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DESIGN OF TRAVELING WAVE PROTON LINAC

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ABSTRACT

A model proton linac of traveling wave type was proposed for a high energy linear accelerator above 1 GeV and for high duty above one percent. The model linac was designed to be based on parameters studied for buncher section of electron linac. Beam trace simulation for the linac had been done by using of a computer, energy spectrum of proton beam were calculated. A narrow energy spread within about 1% is obtained from the simulated results and without any compensation of rf power for beam loading. The paper reports the specification parameters of the model linac and the results of beam traces.

INTRODUCTION

Recently, some plan of proton linac above 1 GeV were proposed as the large hadron project1) and the nuclear spallation. Ordinary proton linac for high energy have been a form as a combination of post couple drift tube structure 2)and side coupled wave guide3). These structure are expensive for complication. The washer loaded structure is not practicable for some problems of supporting insulators4).

I proposed to be fit such a simple structure as a disk-loaded structure of a traveling wave type for high energy proton linear accelerator in the last year. The one of aim of this proposal is to compact a long linac and the another is to moderate its cost.

It is very important for a demonstration whether proton beam is accelerated well or not by some traveling wave structures to study a trace of the beam through the linac.

A model proton linac was studied for a beam trace and for a cost estimation. 5) A large majority accelerator guide of the model linac was designed the structure as a disk-loaded waveguide. Moreover, it is effective for a simple structure to moderate in price.

There is another approach for the traveling wave structure. It is for a short filling time. Consequently, the accelerator guide in this linac can accept so large rf power in a short time that energy gain increase, and can operate at a fast cycle with heavy beam loading that duty factor also increase. In this case the energy spectrum of proton beam may disperse for a transient shaking phenomena depend on the heavy loading. Thus, the beam trace for the model linac is more important for searching for the transient effect.

The effect was continuously simulated from initial state to final state of accelerating proton beam, and the energy spectrum and the bunching phase was calculated by a computer. The simulation suggest that the linac of traveling type is more effective for compression of dispersive energy of proton beam.

MODEL PROTON LINAC

On the assumption that energy gain of a preinjector may be 5 MeV, I have been promoting this proposal. In this case, the pressured Cockcroft-Walton's apparatus should be developed for the preinjector. The following model linac, which shall accelerate proton beam at energy from 5 MeV to 1 GeV, should be composed of structures of β-type from the limitation for the disk space.

In this case, the normalized velocities of the proton beam shall increase from 0.1028 to 0.875. If you exchange from proton to electron under the reference velocity, you shall be found it to correspond to accelerate electron from 2.723 keV to 544.6 keV.

Consequently, the design for the model linac also corresponds to design a buncher section for the described electron. From reasons of the manufacturing technology the accelerator structures is designed to be classified 3 sections of a low , a mid and a high . It is not advisable that the accelerator guide in the low β section is composed as the disk-loaded structure. Because the shunt impedance of the structure decrease extremely from the reason of the limitation depend on its disk space. The structure in this section are suitable to be composed by either type of drift tube or single cavity.

Operating frequencies have been divided in two stages of 433.33 and 1300 Mhz, and the relation between the two just corresponds to 3 harmonics. All parameters for the cavity as Q value, shunt impedance, group velocity, disk aperture and cylinder diameter were calculated by the ones which modified those data for a buncher section in a S band electron linac. An ordinary example for the line up of the model linac is shown in Fig. 1.

The overall specifications of the preinjector and the linear accelerator describe in Table 1, and these detail of the low β , the mid β and the high β also describe in Table 2.

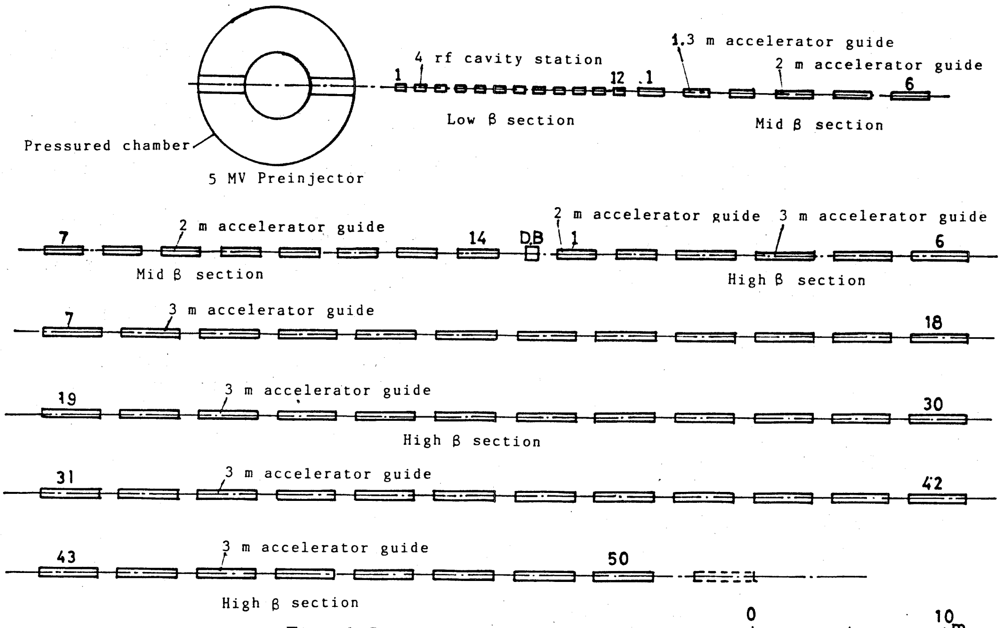

Fig. 1 Line up of model linac.

Table 1 Overall specifications of preinjector and linear accelerator.

	Preinjector	Linac
Type	pressured Cockcroft-Walton	single cavity+ traveling wave
Energy (MeV)	5	5-->1000
Peak beam current (mA)	800	400
Average beam current (mA)	0.4-->6	0.2-->3
Pulse duration of beam (S)	10	10
Repeat cycle (cps)	50-->750	<--
Duty factor (%)	0.05-->0.75	<--
Beam power (KW)	2-->30	200-->3000

Table 2 Specific parameters of model linac

	Low β	Mid β	High β
Structure	single cavity	disk-loaded traveling	<--
Phase shift		2π/3	<--
Energy (MeV)	5-->20	20-->60	60-->1000
Peak beam current (mA)	400	<--	<--
Pulse duration (S)	10	<--	<--
Repeat cycle (cps)	50-->750	<--	<--
Duty factor (%)	0.05-->0.75	<--	<--
Operation Frequency (Ghz)	0.43333	0.43333	1.300
Wave length (mm)	691.82	<--	230.61
(vp/C)	0.1028--> 0.2032	0.2032--> 0.3415	0.3415--> 0.875
Space of cavity's wall (mm)	71.11--> 140.57	46.816--> 78.752	26.251--> 67.261
Numbers of cavity	4*12		
Accelerator guide Length(m)*Numbers		1.4*3+2*11	2*3+3*47
Shunt impedance(Mohm/m)	2.2--> 2.9	1.2--> 6.7	12.3--> 38.7
Q-value	15000--> 20000	4000--> 12000	6700--> 17800
Filling time (S)	2.75--> 3.6	2.1--> 3.1	0.98--> 1.36
Numbers of Klystron	3	14	50
Output Power of Kly.(MW)	5	5	20
Total rf power (MW)	13.6	70	1000
Supplied power (MW)	0.43	2.2	31.5
Length of accelerating section (m)	8.44	40	200

BEAM TRACE

In an accelerator guide of a traveling wave type, if a normalized accelerating factor and a normalized length may be defined as $\alpha=eE\lambda/M$ and $\xi=z/\lambda$ respectively, an energy gain and a phase slip per unit length are expressed as (1) and (2),

$$d\gamma/d\xi=\alpha \sin\phi \qquad (1)$$

$$d\phi/d\xi=2\pi(1/\beta_w -1/\beta_p) \qquad (2)$$

where $\gamma=(T+M)/M$ and T and M are the proton's kinetic energy and the rest mass, z is a length of forward direction, λ is the free space wavelength of the rf field. If a light velocity, a phase velocity and particle's velocity are written as C, Vw and Vp respectively, βw and βp are given as Vw/C and Vp/C. Moreover, is given by (3).

$$\beta_p=(\gamma^2-1)^{\frac{1}{2}}/\gamma \qquad (3)$$

The E(z) is the complex amplitude of the electric field on the axis, it is defined as (4),

$$E(z)=(r*dP(z)/dz)^{\frac{1}{2}} \qquad (4)$$

where r is a shunt impedance of the fundamental space harmonic and dP/dz is a given rf power per unit length in the structure. From the definition of factor of merit Q and from the relation among the stored energy in the structure, the given rf power flow P and the group velocity Vg, dP(z)/dz may be also rewritten as (5).

$$dP(z)/dz=\omega P(z)/(VgQ) \qquad (5)$$

In the case of the structure of a constant impedance type, the parameters of r,Q and Vg are the constant numerically, so that the E(z) can be easily calculated by put into (4) the form (5). On the steady state, the most common approach to beam loading in the traveling wave structure is defined as (6) from the energy conservation,

$$dP(z)=-2IP-iE(z) \qquad (6)$$

where i is a beam current passing through the structure and I is the field attenuation factor expressed as $I=\omega/2VgQ$. The results of the beam trace using from (1) to (6) are shown in Fig.2 (a), (b) and Fig.3 (a),(b),(c) with beam loading of 400mA, respectively.

The energy & phase diagram with beam loading from 100 mA to 400 mA are shown in Fig. 4 at end of high section under the special boundary condition.

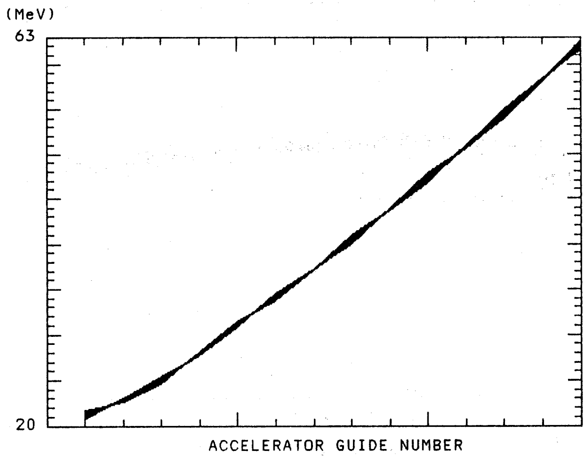

Fig. 2 (a) Energy gain in mid β section.

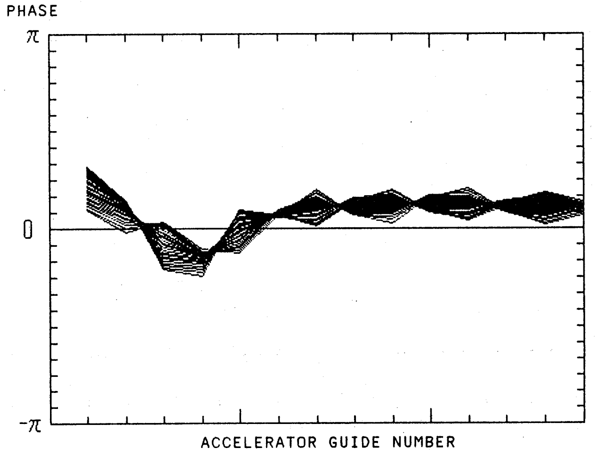

Fig. 2 (b) Phase diagram in mid β section.

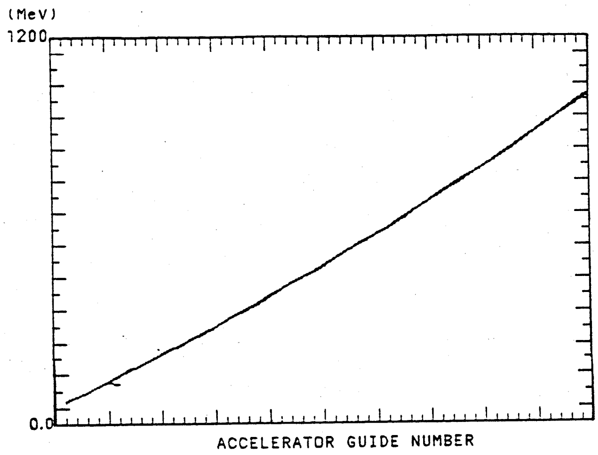

Fig. 3 (a) Energy gain in high β section.

CONCLUSION

From the result of the beam trace, the beam loading effect for energy dispersion is not so large as thinking about the one. Because the electrical field in the structure modulate the velocity of a particle on the nonrelativistic state, it make the particle oscillate on the rf phase like the synchrotron oscillation and during the particle pass through it. This fulfill the function as a stabilizer for the energy gain of the particle.

For example, if an amplitude of electric field is decreasing by beam loading, then particles shall delay on the rf phase. Consequently, it work the energy gain of the particle keep constant level. For the traveling wave structure without the extremely heavy loading, it is not necessary to compensate the effect of beam loading.

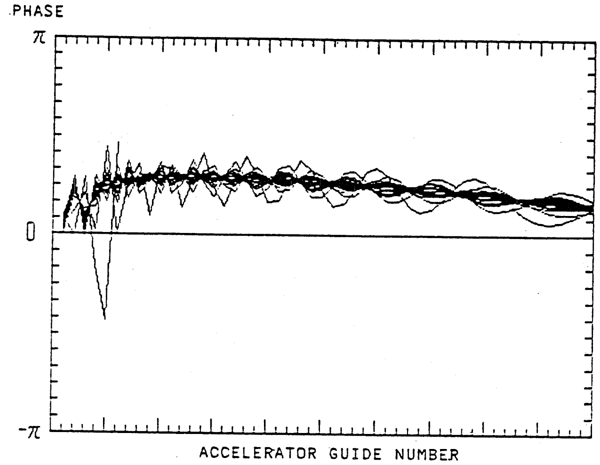

Fig. 3 (b) Phase diagram in high β section

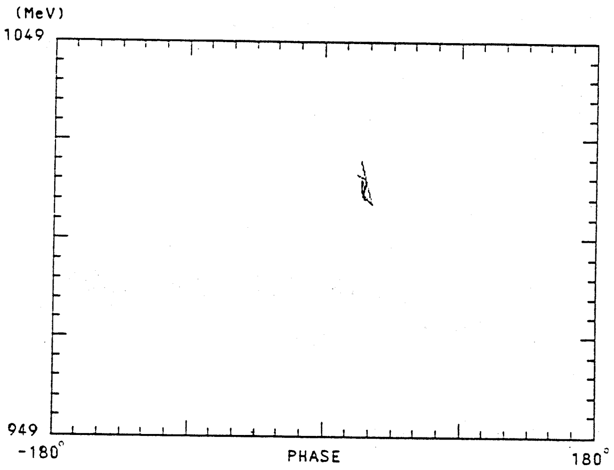

Fig. 3 (c) Energy & phase diagram at end of high β section.

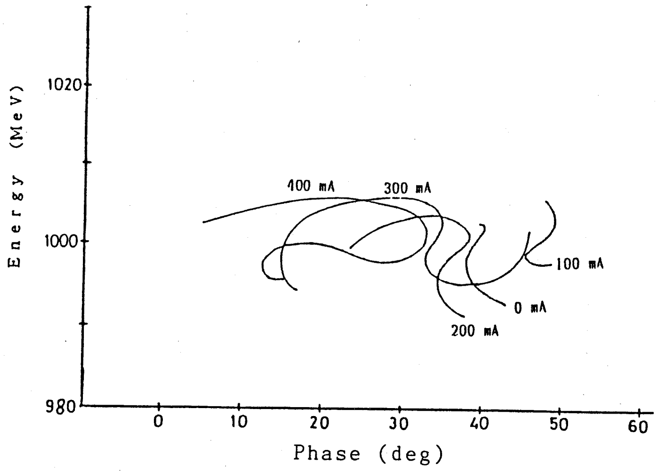

Fig. 4 Energy & phase diagram with beam loading from 100 mA to 400 mA at end of high section without drift space.

The simulation for beam trace has included the estimation for the drift effect of the space among the structures, but from the time limit for the computer it has excluded the estimation for the space charge effect of particle in the structure.

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