Megawatt Recirculating Superconducting Proton Linac for Neutrinos

Ji Qiang (jqiang@lbl.gov) and Lucas Brouwer

Lawrence Berkeley National Laboratory, Berkeley CA, USA, 94720

Introduction

A high power GeV superconducting proton (H^+/H^-) linac can be used as a driver for nuclear waste transmutation in subcritical nuclear power plant [1-5], for production of tritium [6], and for high intensity neutrino physics study [7-9]. One of the main goals of the US domestic high energy physics program, as outlined in the 2014 P5 report, is to "pursue the physics associated with the neutrino mass" in the intensity frontier [10]. There is a large effort underway to design and build an advanced underground neutrino detector. However, the time associated with this experimental effort is proportional to the neutrino flux which depends on the proton beam power used to create the neutrino beam. There are several options to increase the power from the present megawatt (MW) level at Fermilab by using conventional approaches including superconducting linacs (SCL) and rapid cycling synchrotrons (RCS).

In RCS, the proton beam bunch will be accelerated and stored in a circular accelerator for many turns before reaching the final designed GeV energy. It is efficient in the use of RF cavities (through many passes) but is limited in the beam intensity due to resonance induced particle losses driven by nonlinear space-charge fields and accelerator machine nonlinearity during many-turn passes inside the accelerator. It is also limited in the beam power due to the relatively low repetition rate (~10 Hz).

A single pass superconducting high power proton linac is architecturally simple, much less subject to resonance instability (due to single pass), and can achieve high repetition rate (MHz). However, it is inefficient in the use of RF cavities compared with circular accelerators such as the RCS. Moreover, building and operating superconducting cavities are expensive.

Recently, a concept of recirculating superconducting proton linac that reuses each section of the superconducting linac multiple times to accelerate the beam to multiple GeVs was proposed [11-12]. It provides a cost/performance optimum between the straight single-pass linear accelerator and the circular accelerator. Here, the proton beam is accelerated in three sections using three types of RF cavities separately. In the first section, the proton beam is accelerated from 150 MeV to 500 MeV in a double pass linac. A total of 17 cavities are needed in this section instead of the original 34 cavities in a single pass linac. In the second section, the proton beam is accelerated from 500 MeV to 2 GeV using 39 cavities instead of the original 156 cavities. The proton beam will pass through the superconducting linac four times in this section. In the third section, the proton beam will be accelerated from 2 GeV to 8 GeV using 50 cavities instead of the original 300 cavities. The proton beam will pass through the linac six times in this section. **This new concept drastically reduces the number of superconducting cavities needed to reach the same final beam energy from near 500 to around 100.** It also avoids the potential intensity and repetition rate limits of the RCS.

Current and future challenges

Beam dynamics studies have been carried out for the first section of the above proposed concept to accelerate a proton beam from 150 MeV to 500 MeV passing through superconducting RF cavities twice [13-14]. For more efficient usage of the superconducting RF cavities, the proton beam will pass through the same cavity multiple times in the second and the third section of the above multi-GeV recirculating accelerator concept. A challenge associated with the multiple passes is to design and to construct a number of phase shifters between two neighboring RF cavities. Such a phase shifter needs to provide synchronous phase delays among multiple passes and appropriate transverse focusing for a variety of energy beams. As the high energy proton beam has a large magnetic rigidity, the magnetic field strength used in the phase shifter will be high and superconducting magnets are needed. This leads to another challenge of designing and constructing superconducting magnets with complex field profile and large amplitude for the recirculating proton accelerator application. In a multi-pass recirculating proton linac, the proton beam needs to be injected and extracted from the accelerator effectively. This needs to be addressed to build a real recirculating accelerator. Multiple beam energy diagnostics are needed in such types of accelerators.

Advances needed to meet challenges

In order to meet the above challenges, we need to develop advanced simulation tools and to carry out detailed design and optimization of a multi-pass recirculating proton linac including machine nonlinearity, imperfections and space-charge effects. A prototype of the phase shifter superconducting magnets needs to be built to test the achievement of desired magnetic field strength and profile distribution. The proton beam injection and extraction systems need to be designed. An experimental multi-pass recirculating proton linac needs to be built to demonstrate the multiple acceleration of proton beam using the same RF cavity while still maintaining good beam quality.

REFERENCES

[1] H. Ait Abderrahim et. al., Nuclear Physics News, vol. 20, no. 1, 2010, p. 24.
[2] Z. Li et al., Phys. Rev. ST Accel. Beams 16, 080101(2013).
[3] R. Pande et al., Pramana - J. Phys. 78, 247 (2012).
[4]H. Abderrahim et al., “Accelerator andtarget technology for accelerator driven transmutation and energy production,”
[5]http://science.energy.gov/~media/hep/pdf/files/pdfs/ADS White Paper final.pdf (2010).
[6] G. P. Lawrence and T. P. Wangler, “Integrated normal conducting/superconducting high-power proton linac for the apt project,” p. 1156 (1998).
[7] S. Holmes et al., “Project X Reference Design Report,” Project X-document 776-v7, (2013).
[8 P. Ostroumov, New Journal of Physics 8, 281 (2006).
[9]F. Gerigk et al., “Conceptual design of the SPL II,” CERN-2006-006, 2006.
[10] Building for discovery: Strategic plan for U.S. particle physics in the global context, report of the particle physics project prioritization panel (P5), May 2014.
[11]J. Qiang, “Wide energy bandwidth accelerating cavities,” Nuclear Instruments & Methods in Physics Research A 795, p. 77 (2015).
[12]J. Qiang, “A Multi-GeV Recirculating Proton Linac,” in Proc. IPAC 2016, Busan, Korea, May 8-13, TUPOR16 (2016).
[13]K. Hwang and J. Qiang, “Beam Dynamics Simulation of a Double Pass Proton Linear Accelerator,” accepted by Phys. Rev. Accel. Beams, (2017).
[14]Y. Tao, J. Qiang, K. Hwang, “Overtaking collision effects in a CW double-pass proton linac,” Phys. Rev. Accel. Beams 20, 040401 (2017).