OUTLINE LINAC AND RING DESIGNS FOR POTENTIAL ISIS UPGRADES

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Abstract

Features of a linac and ring for potential ISIS upgrades are outlined. Maximum parameters are 0.8 GeV, 0.5 MW for the H^- linac and 3.2 GeV, 2 MW for the ring, both at 30 or 50 Hz. The linac is based on a 324 MHz frequency at low energies, having an ion source, LEBT, 3 MeV RFQ and MEBT, with a 74.8 MeV drift tube linac (DTL) and intermediate energy beam transport (IEBT). The MEBT chopper stage uses solenoid and triplet focusing, and both MEBT and IEBT have long regions for beam collimation. There are three options for the higher beam energies, a 648 MHz superconducting linac (ScL1, ScL2, ScL3), a 648 MHz (CCL, ScL2, ScL3), and a 324 MHz (ScLa) with a two-stage 972 MHz (ScLb, ScLc). The ScL1, CCL and ScLa accelerate the beam from 74.8 to ∼200 MeV. The proton synchrotron ring design is based on a five superperiod lattice of doublet and triplet cells, and has a circumference of ∼370 m.

INTRODUCTION

The cheapest (but not simplest) upgrade for the ISIS accelerator is to replace the existing ∼70 MeV H^- linac injector by a new ∼200 MeV linac and to redesign the injection and ejection systems of the present 800 MeV proton ring, adding protection for potential instabilities. Another upgrade considered for ISIS is to develop the new linac up to 800 MeV, at 30 Hz and 0.5 MW, for injection into a new 3200 MeV, 30 Hz, 2 MW, proton synchrotron, with ejection to a higher power target station, as outlined in [1].

The 200 MeV linac includes an H^- ion source, voltage platform, low energy beam transport (LEBT), 3 MeV RFQ, 3 MeV beam chopper stage (MEBT), 74.8 MeV drift tube linac (DTL), intermediate energy collimation (IEBT), and with three options for 74.8 to ∼200 MeV. These include a 648 MHz superconducting linac (ScL1), a 648 MHz cavity coupled linac (CCL), and a 324 MHz superconducting linac (ScLa), with the ScL1 and ScLa designed for a geometric β_g value of 0.45.

All three options then employ superconducting stages to reach 800 MeV. Options 1 and 2 both use 648 MHz cavities, with a β_g value of 0.62 for an ScL2 of ∼400 MeV and a β_g value of 0.76 for an ScL3 of 800 MeV. For the third option, a third harmonic frequency of 972 MHz is used for both an ScLb and an ScLc stage, again with the β_g values of 0.62 and 0.76.

Charge exchange injection for a 370 m circumference, 800-3200 MeV synchrotron, over 500 turns, needs 43 mA linac beam current, of ∼0.75 ms pulse duration, chopped at 70% on-duty cycle. A new type of funnel [2] has also been studied, not for ISIS, but for merging H^-beams of up to 2×75 mA for long pulse, high power proton linacs.

LINAC DESIGNS

The main design issues are listed and then discussed:

- Choice of linac structures and frequencies
- Consideration of input design emittances
- Design for the MEBT chopper section
- Inter-tank matching for four DTL structures
- Design of a scraper system for the DTL output
- Energy for change to (×2 or ×3) higher frequency
- Matching for the higher energy stages
- Arrangement of the ScL cavities and cryostats
- Control of emittance and halo growth

Designs follow those of the SNS [3] and ESS [4] linacs apart from the choices for energy and frequency and the use of superconducting elliptic cavities at lower energies in two of the options. Initial stages employ the 324 MHz, 2.5 MW peak power, Toshiba klystron, used in the linac at J-PARC [5]. A choice of 324 MHz instead of the SNS 402.5 MHz eases the design for the MEBT choppers.

Normalised rms emittances assumed for the transverse and longitudinal planes, at the MEBT input, are 0.25 and 0.39 π mm mr, respectively, values close to those achieved at the SNS and J-PARC. Emittances obtained at RAL's front end test stand need to be reduced to these values to allow the use of current beam chopper designs.

Two MEBTs have been designed, based on the chopper systems of [6]. Both have halo and rms emittance growth, the latter typically to 0.30 π mm mr transversely and to 0.42 π mm mr longitudinally, after entry into the first of four DTL tanks. A new MEBT uses solenoids and triplets to provide longer drifts, allowing 30% lower chopper voltages, and without any loss of the un-chopped beam. Longitudinal halo is less than for the earlier MEBT.

DTL matching is improved by use of phase offsets in three of the four tanks. An end cell is used together with a cell four or five periods upstream. Smooth transverse matching is obtained by adjusting six quadrupoles near the tank transitions. Apart from these, permanent magnet quadropoles are used. Equipartition between longitudinal and transverse beam energies is obtained after matching into the first tank, and is maintained up to 800 MeV.

After the DTL is a three, doublet-cell collimator. In the first and third cell is a buncher cavity and in the second, a symmetrical orbit bump. The aims are to remove halo, H^-, H^+ and far off-momentum beam after the DTL and prevent the type of low losses seen at the SNS, ScL linac.

The 324 to 648 MHz transition for the options 1 and 2 requires the development of a 648 MHz klystron, whereas Toshiba units exist for the option of a 324 MHz, ScLa, a 972 MHz, ScLb and a 972 MHz ScLc after the DTL.

Doublet focusing is adopted in the ScLs and, for ease of input and output matching, also in the CCL, despite the need for long CCL coupling cells ($2.5\beta\lambda$). The lattice cell length for the ten-cell CCL cavities is then $7.5\beta\lambda$.

Six-parameter, transition matching at higher energies is obtained by adjusting six quadrupole gradients, together with a linear ramp of cavity phases at the output of one stage and input of the next. Large energy gains per cell result in different matched parameters for adjacent cells, so matching is not as exact as for a ring or a beam line.

ScL design involves choices of β_g value, accelerating field gradients, synchronous phase angles (φ_s), cavity geometry, number of cavities and cells per cavity, number of cavities per cryostat and per focusing period, and parameters for the doublet quadrupoles. The main design aim is to minimize the numbers of cavities and cryostats without prejudicing practical and beam dynamics issues.

Factors that affect beam halo and rms emittance growth include evolution of a non-stationary input distribution, rate of change of beam amplitudes and aspect ratios, inter-stage matching, and resonance induced effects due to space charge tune spreads. The MEBT uses solenoids and triplets to limit beam aspect ratio changes, which alter the ratios of linear to non-linear space charge forces. The cell tunes are chosen for energy equipartition and to limit effects of machine errors and space charge forces on the coherent longitudinal-transverse coupled envelope modes. Lattice parameter matching routines, used for inter-stage matching, need checking with beam tracking studies.

3 MeV, MEBT CHOPPER SECTION

The MEBT has to provide space for beam choppers and associated beam dumps, collimators for removing beam halo, diagnostics for characterizing the RFQ output beam, and also quadrupoles and buncher cavities for smooth, transverse and longitudinal matching from RFQ to DTL.

Included in the new MEBT are two input quadrupoles, a solenoid split at its centre (for diagnostic units), two sets of asymmetric triplet quadrupoles, and four, 324 MHz buncher cavities. The input quadrupoles transform input beam cross sections from an elliptical into a circular form. The solenoids focus the circular beam into a 1.48 m long drift, with “fast and slow type” beam choppers, as in [6]. There follows a triplet set, a 1.14 m drift, and a second triplet to assist matching the 43 mA beam into the DTL.

Figure 1 is a schematic drawing of beam amplitudes in the MEBT. Buncher cavities are near the input and output of the solenoids and at each end of the 1.14 m drift, which also houses the beam dump, scrapers and diagnostic units. The bunchers provide beam bunch lengths suitable for DTL

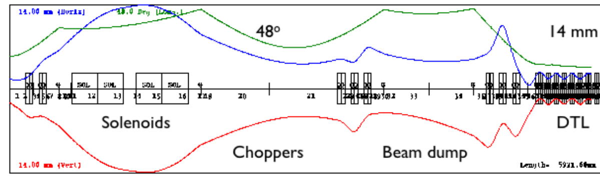

Figure 1: The beam amplitudes through the MEBT unit.

matching. Choppers are pulsed at the injected beam revolution frequency of the ISIS or 3.2 GeV ring, with the plate voltages depending on the input beam emittances.

74.8 MeV, DRIFT TUBE LINAC

The four DTL tanks have successive output energies of 19.4, 37.7, 56.4 and 74.8 MeV, and occupy ∼37.0 m. Superfish code studies have been used to optimize drift tube shapes for shunt impedance and Kilpatrick factor. Large φ_s values are used to limit beam halo growth and simplify matching at later (×2 or 3) frequency transitions. For example, the first tank of 62 cells has φ_s ramped from -42° to -35°. Tanks are designed for a beam and structure power <1.7 MW, allowing the 2.5 MW klystrons margins for extra losses and control power. Inter-tank matching is improved by two-cell phase offsets in the tanks 1, 2 and 3.

NEW FUNNEL CONCEPT

A redesign of MEBT, DTL1 and DTL2 has allowed a study of a 25.6 MeV funnel at currents up to 2×75 mA. The funnel has three buncher cavities and one dipole unit per channel, with foils that strip the H^-beams separately, one before and one after a final dipole. No septum units, deflection cavity, or two-beam buncher are needed. Gains are a reduction in space charge forces at all linac energies, frequency doubling at low energy, reduced higher-order mode excitations, less growth of emittance and halo, and thus a better long pulse proton beam on target [2].

IEBT COLLIMATION SECTION

Beam amplitudes through the DTL4, the three doublet cells of the intermediate energy beam transport (IEBT), and the ScL1 input are shown schematically in Figure 2. The cell lengths are $12(6)\beta_g\lambda$, where β_g is 0.45 and λ is that for the 648(324) MHz frequency of the two buncher cavities. There are four dipoles in the central cell, to provide an adjustable $\theta, -\theta, -\theta, \theta$ symmetrical orbit bump. Foil collimators intercept halo and far off-momentum particles before the ScL stages, with the aim of avoiding outscattering and the type of loss ($\sim 10^{-4}$) seen at the SNS.

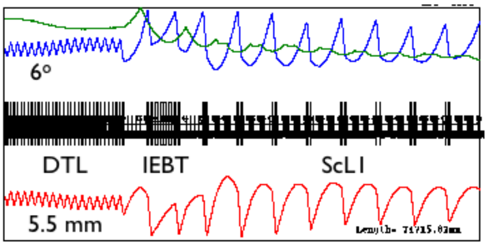

Figure 2: Beam amplitudes over the IEBT transition.

OPTION 1: 648 MHz ScL LINAC

The 648 MHz, ScL1, ScL2, ScL3 have, respectively, 196.4, 412.4 and 800 MeV output energies, 0.45, 0.62 and 0.76 geometric β_g values, 32, 32 and 33 cavities, 16 (or 8), 16 and 11 cryostats, 4, 5 and 6 cells per cavity, -22°, -22° and -21° main synchronous phase angles, 3.8, 6.75 and 11.745 MeV energy gains per cavity, 14.5, 15 and 18 $\beta_g\lambda$ focusing period lengths (3.019, 4.303 and 6.329 m) and 48.30, 68.84 and 69.62 m, stage lengths.

OPTION 2: 648 MHz CCL AND ScL

The 91.41 m CCL has 56, ten-cell cavities for the 74.8 to 193.344 MeV energy gain. There is constant φ_s of -22° and constant accelerating field gradient of 2.43 MV/m for all cavities. The 2.5$\beta\lambda$ spaces for the coupling cells and doublet quadrupoles give 7.5$\beta\lambda$, lattice cell lengths. The ScL2 and ScL3 are similar to those of the first option apart from parameter differences for the input matching.

OPTION 3: 324 AND 972 MHz ScL

ScLa, ScLb and ScLc have, respectively, 324, 972 and 972 MHz cavity frequencies, 227.8, 419.8 and 800.0 MeV output energies, 0.45, 0.62 and 0.76 geometric β_g values, 32, 32 and 44 cavities, 16, 16 and 11 cryostats, 4, 6 and 6 cells per cavity, -28°, -22° and -20° synchronous phase angles, 4.25, 6.0 and 8.64 MeV energy gains per cavity, 10 (30), 28 and 27$\beta_g\lambda$ focusing period lengths, and 66.62, 85.67 and 69.62 m, stage lengths.

OPTION COMPARISONS

Option 1 uses less power and is shorter by ∼42 m than option 2. Both require a 2.5 (5) MW, 648 MHz klystron development. Option 3 needs no new klystron, but has large, ScLa 324 MHz cavities, the transition to 972 MHz, a greater error sensitivity and large growth of emittances. Increases of rms emittance are small for the DTL, ScL1, CCL and ScLa, and modest for ScL2 and ScL3, but transition to 972 MHz at 227.8 MeV leads to halo and a doubling in transverse rms emittance for ScLb and ScLc. An option of ScLa with ScL2 and ScL3 is untested.

3200 MeV SYNCHROTRON DESIGN

The preferred design for a 3200 MeV, 30 Hz, 2 MW synchrotron ring [1] is outlined in Figure 3. A choice of five superperiods satisfies the criteria of low dipole stored energies, scope for orienting the ring on the ISIS site, and enough small aperture straights for economic rf (radio frequency) systems. Each 74.0 m superperiod has two triplet sets, and four doublet sets of quadrupoles, with two back-to-back doublets at the centre of each long straight.

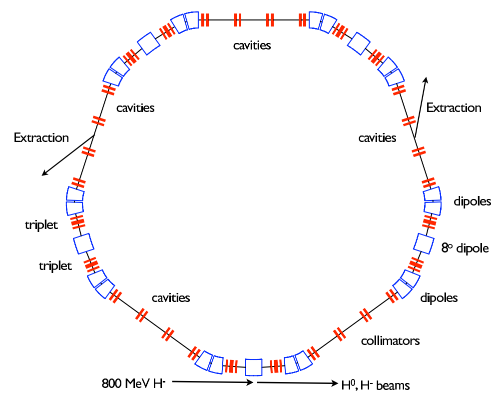

Figure 3: Lattice choice for a 3200 MeV, ISIS upgrade.

An 8°, 5.4446 m, dipole is in the centre cell of each of the five arcs and adjacent cells each have two 16°, 3.8 m, main dipoles. The two field gradients of the symmetrical triplets are varied to adjust the dispersion and to obtain dispersion free straight sections. Doublet quadrupoles are then set for betatron tunes, $Q_h = 7.21, Q_v = 7.73$, and for normalised dispersion values at the arc centres $\approx 1.6\,\mathrm{m}^{1/2}$.

The stripping foil for H^- injection is at an 8° arc dipole centre, and all injection elements are between the triplets of this arc, for a fully separated injection scheme. Phase space painting in the horizontal and longitudinal planes is obtained by momentum ramping of the input beam and, in the vertical plane, by the use of four steering magnets.

Rf acceleration, at the harmonic number of four for the 1.8 eV sec bunches, and for the biased, 30 Hz, cosine guide field, needs a peak voltage gain per turn of 422 kV. One superperiod is reserved for beam loss collimation.

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