LATTICE DESIGN FOR SUPERCONDUCTING CW LINAC FOR PROJECT-X FACILITY AT FERMILAB*

A. Saini [#], K.Ranjan, University of Delhi, Delhi, India
J.P. Carneiro, S. Mishra, J.F. Ostiguy, N. Solyak, A.Vostrikov, V. Yakovlev, FANL, Batavia, IL,USA

Abstract

Project-X is the proposed high intensity proton facility to be built at Fermilab, US. The Project-X facility consists of superconducting Linac which will be operated for 1mA average current with a peak current of 5mA in continuous wave (CW) mode. The Linac is divided into two sections on the basis of operating frequencies & five sections on the basis of family of RF cavities to be used for the acceleration of beam from 2.5 MeV to 3 GeV. This paper presents layout of beam transport system and preliminary results of study of beam optics for the linac.

INTRODUCTION

Project-X is a high intensity multi mega-watt (MW) facility to be built at Fermilab [1].

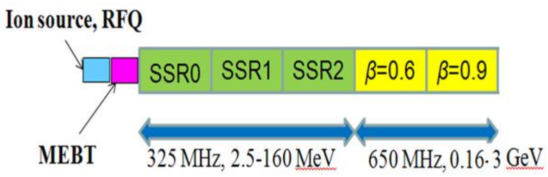

Figure 1: Acceleration scheme

The proposed facility is based on 3 GeV, 1mA CW SC linac. Schematic of the baseline configuration of the linac is shown in Fig. 1. It includes an ion source which provides 5 mA pulsed beam of H^- ions. Beam is accelerated through the RFQ which is operated at room temperature at 325 MHz frequency. The RFQ is followed by Medium Energy Beam Transport (MEBT) section which is used to chop the beam in order to get the time structure which is necessary to operate the different experiments simultaneously. The MEBT is followed by SC linac, which is segmented into two sections: low energy part and high energy part. The low energy section (2.5-160 MeV) uses three families of SC single spoke resonators i.e. SSR0, SSR1 & SSR2 which are operated at 325 MHz. The high energy section of the SC linac (160 MeV-3.0 GeV) uses two families of 5 cell SC elliptical shape cavities i.e. β=0.61 and β=0.9 which are operated at 650 MHz.

LATTICE DESIGN & BEAM DYNAMICS

Beam optics is based on the following principles:

- In order to avoid possible mis-match and make the SC linac lattice independent of beam current, wave numbers (phase advance per unit period length) of transverse and longitudinal oscillations should be smooth through the SC linac and should change only gradually.
- Longitudinal phase advance (under zero beam condition) should be smooth without discontinuities throughout the SC linac to avoid halo excitation.
- Length of the focusing period is kept short, especially in the low energy section where space charge dominates.
- Matching between each cryomodule should be smooth to avoid halo generation and emittance growth. Beam matching is achieved by adjusting the gradients and phases of the outermost elements of each side of the transition.
- Lattice design should be robust to allow for spread in designed parameters like spread in cavity gradient, operation of linac with failed beamline elements, misalignments etc.
- Working gradient of the cavities are limited by the peak surface magnetic field & cryogenic losses. Maximum surface field which is chosen to protect the RF cavity from quenching is 60 mT for all the cavities operating in 325 MHz section and 70 mT for the ones which are operated in 650 MHz section. Cryogenic losses per cavity should be less than 25 W.

BASELINE DESIGN

The SC linac lattice has been designed with the consideration of above principles and constraints. Table 1 summarizes the number of beamline elements (RF cavities, solenoid and quadrupole) and number of cryomodules corresponding to each section along with the transition points between each section.

Table 1: No. of Elements along with Transition Energy.

	SSR0	SSR1	SSR2	β=0.6	β=0.9
Cavities	18	20	40	36	152
Solenoids	18	20	20	0	0
Quads	0	0	0	24	38
CM	1	2	4	6	19
Length, m	10.98	16.40	33.20	60.00	292.60
Position, m	0.00	11.38	28.18	62.72	124.69
Period length, m	0.61	0.80	1.60	5.00	15.40
Periods	18	20	20	12	19
Transition energy, MeV	10.18	42.58	160.5	515.4	3028.3

The SC linac lattice has been studied using different beam dynamics codes e.g. Track v39, TraceWin/PARTRAN & ASTRA. All the calculations are done for 10 mA peak current. Beam propagation through the SC linac is shown in Fig. 2.

*Work supported by IUSSTF and US DOE
[#]asaini@fnal.gov

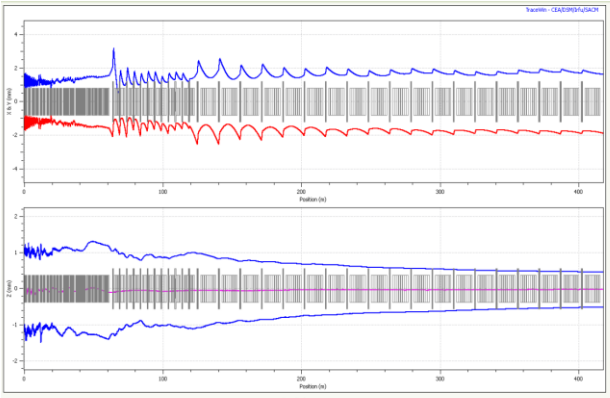

Figure 2: Beam envelope in the transverse plane (top plot: X blue, Y red) and in longitudinal plane (bottom plot) is shown for SC linac.

Transverse and longitudinal wave numbers are shown in Fig. 3. It can be seen that wave numbers in both planes are smooth and any major discontinuity is avoided by proper selection of length of the focusing period in both planes. Longitudinal focusing is adjusted by proper selection of cavity's gradient and phase while transverse focusing is adjusted by varying field gradient of solenoid and quad.

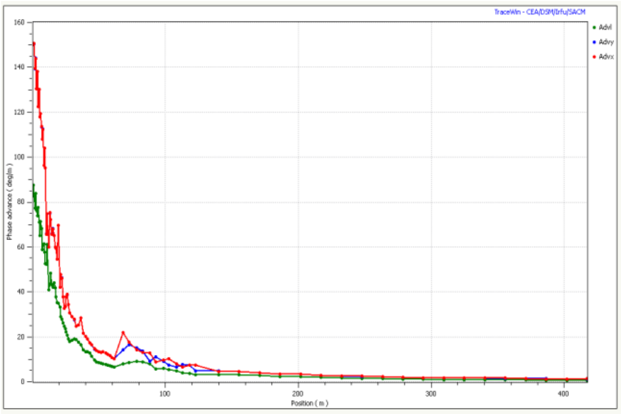

Figure 3: Transverse (red & blue) and longitudinal (green) wave numbers along the SC linac.

Evolution of emittance in both the planes along the linac is shown in Fig. 4. Emittances at the end of the 325 MHz section and at the end of the SC linac are summarized in Table 2. Initial values of transverse and longitudinal emittances at the start of SC linac are 0.25π mm-mrad and 0.127π mm-mrad respectively.

Table 2: Emittance in longitudinal & transverse planes.

Emittance (π mm-mrad)	Initial	325MHz section end	Linac end
ε_z	0.127	0.156	0.169
ε_t	0.25	0.265	0.274

Emittance dilution in transverse plane is about 6% and 10% at the end of the 325 MHz section and at the end of Linac respectively, whereas emittance dilution in longitudinal plane is about 23% at the end of the 325 MHz section and 33% at the end of the SC linac. Distribution of gradient of cavities for the complete linac is shown in Fig. 5.

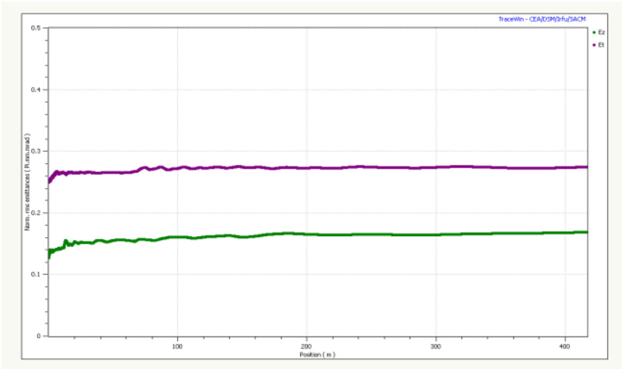

Figure 4: Emittance dilution in Transverse (magenta) and longitudinal (green) plane along the linac.

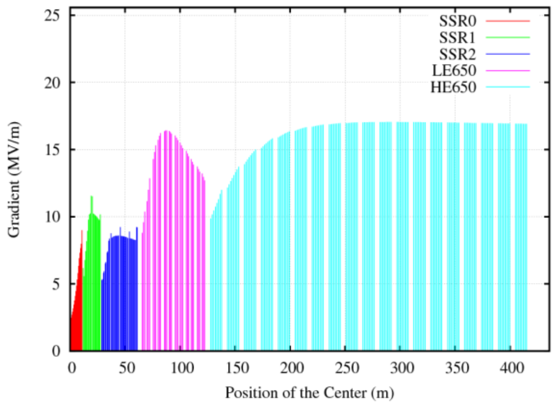

Figure 5: Cavity gradient along the linac.

MISALIGNMENT & H^- STRIPPING

Estimation of the beam losses due to stripping and misalignments have to be studied for the present SC linac lattice. A similar study has been performed earlier for an alternative design [2] which gives encouraging results. It is found that losses due to stripping are well below 0.1W/m. Emittance dilution due to misalignments, after 1-to-1 correction, which is used to correct the beam centroid offset, is found to be less than 20%.

SUMMARY

The conceptual design of the CW superconducting H^- linac lattice for 3GeV, 1 mA beam, has been proposed for project –X. The lattice design looks feasible, however, study for beam losses due to misalignments and stripping have to be performed.

REFERENCE

[1] S.D. Holmes "Project X: A Multi-MW Proton Source at Fermilab", IPAC 2010.
[2] N.Solyak et. al."Design of The Project X CW Linac", LINAC 2010.