BEAM DYNAMICS DESIGN OF A PROTON LINAC FOR THE NEUTRON SCIENCE PROJECT AT JAERI

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Abstract

Beam dynamics design of a high intensity proton linac has been performed for the Neutron Science Project at JAERI. The front end part of the linac, which consists of RFQ, DTL and SDTL, uses normal conducting structures and the higher energy part uses superconducting structures. The linac parameters and the results of the beam dynamics study are presented.

1 INTRODUCTION

A high intensity proton linear accelerator with an energy of 1.5 GeV and an average beam power up to 8 MW has been proposed for the Neutron Science Project (NSP) at JAERI [1].

The operation modes with three construction stages are tabulated in Table 1. The operation in the first stage is a pulse mode for the neutron scattering experiments with beam power of 1.5 MW. By increasing a duty factor and peak beam current, beam power will be upgraded to 8 MW in the second stage. A simultaneous H-/H+ acceleration by using a macro pulse switching injection will be accomplished in this stage. The 8 MW CW beam will be provided for the nuclear waste transmutation experiments in the CW stage.

The linac system design and the beam dynamics study are carried out considering the compatibility of the different beam currents and the duty factors.

Table 1. Operation mode of the NSP Linac

Construction Stage	1	2		CW
Operation Mode	Pulse	Pulse		CW
Accelerated Particle	H-	H-	H+	H+
Beam Energy (GeV)	1.5	1.5	1.5	1.5
Peak Current (mA)	16.7	30	30	5.3
Pulse Width (msec)	2	3.7	2.2	CW
Repetition (Hz)	50	50	50	CW
Duty Factor (%)	10	18.5	11	100
Beam Power (MW)	1.5	5	3	8

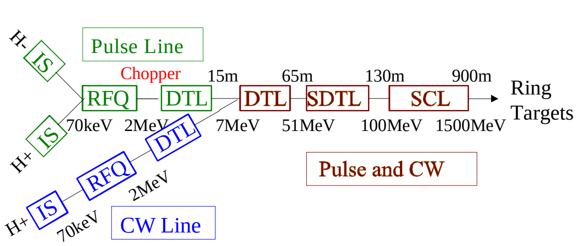

Figure 1. A schematic drawing of the linac system

2 LINAC SYSTEM DESIGN

A schematic drawing of the linac system is shown in Figure 1. The front end part of the linac, which consists of RFQ, DTL and separated-type DTL (SDTL), uses normal conducting structures and the higher energy part uses superconducting linac (SCL).

For the pulse mode operation at the NSP linac, the intermediate pulsing choppers for the ring injection and extraction have to be installed, whereas no choppers are required for the CW operation. The better beam quality will be expected by using optimized and simpler matching sections for each operating conditions. In addition to that, the lower electric field is suitable for the CW operation to reduce the RF heat dissipation, but the higher field is expected to suppress the space charge effects in the pulse mode. Based on the above reasons, injector lines for the pulse and for the CW operations are optimized separately to obtain the better beam qualities, respectively. The two lines merge in the DTL section at 7 MeV, where the neutron generation due to the beam loss risks can be avoided.

The SDTL structure[2] is adopted for the higher energy DTL region because of some advantages such as the simpler structures and the smoother matching properties to the following section.

The superconducting linac (SCL) is a main option between 100 and 1500 MeV, because the characteristics of the cavities are suitable for the high duty factor operation and less beam loss is expected due to the large bore size.

3 RFQ DESIGN

3.1 Design Descriptions

Two RFQs suitable for the pulse and the CW modes have been designed, respectively. The RFQUIK and CURLI codes are used to design. The parameters at the shaper entrance part are adjusted by hand. The main parameters are listed in Table 2.

The pulse mode RFQ is optimized at a beam current around 30 mA. The maximum peak electric field of 1.65 Ek was taken. The CW mode RFQ is optimized below 10 mA with lower electric field of 1.5 Ek. The lower field leads to a longer RFQ, but less structure RF power loss density is suitable for the higher duty factor operations.

Figure 2 shows design parameters vs. length for the pulse mode and the CW mode RFQs. The previous parameters[3] have been restudied based on some reasons. 1) The shaper sections with too gentle modulation slopes are reconsidered to ease the vane fabrication and alignment error tolerances. 2) Less than 2.0 of the maximum modulation factors are chosen to reduce the higher order components of the electric fields.

Table 2 RFQ Parameters

	Pulse	CW
Beam Current (mA)	20 - 40	~7
Energy (MeV)	0.07 - 2	0.07 - 2
Frequency (MHz)	200	200
Length (m)	3.45	3.57
r_0 (cm)	0.592	0.593
Inter-vane Voltage (kV)	98	89
Peak Field (Ek)	1.65	1.5
Focusing parameter, B	6.7	6.1
Peak RF Power* (kW)	325	266
Duty Factor (%)	~30	100
Average RF Power* (kW)	~100	266

* Including 43 % margin of the SUPERFISH results

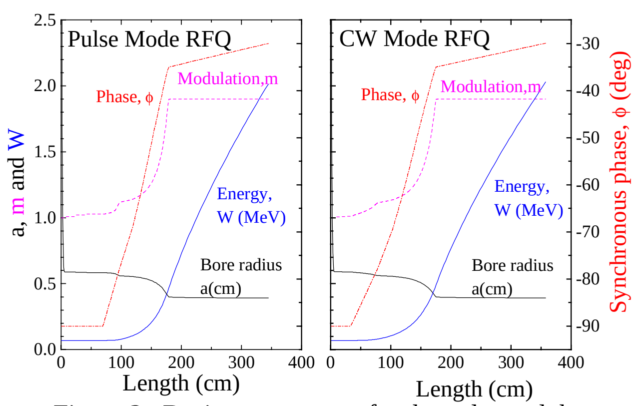

Figure 2. Design parameters for the pulse and the CW RFQs

3.2 *Simulation Results of the RFQs*

The beam simulation is performed with the PARMTEQ and PARMTEQM codes. Figure 3 shows the transmission rate and the rms emittance for the pulse and the CW mode RFQs. Both RFQs have the similar performances for the transmission rates and the transverse emittances. The CW RFQ has better longitudinal emittance up to 30 mA.

4 DTL AND SDTL DESIGN

4.1 Design Descriptions

The 200 MHz DTL follows the RFQ at 2 MeV. The main parameters are shown in Table 3. Up to 7 MeV, two DTLs are prepared for the pulse and the CW lines. The

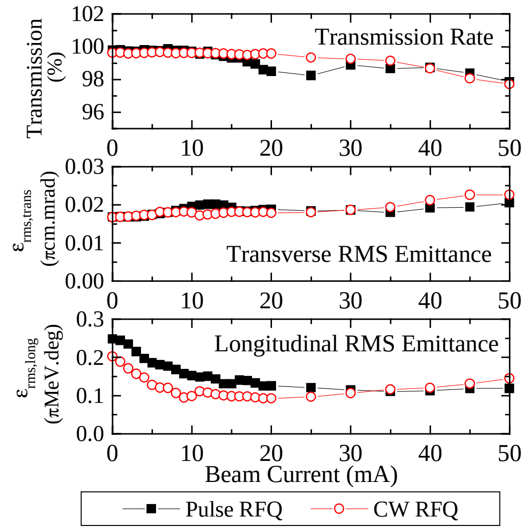

Figure 3. Transmission rate and normalized rms emittance for the pulse mode and the CW mode RFQs

lower E_0 of 1.5 MV/m is taken to reduce the heat dissipation of the structures. The lengths of the DTL and the SDTL are 58 m and 64 m, respectively

The SDTL structure is adopted from 51 to 100 MeV. The principles of the SDTL are very similar to those of the DTL, but the Q magnets are installed outside of the tank. As a beam dynamics design aspect, smoother transverse matching to the next section is expected, because the following SCL has a similar doublet focusing system.

For the system design of the DTL, the SDTL and the SCL sections, an equipartitioning design approach[3,4,5] is taken to reduce the emittance growth.

Table 3 DTL Parameters

	DTL	SDTL
Energy (MeV)	2-51	51-100
Frequency (MHz)	200	200
Beam Current (mA)	~ 40	~ 40
Operation Mode	Pulse and CW	Pulse and CW
E_0 (MV/m)	1.5	1.5
Number of Tank	3+1(CW)	17
Length (m)	58	64
Focusing	FD	Doublet
ϕ_s (deg)	-55 to -30	-30
Q-mag. Field (T/m)	51 to 5.0	8.5 to 7.9
ZTT (MΩ/m)	30 to 43	49 to 33

4.2 *Simulation Results*

The equipartitioned design and the beam simulation are performed with the modified PARMILA code. The beam sizes in the simulation results are shown in Figure 4. There is an increase of the beam sizes both in the transverse and the longitudinal directions. The beam bunch keeps a nearly spherical shape in the DTL and the SDTL sections.

The rms and the 90 % emittance growth rates are about 7 % and 10 % at the highest, respectively. Further matching work is required to eliminate modulations of the beam sizes.

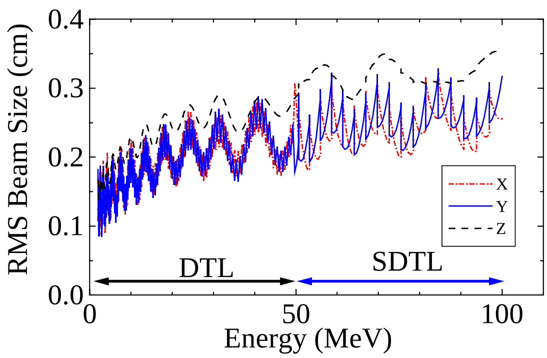

Figure 4. Beam sizes at the DTL and the SDTL

5 SUPERCONDUCTING LINAC

The superconducting linac parameters are shown in Table 4. The SCL is composed of 8 sections optimized for the phase slips due to the particle velocity and the cavity length difference. Each section has identical 5 cell cavities with surface peak field of 16 MV/m. Two cavities are laid in one doublet focusing period. The frequency is 600 MHz, which is 3 times of the lower energy sections. The total number of cavities is 284 and the length is 690 m. The detailed design and optimization study is described in reference 6.

The designed wave numbers, the beam sizes, rms emittances and the equipartitioning factors are shown in Figure 5. The equipartitioning factor is defined by $\gamma_0(\varepsilon_{nx}/\varepsilon_{nz})(z_m/a)$, where z_m and a are radius and longitudinal half-length of ellipsoidal bunch, respectively. The design results show a decrease of wave numbers both in transverse and the longitudinal directions. There is a monotonous decrease of the longitudinal beam size, while slight increase of the transverse beam size. The equipartitioning factor around 0.9 shows the design parameters are nearly equipartitioned, which means the beam size ratio z_m/a has a dependence of $1/\gamma_0$.

There is only 1 % increase of the transverse and the longitudinal rms emittances.

6 SUMMARY

Beam dynamics design have been performed for the NSP linac. To meet the pulse and the CW operation modes with better performances, two injector lines and optimized RFQs are designed. The equipartitioning design approach for the DTL, the SDTL and the SCL sections is taken to reduce the emittance growth. Further optimization study and matching work are expected to improve the performance.

7 REFERENCES

[1] M. Mizumoto et al.: 'High Intensity Proton Accelerator for Neutron Science Project at JAERI', these proceedings.

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[6] Y. Honda et al.: 'A Conceptual Design Study of Superconducting Proton Linear Accelerator for Neutron Science Project', Proceedings of the first Asian Particle Accelerator Conference, Tsukuba, Japan, 1998

Table 4 Supserconducting linac paramters

Energy (MeV)	100 - 1500
Frequency (MHz)	600
Beam Current (mA)	up to 30
Operation Mode	Pulse and CW
Surface Epeak in the Cavity (MV/m)	16
Number of Cells / Cavity	5
Synchronous phase (deg)	-30
Focusing Type	Doublet
Number of Cavities / Focusing Period	2
Number of Cavity Sections	8
Number of Cavities	284
Length (m)	690
Q magnet Field Gradient (T/m)	3.6 - 5.5

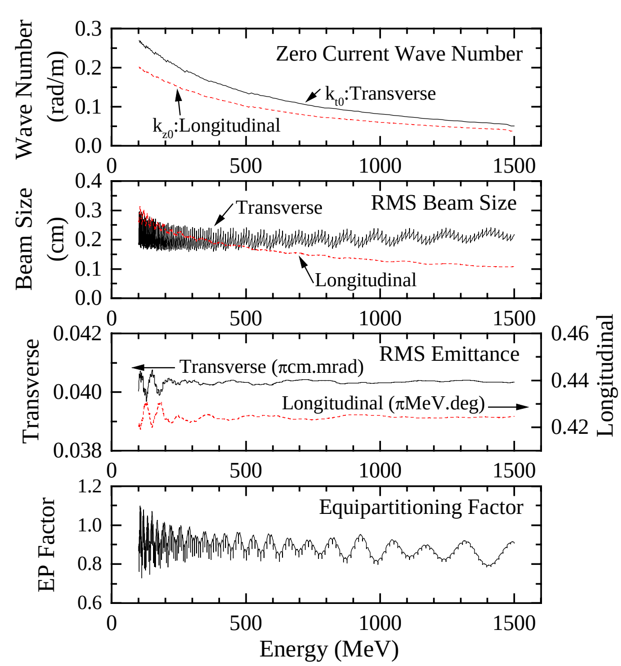

Figure 5. Design and beam simulation results of the superconducting linac section