NEW RF STRUCTURES FOR THE FERMILAB LINAC INJECTOR

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Abstract

The critical parameters which may limit the luminosity of the Fermilab Tevatron Collider are the beam intensity and emittance growth at each stage in the acceleration chain. It is commonly believed that the major emittance growth occurs at the low energy acceleration stage. In this paper we examine recent advances in RFQ, DTL and superconducting linac technology that should permit a significant increase in the beam brightness of the Fermilab Linac.

I. INTRODUCTION

The Fermilab Linac Upgrade increased the energy of the H^- linac from 201 to 401.5 MeV[1]. This was achieved by replacing the last four 201.24 MHz drift-tube linac cavities with seven 804.96 MHz side-coupled cavity modules. The energy increase has improved the beam brightness in the Booster and the rest of the Fermilab accelerator complex. In the last couple months we have increased the linac's peak current from 35 mA to 45 mA which has lead to a further increase in the beam brightness and an increase in collider luminosity. The recent measurments of the emittances along the linac are summarized in Table 1. We quote normalized emittances for 90% of the beam.

Energy(in MeV)	.75	.75	10	116	400
Emitt. Horizontal	1.6	2.6	3	4	6
Emitt. Vertical	1.8	2.6	3	3	5

Emittance measurements are in units $\pi\ mm\ mrad$

The increase in the H^- peak current to values above 45 mA at the end of the linac is a result of work done in the linac's low-energy injector area. Currently measured emittances with 45 mA output current do not show any noticeable increase as the result of the beam current increase. It is believed that the beam coming from the ion source at 18 keV has emittances in both planes of about 1 $\pi\ mm\ mrad$. Some old records show that the emittances at 10 MeV were measured at between 2.5 and 3.5 $\pi\ mm\ mrad$. Due to the need for continuous collider operation, we have not been able to measure emittance at this position since the completion of the 400 MeV upgrade. All this information leads us to believe that there is room for improvement at each stage in the linac chain. In the next section we will analyze the RFQ as a possible accelerating structure from the source at 35 keV to 10 MeV. This would replace the existing DTL Tank 1. Section 3 will describe our work on asymmetric drift-tube structures to improve beam focusing, and Section 4 discusses our new high-gradient, superconducting cavity program.

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II. RADIO-FREQUENCY QUADRUPOLE

A redesign of the low energy section of the linac was considered earlier by C. Schmidt et al[2]. In that paper, the H^- source was assumed to have a circular aperture, the RFQ had a final energy of 2 MeV and a new, post-coupled Alvarez tank was proposed to accelerate beam to 10 MeV. We have considered four possible examples of RFQ's to accelerate a 50 mA H^- beam to 0.75, 2, 5 or 10 MeV. We are assuming that the beam's input energy will be 35 keV and that the beam comes from a slit aperture with a 90° magnetic bend and a field index $n = 1/2$. Our main concern is space charge degradation of the emittance. To reduce this effect, we allow the beam to remain wide at the early stage of transport and minimize undulations during acceleration. We estimate that after the 90° bend, we will have a round beam of radius 0.5 cm. This beam will be matched to the RFQ entrance using a short quad triplet. In this study we have limited ourselves to the frequency 201 MHz, a final energy less than 10.2 MeV, a peak surface field of 1.9 Kilpatrick and peak powers less than 4 MW. As an extreme case, we have analyzed L. Young's long coupled cavity RFQ linac[3]. In all our designs we found that the minimal bore radius was 0.3 cm for a 50 mA beam.

III. ASYMMETRICAL DRIFT-TUBE LINAC

The asymmetrical drift-tube linac has elliptical inner and outer surfaces on the drift-tubes to achieve both acceleration and focusing (Figure 1).

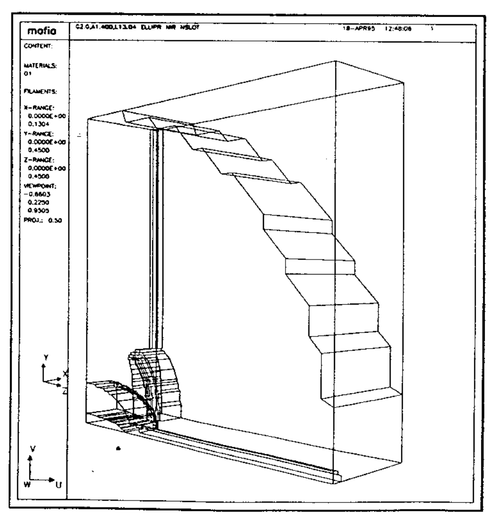

Figure 1. Asymmetric DTL, Mafia calculation.

This type of DTL is useful for low-energy beams (protons below 10 MeV). The major axis of a drift-tube is rotated ninety degrees with respect to the major radius of adjacent drift tubes. This produces a focusing and defocusing set of transverse fields in the horizontal and vertical planes similar to the field pattern in an RFQ. This structure at 200 MHz has been studied using the MAFIA 3-D electromagnetic code to determine the field strengths and shunt impedance (ZT^2). The shunt impedance of the structure has been found to be nearly ten times higher than for an RFQ in the same energy range. The structure has relatively higher accelerating fields but lower focusing fields than a comparable RFQ.

Thin lens calculations have indicated that the fields are strong enough to contain a space charge dominated beam for all energies below 10 MeV with a minor bore radius of 1.4 cm. The fields are strong enough to allow a 200 MHz linac to be designed in the form of short tanks of five gaps followed by an external quadrupole magnet. These quadrupoles allow independent control for beam transport and tuning in the asymmetric DTL. A filling factor of 90% will not significantly reduce ZT^2 which ranges from 8.4 MΩ/m at 750 keV to 37.4 MΩ/m at 10 MeV.

To further increase the beam intensity in the 8 GeV Booster synchrotron at injection for high energy physics and antiproton production as well as to provide an intense proton source for a future muon collider, a 2 GeV H^- linac is being studied. The linac would be capable of accelerating up to 10^{14} protons per pulse at 60 Hz. Two designs are being investigated (Figures 2 and 3), both of which use superconducting 805 MHz cavities for the final acceleration stage. Peak beam currents of 80 mA in 200 μsec pulses are envisioned. Multi-cell superconducting cavities at 805 MHz have recently supported CW accelerating fields up to 17 MV/m with cavity conditioning limited only by available RF peak power.[4] Higher gradients are certainly possible making a short, high-energy proton linac feasible.

The 2 GeV linac may take one of two forms depending on the low energy arrangement adopted. The first option is to build a complete new linac (Figure 2), consisting of a 400 MHz RFQ, a normal conducting 400 MHz DTL (part of which may be asymmetrical), a normal conducting 800 MHz coupled-cavity linac (CCL) and a high-gradient, 800 MHz superconducting linac (SCL). The RF plus structure costs are estimated at $9M for the RFQ plus DTL, $16M for the CCL and $29M for the SCL. The SCL costs assume a cavity plus cryostat cost of $200K/meter and an RF cost of $100K/MWatt of peak power. The total linac length would be about 180 meters. Adding ancilary systems, beamlines, utlities and civil construction results in a total cost of about $70M for a complete 2 GeV linac.

An alternate approach would be to use the existing Fermilab 400 MeV Linac, upgrade its RF systems and add a superconducting linac to the existing enclosure. The arrangement however is somewhat novel, and is called the “hairpin linac” (Figure 3). The normal conducting, 200 MHz DTL and 800 MHz side-coupled linac would be physically reversed in the linac enclosure as would be the RF systems in the upstairs gallery. A 200 MHz RFQ would be added as a new injector. The 400 MeV beam emerging from this linac is then turned 180 degrees with low-field magnets in the vacated Cockcroft-Walton Pre-acc pits and injected into a new superconducting linac, anti-parallel to the 400 MeV linac, for accceleration to 2 GeV. The cost of this option is about $45M due to savings incurred by using much of the existing 400 MeV linac.

An 805 MHz superconducting cavity R&D program was started at Fermilab in early 1994. The goals are to increase accelerating gradients beyond previously achieved values and to fabricate and test a 4-cell superconducting cavity with 400 MeV linac beam in late 1997. A high power processing (HPP) facility is being constructed using the 12 MW RF system and shield cave at the A0 lab, leftover from the Linac Upgrade Project. A horizontal cryostat is being fabricated using a former vertical dewar on loan from Loa Alamos National Lab as the outer vacuum vessel (Figure 4). Two input power couplers have been built and the cryostat is about 25% complete. In early 1996 single-cell niobium cavities previously tested at Los Alamos will be conditioned. Fabrication of a 4-cell cavity and a special beamline cryostat will begin in mid-1996.

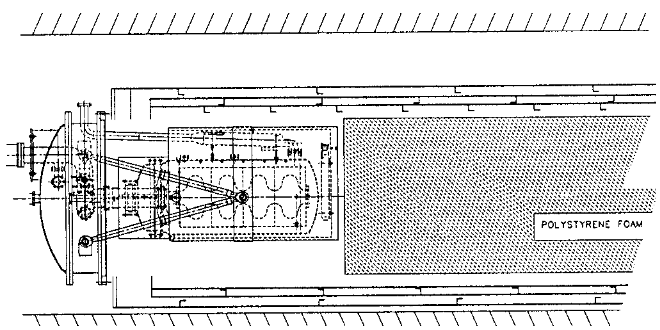

Figure 2. Cryostat, and 4-cell superconducting cavity.

IV. SUPERCONDUCTING LINAC

References

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[4] B. Rusnak, LANL, private communication.

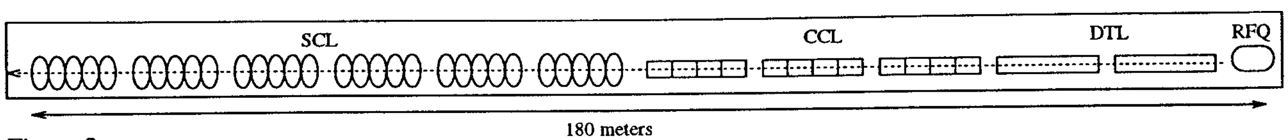

Figure 2.

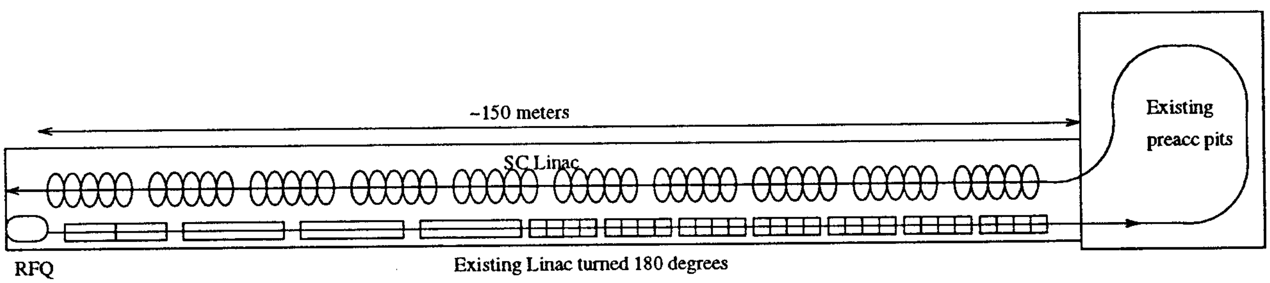

Figure 3.