MEDICAL HEAVY ION ACCELERATOR

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1. Introduction

Biomedical effectiveness of the high LET particles such as protons, α particles, light heavy ions(C, Ne, Si and Ar) and π^-mesons has been confirmed. As was experimentaly shown, these high LET particles exhibit high RBE, low OER and excellent dose distribution.

Among these high LET particles, Ne, Ar and Si ions have been extensively used for the tumor treatments and various biological investigations.

We have been carrying out the design studies of a complex heavy ion accelerator for medical usages of the protons and heavy ions for several years[1]. Based on these studies, we are now proceeding to design a medically dedicated heavy ion accelerator complex, which is considered as a substituent for a planned Kyushu University Accelerator Center. As the first approach, we have tryied to design an accelerator complex which is composed of (1) RFQ Linear Accelerator as low energy injector, (2) two Alvarez Linear Accelerators between which a charge exchange stripper is to be inserted to increase the charge state of the heavy ions and then follows (3) strong focusing synchrotron as a main accelerator.

Our design aims are as follows; particle species is Si, ion energy is about 800 MeV/u, and intensity is more than $3.0*10^7$ sec^{-1}, which are expected to be sufficient to deliver more than 100 rad/min at an range of about 30 cm of tissue. In the followings, we will briefly describe some preliminary results and summarize the tentative parameters obtained so far for each constituent accelerators.

2. Results of Calculations

Fig.1 shows a conceptional layout of accelerator complex. A radio frequency quadrupole(RFQ) accelerator with 4 vanes is chosen because of it's reliability. Si^{4+} ions extracted at 50 kV from a PIG heavy ion source are injected into the 6.73 m long RFQ with average shunt impedance of 92.6 MΩ/m. PARMTEQ was used to calculate the beam trajectories and RF power and resonant frequency were calculated by SUPERFISH. Obtained parameters are summarized in Table 1.

750 keV/u Si^{4+} ions are then accelerated successively by two Alvarez linear accelerators. In between a charge stripper is placed converting Si^{4+} into Si^{10+} ions. On leaving the 2nd Alvarez, another charge stripper is being placed generating Si^{14+} ions. Tentative parameters of two Alvarez I and II are shown in Table 2.

Main accelerator is a strong focusing synchrotron whose β-tron function (β_x, β_y) and dispersion function (η_x) are shown in Fig.2 together. N and L represent normal cell and long straight sections, respectively. Code MAGIC was used for these calculations. Table.3 shows obtained parameters for the main accelerator.

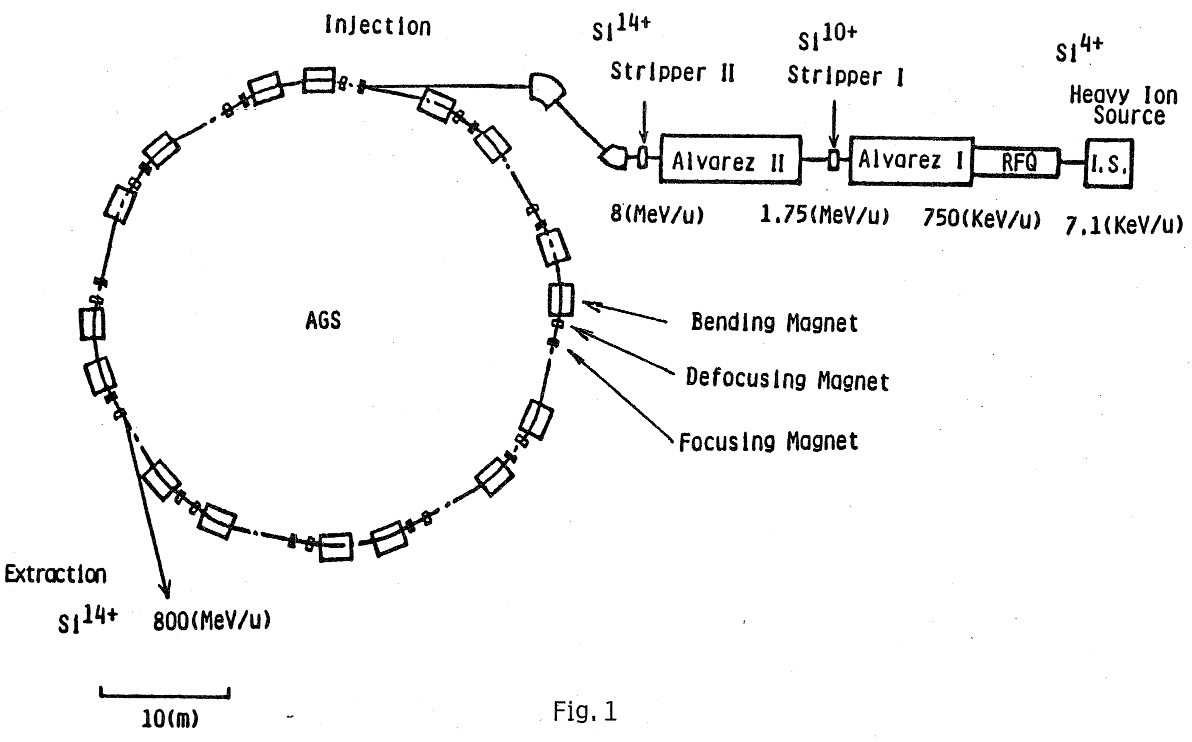

Fig.1

3. Conclusion

A conceptional design of the medically dedicated heavy ion accelerator system has been carried out. Further refinements and modifications in design studies are of course necessary in order to reach final parameters of each constituent of the accelerator complex.

From medical point of view, it is urgent to construct the dedicated heavy ion accelerator for which deliver high enough energy and intensity of heavy ions to promote both fundamental and clinical researches.

References

1) K.Noda and Y.Wakuta : Technology Reports of the Kyushu University 52(1979)719.

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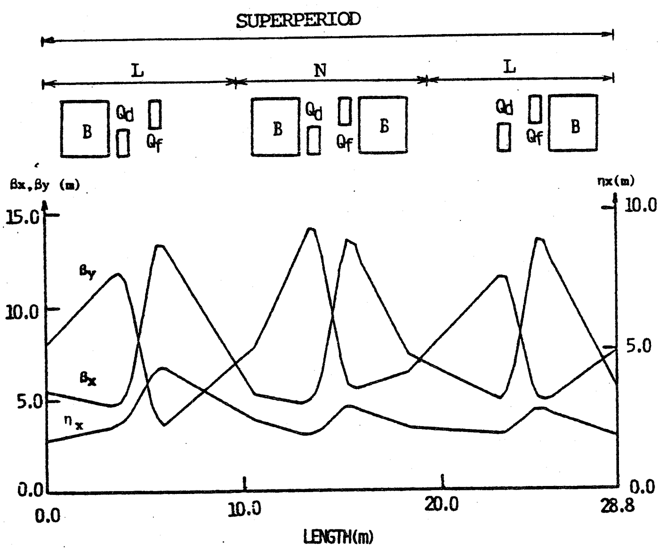

Fig. 2

Table 1. RFQ parameters

Particle species	Si^{4+}	
Charge to mass ratio	0.143	
Injection energy	7.14	keV/u
Ejection energy	750	keV/u
Vane length	6.73	m
Tank inside diameter	31.13	cm
Number of cells	256	
Maximum modulation	2.5	
Minimum bore radius	0.288	cm
Resonant frequency	100	MHz
Vane-vane voltage	81	kV
Normalized acceptance	1.2	πmm-mrad
Averaged shunt impedance	92.6	MΩ/m
Transit time factor	π/4	
RF power	104.9	kW

Table 2. parameters of Alvarez I and II

	Alvarez I	Alvarez II	
Particle species	Si^{4+}	Si^{10+}	
Charge to mass ratio	0.143	0.357	
Injection energy	0.75	1.75	MeV/u
Ejection energy	1.75	8.00	MeV/u
Tank length	9.65	11.13	m
Tank inside diameter	94	94	cm
Number of cells	64	78	
Gap length to cell length ratio	0.269~0.304	0.253~0.311	
Bore radius of drift tube	1	1	cm
Resonant frequency	200	200	MHz
Averaged electric field strength	2.4	2.4	MV/m
Focusing sequence	FFDD	FFDD	
Field gradient of quadrupole magnets	7.33~4.79	6.83~3.22	kG/cm
Length of quadrupole magnets	3.59~5.51	2.74~5.86	cm
Acceleration mode	4π	2π	
Normalized acceptance	4.6	6.5	πmm-mrad
Averaged shunt impedance	73	70	MΩ/m
Transit time factor	0.330~0.375	0.727~0.797	
RF power	0.978	1.16	MW

Table 3. AGS parameters

Particle species	Si^{14+}	
Charge to mass ratio	0.5	
Injection energy	8.00	MeV/u
Ejection energy	800	MeV/u
Rigidity	9.76	T·m
Circumference	115.2	m
Averaged orbit radius	18.33	m
Beta-tron frequency	2.75	
Number of cells	12	
Number of superperiods	4	
Cell structure	OFDO	
Bending radius	6.11	m
Number of bending magnets	16	
Length of bending magnets	2.4	m
Maximum field of bending magnets	1.597	T
Number of quadrupole magnets	24	
Length of quadrupole magnets	0.6	m
Maximum field gradient of quadrupole magnets G_f	6.127	T/m
G_d	5.515	T/m
Maximum β-function β_x	13.423	m
β_y	14.099	m
Maximum dispersion function	4.451	m