PRELIMINARY DESIGN OF A DEDICATED PROTON THERAPY LINAC[1]

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Abstract

The preliminary design of a dedicated cancer therapy proton linac is described in this paper. The short beam pulse and high repetition rate make the linac similar to high energy electron linacs. This linac consists of ion source, RFQ, DTL, SCDTL and SCL, with total length 27 meters. The energy of the output proton beam is 70200MeV, and the average beam current is 1040nA.

1 INTRODUCTION

Radiotherapy is one of the efficient weapons against cancer. X-ray and high energy neutron are traditional methods and mostly used for tumour therapy. Proton therapy was proposed by Wilson in 1946, from then on nearly 20,000 patients were treated by proton or heavy ion beams. Despite of its advantages, proton therapy is not yet universally accepted due to the complicated equipment and expensive costs. The construction of compact dedicated therapy proton accelerators is still a technical problem to be solved.

The first dedicated proton therapy facility was established in Loma Linda University Medical Center(LLUMC) in 1990[1,2]. Although the LLUMC facility uses a synchrotron, other types of proton accelerator, clystron and linear accelerator, can also be used for medical purpose. Comparing to circular-orbit accelerators, a proton linac has its own advantage: proton beam can be easily injected and extracted, the beam is well focused and has small emittance, this advantage simplifies the high energy beam transport line(HEBT) and the facility no longer needs a big gantry. Even though, a traditional proton linac has quite long length and large transverse size as well as high cost. To avoid these disadvantages, an S-band proton linac is considered to be likely more suitable for medical purpose because it’s compact and uses commercial RF power supplies so the total price of the therapy facility is obviously reduced.

2 PARAMETERS

The beam energy region of proton beam for cancer therapy is about 70 to 200MeV. Because no single structure is effective in such a wide energy region, four accelerating structures are used in the S-band proton linac: RFQ, DTL, and S-band structures SCDTL and SCL. Parameters of the linac is shown in table1. Particle dynamics simulation and beam matching design is underway.

Table1. Parameters of the S-band Proton Linac

Injection Energy	30keV
Injection Current	1mA
Final Energy	70-200MeV
Output Current	10-40nA
Trans. Emittance	<0.2π mm mrad
Long. Emittance	<0.6π deg MeV
Energy Spread	± 0.2%
Pulse Width	1-3ms
Repetition Rate	30-120Hz
Duty Factor	0.036%
Beam Size	f2mm
RF Peak Power	50MW
Frequency	357,714,2856MHz
Total Length	27m

The main accelerating section is made up of two S-band structures operating at 2856MHz: a side-coupled drift tube linac (SCDTL) and a side-coupled linac (SCL), the frequencies of the front end structures are selected to be suboctuple (RFQ-357MHz) and subquadruple (DTL-714MHz) of the main section. The front end of the linac comprises a 3MeV RFQ and a 12.9MeV drift-tube linac (DTL) tank. The SCDTL and SCL sections accelerate proton beam up to 70MeV and 200MeV separately, they are driven with 9 short pulse 5MW S-band RF klystrons. The focusing quadruples in this linac are all permanent magnetic quadrupoles (PMQs).

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[1] work supported by National Climb-B Plan

3 RFQ

The pre-injector of the S-band linac is a vane-type RFQ. The output beam from ion source is 1mA, 30keV, which is injected into the RFQ through a short low energy beam transport line(LEBT) and accelerated by the RFQ up to 3MeV. The diameter of the RFQ cavity is 19cm, the aperture is 4mm and the modulating factor is 1-2. The intervane voltage is selected to be 45kV. The transport efficiency of the RFQ is about 95%.

4 DTL

The 714MHz DTL tank consists of 32 accelerating cells and 33 permanent magnet qradrupoles. Proton beam is injected into the DTL tank directly from RFQ exit. To match the proton beam, the gradients of the first four PMQs should be carefully managed and the synchronous phase of the DTL tank ramps from -60° to -30°. The axial electric field E_0=8.5MV/m, the average accelerating rate E_0T is about 7MV/m. The DTL cells are optimized with SUPERFISH codes. The bore radius of the DTL tank is 3mm, the diameter of drift tubes is 5cm, the tank diameter is 27cm. The estimated effective shunt impedance ZT^2 is around 60-70MΩ/m.

5 SCDTL

Coupled-cavity drift tube linac was proposed by LANL several years ago[3].This structure has higher efficiency than DTL structure and can operate at higher frequency. The SCDTL section is made up of short DTL tanks which are coupled by side-coupled cavities. The SCDTL tanks are divided into five modules. The first module consists 11 tanks, each tank has 6 accelerating cells, the length of the drift space between tanks is 2.5βλ/2. The second module consists of 9 tanks, each tank has 6 cells, the length of the drift space is 2.5βλ/2. Each of the other modules consists of 7 tanks, each tank has 7 cells, the drift space is 1.5βλ/2. PMQs are installed between tanks, the gradient of magnets ramps from 200T/m to 155T/m. The bore radii of the SCDTL tanks are 2mm, 2.5mm and 3mm for $\beta<0.2$, $\beta=0.2-0.25$, and $\beta>0.25$ respectively.

6 SCL

The SCL section is made up of seven modules, each has an individual RF power supply. Each of the first three modules consists of 4 tanks, and each of the other four modules consists of 3 tanks. Each SCL tank has 17 accelerating cells, neighboring tanks in the same module are connected with 1.5βλ length bridge couplers, and PMQs are placed between tanks. To treat tumours in different depth in the body, the output beam energy should be modulated continuously. For this purpose, the output energy is designed to be stepwise, the nominal final energy of the seven SCL modules are 88, 108, 130, 147, 165, 184, 203MeV respectively. By shut off the RF power supplies, eight output energy steps(including 70MeV) can be reached. By means of properly adjusting the output RF power and phase of the last operating RF power supply, the precise required output energy can be achieved.

Table2. Parameters of Accelerating Sections

Section	f(MHz)	E_k(MeV)	P_{rf}(MW)	L(m)
RFQ	357	3.0	0.3	3.36
DTL	714	12.95	0.9	1.62
SCDTL	2856	70.69	7.5	9.8
SCL	2856	203.2	30	11.91

7 REFERENCES

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