DESIGN STUDIES OF A 100 MeV H^+/H^- LINEAR ACCELERATOR AS INJECTOR FOR ADS LINAC / SNS SYNCHROTRON

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Abstract

It is proposed to construct a 100 MeV proton linac which will form the initial part of a 1 GeV proton linac to be built in future for ADS (Accelerator Driven System) applications. Additionally, the linac will be used as injector for the Spallation Neutron Source (SNS) to be constructed at CAT based on a 1 GeV proton synchrotron. In this case the linac will accelerate 25 mA H^- ion beam for injection into the synchrotron. We have explored many configurations of the 100 MeV linac which will consist of an H^+/H^- ion source, a 4.5 MeV RFQ followed by a 100 MeV SDTL (Separated Function Drift Tube Linac). We have also studied options involving DTL and CCDTL (Coupled Cavity Drift Tube Linac) structures. In this paper, we present the results of our preliminary physics design studies of the RFQ-SDTL configuration. The design of MEBT is also discussed. The choice of the accelerator configuration and that of various parameters of the individual accelerator structures under consideration are discussed.

1 INTRODUCTION

The SNS synchrotron will be a Rapid Cycling Synchrotron (RCS) with repetition rate of 25 Hz and needs pulsed H^- ion beam for charge exchange injection into it. The 1 GeV linac on the other hand will need a CW proton beam for ADS applications [1]. Therefore the RFQ as well as the following accelerator up to 100 MeV was required to be optimized for CW operation. The beam loss control is considered to be the main issue while the linac configuration and the operating parameters are optimized. A special care is required to be taken especially during the design of the low energy part of the linac or the linac front end. A mismatch between the beam and the focusing channel may lead to production of beam halo, which is considered to be the main cause of particle loss. Therefore the linac front end must deliver a high quality beam for low beam losses at higher energies where the effects of beam losses are more dangerous [2,3]. The other consideration which has the influence on choice of parameters is the high duty factor / CW operating mode. Figure 1 shows the general schematics of the 100 MeV linac. This will consist of an ion source at 50 keV followed by LEBT, a 4.5 MeV RFQ [4] followed by MEBT and 100 MeV SDTL[5]. Two other options with 20 MeV DTL followed by 100 MeV SDTL and a 4.5 to 100 MeV CCDTL[6] were also studied with the help of PARMILA[7]. The DTL provides best possible focusing among the three structures studied and so the best beam quality. But it offers more difficulties in cooling circuit design and its realization due to the presence of quads inside the drift tubes. The DTL for CW operation should be designed with a lower gradient to reduce the power dissipation in the structure. The CCDTL structure which uses external focusing was adopted for CW accelerators APT [8] and KOMAC [9] also provides beam quality quite comparable to DTL. The possibility of using SDTL concept at lower energies is explored at many places. SDTL uses empty drift tubes which eases cooling circuit design and fabrication of DT with focusing quads in the inter-tank space. Results of our preliminary design study for 100 MeV SDTL with PARMILA are described in the following section.

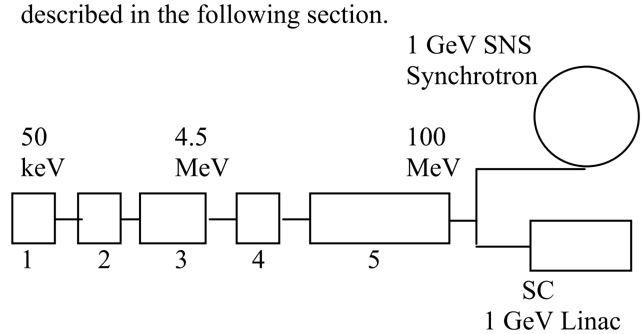

Figure 1. General schematics of the 100 MeV linac
1. Ion Source, 2. LEBT, 3. RFQ, 4. MEBT and 5. SDTL

2 THE SDTL DESIGN

Design specifications of the 100 MeV linac are given in Table-I. The 1 GeV ADS linac will need 10 mA CW proton beam at injection where as the SNS synchrotron needs 20 mA H^- ion beam. The RFQ and the SDTL, both are designed for a current of 25 mA.

Table-I: Design Specifications of the 100 MeV Linac

	ADSS	SNS	
Input energy	4.5		MeV
Output energy	100		MeV
Beam current	10	20	mA
Particles	H^+	H^-	
Operating mode	CW	Pulsed	
Pulse duration	–	500	μsec
Repetition rate	–	25	Hz

2.1 MEBT

The SDTL structure uses quadrupole triplet lattice for focusing. Matching between RFQ and the SDTL is studied with the help of TRACE3D [9]. The MEBT uses two quadrupole doublets, one RF gap and a combination of drift spaces for matching in transverse and longitudinal planes. The MEBT has adequate space to accommodate diagnostics and pumping etc after the RFQ. The total length of MEBT is 117.2 cm. Figure 2 shows the TRACE3D output plots for the MEBT.

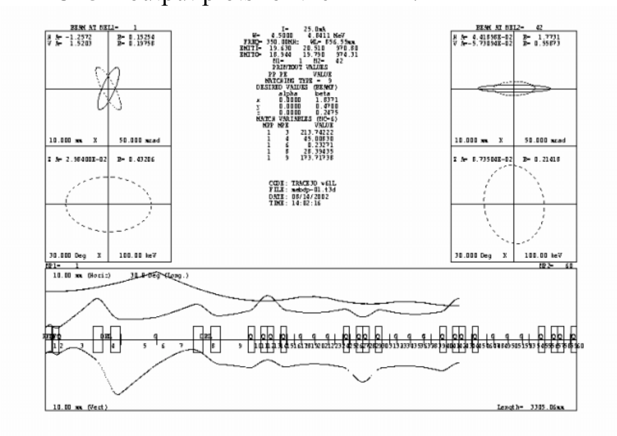

Figure 2. TRACE3D plot of MEBT

2.2 Choice of Parameters

The SDTL has been optimised for lower power dissipation. The power dissipation in the structure varies with the square of the accelerating gradient and the length of the accelerator for fixed output energy varies directly with the accelerating gradient. Therefore relatively lower gradient will be preferred to reduce the total power dissipation in the accelerator. We worked out many accelerator layouts at 700 MHz and 350 MHz and different number of gaps/tank. As the RF and space charge defocusing is stronger at lower energies, lesser number of gaps/tank would be preferred on low energy side of the linac to have smaller RF defocusing within the focusing period and the smaller period length. The number of gaps/tank can be increased in groups. In order to avoid step changes in the accelerating structure and the focusing period, we held the number of gaps/tank constant and the inter tank spacing of integral βλ, varying in groups.

Two configurations at 700 MHz were studied one with 8 and 6 gaps/tank and another with 4 and 6 gaps/tank. The first configuration found to be suitable for operation at 10 mA but is difficult for matching in the intermediate energy range for current about 25 mA. The second design with 4 and 6 gaps/tank is found to be acceptable. The accompanying paper [10] describes the thermal and structural design of this SDTL. To have advantage of better power handling capability of the accelerating structure at lower frequencies, another configuration at 350 MHz was studied. This design uses 3 gaps/tank up to 100 MeV. The beam aperture diameter is chosen to be 2 cm and is held constant throughout the linac. The drift tube parameters and the tank diameter were varied to maximise ZT^2. Considering the CW operating mode, the drift tube parameters were selected so that the power density is much below 15W/cm^2 at the design gradient to ease the cooling.

2.3 Beam Dynamics studies

Beam dynamics studies were performed with the help of code PARMILA. The accelerating gradient E_0 was ramped slowly from 1.6 MV/m to 2.2 MV/m in first 12 tanks (36 cells) where the proton energy is 8 MeV and the synchronous phase φ_s was ramped from -60° to -30° over about 35 tanks corresponding to proton energy of about 22 MeV. Above this, E_0 and φ_s were held constant at 2.2 MV/m and –30° respectively over rest of the linac. The E_0 and the φ_s were ramped to have constant separatrix width and constant longitudinal focusing strength. The linac was generated with the above parameters. We decided to use triplet focusing lattice after studying various schemes with TRACE3D. The triplet is placed at the centre of the inter tank space which is an integral multiple of βλ. The inter tank space can also accommodate beam diagnostic devices and steerers etc. In order to have a symmetric focusing in x and y planes, each triplet is rotated by 90 degrees wrt to the preceding one. Figure 3 shows the layout of one focusing period. The beam from RFQ is matched in to the SDTL lattice in all the three planes using drifts quads and an RF gap,. The inter tank matching is also performed using TRACE3D. The RFQ was simulated with 10,000 particles at its input. The particle distribution available at the end of RFQ is traced through the entire linac up to 100 MeV simulating the linac end to end from the RFQ input to SDTL last tank. The design parameters of the 100 MeV SDTL are listed in Table-II. Figure 5 shows the beam profiles in x, y and Δϕ

Table-II: Design parameters of the SDTL

Frequency	350	MHz
Energy	100.43	MeV
Beam current	25	mA
Synchronous Phase	-60- -30°	
Average accel. grad.	1.6 – 2.2	MV/m
Number of Tanks	98	
No. of cells/tank	3	
DT bore ID	20	mm
DT OD	60 – 100	mm
DT Face angle	37.5 – 45	°
Tank Diameter	520 – 560	mm
Tank length	252.98–1099.5	mm
Total length	130	m
Shunt Imp. (eff.)	43 – 52	MΩ/m
Beam Power	2.4	MW
Cavity losses	4.76	MW
Total RF Power	7.16	MW
Focusing Lattice	Triplet	
Quad gradient	40 – 75	T/m
RMS O/P emitt. x	0.31	π mm.mrad
y	0.32	π mm.mrad
z	0.109	deg.MeV

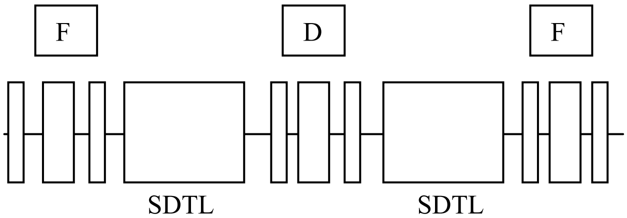

Figure 3. One period of the SDTL focusing lattice

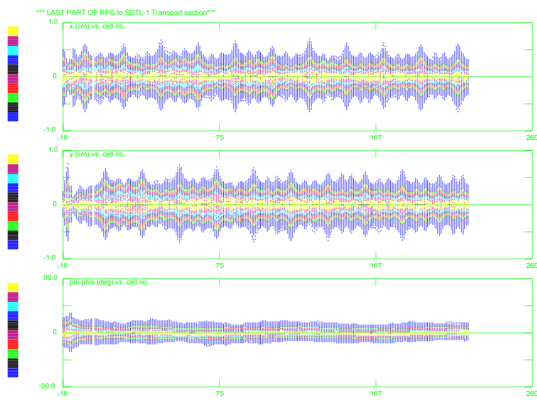

Figure 4. Beam transmission through first 22 tanks of the100 MeV SDTL; Top x vs cell no; middle y vs cell no and bottom W-W_s vs cell no.

vs cell number through MEBT and first 22 tanks. Figure 5 and fig. 6 show the beam phase space plots at the beginning of the MEBT and at the end of SDTL tank 98 at 100.43 MeV respectively. The rms beam size is between 0.9 to 2.5 mm through out the linac. The beam makes larger transverse excursions only in the inter-tank drift spaces where the diameter of the beam tube can be increased. Thus the beam pipe to rms beam radius ratio can be maintained to about 5 to 6 throughout the accelerator.

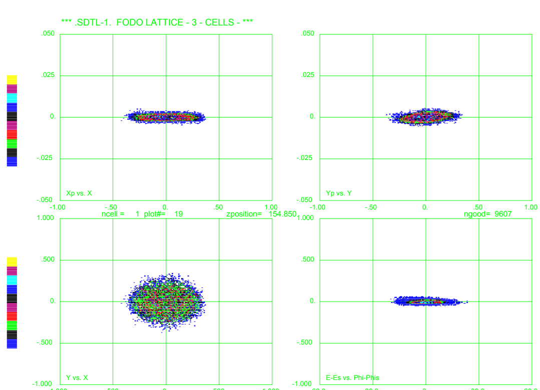

Figure 5. Beam phase space at the beginning of the MEBT Top left x′ vs x, top right y′ vs y, bottom left y vs x and bottom right W-W_s vs φ-φ_s

2.4 Design of Tanks

The SDTL tanks are designed with SUPERFISH. The Tank diameter is varied from 520 mm to 560 mm. The drift tube OD is between 120 to 140 mm. The DT geometry is optimized for maximum shunt impedance. The drift tube angle is variable. The maximum power density is about 12 Watts/cm^2.

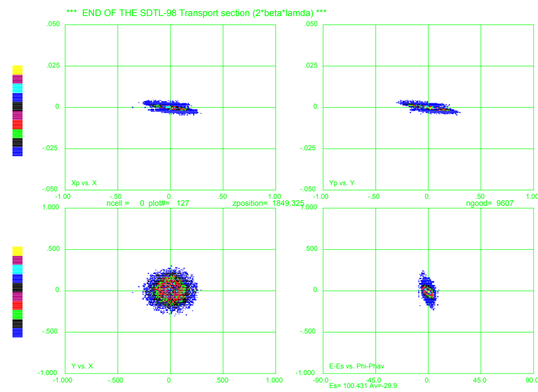

Figure 6. Beam phase space at the exit of the 98th tank of SDTL Top left x′ vs x, top right y′ vs y, bottom left y vs x and bottom right E-E_s vs φ-φ_s

3 ACKNOWLEDGEMENTS

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