A Mechanically-Tuned Superconducting Main Injector Cavity

Brian J. Vaughn, Fermi National Accelerator Laboratory

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Future of the Main Injector Ring

The Fermilab Accelerator Complex Evolution (ACE) initiative calls for a 2.3 MW upgrade of the lab's accelerator complex. To achieve this, the Main Injector (MI) gradient will need to double, which will quadruple the power lost in the RF systems relative to the current value. This cuts against sustainability priorities and exacts a major financial cost.

RF Superconductivity

When large gradients are required, other accelerator applications typically turn toward superconducting technology. When done correctly, use of this technology increases power efficiency considerably.

# of Cavities	Voltage per Cavity	Total Power Dissipation	Total Electricity Cost per Year
37 NC	240 kV	4.534 MW	$4.1 million
3 SC	2.96 MV	50.0657 kW	$45,000

Table 1: Superconducting implementation electricity savings.

Tuning Challenges

The Main Injector is a proton synchrotron that accelerates particles between 8 GeV and 120 GeV. The cavities need to have a .6% tuning fractional bandwidth to support this, which is far beyond the tuning ranges of demonstrated superconducting technologies to date.

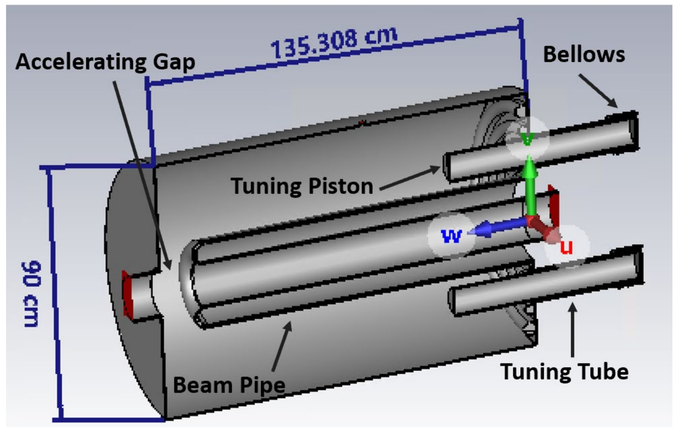

Fig. 1: Simplified proof-of-principle quarter-wave SC cavity design cross-section.

Tuning through Piston Actuation

Both the required tuning range and rapidity can be achieved with a mechanical solution. The cavity's resonant frequency is dependent on the insertion depth of superconducting pistons. High MI beam current reduces required tuning precision, so the technology to accomplish this design is available.

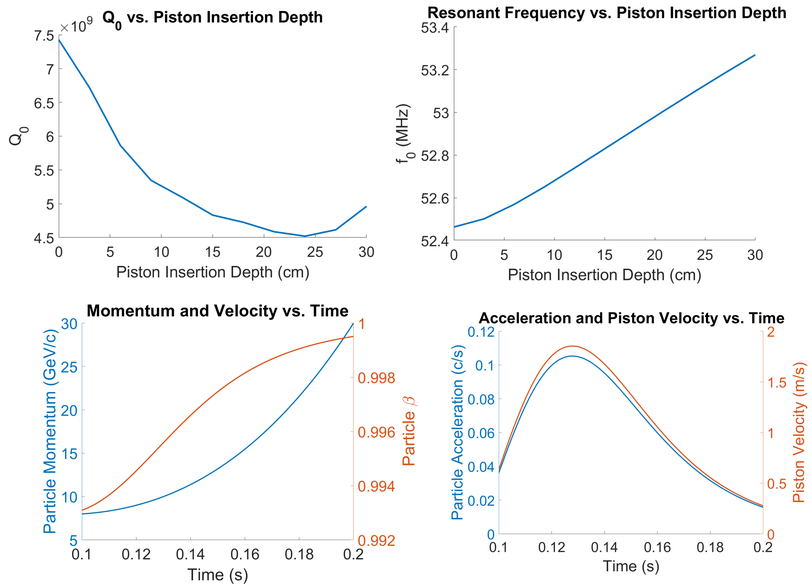

Fig. 2: Simulated superconducting cavity performance and mechanical actuation requirements.

Linear Motor and Bellows

Actuation can be accomplished with several off-the-shelf linear motor solutions, with one pictured below. Inconel 625 edge-welded bellows can achieve theoretically > 5 million 20 cm-stroke cycles before failure. With distributed piston pairs, the cavities can be made to last between Summer shutdowns. Bellows replacement cost for materials and labor estimated to be < $500K.

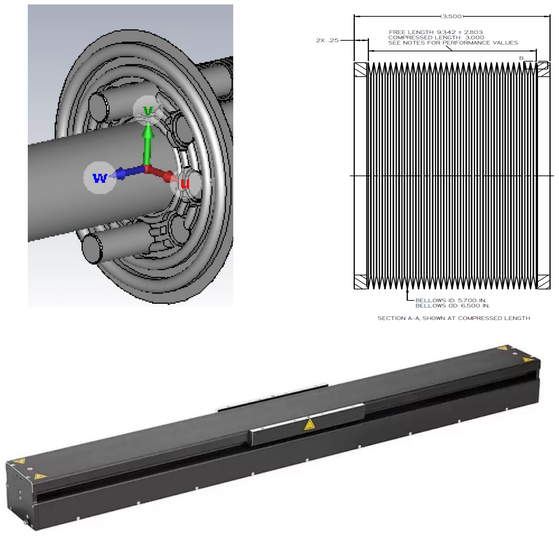

Fig. 3: Distributed piston pairs, edge-welded bellows part, and PI 857 Linear Stage capable of handling MI tuning requirements.

Conclusion

Required Main Injector upgrades are associated with massive increases in electricity costs to the RF systems. These costs may be side-stepped by adopting superconducting techniques. A superconducting cavity implementation is feasible with current technology and is worthy of pursuit.

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