The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Accel-Decel Strong Focusing Method for a Tandem Accelerator

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Abstract

A new acceleration method for a tandem accelerator was designed and tested to obtain a high-intensity low-energy beam for an astro-nuclear experiment. The method uses accel-decel strong focusing. In a normal tandem accelerator the electric potential uniformly increases to the maximum voltage V, however, in the new method the potential goes up to V abruptly in a short length (=1/5 of the total length), then goes down to V/4 in the same short length, again goes up to V and down to V/4, and finally goes up to V. The beam is strongly focused due to alternating focusing and defocusing actions. The transmission of low-energy ^{12}C beam was found to be an order of magnitude increased by this method.

1 Introduction

Astro-nuclear reactions take place at low energy and their cross sections are very small due to the Coulomb barrier. To measure such reactions we need very high-intensity low-energy beams together with high-efficiency detectors and particular targets.

At Kyushu university tandem accelerator laboratory (KUTL), an experiment on $^4He(^{12}C,^{16}O)\gamma$ reaction down to $E(^{12}C)$ = 2.8 MeV (E_{cm} = 0.7 MeV) is planned. This reaction is a famous key reaction in astrophysics and many experimental attempts have been made so far, however, no precise data have been obtained yet. The cross section of the reaction is very small as 1 pbarn at E_{cm} = 0.7 MeV.

First, we use the inverse kinematics to detect ^{16}O particles in all the c.m. solid angle, instead of detecting γ rays in a small solid angle. Therefore the detection efficiency is very high as about 35 % which is the fraction of 3^+ charge state of ^{16}O. Second, the ^4He gas target has to be thick enough and windowless because of the low-energy experiment. A new high-performance windowless gas target has already been developed at KUTL [1]. The target is now 10 Torr x 3 cm thick, and it will be made thicker as 25 Torr x 3 cm which is practically the maximum thickness because the energy spread of the ^{12}C beam and of ^{16}O recoil should be below a certain level.

The last way to increase the counting rate in the experiment is to increase the beam intensity. To make the $^4He(^{12}C,^{16}O)\gamma$ experiment at E_{cm} = 0.7 MeV with 10% statistical accuracy in one month, we need a high-intensity 2.8 MeV ^{12}C beam of about 10 particle μA. Higher beam intensity is more preferable.

The beam optics of KUTL 10 MV tandem accelerator is designed for the operation above 6 MV. When the terminal voltage is decreased from 6 MV to 1 MV, the beam transmission through the tandem accelerator becomes worse as 1/10 or less.

So far in the operation above 6 MV, the ^{12}C beam intensity of about 100 nA has been obtained. The beam intensity is limited by the electric loading due to the secondary electrons in the accelerator tube.

To get a ^{12}C beam of 2.8 MeV, the terminal voltage is 1.35 MV or 0.9 MV provided that the ^{12}C beam of 0.1 MeV is injected into the tandem accelerator. At this low voltage, the loading becomes weak, however, the beam transmission becomes much worse due to weak focusing. Therefore to obtain 10 pμA ^{12}C beam has been considered as an impractical hope.

Our new idea of application of accel-decel strong-focusing to the tandem accelerator turns the impractical hope to a practical plan. The beam transmission in the accel-decel operation at 1 MV is estimated to be higher than the transmission in the normal operation at 6 MV. Besides the electric loading caused by the 10 pμA beam can be stably controlled. The new method is described in this report.

2 Strong focusing in tandem accelerator

2.1 Focusing in normal tandem operation

In the normal operation of a tandem accelerator, the electric potential uniformly increases from the tandem entrance and the exit to the center terminal. The uniformity is necessary to suppress the electric discharge and to realize the maximum acceleration voltage.

The focusing and defocusing actions in the tandem accelerator is as follows;

1) focusing due to electric field increase at the entrance,
2) focusing due to acceleration from the entrance to the center terminal,
3) defocusing due to electric field decrease at the entrance of the terminal,
4) defocusing during the charge exchange process in the terminal,
5) focusing due to the field increase at the exit of the terminal,
6) focusing due to acceleration from the terminal to the tandem exit,
7) defocusing due to electric field decrease at the exit.

As the whole the beam is focused. All the focusing or defocusing forces except for 4) are proportional to the electric field (proportional to the terminal voltage). At low acceleration voltage, therefore, the focusing becomes weak and the beam transmission becomes worse.

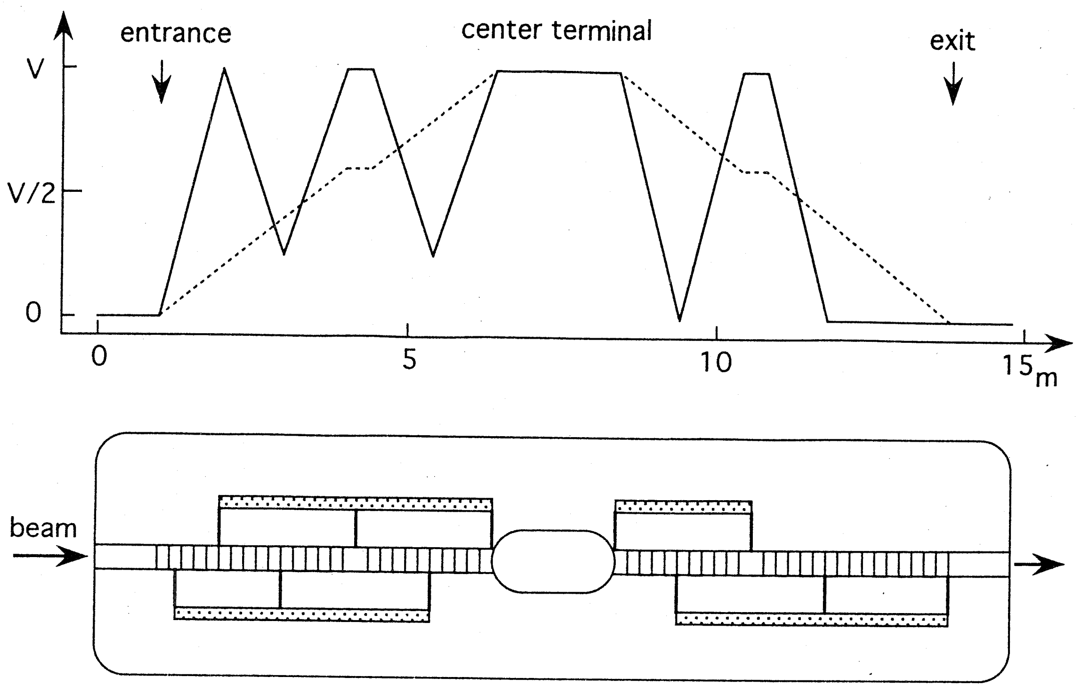

Fig. 1. Upper part: Potential profiles along the beam axis in a tandem accelerator for the normal operation (dashed curve) and for the accel-decel operation (solid one). Lower part: Schematic view for the four shorting bars to make the accel-decel potential profile. The scale along the beam axis is common for both the upper and lower parts.

2.2 Is small tandem a good solution ?

Is there any way to recover the focusing force at low voltage acceleration ? For the strong focusing force, strong electric field is essentially necessary.

The straightforward solution may be install of a short-length small tandem accelerator. However, it is not a practical solution because (a) a small tandem is not cheap, (b) a new beam transport system is also necessary, (c) new place for the small tandem and the beam line is necessary, (d) a long time is necessary to design, to install, and to adjust the small tandem and the beam transport system. We have no extra fund, no place and no long-time.

2.3 New idea of accel-decel strong focusing

The strong electric field in the low-voltage operation of the high-voltage tandem accelerator is easily produced if whole the accelerating sections except for a short part is shorted to be on the same potential. The shorting method, however, does not increase the total focusing force.

We arrived at a new idea of accel-decel method. In this method the electric potential first goes up in a short length (strong focusing), next the potential goes down and up in a short length like the einzel lens. The down-up process must has focusing force. If the down-up process is repeated until reaching to the center terminal, strong focusing must be achieved.

3 Easy switching to accel-decel mode

The upper part of Figure 1 shows the electric potential profile (solid) for the accel-decel method together with the normal potential (dashed). The minimum voltage in the accel-decel method was determined as 1/4 of the maximum voltage from the estimation of beam acceptance. Much more accel-decel actions may produce stronger focusing, however, resulting stronger electric field causes severe problems of spark discharge. The potential profile in Fig. 1 is a practical solution. In the region from the center terminal to the exit the electric field is not sensitive to the beam transmission, and an easily accomplished potential was chosen. As described in the following sections, the accel-decel operation was found to be very successful to produce high-intensity low-energy beam.

Only 4 shorting bars are necessary to realize the accel-decel method, as shown in the lower part of Fig. 2. The shorting bars disturb the electric field in the tandem accelerator tank, however, spark discharge does not occur because the accelerating voltage is low in the accel-decel operation.

The shorting bars can easily set and easily removed. Therefore we can switch the tandem accelerator both in the normal mode and in the accel-decel mode. This means that we obtained a small tandem accelerator at the cost of only 4 shorting bars. We need no new beam line, no extra space, no long-time construction, no large fund.

4 Estimation of beam acceptance

KUTL tandem accelerator has a foil stripper with an effective aperture of 10 mm in diameter and has apertures of 28 mm in diameter in all the 40 accelerating tubes. The beam envelope was calculated by multiplying the successive beam-transfer 2 x 2 matrices for the accelerating tubes. The diameter of the envelope was required to be smaller than 10 mm at the terminal and smaller than 20 mm everywhere in the accelerator. The 28-mm-diameter aperture was thought to have a effective aperture of 20 mm in diameter because of the aberration near the edge of the aperture. The beam acceptance of the accelerator was defined as the emittance of the beam that satisfied the above requirement. In the following we consider, for simplicity, the acceptance of the beam only from the tandem entrance to the center terminal, because the acceptance from the terminal to the exit is usually larger and has no restriction, and the effects of the charge stripper is hard to estimate.

As the accelerating section is axial symmetrical with respect to the beam axis, the acceptance was calculated in one dimension, and the beam transmission was assumed to be proportional to square of the 1-dimensional acceptance.

The estimated beam transmission in the normal operation at 1 MV was about 1/4 of that at 6 MV. In practical case, the transmission became about 1/10. This is because the beam envelope calculated at 1 MV has a waist at a quadrupole lens in the beam injection line and such a waist is impossible to make. Hence the practical beam transmission at 1 MV is 2-3 times smaller than the estimated value.

The estimated beam transmission in accel-decel operation at 1 MV is about 13 times higher than that in the normal operation at 1 MV. This implies that the accel-decel transmission at 1 MV is estimated to be about 3 times higher than the normal transmission at 6 MV. It implies the accel-decel operation is a very promising method to obtain a high-intensity low-energy beam.

When the beam emittance is smaller than the accelerator acceptance, the beam transmission becomes 100 %. We expect nearly 100 % beam transmission in the accel-decel operation.

5 Performance of accel-decel operation

5.1 High beam transmission

For a terminal voltage of 1 MV, a ^{12}C beam of about 1 μA was accelerated both in the accel-decel method and in the normal mode. The beam transmission (sum of the whole charge states) was 46 % and 4.7 % in the accel-decel method and in the normal method, respectively. The beam intensity increased about 10 times. The accel-decel method was proved to be very effective way to obtain a high intensity low-energy beam.

We think that the beam transmission can be increased up to about 90 %, because the present test was made using a carbon foil stripper of 7 $\mu g/cm^2$ which was too thick for the low energy ^{12}C beam. Indeed the accelerated ^{12}C beam in the above test had broad energy width. If the gas stripper under construction is used, the transmission will increase and the energy width will become sharp.

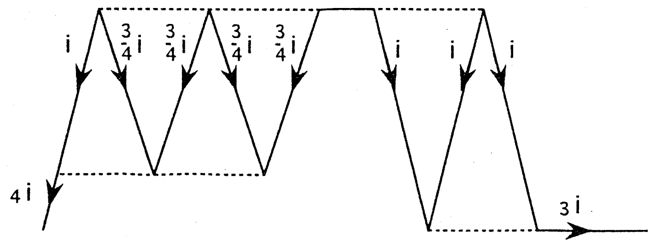

Fig. 2 Electric current along the acceleration tube in the accel-decel operation. Dotted lines show the shorting bars.

5.2 Stability for high intensity beam

In the normal mode the electric current is uniform along the acceleration tubes, whereas in the accel-decel mode there are many paths for the electric current as shown in Figure 2. Besides the electric field in the accel decel mode is 4-5 times steeper. than that in the normal mode. Hence the current necessary for the accel-decel operation is 35/2 times higher than that in the normal operation. KUTL tandem accelerator has 3 pellet chains and can bring the electric charge of about 300 μA which is enough to hold 2.5 MV in the accel-decel operation.

The high current is another advantage of the accel-decel operation. For higher-intensity beam acceleration, higher current is necessary to stabilize the terminal voltage. Since 150-300 μA current is used for the accel-decel operation, the acceleration of 10 pμA beam is expected to be stably made.

6 Conclusion

A new accel-decel operation of a tandem accelerator has been found to be a very promising way to obtain high-intensity low-energy beam with a very low cost and a short time. A high-energy tandem accelerator is easily changed to a small tandem. The method will greatly promote astro-nuclear experiments.

Acknowledgments

The authors wish to thank H. Koga and T. Maeda for their supports in preparation and adjusting accessories in the tandem accelerator. This work is supported in part by Japan Ministry for Education, Science and Culture under Grant-in-Aids No. 10874044 and No. 08404017.

References

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