AN UPDATED ASSESSMENT OF A MEDICAL CYCLOTRON AS AN INJECTOR FOR AN ENERGY UPGRADE

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Abstract

The 60 MeV cyclotron at Clatterbridge operates as the UK centre for proton therapy, concentrating on treatment of eye tumours; the accelerator is a Scanditronix model MC60PF fixed energy isochronous cyclotron with a high current ion source. Although possible energy upgrades have been previously considered interest has now been reawakened by the activities of the Italian TERA Foundation, which has proposed a compact high frequency booster linac as a potential solution to achieve the 200 MeV needed for a broader therapy programme. The paper reports progress on studies to assess if the Douglas cyclotron is suitable for a test of such a prototype booster linac. The results demonstrate that a cyclotron beam pulse of about 25 microseconds can be achieved by application of amplitude and phase modulation to its RF system. The most recent measurements of output emittance and energy spread of the accelerator are presented and compared with the normal CW values. Compatibility with the acceptance of the proposed linac is discussed.

1 INTRODUCTION

An overview of the use of accelerators for medical applications has been given by Amaldi [1]; this includes the important technique of hadron therapy using a variety of particles. Of these the potential for proton therapy in the treatment of a broad range of cancers is now widely accepted and has already been identified by an EU Working Party as deserving of priority support [2]. It is already used effectively for eye melanomas in the range 60-70 MeV but for deep seated tumours requires energies of at least 200 MeV. Few hospitals have such higher energy facilities and most patients have had to be treated at nuclear physics laboratories, a less than satisfactory situation. What is needed is a compact, economical solution for provision of these 200 MeV proton beams.

One route proposed by the Italian TERA Collaboration [3] is the production of a novel 3 GHz protontherapy linac, using an injector followed by two side-coupled linac structures with energies respectively of 70 MeV and 200 MeV; this challenge has been taken up by the Frascati team in its TOP project [4].

An attractive option is to exploit the same economical technology to boost the energy of existing therapy facilities, especially those in medical centres. Many are intermediate energy cyclotrons and it is necessary to assess whether their extracted proton beams can be successfully matched into the small physical aperture and restricted longitudinal phase space of a high frequency linac structure. In particular the Italian design has an acceptance of about 10π mm-mrad and 0.1 % rms energy spread [5]. Beam intensities for treatment need only be 10-20 nA average current and the linac is assumed to have a typical duty cycle of about 0.1 %, leading to an instantaneous cyclotron current of a few 10ís of μA. Especially in a hospital environment it is crucial to minimise beam losses in the transfer between the two accelerators so that it will be important to develop pulsed operation of the cyclotron matching that of the linac (~10μs) as closely as possible.

The initial studies of the suitability of extracted beam characteristics of one such cyclotron, at the Clatterbridge Oncology Centre in the UK, were recently reported at the EPACí98 conference in Stockholm [6]; updated studies are reported in this paper. It may be possible for this accelerator to be used as a test bed for the proposed concept, perhaps in collaboration with the Italian project [7]. A suggestion to boost the energy of the Clatterbridge accelerator with a linac, albeit of somewhat lower frequency, had previously been made in an earlier study by AEA Industrial Technology [8].

2 THE CLATTERBRIDGE CYCLOTRON

The Douglas Cyclotron Unit at Clatterbridge has operated a cyclotron for proton therapy since 1988. However for several years before that tests were carried out on the efficacy of neutron therapy, necessitating an accelerator with exceptionally intense proton currents of at least 50-100 μA to produce the required neutron fluxes from its beryllium target. A large switching magnet steered the protons into a neutron area and this separate beam line still exists, providing a useful facility for test purposes.

The commercially supplied isochronous cyclotron is a Scanditronix model MC60PF, whose principal parameters are summarised in Table 1.

Table 1. Principal Cyclotron Parameters

Energy	(MeV)	62
Current	(μA)	50+
Emittance/1σ	(π mm-mrad)	2-3
Energy Spread	(%, FWHH)	0.25
Radiofrequency	(MHz)	25.7
Harmonic Number		1
Dee Voltage	(kV)	40
Bunch Length	(deg)	13

These are notional parameters, as specified by the manufacturer, and in some cases are probably conservative. The current rating reflects the earlier utilisation as a neutron source and in recent years the accelerator has rarely exceeded 50 nA in CW mode. Emittances were measured at the factory and the energy spread and phase length are assumed to be equal to that of another Scanditronix model (MC35). The energy has been estimated from transmission through aluminium foil absorbers and for this type of cyclotron is fixed.

The intense ion source is a cold cathode (PIG) discharge type. Extraction is by utilising a radial integer resonance, together with an electrostatic deflector and focusing magnetic channel. This makes it difficult to predict the exact properties of the output beam.

3 MODIFIED PULSE DURATION

The obvious and most straightforward method of modulating the beam in a cyclotron would be to pulse the source of ions whilst they are at low energy. Unfortunately the ion source of the Clatterbridge accelerator, as with the majority of medical cyclotrons, is positioned at the centre of the dees and is very inaccessible. Furthermore, no modifications to the cyclotron could be considered which might reduce its availability in its primary function as a source for therapy. For these reasons an alternative approach to achieving a pulsed output beam was selected, that is to modulate the RF accelerating voltage.

If the RF accelerating voltage is not optimum, the first few orbits of ions which have been emitted from the ion source are perturbed, resulting in them colliding with collimators which are critically placed near the centre of the dees. Running the cyclotron with reduced RF amplitude and pulsing the RF up to the correct level when the beam pulse is required will produce a pulsed output beam. In practice this technique must be constrained by the need to keep the RF within certain limits so that the auto-tuning loops remain functional.

An alternative technique is possible in cyclotrons of the type used at Clatterbridge where there are two pairs of dees used. Adjusting the relative phase of the drive to the separate RF amplifiers feeding the dee pairs can alter the RF accelerating voltage effectively seen by the ions. This has the advantage of not disturbing the tuning loops. A highly simplified block diagram of the RF system is given in fig 1, showing how the amplitude and phase modulating signals are applied. The Clatterbridge system was modified to allow the two types of modulation and a series of tests were made in which short rectangular pulses of both amplitude and phase shift were applied at a repetition rate of 50 Hz and synchronised to the electricity main.

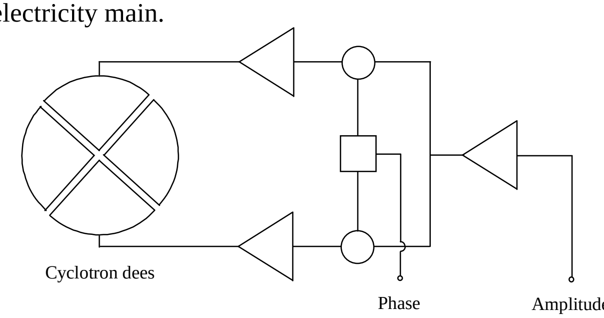

Figure 1: Block diagram of the modified RF system

The results showed that both modulations were fully effective in producing a pulsed output beam, which was detected from a faraday cup signal. The amplitude modulation was limited to the rise time of the RF system and gave a beam pulse of about 100 μs half width. Shorter pulses of about 25 μs were obtained by driving the RF rapidly through the optimum level, but this of course gave rise to 2 beam pulses, on the upward and downgoing edges of the drive pulse. The phase modulation system gave slightly shorter beam pulses of about 20 μs, as shown in fig 2, but a measurement of the basic system response to step phase changes has not yet been made so that it is not clear what the ultimate shortest pulse would be. At present it is likely that the best technique for generating a single short beam pulse is to apply shifted, overlapping, phase and amplitude modulations.

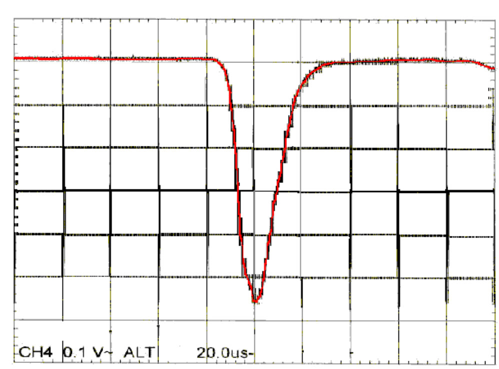

Figure 2. Successful RF pulsing of the cyclotron beam

4 EXTRACTED PROTON BEAM TESTS

The extracted beam properties have been assessed in an experimental programme making use of the beam line previously devoted to feeding the neutron target. This line has quadrupole triplets before and after a 55^0 dipole magnet and the latter allows a large dispersion to be set if required. The available diagnostics in the experimental beam line has been quite limited; a fluorescent screen at the downstream end supplements spinning wire profile monitors at two fixed locations. Viewing the screen image with a CCD camera the beam sizes were estimated by fitting to Gaussian profiles using framegrabber and image analysis software written with LabVIEW [9].

Systematic scans of single quadrupoles with the beamline set to give both high and low dispersion at the screen [6] gave a range of data that was then fitted to a linear model of the beamline written using Microsoft EXCEL [10]; quadrupole field gradients were calibrated using a Hall plate. Although the predicted beam sizes are only weakly dependent upon the model energy spread an upper bound of 0.1% rms can be given for this cyclotron parameter; Twiss functions and emittances have also been estimated, the latter being consistent with those given in Table 1. An example is shown in Figure 3 where the horizontal beam size is compared with model energy spreads of 0.1%, 0.05% and 0.01%.

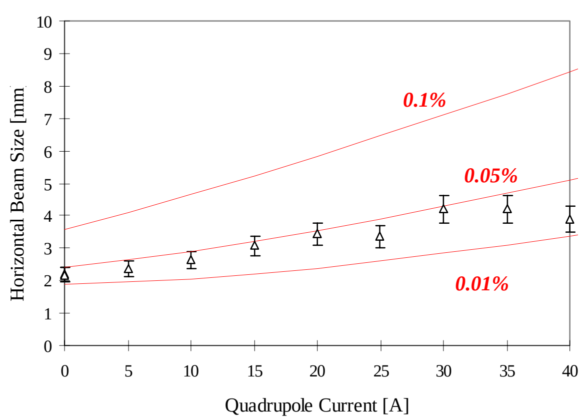

Figure 3. Typical fit of cyclotron parameters

5 CONCLUSIONS

The first phase of assessment of the properties of the extracted proton beam from the 62 MeV Clatterbridge cyclotron has been successfully completed. Emittances in both planes have been confirmed to be at or even below the expected values of about 2-3 mm-mrad and the energy spread appears to be exceptionally good, with an upper value (rms) of 0.1 % and probably considerably lower. Pulsed beam operation has been commissioned by modification to the RF drive circuitry and a pulse width of 20 µs at 50 Hz demonstrated; since the modulation is effectively onto the low energy beam acceptance in the accelerator it is not expected that the high energy beam properties will be adversely affected, but this has yet to be confirmed experimentally. Nevertheless it is clear that the cyclotron could be a suitable injector into a high frequency proton linac booster. The possibility of testing this with a real accelerating structure will now be pursued, perhaps in an international collaboration.

6 ACKNOWLEDGEMENTS

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