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A New 180 MeV H^- Linac for Upgrades of ISIS

Frank Gerigk, ASTeC Intense Beams Group, CCLRC, Chilton, Didcot, UK

Abstract

Several options have been studied to raise the beam power of the ISIS spallation neutron source to a level of 1 MW with the possibility of going to 4-5 MW in the longer term [1]. All scenarios can operate in 2 modes, where the beam power is either delivered to a spallation target or, alternatively, to a target suitable to produce muons via pion decay for a neutrino factory. A more recent upgrade option takes an intermediate step and uses a 180 MeV H^- linac, which is also foreseen for the 4-5 MW upgrade, as a replacement for the current 70 MeV injector. First estimates indicate that, due to the lower space charge forces, the ring would be able to carry twice as many particles as are expected in the current 2^{nd} harmonic upgrade, thus doubling the final beam power to 0.5 MW. A further step in this scenario could be to extend the 180 MeV linac to 800 MeV, the actual ISIS output energy, and to use the ISIS synchrotron as an accumulator/compressor ring. This paper presents a first design for the 180 MeV linac, using a triple frequency jump from 234.8 to 704.4 MHz. The design benefits from the development of 704.4 MHz cavities and RF equipment within the framework of the European HIPPI collaboration. The low frequency for the front-end was chosen to ease the DTL design as well as the development of a low energy beam chopper, which will be necessary to reduce beam losses at injection into the synchrotron.

INTRODUCTION

The R&D programme for the new ISIS linac is part of a European effort by 9 major accelerator laboratories to develop technologies for next generation high-intensity proton linacs. HIPPI is an acronym for High Intensity Pulsed Proton Injectors and represents one of four Joint Research Activities which are funded within the European Framework Program 6 (FP6). Within HIPPI the Rutherford Appleton Laboratory (RAL) is active in the fields of low-energy beam chopping, normal conducting accelerating structures and beam dynamics.

The basic linac layout is shown in Fig. 1 and starts with an H^- ion source [2] followed by a RFQ and a Medium Energy Beam Transport (MEBT) line containing a low energy beam chopper [3] which has evolved from the ESS design [4]. Seven Alvarez Drift Tube Linac (DTL) tanks then raise the beam energy to 90 MeV, followed by a Side Coupled Linac (SCL) up to the final energy of 180 MeV. Figure 2 shows a possible site layout which will allow for uninterrupted operation of the present ISIS facility during construction. This first proposal for a 180 MeV linac at RAL uses well known accelerator technology but explores the most challenging set-up for this scenario. The parameters are chosen to raise the ISIS output power to 0.5 MW while stretching the injection time (250 μs to 300 μs). This choice results in a high-current design with high RF peak-power requirements and good RF efficiency ($P_{beam}/P_{tot} \approx 0.5$). While the high-current normal conducting design makes a possible superconducting option less competitive because of its efficient use of RF power, it poses more challenges on the development of a viable beam dynamics design. One of the goals of this paper is to show that high-current operation is feasible, whilst keeping the option of reducing the peak currents by further raising the ring injection time to 400 μs.

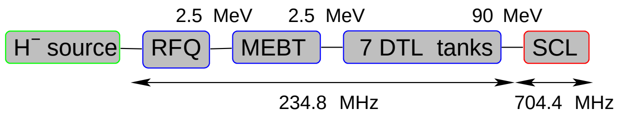

Figure 1: Layout for the 180 MeV linac.

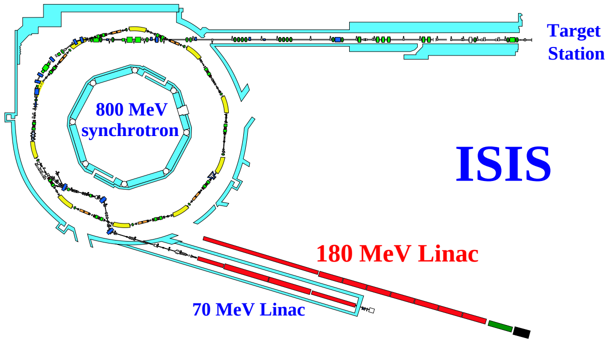

Figure 2: Site layout for the 180 MeV linac.

LATTICE & BASIC PARAMETERS

The SCL section, operating at 704.4 MHz, is an almost exact copy of the Linac4 [5] structure at CERN, the only difference being an increase of the mean pulse current from 30 mA to 57 mA. The frequency of the DTL is chosen to be one third of the SCL frequency in order to provide: a) a long rise time for the low-energy beam chopper, b) a higher RF efficiency and more space for quadrupoles inside of the drift tubes, and c) a reduced alignment precision for quadrupoles and drift tubes.

The costs for a beam chopper are mainly driven by the requirements for the RF amplifier which provides the voltage for the deflecting electric field. To achieve clean chopping the field rise time must be shorter than the distance between pulses and thus a low RF frequency eases these demands.

The RF efficiency of the DTL is partly determined by the diameter of the drift tubes relative to the diameter of the tank. Smaller drift tubes raise the RF efficiency because less surface material is heated by the electric fields. Since the quadrupole diameter is more or less independent of the choice of RF frequency, the outer drift tube diameter remains basically unchanged for DTLs of different frequencies. This means that rising RF frequencies yield reduced shunt impedances and reduced drift tube lengths (leading to less space for quadrupoles), but also lower peak field values and smaller tanks. Figure 3 shows the dependencies for a DTL cell at 15 MeV assuming that the inner drift tube radius scales with the square root of the frequency. One can see that choosing half of the SCL frequency for the DTL (352.2 MHz instead of 234.8 MHz) would reduce the RF efficiency by ≈ 22% and the tank diameter by ≈ 41%. Furthermore the available length for the first quadrupole would shrink by 33% making it impossible to use electromagnetic quadrupoles inside the drift tubes of the first DTL tank.

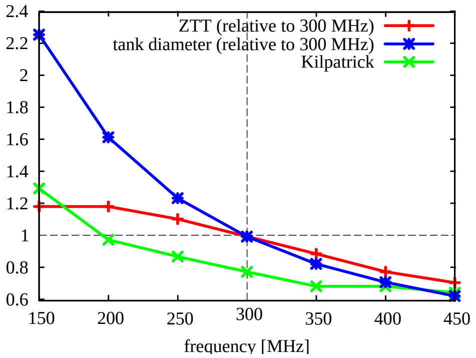

Figure 3: ZTT, Kilpatrick, and tank diameter versus frequency for a DTL cell at: 15 MeV, gap/$\beta\lambda$ = 0.3, drift tube face angle: 10 deg, drift tube diameter: 160 mm, E_0 = 2.5 MV/m.

The peak electric field levels are limited to ≈ 1.2 Kilpatrick in the DTL and to ≈ 0.85 in the SCL. In the DTL Diacrodes (Thales TH628) will be used to provide a maximum power per tank of 1.9 MW including a 20% reduction in shunt impedance from the calculated (superfish [6], [7]) value as well as a 25% margin for control power. A summary of the RF parameters for DTL and SCL is given in Table 1.

Transverse focusing will be provided by electromagnetic quadrupoles throughout the linac in order to maintain the flexibility of transverse matching between tanks and structures, and to be able to provide beam steering by means of independent coil powering inside selected quadrupoles.

BEAM DYNAMICS

The lattice is designed to keep the ratio of longitudinal to transverse full current phase advance more or less constant at a level of 0.6 to avoid emittance exchange between the transverse and the longitudinal planes. A second guideline is to keep the phase advance per metre as smooth as possible in order to decrease the sensitivity of transition areas towards mismatch. Between the 7 DTL tanks which are separated by a 'missing gap', matching is achieved using the existing DTL quadrupoles and by raising the longitudinal focusing before and after the tank transitions. A smooth transition between DTL and SCL is obtained by gradually increasing the longitudinal focusing in the last DTL tank using a phase and field ramp as shown in Fig. 4 (IMPACT [8] calculation).

Table 1: RF Parameters for DTL/SCL

		DTL	**SCL**
frequency	[MHz]	234.8	702.2
energy	[MeV]	2.5 - 90	90 - 180
peak current	[mA]	57	171
peak power	[MW]	10.5	20.0
RF efficiency P_{beam}/P_{tot}		≈ 0.5	≈ 0.5
E_0	[MV/m]	2.5	4.0
length	[m]	55	35
no. of tanks		7	25
RF tubes/klystrons		7	6-7

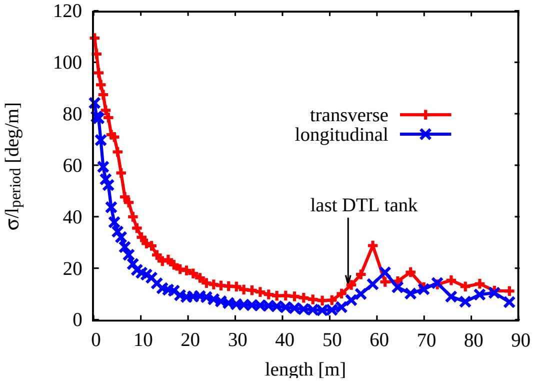

Figure 4: Transverse/longitudinal phase advance per meter.

The matching itself can now be achieved by introducing one additional quadrupole and a small drift section as shown in Fig. 5. The first envelope match with TRACE3D [9], however, still needs improvement as there are still considerable phase advance oscillations in the SCL section (see Fig. 4). Despite this imperfect matching across the frequency jump there is only a moderate rms emittance growth (< 20%) after the transition (Fig. 6).

Every frequency jump amplifies the effects of RF phase and energy errors and therefore requires a well tuned RF

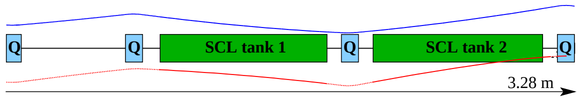

Figure 5: Envelope matching between DTL and SCL with TRACE3D.

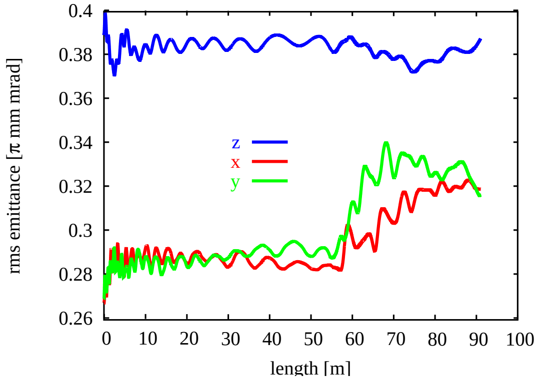

Figure 6: RMS emittance evolution.

control system. Assuming an error of ±0.5% (rms, Gaussian with cut-off at 2σ) and ±0.5 deg for the electric fields in the cavities one obtains the uncompensated energy and phase jitter which is depicted in Fig. 7.

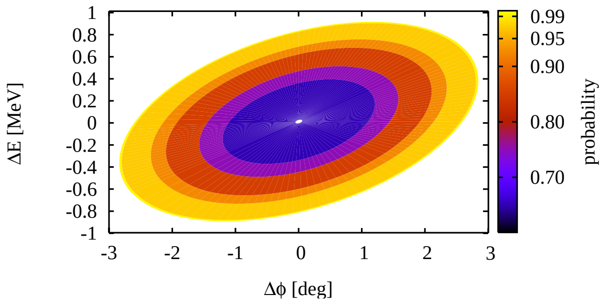

Figure 7: Probability for final energy & phase jitter due to ± 0.5%/±0.5 deg rms field errors.

Using a debunching cavity after the linac, as in the present ISIS linac, will reduce the energy spread and stretch the phase width in order to inject into the RF bucket of the synchrotron.

SUMMARY AND OUTLOOK

A first design for a 180 MeV linac, which could raise the ISIS beam power to 0.5 MW is presented. The design assumes a difficult scenario with 6 DTL transitions, a triple frequency jump, and peak currents up to 170 mA in the high-energy part. This preliminary study indicates the feasibility of the scheme but also highlights some challenges such as the problem of matching between two structures across a triple frequency jump as well as the issue of RF phase and energy errors which are amplified by the frequency jump. Possible improvements to the scheme might include reducing the energy at which the frequency jump occurs and using SDTL tanks to replace large parts of the DTL. Thus the energy and phase jitter at the end of the linac can be reduced along with the number of DTL transitions, which would eliminate the problem of tank to tank matching. Further subjects to be studied include the design of the MEBT and the RFQ as well as detailed end to end simulations with errors.

Table 2: General Parameters

average beam power	110 kW
repetition rate	50 Hz
beam chopping (at 2.5 MeV)	35 of 118
chopper rise time	3.4 ns
injection period	300 μs
linac pulses per cycle	600
duty cycle	1.5%
tune depression	$\approx$ 0.5
transverse output emittance	0.32 π mm mrad
longitudinal output emittance	0.39 π mm mrad

The beam dynamics in the synchrotron have to be verified as well as the feasibility of the injection process. First studies of the electron cloud instability, which so far has not appeared in ISIS, predict an increased build up of charge within the synchrotron [10]. Further analysis is, however, needed to come to a final judgement.

First steps are now being taken to set up a front end test stand at RAL, including an ion source, RFQ, and MEBT with design studies of the remainder of the linac continuing in parallel.

ACKNOWLEDGMENTS

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