MODELLING THE ISIS 70 MeV LINAC

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Abstract

The ISIS linac consists of four DTL tanks that accelerate a 50 pps, 25 mA H^- beam up to 70 MeV before injecting it into an 800 MeV synchrotron. Over the last decades, the linac has proved to be a stable and reliable injector for ISIS, which is a significant achievement considering that two of the tanks are nearly 60 years old. At the time the machine was designed, the limited computing power available and the absence of modern modelling codes, made the creation of a complex simulation model almost impossible. However, over the last few years, computer tools have became an integral part of any accelerator design, so in this paper we present for the first time a beam dynamics model of the ISIS linac. A comparison between the simulation results and machine operation data will be discussed, as well as possible linac tuning scenarios and recommended upgrades based on the new model.

INTRODUCTION

Over the past 25 years, the ISIS spallation source has been delivering neutrons to generations of scientists from all over the world, creating a key centre for physical and life sciences research at Rutherford Appleton Laboratory in the UK.

The accelerator consists of a 70 MeV H^- injector, an 800 MeV synchrotron and two target stations [1].The injector starts with an H^- ion source, followed by a three solenoid low energy beam transport line (LEBT) and a 665 keV, four-rod RFQ operating at 202.5 MHz. A Drift Tube Linac (DTL) accelerates the beam to 70 MeV. The DTL consists of four tanks which have been recycled from previous high energy physics projects. Tanks 2 and 3 were commissioned in the 1950s for the RAL Proton Linear Accelerator, while tanks 1 and 4 were copies of part of the Fermilab DTL built in the 1970s, originally intended for the Nimrod accelerator, but first used in ISIS [2]. A schematic layout of the linac can be seen in Figure 1 and a list of parameters is given in Table 1.

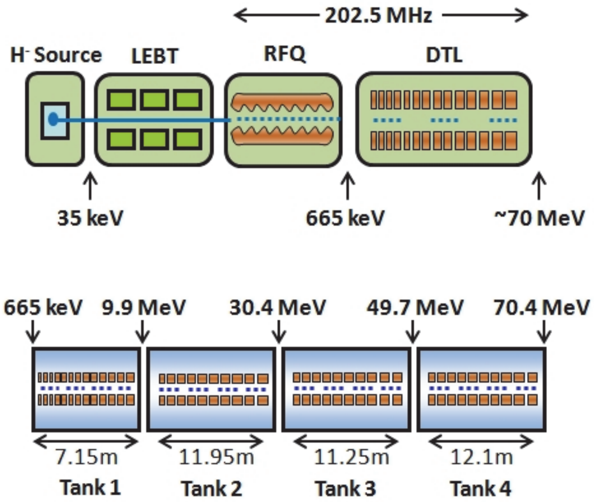

Figure 1: Schematic layout of the ISIS linac (top), with details of the DTL section (bottom).

However, ISIS is an aging machine. Whilst the need for an upgrade to the linac has been clear for some time [3], this report does not propose a replacement, but rather potential improvements to the present DTL which may be achieved with little more than extended maintenance.

SIMULATION MODEL

There are multiple challenges in developing accurate simulation models for such an old machine like ISIS and every effort has been put into reconciling the original design data with changes implemented over the years as well as operational parameters.

The baseline DTL design uses an FFDD focussing scheme that is only broken at transition between tanks 1 and 2. The synchronous phase is kept constant at -30° and the transverse zero current phase advance per period is generally kept below 90° although it varies significantly (see Figure 2). The accelerating gradient is slowly ramped in tank 1 from 1.6 – 2.2 MV/m, while in tanks 2, 3 and 4 is kept approximately constant in the region of 2.5 MV/m. A detailed DTL parameter list can be seen in Table 2.

To understand the linac behaviour, 2D and 3D electromagnetic models have been developed for each individual accelerating cell based on the original DTL

Table 1: ISIS Linac Parameters

Energy	70.4	MeV
Frequency	202.5	MHz
Pulse Length	200 – 250	μs
Peak Current	25	mA
Repetition Rate	50	Hz
Total Length	55	m
Duty Cycle	1 – 1.25	%

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ISBN 978-3-95450-115-1

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Table 2: Main DTL Parameters

		T1	T2	T3	T4
Input Energy	MeV	0.665	9.90	30.4	49.7
Output Energy	MeV	9.90	30.4	49.7	70.4
Accelerating Gradient (E_0)	MV/m	1.6–2.2	2.45–2.55	2.3–2.4	2.6
Sync Phase	Deg	-30	-30	-30	-30
Max. Surface Electric Field	Kilp	0.67	0.81	0.84	0.87
Focussing Scheme		FFDD			
Total Length	m	7.15	11.95	11.25	12.1

manufacturing notes [4]. This allowed the correct calculation of the transit time factors and formed the basis of a complex beam dynamics model. Several optics codes have been used for this study including GPT, Impact, Parmila, TraceWin and Trace3D [5], [6].

Figure 3 shows the transverse RMS beam envelopes from the RFQ output to the end of the DTL, when using the baseline lattice with a typical machine setup employed during normal operation. A waterbag distribution has been used ($\varepsilon x=0.5$ mm.mrad (RMS normalised), $\alpha x=0.338$, $\beta x=0.147$ mm/mrad, $\varepsilon y=0.55$ mm.mrad, $\alpha y=-0.295$, $\beta y=0.0818$ mm/mrad, $\varepsilon z=0.12$ deg.MeV, $\alpha z=0.0294$, $\beta z=1076$ deg/MeV), based on the Twiss parameters predicted by RFQSIM, the simulation code used to design the ISIS RFQ [7]. A clear mismatch between the RFQ and the DTL can be seen, leading to a beam loss in excess of 15% in the first metre of Tank 1. The mismatch has been expected after a new RFQ was installed to replace the old Cockroft-Walton injector. The RFQ improved dramatically the machine reliability, but it required direct injection into the existing DTL, without the possibility of adding a matching section, due to space and layout restrictions.

The losses predicted by simulation are confirmed by measurements performed at the end of each tank with current monitors, as it can be seen in Figure 4. The small discrepancy is of course expected when considering several factors: an idealised input beam distribution has been used; there are small dimensional discrepancies in the lattice especially in the inter-tank regions that can only be resolved with a systematic dimensional metrology campaign; the measured losses can vary by as much as several percent with every new ion source or different operational settings [8].

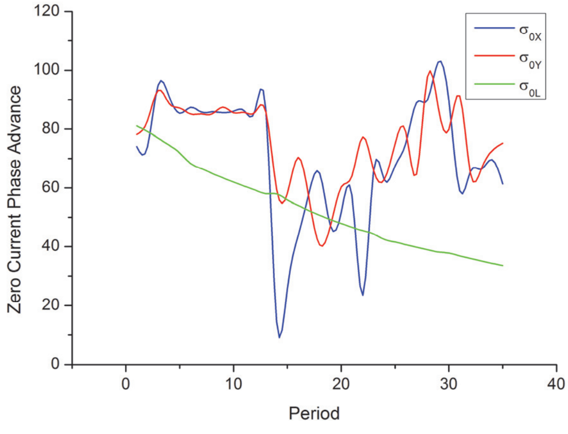

Figure 2: Zero current phase advance per period.

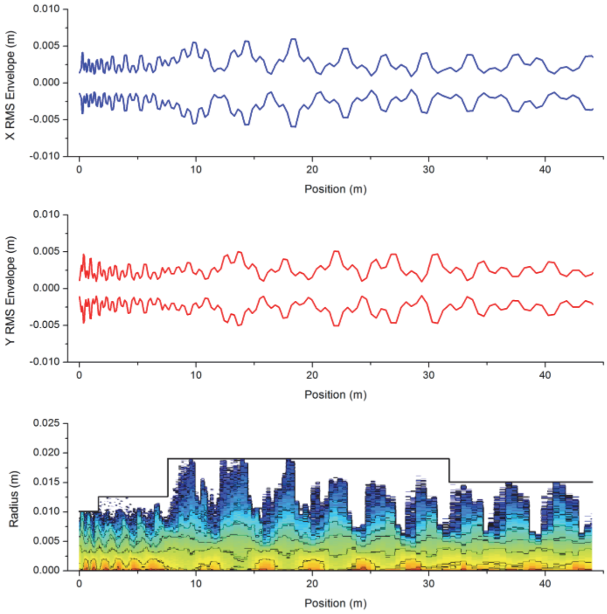

Figure 3: DTL transverse RMS beam envelopes and radial beam density (from TraceWin).

PROPOSED RFQ TO DTL MATCHING SECTION

While efforts have been put into re-tuning the linac by readjusting the quadrupoles, tracking studies indicate that losses cannot be lowered below 10%. It has become obvious that a matching section is required between the RFQ and the DTL.

A potential upgrade MEBT is useful in understanding the DTL behaviour. It differs from higher energy designs like ISIS FETS, J-PARC, Linac4 and SNS [9], where

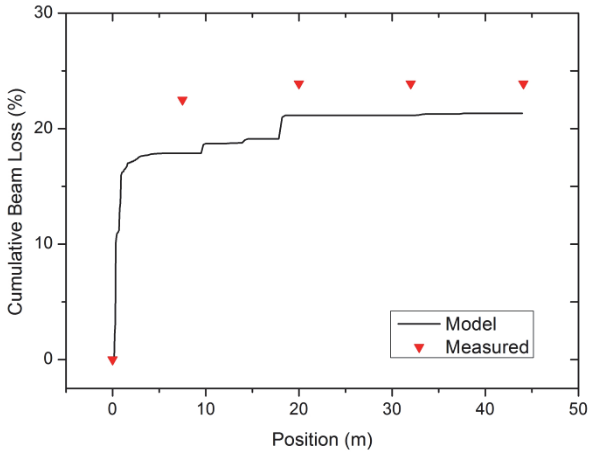

Figure 4: Cumulative beam loss.

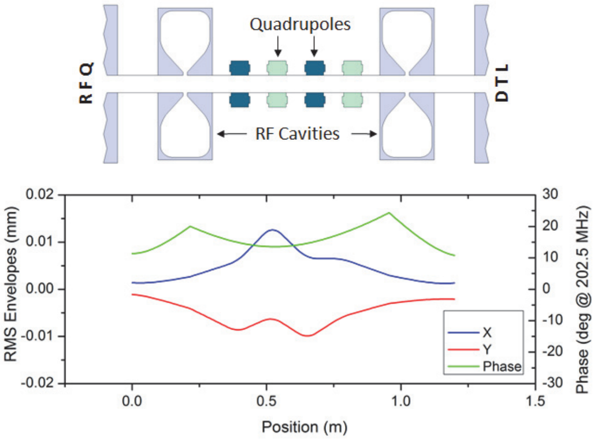

Figure 5: Proposed RFQ to DTL matching section.

choppers were required and the transverse normalised emittances were less than half. The proposed design is ~ 1.2 m long and consists of two re-bunching cavities and 4 quadrupoles, allowing 6D matching into the DTL. Buncher effective voltages are ~60 kV and the quadrupoles lengths are 70 mm. To avoid any MEBT beam loss, the respective quadrupole and buncher bore radii are 30 and 15 mm.

The MEBT allows matching into a modified tank 1, and a match may also be made from tank 1 to tank 2, using four quadrupoles at transition. The beam does not stay matched, however, as quadrupole strengths increase and decrease along tanks 2, 3 and 4, unlike in most linac designs where the quadrupole strengths decrease smoothly with increasing energy (see phase advance plot in Figure 2). To mitigate this problem, a new matched lattice was found by modifying quadrupole gradients throughout the linac, to obtain a smooth phase advance variation. This has been made difficult by the fact that some quadrupoles are connected to the same power supply. Figure 6 shows the new transverse beam envelopes when using the same RFQ output beam, with beam amplitudes clearly smaller. Total beam loss is dramatically reduced to less than 0.5%.

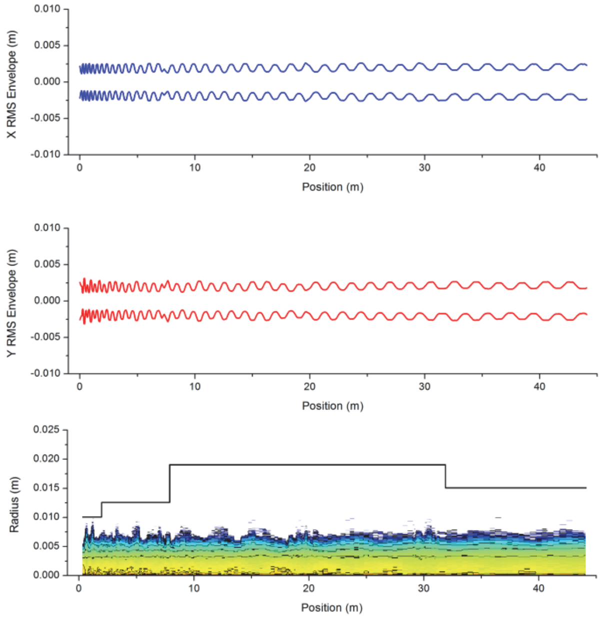

Figure 6: DTL transverse RMS beam envelopes and radial beam with a new RFQ to DTL matching section.

CONCLUSIONS

We have developed new beam dynamics simulation models for the old ISIS 70 MeV injector that correctly predict and explain beam losses along the linac. In addition we hope that these models could be used to improve machine tuning and operation.

Our tracking studies indicate that an increase in beam current of 25 – 30% is achievable if a new MEBT is added between the RFQ and the DTL. This could be implemented during a long shut down period.

It has been suggested that linacs that do not require fast beam chopping could benefit from direct RFQ to DTL injection as the MEBT can severely break the lattice periodicity with possible emittance growth effects. While this is true, the ISIS experience indicates that care has to be taken to avoid mismatch at injection. With most modern linac designs using permanent magnet quadrupoles and in the absence of a MEBT, a potential RFQ to DTL mismatch would be very difficult to correct.

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