FIRST OPERATION OF PROTON INDUCTION LINAC

S. Kawasaki*, Y. Kubota, A. Miyahara, and K. Yamamoto**
Institute of Plasma Physics
Nagoya University
Nagoya, 464 Japan

Abstract

A prototype of proton induction linac was developed to study the beam dynamics and the operational characteristics in this type of the accelerator specifically in the case of the intense ion beam acceleration. The driver system is composed of three identical unit modules, each of which consists three toroidal cores made of laminated silicon-iron foil of 0.1 mm thick and the driving circuit linked with the cores. The accelerating field of 28 kV/module is obtained typically during a period of 2 - 3 μsec. A proton beam of about 200 mA is extracted directly with the field driven inductively by the first module and then accelerated with succeeding two units to give the particles of about 60 keV at the output of the modules. Preliminary results of the measurements of the beam characters are given with the design of the device.

Introduction

This report describes the experiments carried out at the Institute of Plasma Physics in Nagoya Univ., in order to develope the technology and the physics of the ion induction linac, working with a long pulse duration of the order of a few μsec. The final goal of the experiment will be the full understanding of the behavior of the accelerated particles in the ion induction linac. The application of the technology could be in the developement of a new efficient method for accelerating medium or heavy ion beams.

The use of induction field for getting ions of multi(kilo)amperes and megavolts is supposed to have considerable merits and thereby the concept of the heavy ion induction linac was proposed in the course of the heavy ion fusion research as a promising candidate of particle drivers[1]. So far there are only a few examples where the ion induction linac were studied experimentally in rather particular situations for neutralized ion beams[2,3].

We describe here the experiment of proton inductive acceleration, which is operated in the reversed mode of the conventional electron induction one. Aiming at the long pulse operation (essential to the heavy ion accelerator), the design parameters of the devices including the core material, the driving circuit and other elements were determined.

Experimental System

A schematic figure of the whole system is shown in Fig. 1. In a unit module a conductive cylindrical structure with radial fins makes a driving circuit linked with three toroidal magnetic cores. These modules are stacked in series vertically. At the top of the device a compact ion source of the electron beam discharge type is mounted, from which a proton beam is extracted by the inductive field made by the driving current flowing in the first module. The beam is then accelerated with the succeeding two modules. An array of toroidal permanent magnets placed coaxially along the axis of the device supplies the beam with focusing and stability. We will give brief descriptions below on these hardware elements in a little more detail.

Cores

Many factors such as the magnetic and electric properties, manufacturing process and the economic factors involved in the selection of the cores have to be considered. Our choice of the core material is a laminated silicon-iron tape of 0.1 mm thick. It is commercially available with the moderate price from Nihon Cut Core Transformer Co.,Ltd. The cores are stacked coaxially with mylar sheets for insulation between the cores. The dimentions of the core are determined so as to be consistent with the necessary volt-sec required from the designed values of beam duration (2 μsec) and acceleration per module (25 kV). Parameters of the core are given in the Table I.

Driving Circuit

A simple LC discharge circuit gives the magnetization current of a few kA per module. Capacitors of 4 μF charged up to 28 kV are discharged to the driving circuits of the three modules connected in parallel. The trigger element is a pressurized spark gap. An electrical schematic of the circuit is shown in the Fig. 2. The examples of the applied voltage (nearly equal to the inductive voltage per module) and the current flowing in the driving circuit linked with the cores are also shown in the Figs. 3 and 4. The effect of the core saturation is clearly seen in these figs. The duration of the acceleration pulse is 2 - 3 μsec for the low driving voltage and is reduced to 1 μsec finally for the applied voltage of 28 kV due to the core saturation. A large bank of low voltage capacitors provides with the bias magnetic flux a few msec before the main magnetization starts.

Focusing Element

The focusing element in present use is just tentative. Three toroidal ring magnets per module are placed inside the vacuum chamber and produce the focusing (periodic) magnetic fields of 300 gauss at maximum. The field may be too weak to transport the intense ion beam without loss of the particles. In the next paragraph this point will be discussed briefly. The magnets, however, require no power supply and nearly maintenance-free.

Ion Source

A newly designed small ion source is used. Hydrogen gas introduced into the source chamber is ionized with the electron beam emitted from the hot cathode and reflected by the magnetic field made by a pair of permanent magnets located near the extraction ports having multiple holes (19 holes of 0.27 cm diam.). The source can supply with a few hundred mA of proton beam when the discharge current is 2 - 3 A and the applied extraction voltage is 10 - 20 kV. The source is operated pulsively during several sec.

Results

Fig. 5 shows the extracted ion current measured with a Faraday cup placed close to the extraction port. The primary charging voltage of the capacitors was 26 kV. The beam of 160 - 200 mA at the maximum is

*Faculty of Science, Kanazawa Univ., Kanazawa 920 Japan.
**Toshiba Corporation, Tsurumi Works, Tsurumi 230 Japan.

0018-9499/83/0800-3016$01.00© 1983 IEEE

obtained during 1.5 μsec. The beam current is limited only by the characteristics of the ion source. The ion current is reduced down to one tenth of the extracted beam after passing through the three modules. Obiously the guide magnetic field is not large enough to focus the proton beam of 100 mA at the accelerating field of 78 kV. Alternate design of the focusing technique is being prepared. The ion current measured at 75 cm from the exit of the extraction ports is shown in Fig. 6. The beam is guided outside the modules downstream with a pulsed homogeneous magnetic field of 2000 gauss. Nevertheless, the intensity of the beam decreases down to a few mA and moreover considerable fine structure can be seen. This could be owing to the bunching of the beam due to the finite energy spread. The measurements of the particle energy are being carried out by 1) magnetic analyser and 2) time of flight technique. The preliminary results show that the measured energy of particles composing the leading peak in the Fig. 6, is a little lower than the 3 times of the applied module voltage (Table II). The reason of the discrepancy is open to question.

Conclusion

We can make some conclusive remarks as follows:

- A proton beam of 100 - 200 mA is extracted from an ion source during a few μsec and accelerated up to about 60 keV by the inductive fields driven with the three acceleration modules.
- The particles, however, have a complicated energy spectrum and the maximum energy of the accelerated particles is nearly 2.4 times of the applied voltage per module.
- It is very desirable to apply the acceleration gap voltage which is constant or gradually rising in time using a tappered PFN, for instance.
- The magnetic guide field of several hundred gauss is not large enough to transport the beam of a few hundred mA. Much more efficient focusing element is required to reduce the particle loss in the drift space.

Scaling up to 200 kV and 1 A and the improvements in the experimental set up will be tried in near future. Studies of the beam stability on the beam and focusing parameters are also being planned.

References

1) A. Faltens and D. Keefe, Proceeding of the 1981 Linear Accelerator Conference, LA-9234-C page 205 (1981).
2) J. D. Ivers, J. A. Nation, and I. Roth, IEEE Trans. on Nucl. Sci., NS-26 (3) page 3380-3382 (1981).
3) S. Humphries Jr., "Intense Pulsed Beams for Fusion Applications", Sandia Report 80-0402 (April 1980).

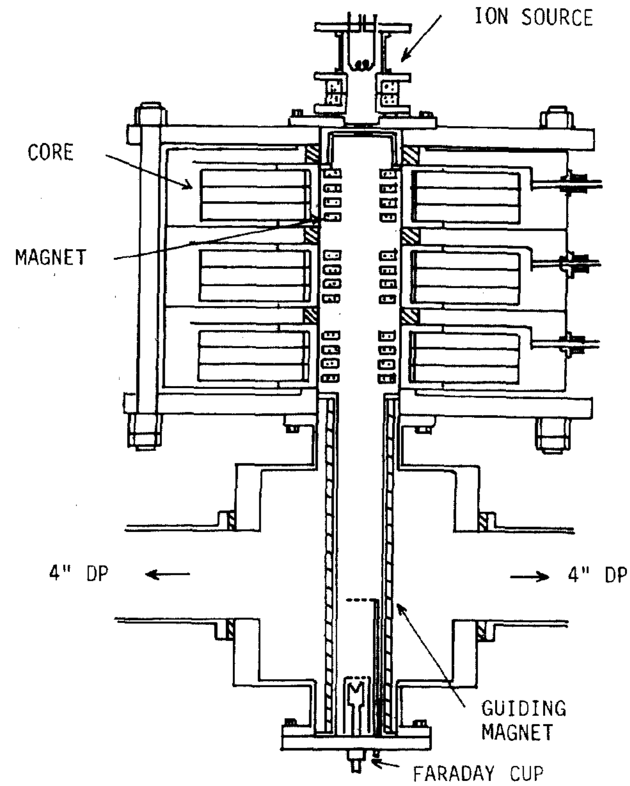


Fig.1 Cross-sectional view of the whole system.

Table I Parameters of the core

Material	Silicon steel
Inner diameter	135 mm
Outer diameter	375 mm
Width	20 mm
Thickness	0.1 mm
No. of cores/module	3
Specific permeability	1000
Coercive force	20A/m

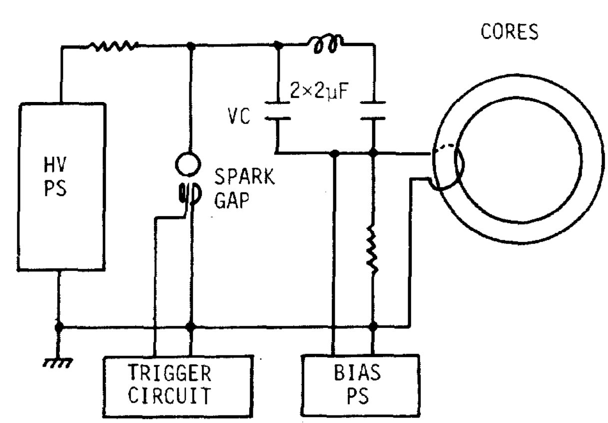
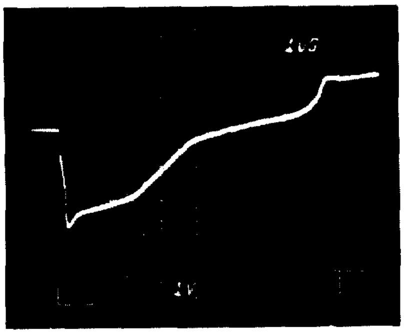
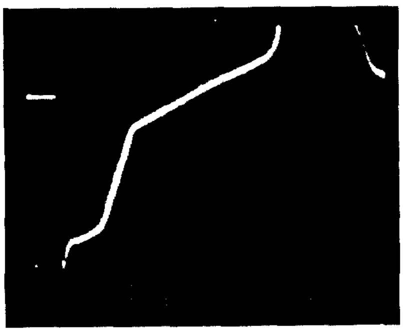


Fig.2 Electrical schematic of the driving circuit.



(a)

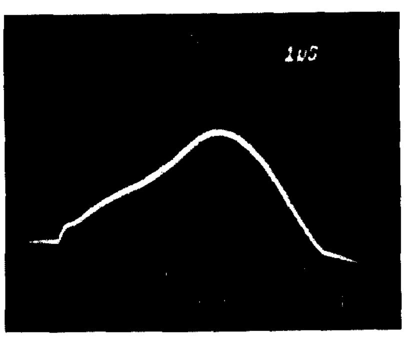
V: 5 kV/div
H: 1μs/div



(b)

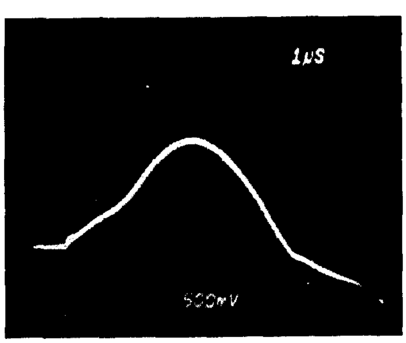
V: 5 kV/div
H: 1μs/div

Fig.3 Voltage waveforms applied to the cores at Vc= 16 kV (a), 28 kV (b).



(a)

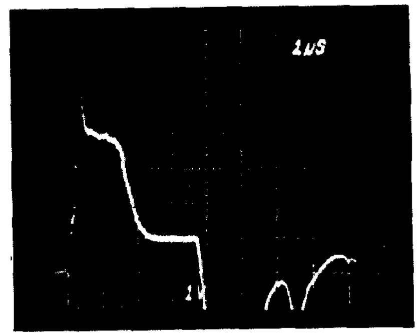
V: 8 kA/div
H: 1μs/div



(b)

V: 20 kA/div
H: 1μs/div

Fig.4 Current waveforms flowing in the driving circuit at V_C=16 kV (a), 28 kV (b).

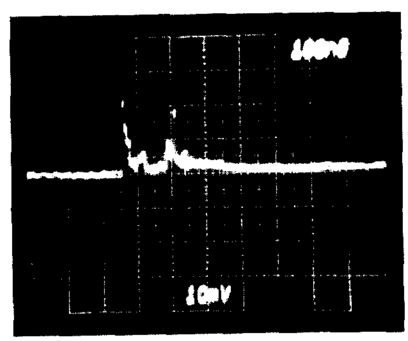


V: 40mA/div
H: 1μs/div

Fig.5 Ion current measured with a Faraday cup placed close to the extraction port at Vc=26 kV.

(a)

H: 1μs/div



(b)

H: 0.1μs/div

Fig.6 Ion current waveforms measured at Vc= 18kV.

Table II Proton energy (E) vs. charging voltage (Vc) of the driving circuit.

Vc(kV)	E (keV)
12	20.8
14	22.6
16	26.7
18	35.5
20	40.5
22	42.5
24	49.2
25	53.2
26	57.0