# POSSIBLE MEGAWATT UPGRADES FOR ISIS

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## 1 INTRODUCTION

ISIS, at the Rutherford Appleton Laboratory in the UK, is the world's most intense pulsed neutron source. Beam power is presently 160 kW, and is set to increase to 240 kW on installation of a dual harmonic RF (DHRF) system now under development. This paper explores upgrade options for higher beam powers, between 0.5 and 5.0 MW. A summary of options for a scheme of staged upgrades, which exploit the existing accelerators and infrastructure, and provide long term flexibility, is given. Initial results of studies looking at options for a 3.5 GeV RCS required for these upgrades, are also presented.

## 2 UPGRADE OPTIONS

### *2.1 Existing Machine and Present Upgrade*

Presently, ISIS is based on a 50 Hz high intensity proton synchrotron which accelerates $2.5\times10^{13}$ protons per pulse to 800 MeV [1], providing two 100 ns pulses spaced by 220 ns on the spallation target. Installation of the DHRF system, adding four new h=4 RF cavities to the six existing h=2 devices, is expected to increase the intensity to $3.75\times10^{13}$ ppp.

### *2.2 Upgrades to 1 MW*

Worthwhile increases above the 0.24 MW level, as provided by the DHRF upgrade, require substantial increases in current, energy or both. Beam loss is a critical issue in any upgrade and should be limited, at most, to present ISIS levels. Increasing the injection energy into the existing ring would reduce space charge related losses, and provide increases in current. However, losses associated with a larger extracted emittance, the problems of injecting higher energy beam in limited space, and the practicalities of upgrading the injector with minimal interruption to operations, do not make this a favoured option. The scheme with the most potential is the addition of further rapid cycling synchrotrons (RCS's), raising the energy of the existing beam to 3.5 GeV and providing up to 1.0 MW beam power.

Principle concerns for the 3.5 GeV RCS are provision of space for the required RF systems, and keeping beam losses below 0.1%. This has influenced the selection of a repetition rate of 25 Hz and a circumference twice that of the existing ring. The RF system provides four RF buckets, matched to the structure of the 0.8 GeV fast injected bunches, for near lossless capture.

There are a number of possible schemes for operating 25 Hz high energy rings, with a 50 Hz 'injector', to achieve 1.0 MW. The preferred option, which is more expensive but has much potential, uses two 25 Hz 3.5 GeV RCS's filled on alternate 50 Hz cycles, with two out of four RF buckets being occupied during acceleration. The other, cheaper option, uses a 25 Hz, 3.5 GeV RCS plus a 0.8 GeV storage ring (SR). Here, two 0.8 GeV bunches are stored for 20 ms, until the next two bunches emerge from the 50 Hz RCS, and all four are then injected into the high energy ring. Following the 20 ms acceleration interval the beam is extracted in a single turn and transported to the appropriate targets.

To provide convenient, manageable stages for the upgrade, a single 25 Hz RCS could be added initially, providing 0.5 MW to a new target, leaving the remaining 25 Hz, 0.12 MW beam going to the existing target. Beam could also be directed to the planned new low power second ISIS target station. At a later stage, a second RCS or storage ring would be added, taking the power to 1.0 MW. These upgrades should all be possible with minimal interruption to the ISIS operational programme.

Table 1: Upgrade Routes for ISIS

| | Description | Power (MW) |
|---|---|---|
| 0 | Present status | 0.160 |
| 1 | Current DHRF upgrade | 0.240 |
| 2 | Add 1x3.5 GeV RCS, 25 Hz | 0.525 + 0.120 |
| 3 | Add 2x3.5 GeV RCS, 25 Hz | 1.05 |
| 3(a) | Add 1x3.5 GeV RCS + SR | 1.05 |
| 4 | Add 2x3.5 GeV RCS<br>+ 800 MeV Linac | 5.0 |
| 4(a) | Add 2x3.5 GeV RCS<br>+ 0.8 GeV RCS | 2.0 |

### *2.3 Upgrades beyond 1 MW*

The addition of a second 800 MeV RCS, fed from the present 70 MeV injector, could be used to fill the two free RF buckets in each new 3.5 GeV RCS. In this scheme all four RF buckets of each 3.5 GEV RCS would be occupied on each 25 Hz cycle, taking the power to 2.0 MW.

To take beam power to 5.0 MW levels, the most promising route would involve converting the two 3.5 GeV RCS's to multi-turn charge-exchange injection, and adding an 800 MeV linac. This is similar to a scheme already studied for the European Spallation Source [2].

This would require some careful ring lattice design to allow conversion to the highly optimised multi-turn injection scheme.

## 3 STUDIES FOR A 3.5 GEV RCS

### *3.1 Outline Requirements*

All the proposed upgrades, which use ISIS as an injector, centre on the use of a 3.5 GeV RCS. The main parameters for this ring are summarised in Table 2.

Table 2: Main Parameters for 3.5 GeV RCS

| | |
|---|---|
| Energy (GeV) | 0.8 - 3.5 |
| Repetition Rate (Hz) | 25 |
| Mean Radius | 52 |
| Injection System | Single Turn |
| Extraction System | Single Turn |
| Protons per pulse (for 0.525 MW) | $3.75\text{x}10^{13}$ |
| RF System harmonic numbers | h=4,8 |
| Peak RF Volts per Turn (kV/turn) | ~300 |
| RF Frequency h=4 (MHz) | 3.09-3.59 |
| Loss Levels | < 0.1 % |

The initial lattice requirements are: a ring with long low dispersion straight sections for the accelerating cavities, betatron collection system and the injection and extraction systems; a high normalised dispersion straight for momentum collimation; and, to simplify the RF requirements a transition energy > 3.5 GeV. A number of lattices are presently under study, the most promising is described below.

### *3.2 Lattice Description*

The candidate lattice currently under study is a super period 3 ring with 11 cells per period. Each cell has a quadrupole doublet and either a dipole (B cell) or drift space (O cell). The superperiod structure is 'BBBBBOBOOOO'. To meet the dispersion constraints the lattice has two double bend achromat sections, hence the horizontal phase advance is 90° per cell. The horizontal and vertical tunes are 8.25 and 6.3 respectively.

The lattice, shown in Figure 1, has four zero and one dispersive straight per superperiod. The maximum beta values are 13.92 m and 18.99 m horizontally and vertically, respectively. The main dipoles are parallel edge magnets. This adds a focusing component to the vertical plane. The maximum horizontal dispersion is 4.02 m. The maximum normalised dispersion in the non achromatic drift, cell 6, is ~ 0.81 $m^{1/2}$. Gamma transition, $\gamma_t$, is 7.43 which lies well above the top energy of the ring.

The main dipole and quadrupole lengths have been chosen to reduce the peak field on the pole tips to 1 T and < 0.8 T respectively. The magnet parameters are given in Tables 3 and 4. The magnet apertures are based on a machine acceptance of 520 and 430 $\pi$ mmmrad in the horizontal and vertical plane respectively and a momentum spread of ±0.8 %. These initial choices are equivalent to the existing ISIS ring but may be changed after further study.

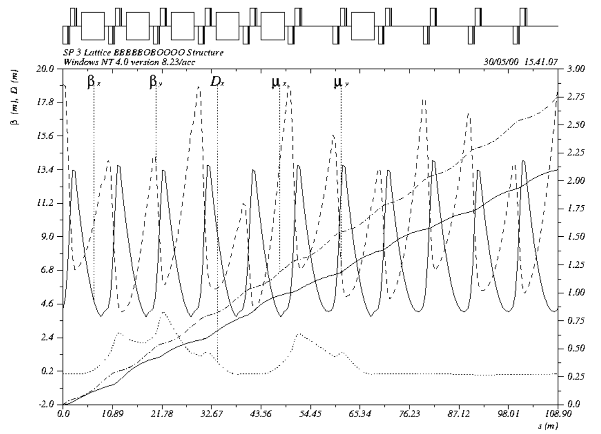


Figure 1: Lattice Parameters

Table 3: Dipole Magnet Parameters

| | Ring Dipole | Inj Septum | Ext Ver septum | Ext Hor septum |
|---|---|---|---|---|
| Length (m) | 5.052 | 2.0 | 3.65 | 4.0 |
| Angle(deg) | 20.0 | 23.48 | 14.45 | 15.83 |
| Field (T) | 1.0 | 1.0 | 1.0 | 1.0 |
| Gap (mm) | 220 | 130 | 100 | 100 |

Table 4: Quadrupole Magnet Parameters

| | QD | QTD | QF | QTF |
|---|---|---|---|---|
| Length (m) | 1.0 | 0.2 | 1.0 | 0.2 |
| Gradient (T/m) | 6.11 | 0.63 | 5.46 | 0.67 |
| Radius (mm) | 130.0 | 125.0 | 130.0 | 125.0 |

## 4 INJECTION AND EXTRACTION SYSTEMS

The injection and extraction systems are located in the superperiod long straight, in cells 10-11 and cells 9-10 respectively, and are based on the conventional fast kickers and DC septum arrangement. In each case the kickers and septum lie either side of a doublet module.

Injection is in the horizontal plane and extraction is in the vertical plane. Two options for vertical extraction are being studied. The first will use a septum in the vertical plane to clear the downstream magnets. The second will use a '*lambertson*' septum magnet in the horizontal plane. This latter option is being considered to accommodate two vertically stacked rings where a vertical extraction septum magnet would pose a layout problem. The beam injection and extraction emittances are shown in Table 5. The kicker and septum solutions, Table 3 and 6 are based on a septum thickness of 20 mm and a beam displacement at the quadrupole magnet upstream/downstream of the injection/extraction septums of 0.6 m.

Table 5: Injection and Extraction Beam Parameters

| | Injection | Extraction |
|---|---|---|
| Un-normalised emittance<br>($\pi$ mm mrad) | 300 (H)<br>283 (V) | 103 (H)<br>98 (V) |

Table 6: Injection and Extraction Kicker Parameters

| | Deflection Angle (mrad) | Kicker Rise time (ns) | Number of kicker modules |
|---|---|---|---|
| Injection | 15.76 | < 230 ns | 4 |
| Extraction 1 | 13.53 | <195 ns | 8 |
| Extraction 2 | 13.04 | < 195 ns | 8 |

The kickers will be based on the existing ISIS designs [1]. These are lumped kickers in push-pull configuration resulting in two magnets per kicker module. Each magnet will be powered to a peak field of 0.04 T in ~200 ns by discharging ~40 KV through a pulse forming network.

## 5 FURTHER RCS DETAILS

The RF systems will be largely based on those of the existing ISIS ring: ferrite tuned cavities with appropriate precautions against beam loading effects. Achieving the required peak volts per turn at the required rep rate and energy, within the lattice space available, will require careful design. The details of the system are presently under study, but are expected to be dual harmonic, (h=4,8), with a total peak of ~300 kV per turn. Optimised longitudinal capture is essential to keep losses down. Estimates based on simple scaling of present ISIS cavities indicate space will be tight. However, it is expected problems can be eased by making cavities shorter, and perhaps by modifying the main magnet field from the assumed sinusoidal form.

Maximum incoherent space charge tune shifts are estimated to be ~ -0.1, with coherent shifts smaller. A set of programmable trim quadrupoles is to be included, configured so as to allow independent control of ($Q_h$,$Q_v$), within limits of about ±0.1. A similar system on the present synchrotron has been essential for reaching high intensities.

## 6 SITE LAYOUT

The 0.5 to 5 MW upgrade paths detailed above require the siting of a new 800 MeV RCS, one or two vertically stacked 3.5 GeV RCS's, a new 800 MeV linac, a Target Station and the associated injection/extraction beam lines. A possible layout is shown in Figure 2.

Upgrades to 1 MW use the existing ISIS infrastructure as an injector. An 800 MeV beam could feed the new 3.5 GeV ring(s) using a beam line which extracts from the proposed Second Target Station beam line [3]. This would have minimal effect on the ISIS user run schedule since the extraction point could be built within a scheduled maintenance period.

A 2 MW upgrade uses a new 'ISIS like' 800 MeV ring. This would probably be stacked on top of the existing ring to make optimal use of the 800 MeV beam lines. The major impact on the ISIS user schedule would have to be carefully considered.

The 5 MW upgrade requires a new 800 MeV linac and injection collimation line and could be sited as shown.

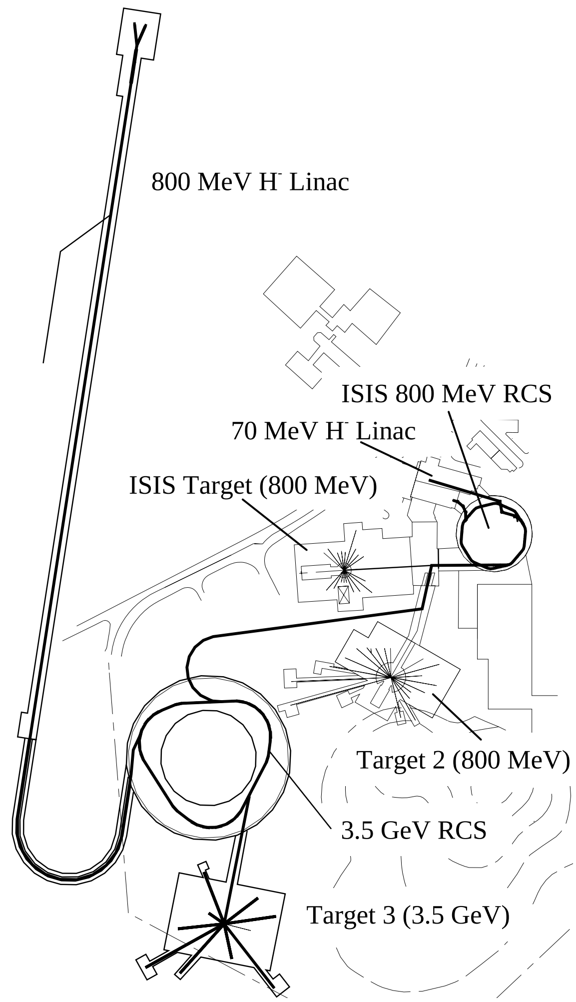


Figure 2 : Possible layout of the ISIS upgrades

## 7 CONCLUSIONS

A staged ISIS upgrade up to 1-5 MW and the layout of such a facility on the RAL site appears feasible. Initial studies on the main accelerator, a 3.5 GeV RCS, look promising but requires further study.

## REFERENCES


[1] Spallation Neutron Source: Description of Accelerator and Target, B Boardman, RL-82-006

[2] ESS Feasibility Study. Vol 3, ESS 96-53M.

[3] A Second Target Station at ISIS.