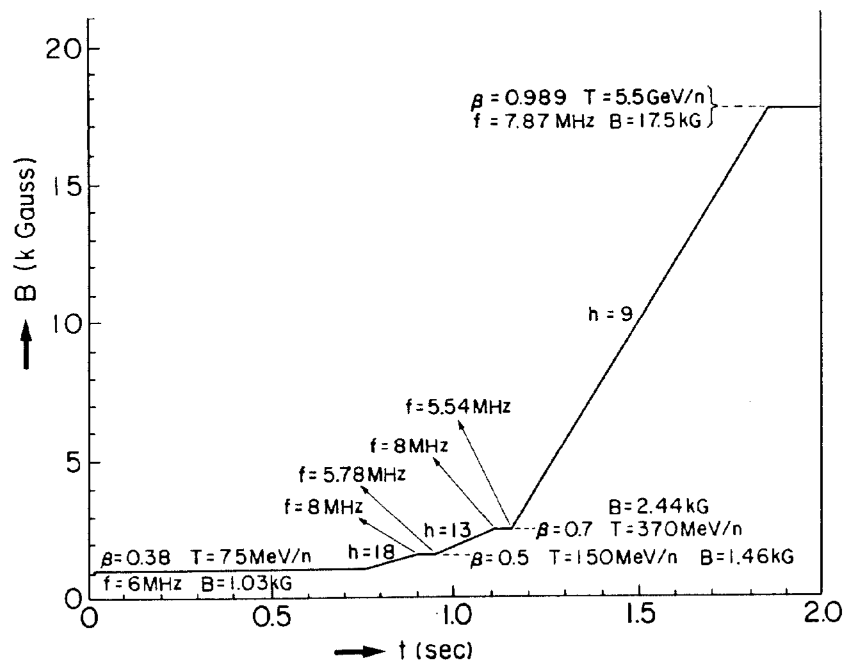

Fig. 1 An example of magnetic field pattern and some parameters on the way of acceleration in main ring.

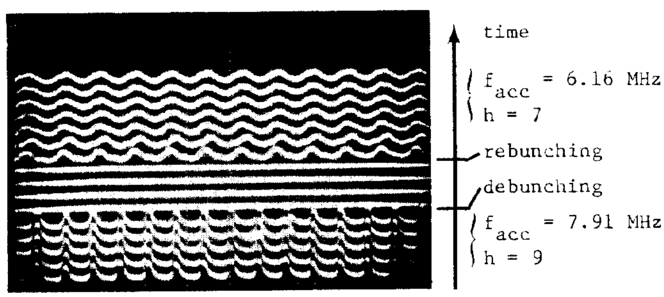

Fig. 2 A mountain view display of debunching and rebunching process at the flat top of main ring with proton beam.