DEPENDENCE OF THE SNS TRANSFER LINES AND ACCUMULATOR RING ON LINAC ENERGY*

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Abstract

One of the options considered for the SNS linac, to reduce the cost, was to lower the energy to 840 MeV and leave space in the tunnel for a future upgrade to 1.3 GeV either by adding cryo-modules or increasing the gradient in the SC linac. A linac energy other than 1.0 GeV will have an impact on the transfer line and accumulator ring. The energy impacts the location of the corrector cavity in the HEBT, the injection magnet, beam power, dE/dx, multiple scattering and H^- stripping, neutron production at the target etc. These issues will discuss, and changes required in the transfer lines and accumulator ring to accommodate lower energy beam are presented.

1 INTRODUCTION

The SNS accelerator complex includes a 1.0 GeV Superconducting (SC) linac[1], High Energy Beam Transport (HEBT), accumulator ring, and Ring to Target Beam Transport (RTBT)[2,3]. For the SC linac, one cavity per klystron was chosen to achieve high quality and reliable beam. This option increased the cost of linac. To fit the cost within the budget, one of the options considered was to lower the linac energy to about 840 MeV. The proposal is to leave the space in the tunnel for future to go to 1.0 GeV. A linac energy other than 1.0 GeV will have the following impact on the transfer line and accumulator ring. (1) location of the Energy Corrector Cavity (ECC) in the HEBT, (2) injection magnet, (3) beam power, (4) RF frequency, and RF system, (5) issues related to dE/dx, multiple scattering, and H minus stripping, and (6) neutron production at the target.

2 LOCATION OF THE ECC IN THE HEBT

Due to amplitude and phase control error in the linac, the beam will suffer from energy jitter. This energy jitter will result in there being beam in the extraction beam gap in the accumulator ring, which will be lost during the rise time of the extraction kickers. To correct the energy jitter from the linac, there is ECC in the HEBT whose phase is locked with the last linac cavity such that the synchronous particle arrives at the cavity at zero phase and does not lose or gain the energy. The lower/higher energy particle arrives at the cavity late/early and gain/lose the energy accordingly [4]. If the linac energy is lowered this phase slip will increase due to length change and the energy change. This phase slip $\Delta\phi_L$ is given by

$$\Delta\phi_L \equiv \frac{1}{\gamma(\gamma+1)}\frac{\Delta T}{T}\frac{L}{\beta c}2\pi f \qquad (1)$$

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where β,γ are the relativistic parameters, T is the design energy and ΔT is the energy deviation from the design energy, L is the length in which phase slip occurs and f is the frequency. Figure 1 shows the phase slip per MeV as a function of distance.

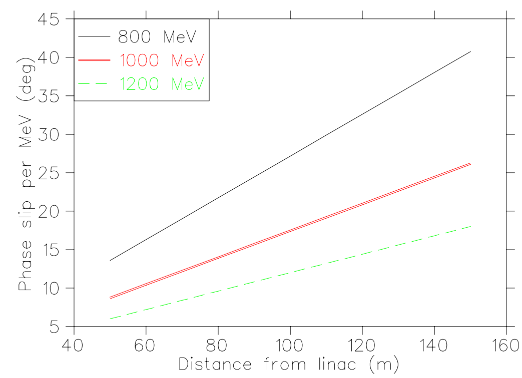

Figure 1: Phase slip per MeV as a function of distance between the last linac cavity and energy corrector cavity.

3 INJECTION CHICANE MAGNET

The 1 ms long linac beam pulse will be injected into the accumulator ring via charge exchange injection in about 1200 turns[5]. To reduce the foil traversals and space charge density, linac beam with very low emittance (0.28 pi mm mrad, rms) is painted into to a very high emittance area of 120-160 pi mm mrad[6]. This is accomplished by moving the closed orbit at the charge exchange foil using a chicane made of four vertical dipoles and four horizontal dipoles. The chicane magnet at the foil has following constraints. (1) the field in this magnet should be such that the Lorenz stripping of H^- should be acceptable with the loss criteria, and (2) the field should also prevent foil stripping to H^0 in n=4 and lower exited states. As pointed out in reference 7 due the quantum nature of excited state of H^0, if the energy difference is more than ± 5%, two injection chicane magnets have to change. Table I shows the required magnetic field for different injection energies.

Table I: Required magnetic field for the middle chicane magnet

Injection Energy (MeV)	Magnetic field in middle chicane magnet (T)
800	0.29
900	0.27
1000	0.25
1100	0.23
1200	0.215
1300	0.205

4 BEAM POWER

The space charge tune shift in the accumulator ring is proportional to current and inversely proportional to $\beta^2\gamma^3$.

$$\Delta\nu \propto \frac{I}{\beta^2\gamma^3} \qquad (2)$$

In order to keep the same space charge tune shift, beam current has to be lower for lower linac energy. Figure 2 shows the beam power as a function of linac energy for a given space charge tune shift (0.15).

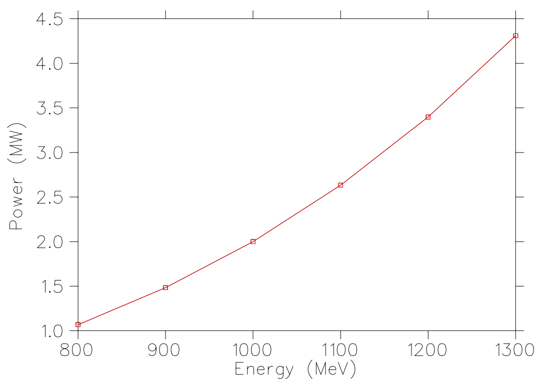

Figure 2: Beam power as function of injection energy in the accumulator ring for space charge tune shift of 0.15.

5 RF FREQUENCY

The beam revolution frequency will be lower for lower linac energy, so the RF frequency in the accumulator ring must also be lower. This might require tuning the power supply. No change in the ferrite is required. With β=0.875 at 1 GeV and β =0.842 at 800 MeV, 10 kV per gap at 1GeV reduces to 9.6 kV per gap at 800 MeV and should be no problem.

6 ENERGY STRAGGLING, MULTIPLE SCATTERING AND H$^-$ STRIPPING DUE TO RESIDUAL GAS

In the transfer line and accumulator ring the beam traverses material at two places. First during the injection process (charge exchange injection) beam passes through the 300 μg/cm^2 thick carbon foil and suffers energy straggling and multiple scattering. The other time is when beam passes through a 4 mm thick inconel window in the RTBT about 2 meters in front of target.
The mean rate of energy loss is given by Bethe-Bloch equation

$$-\frac{dE}{dx} = Kz\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{MAX}}{I^2} - \beta^2 - \frac{\delta}{2}\right] \qquad (3)$$

$$T_{\max} = \frac{2m_ec^2\beta^2\gamma^2}{1+2\gamma m_e/M + (m_e/M)^2} \qquad (4)$$

Here T_{MAX} is the maximum kinetic energy which can be imparted to a free electron in a single collision. K/A=0.307075 MeV g^{-1} cm^2, Z is the atomic number of the media, m_e is the mass of the electron, I is the mean excitation energy, δ is density effect correction to the ionization energy loss, c is velocity of light and β,γ are the relativistic parameters. The multiple scattering angle is given by

$$\theta_0 = \frac{13.6MeV}{\beta cp}z\sqrt{\frac{x}{X_0}}\left[1+0.038\ln\left(\frac{x}{X_0}\right)\right] \qquad (5)$$

Here p, βc and z are the momentum, velocity, and charge number of the incident particle, and x/X_0 is the thickness of the scattering medium in radiation lengths. Figures 3 shows the energy losses due to this processes as a function of the energy. Figure 4 shows the multiple scattering angles as a function of energy.

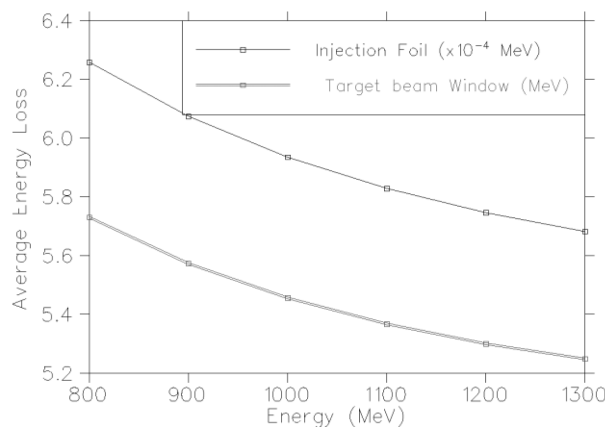

Figure 3: Average energy loss as a function of energy for proton beam window in RTBT which is 4 mm thick made of inconel and injection carbon foil 300 μg/cm^2.

H minus gas stripping will also be affected by lower energy. At 1 GeV for residual gas consisting of 40% H_2, 40% H_2O, and 20% CO will have stripping cross section < 1×10^{-18} cm^2 and corresponding stripping losses at 5×10^{-8} Torr, will be 0.3 nA/m. For 800 MeV this loss will increase by 8% since the stripping cross section varies as $1/\beta^2$.

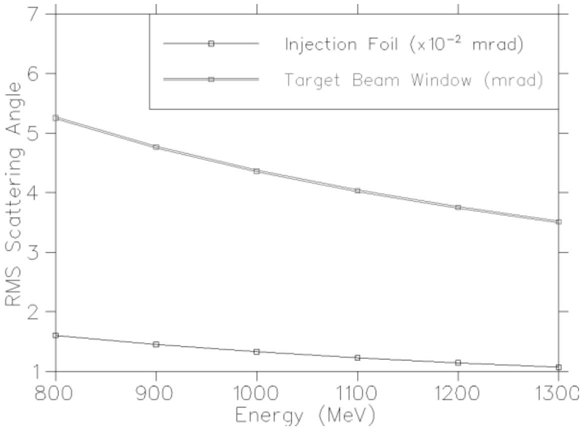

Figure 4: RMS multiple scattering angles as a function of energy for proton beam window in RTBT which is 4 mm thick made of inconel and injection carbon foil 300μg/cm^2.

7 NEUTRON PRODUCTION AT THE TARGET

Neutron production at the target is proportional to the proton beam power; therefore neutron production at 1 MW (800 MeV, see figure 1) will be about half that of 1 GeV protons. Figure 5 shows neutron yield per MW of beam power as a function of proton energy on a lead target[8]. Below 1 GeV the curve decreases rapidly.

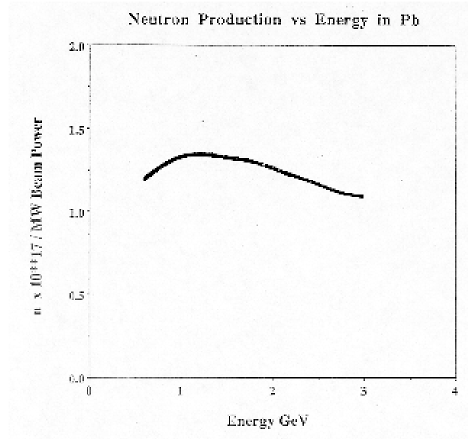

Figure 5: Neutron yield per MW of beam power for a lead target.

8 REFERENCES

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