DRAFT

Energy Corrector Cavity for the 8 GeV Linac Proton Driver

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Introduction

The design of the beam central energy correction can be expected to change as actual performance of the SNS linac becomes known. Until then one must rely on model results and a modicum of caution. It is rather likely that some concerns founded on general concepts and an ignorance of the performance of real systems will prove unwarranted, but, of course, one does not know which ones. This note describes the concept of an energy jitter correction scheme that is sufficiently flexible and robust to serve in the circumstances currently envisaged. The scheme is predicated on the idea that a classic debuncher is not required because the predicted energy spread of the linac bunches is acceptable. The jitter, however is nearly ten times as large as desirable for controlled energy painting. Table I displays the beam parameters assumed to quantify the necessary correction. The jitter value was taken from the calculations of M. Heuning as given in Fig. 16 of the 8 GeV superconducting linac Design study[1]; the energy spread was estimated from P. Ostroumov's end-to-end model with 20 % additional allowed for halo, construction errors, *etc*.[2]

Basic Concepts

The h=588 bunches captured in the Main Injector (MI) must not exceed the bunch area that can be accelerated through transition; preferably they will be smaller in any injector application. The beam is assumed chopped at the MI circulation frequency, so the bunch area from adiabatic capture will be $\Delta E_{\rm beam} \times \tau/h$. Taking 0.7 eVs as the largest bunch area that can be accelerated through transition[3], the energy spread is limited to ± 37 MeV, approximately half of the energy acceptance. The predicted energy spread given in Table I will permit well controlled energy painting if the jitter is held to less than or about the 1.3 GHz bunch height of 3 MeV. Thus the jitter correction required is less than a factor ten reduction. The dispersion needed for momentum collimation is sufficient for measuring the average energy offset. Although the corrector cavity can be designed to reach correcting gradient within a few 1.3 GHz periods, it should not be located in the dispersive arc because the energy kick will spoil the achromaticity of the bend. There will therefore be an unavoidable delay of the half length of the arc in applying the correction. The momentum collimators will need to handle the larger off-momentum beam for about 1 μs per MI cycle. This load could probably be reduced somewhat by feed forward with learning that presets the corrector where it would have been on the prior pulse. A feedforward elaboration is not expected to be necessary.

There are two well known sources of energy variation which are features of the superconducting technology, *viz.*, Lorentz de-tuning and microphonic cavity deformation. The Lorentz de-tuning occurs during the buildup of the cavity excitation before beam is present and is the same from pulse-to-pulse. Thus, it can be compensated by moerately fast tuners without complications of fast beam behavior. The current plans are to include piezoelectric tuners on the cavities, which should be quite sufficient for practically eliminating this problem. The microphonics in the lower energy sections of the linac will probably be rather well controlled by fast phase shifters in the waveguides to the cavities. In the high energy end, where only the vector sum of several cavities is corrected, there will be some residual error. The H^- does not have $\beta = \beta_{geom}$ exactly; thus, the bunches do not have precisely the same phase in each cavity of the group. The model results of Heuning[1] show that the net energy wander is within the range of the proposed corrector section, but there is not much information on the time structure given. However, using the knowledge that typical microphonic oscillations have frequencies in the hundreds of Hz and that there are $\mathcal{O}(100)$ sources, one can be reasonably certain that, even with extreme nonlinear mixing, the frequencies seen in the composite microphonic disturbance will be within the 1 – 2 MHz bandwidth of the corrector system. However, the residual cavity-to-cavity phase and amplitude jitter is much faster than the system response time, so this variability

Table 1: Accelerator and beam parameters for injection into the Main Injector

Parameter	Symbol	Value	Units
injection energy (total)	E_s	8938	MeV
full momentum aperture		$\gtrsim \pm 0.8$	%
physical betatron emittance	ϵ_r	$0.16 \cdot 10^{-6}$	m
max. energy jitter at 8 GeV	ΔE	± 20	MeV
estimated energy spread at 8 GeV	δE	± 3	MeV
MI circulation period	τ	11.14	μs
MI rf harmonic number	h	588	
time chopping	T_2	10	μs/turn
barrier voltage	V_{barrier}	2	kV
barrier width	$2T_1$	1.14	μs
barrier height	$\Delta E_{\mathrm{barrier}}$	16.9	MeV

must be acceptable. The modelling to establish the fast jitter has not yet been done. The example given by D. Raparia[4] suggests that the fast variability ($\pm 2\sigma$) could easily be twice the 3 MeV set as a design criterion, but his example seems to have been based on SNS criteria for LLRF feedback precision that he says have been surpassed at BNL. The obvious solution to such jitter is the one SNS employs, a debuncher cavity at sufficient distance. However, a sufficient distance works out to be $\mathcal{O}(10)$ km; for just this reason a less complete but more compact energy correction scheme is proposed.

To give the correction the maximum bandwidth, a 20 – 30 MeV, 1.3 GHz, copper traveling wave section can be used; a similar section would be suitable for the energy painting function. If momentum collimation is not needed, a single section could be located downstream of the arc and used for both jitter correction and painting. A phased installation in which the downstream traveling wave section is installed and the momentum collimators are omitted might be useful. If needed for higher intensity or because the linac jitter is greater than predicted, the second traveling wave section should be installed upstream of the arc and the collimators installed as planned.

To simplify the low level phase control slightly, it is possible to derive the drive for the traveling wave section(s) from the sum signal of the BPM which measures the energy error. This would have possible advantage in automatically adjusting the 1.3 GHz phase for phase error produced in the linac, although the necessary delay between the BPM and the corrector section would limit this sort of correction to about 1 MHz bandwidth.

Design Features

Because the injected beam is nearly continuous around the MI circumference, it must be contained within rf barriers to preserve the abort/kicker gap established by chopping in the linac. Currently, the available barrier voltage is just under 2 kV. With this rf voltage and the assumed chopping pattern, the barrier can be established to contain[5]

$$\Delta E_{\mathrm{barrier}} = \sqrt{\frac{eV_{\mathrm{barrier}} T_1 2\beta^2 E_s}{\tau|\eta|}},$$

giving the 16.9 MeV entered into Table I . The parameters in the barrier height formula are defined in the table. Thus, it would be useful to increase the barrier voltage to as much as 10 kV to exploit the full momentum spread that could be accelerated through transition.

The standard SLAC 2.856 GHz structure can be scaled to give approximate dimensions for the energy corrector traveling wave section. Scaling by the wave length, one finds that the guide inner radius is about 9.1 cm, the iris radius is about 2.6 cm, the spacing between irises is 7.7 cm, and the iris thickness is about 1.3 cm. At a rather conservative 7 MV/m, a 10 m length is quite sufficient. The power required should be less than 10 MW, perhaps half of that, depending of course on R_{shunt}, which has been estimated by interpolating between SLAC values and 880 MHz values.

Summary

The foregoing presents a conceptual solution to a serious problem in the 8 GeV proton driver linac proposal, viz.,

$$\Delta\beta/\Delta\gamma = \beta^{-1}\gamma^{-3},$$

so that very long drifts are needed to establish energy-dispacement correlation permitting energy correction by a debuncher cavity. Because the energy spread of the bunches is expected to be acceptable without correction, it is satisfactory to correct only the mean energy deviation (energy jitter) by an accelerating structure phased according to energy deviation measured in the momentum collimating arc of the transport line. Specifically, a 10 m 1.3 Ghz traveling wave structure is proposed for immediately upstream of the arc and energy deviation is measured just upstream of the momentum collimator, providing energy correction feedback with 1 – 2 MHz bandwidth

Acknowledgments

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References

[1] “An 8 GeV Superconducting Injector Linac Design Study”, draft v45, Fermilab-TM-2169(Part II) (18 May 2004), unpublished

[2] Petr Ostroumov, “Beam Dynamics in Proton and Heavy Ion Linacs Based on Superconducting Technology”, Acc. Phys. and Tech. Sem., Fermilab (29 Jan. 2004)

[3] Weiren Chou, priv. comm.

[4] D. Raparia, “8 GeV HEBT Example”, talk at Fermilab Workshop on Beam Chopping (16 – 18 May 2004)

[5] S. Y. Lee and K-Y Ng, “Particle Dynamics in Storage Rings with Barrier rf Systems”, Fermilab-Pub-96/403 (November 1996)

[6] A. I. Drozhdin, “Beam collimation in the transfer line from 8 GeV linac to the Main Injector”, unpublished draft (29 July 2004)