CONSTRUCTION AND ACCELERATION CHARACTERISTICS OF THE TOKYO INSTITUTE OF TECHNOLOGY HEAVY ION LINAC

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Summary

A heavy ion accelerator system has been costructed for material science and nuclear physics studies. It consists of a tandem Pelletron as an injector and two heavy-ion linacs. The first module of the linac system was designed to accelerate particles injected at 240 keV/u with charge to mass ratio (q/A) of 1 - 1/4 up to 2.4 MeV/u. The accelerating cavity has an inter-digital H structure. The accelerating resonance frequency is 48 MHz. The linac has succesfully accelerated ion beams of H, C, O, Cl. The overall transmission coefficent has been determined to be 30 - 40 % for a dc proton beam. The effective shunt impedance (Ze) has been determined to be about 180 MΩ/m by the experiment. This Ze is about 5 times as large as Ze of other accelerating structures in the same velocity region.

Introduction

The interdigital H type structure is well known for its high shunt impedance at low particle velocity. In spit of this advantage, there exist serious disadvantages such as the undesirable distribution of accelerating voltage in the cavity. A new method has been developed to control a gap voltage distribution, and a prototype IH linac has been constructed at INS[1]. Adoping this design concept a linac was constructed by Toko Institute of Technology as the main accelerator for study of heavy ion physics.

Construction of the Heavy Ion Linac

Accelerator System

Fig.1 show the layout of the system. The injector is an NEC 5 SDH-HC2 tandem Pelletron with a maxmum terminal voltage of 1.6 MV. A sputter type and a PIG ion sources were connected to the tandem through a switching magnet. This injector is able to accelerate ions up to β = 2 % in the mass-number range 1 to 30. This β value has two advantages : 1) We can design drift tubes with focusing elements adopting π - π mode. 2) For the ions ranging from lithium to chlorine, the fraction of the ions stripped in a carbon foil is not too small at q/A = 1/4, which is the design value for the linac.

Design of Linac Structure

For the design work of the cavity we have constructed several 1/4 scal models[2]. Including resonance frequency and field distribution, every impotant design parameter was checked by measurements on these models in terms of the configuration of the short-circuit wings in low-energy section and the magnetic flux inducer in the high-energy section of the cavity. The particle trajectory was analyzed by mean of a computer programme LINOR[3].

Linac Cavity

The main parameters of the linac are shown in Table 1. The resonator tank is made of a copper-laminated steel (35 mm steel + 3 mm oxygen free copper) . The cavity has a dimension of 1.4 m by 7 m in diameter and in length, respectively, as shown in Fig1. The surface of copper has been polished. Its roughness is estimated to be 3 μm. The heat generated in the cylinder wall is removed by means of cooling panels glued outside the tank.

The drift tubes, the stem and the ridge are copper plated with a layer thickness of more than 50 μm. Other elements are made of oxygen free copper (OXFC).

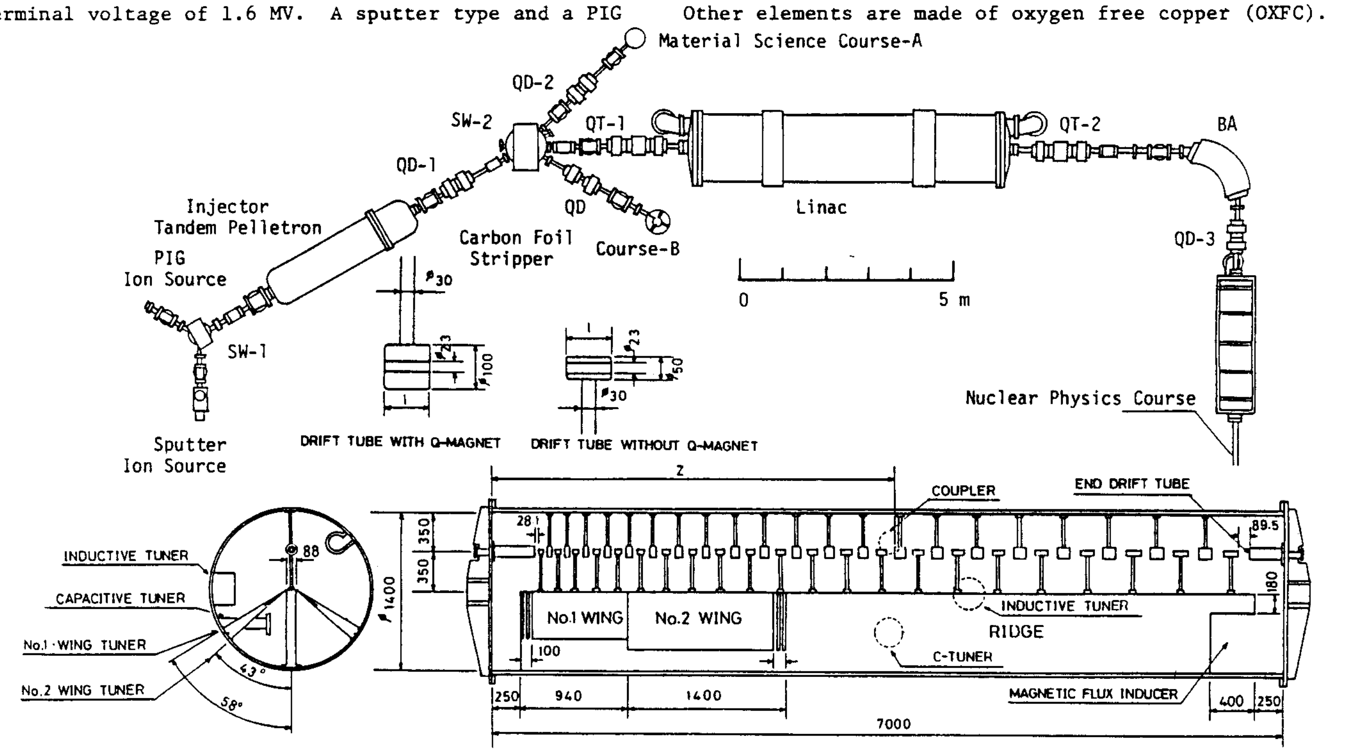

Fig.1 Layout of T.I.T. Heavy Ion Accelerator System and Acceleration Structure of the Linac

Table 1. Parameters of the T.I.T. Heavy Ion Linac

Ions (q/A)	H - Cl (1 - 1/4)
Energy Input	240 keV/u
Output	2.4 MeV/u
Operation Frequency	48 MHz
Acceleration Phase	-30°
RF Maximum Input Power	100 kW
Number of Cells	44
Focusing Sequence	FODO
Element	Q Magnet (G_{max} = 5 kG/cm)
Drift Tube Bore Diameter	23 mm
Outer Diameter	100 mm (tank side)
	50 mm (ridge side)
Tank Inner Diameter	1.4 m
Length	7 m
Ridge Width	8.8 cm
Length	650 cm
Height	70 cm
Wing Tuners Length	94 cm 140 cm
Angle	58° 43°
Magnetic Flux Inducer	40 cm
Vacuum System	3000 l/s 2 Turbo Pumps

Because of fleon cooling and of wiring of the focusing quadrupole magnets in the drift tubes, the beam axis is asymmetrically located in the cavity. The drift tubes without quadrupole magnets are connected to the top of the stems which are mounted on the ridge. The drift tubes with a quadrupole magnets are mounted on the stems that are suspended from the tank wall through diaphragms for center ajusting.

An optical target was put into the bore of each drift tube to measure setting errors using an aligment telescope. We have got final alignment errors of ± 0.1 mm.

The rf is fed through a coaxial line to the cavity. We are using a loop coupler with an area of 180 cm^2. The inner and outer coaxial sections of the loop coupler are cooled with pure water. The two wings are made of OXFC plate and cooled with pure water.

A capacitive tuner consists of a copper disk of 700 cm^2. The stroke of the tuner is 30 cm. An inductive tuner is plunger with a volume of 20 ℓ and cooled with pure water. It is made of copper plated stainless steel. The plunger has an diameter of 30 cm and moving stroke of 30 cm.

The rf contact between two OXFC side plates of the ridge and the tank wall is maintained using Helicoflex type seals (symbol of ● in Fig.2). We use it also for the rf contact between the short circuit wings and the ridge. The Helicoflex type contact is 3.8 mm in diameter and 0.2 mm in thickness and consists of a silver sheath and a spring of SUS-304. The rf contact for the stems of the drift tubes is performed using silver-plated stainless-steel tubes of 3.2 mm in diameter and 0.25 mm in thickness (symbol of Δ in Fig.2).

The cavity has a volumes of 11 m^3 and a copper

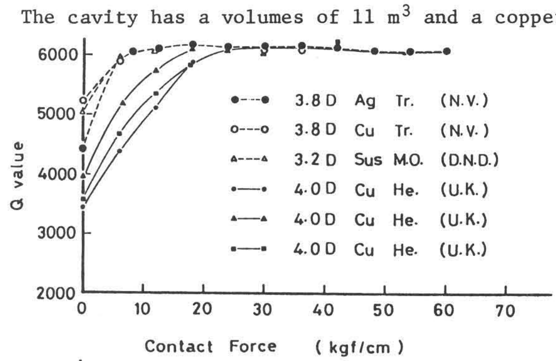

Fig.2 Q factor vs. contact force. The ideal Q factor is calculated at 6800 with SUPERFISH[4]. N.V., D.N.D. and U.K. are abbreviated names of the makers.

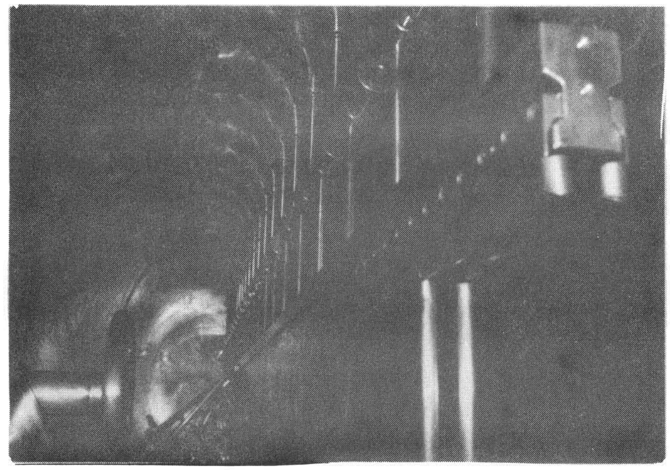

Fig.3 Inside view of the T.I.T. Linac

The cavity has a volumes of 11 m^3 and a copper surfaces of about 85 m^2. The vacuum system includes two sets of 3000 ℓ/s turbo molecular pump backed by 500 ℓ/min. rotary pumps. The vacuum of cavity is sealed with viton o-rings. The rate of outgassing from the copper surface was lower than 10^{-8} Pa·ℓ/cm^2·s. The final pressure in the system is 3 × 10^{-6}Pa .

A photograph of the accelerating cavity is shown in Fig.3.

Quadrupole Magnets

There are five groups of quadrupole magnets : 1) the entrance half lens (the maximum magnetic field gradient G(max) = 1 kG/cm), 2) the low-energy section with 8 lenses (G(max) = 4kG/cm), 3) the middle-energy section with 6 lenses (G(max) = 3 kG/cm), 4) the high-energy section with 7 lenses (G(max) = 2 kG/cm), 5) the extraction-port half lens (G(max) = 1 kG/cm). The quadrupole magnet of prototype is shown

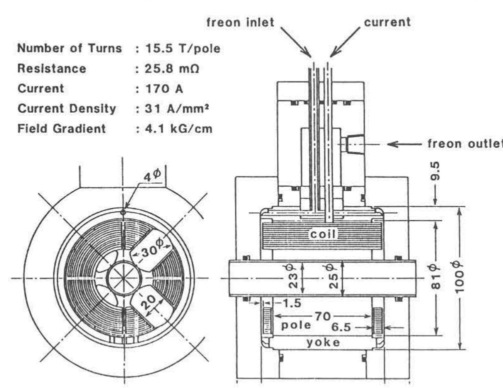

Fig.4 Prototype quadrupole magnet

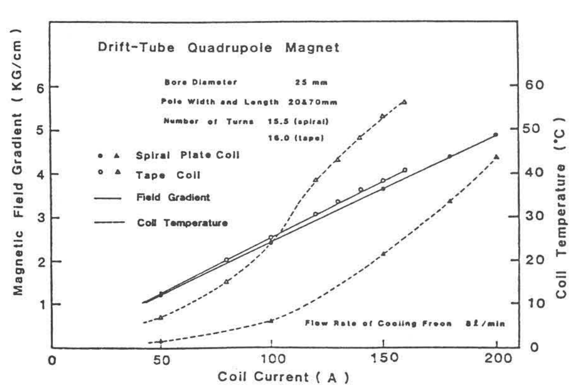

Fig. 5 Performance of the quadrupole magnets

in Fig.4. Figure 5 shows excitation curves and temperatures of two types of quadrupole magnets, namely one with spiral-plate coils and the other with tape coils. Using the spiral-plate coils stable operation was observed up to 4 kG/cm. We had chosen spiral-plate coils for 21 lenses in the drift tubes and tape coils for the entrance and extraction half lenses. The quadrupole magnets of both type were succeeded in a running test of 500 hours.

RF Characteristics of Cavity

Resonance Frequency and Field Distribution

The resonance frequency was measured to be 48 MHz for the TE_{111} mode. The frequency was lower than the design value by 0.5 MHz.

We have obtained an unloaded Q factor of 21500 with weak coupling. This value amounted to 140 % of the design value. We have rotated the loop coupler to minimize the rf reflection and to optimize matching between cavity and the 50 Ω feeder line with an effective area of 130 cm^2.

The field distribution was measured by means of the well known perturbing ball method. The field distribution is shown in Fig.6 where the symbol -) and Δ) represent the design values and measured values of electric field in the cavity, respectively. In the high-energy section, the accelerating field drops at most to 70 % of the design value.

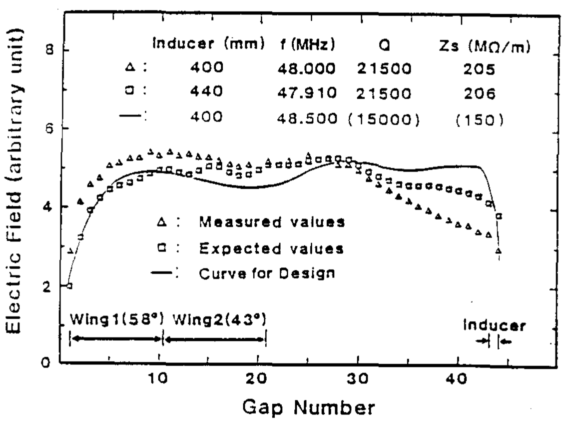

Fig.6 Distribution of accelerating field in the gaps of the cavity

At the last stage of the design work, we found out that the accelerating frequency converged on a value which was lower by 5 % than the original design value of 50 MHz. We have chosen to change the frequency from 50 to 48.5 MHz, to keep the input and output energies as high as possible by modifing the accelrating structure. The number of accelerating gaps was reduced from 46 to 44. The result is that the accelerating field distribution has been deformed as seen Fig.6.

RF Source and Control System

The rf power is supplied from a power amplifier system connected with a master oscillater. A tetrode tube Eimac 4CW-100000E supplies cw power up to 100 kW. The rf power is fed through a coaxial line WX-120D to the cavity with the loop coupler. The system has a tunable band of ± 5 MHz at 50 MHz. Cw and pulse operations are possible. An automatic gain control (AGC) is performed with an accuracy of ± 1 %.

The frequency range of the capacitive tuner was 0.8 MHz. This is used for the coarse tuning. The range of the inductive tuner is 40 kHz with a moving stroke of 30 cm. This tuner is used for the automatic control of the resonance frequency which shifts due to the change of temperature of the cavity. An automatic frequency control (AFC) is stable within a phase shift of 1°.

High Power Test

In the first high power test, multipactoring was observed for 20 hours at input powers between 0.1 and 1.5 kW. The linac operation has been very often interupted by the overheating. The fabricated ridge plates were different from the design structure. Namely, the cooling pipes were not soldered as design. The ridge plates were overheated for cw 50 kW operation. The design work for new ridge plates is now going on.

Acceleration Test

Experimental Results

Beam tests have been performed using ion beams of H^+, C^{4+}, $O^{5,6+}$ and $Cl^{9,10+}$. Momentum spectra, beam bunching spectra and output beam currents were measured as a function of the rf power for protons. The output currents were measured as a function of the injection energy. The linac was operated in cw mode for H and O^{5+} and in pulse mode with duty factor of 30 - 50 % . The emittances of a proton beam were measured to be 9.1 π (horizontal) and 9.9 π mm·mrad (vertical) at 2.5 m downstream of the linac.

Transmission and Effective Shunt Impedance

The transmission of protons is shown in Fig. 7 as a function of the rf power. The transmission of 30 - 40% has been observed for a dc beam of injected protons at the optimum rf power. The momentum spectra of output beam were measured with an analyzer magnet. The momentum distribution of accelerared particles were analyzed of the input rf power of the acceleration voltage as shown in Fig.8 together with results of the orbit calculation. The acceleration characteristics agree well with the computer simulation. The effective shunt impedance of the linac was estimated to be about 180 MΩ/m from rf powers for protons (4.6 kW) and for O^{5+} (47 kW).

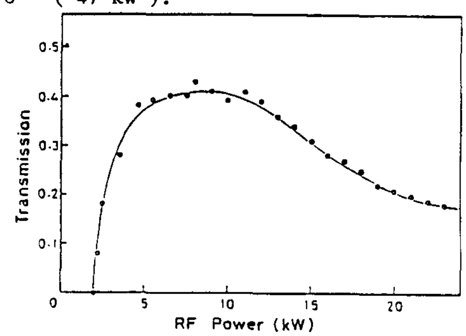

Fig.7 Transmission vs rf power

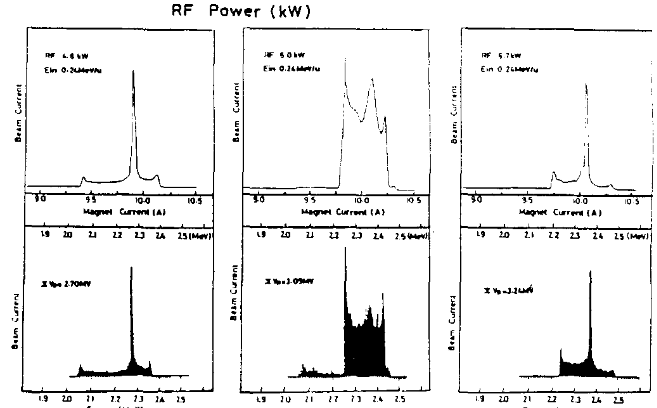

Fig.8 Momentum distribution uper (Exp.) lower (Cal.)

Acknowledgement

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