A POSSIBLE UPGRADE FOR ISIS

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Abstract

The Rutherford Appleton Laboratory's neutron spallation source ISIS is running at its design intensity of 200 μA and demand for experimental time is 2.4 times that available. Studies have shown that it is possible to increase the accelerated current to nearly 300 μA by installing four 2nd harmonic RF cavities in the synchrotron. This scheme, together with the other necessary changes to the ISIS Facility, are described. Compared with the capital value of the Facility, the expense of providing the extra 100 μA is shown to be very modest.

1 INTRODUCTION

ISIS consists of an 800 MeV proton synchrotron feeding a heavy metal target at 50 Hz. Neutrons are generated and moderated to feed 16 instruments which are used for the study of condensed matter. In addition to the large number of neutron users, there are installations for the study of neutrinos and muons. All of these experiments would benefit from an increase in the proton intensity. An additional target station to operate at 10 Hz would suit many of the neutron experiments and there is also great interest in radioactive beams. A study is in progress to see how such facilities can best be fitted into the ISIS complex. This paper describes how it is possible to increase by 50 % the synchrotron beam intensity, which is presently limited by space charge to about $2.5\ 10^{13}$ protons per pulse (ppp). The increase in current must be achieved without losing any more beam than is lost at present.

2 THE DUAL HARMONIC SYSTEM

The power necessary to accelerate 200 μA is provided by 6 RF stations disposed round the synchrotron (see Fig 1). These produce a peak of 140 kV per turn during the 10 ms acceleration period. Typical beam losses are 1% during injection, when the RF volts are extremely low, and 10% during trapping, which lasts for about 1.5 ms. Most of the lost protons are collected on beam scrapers, and with the loss concentrated in less than 1/5th of the circumference hands-on maintenance is the norm. Any increase in intensity should not result in further losses.

When a second harmonic component (h=4) of the correct phase and amplitude is added to the accelerating RF (h=2), the longitudinal phase acceptance is increased so that more particles can be accelerated without necessarily leading to increased loss. Such a scheme was successfully applied to NIMROD, the 7GeV predecessor of ISIS, and has been used on other accelerators, but never (we believe) on a fast-cycling machine.

A detailed analysis of a system for ISIS [1] showed that simply adding an h=4 component, variable in phase and amplitude, does not allow stable acceleration throughout the cycle; it is also necessary to increase the fundamental amplitude. As it would be difficult to find space in the ring for a 7th fundamental station, it is fortunate that the present cavities have a little voltage in hand and should be adequate for the task. A simulation using less than 20,000 particles showed that, with the various restrictions pertaining with ISIS, the phase and amplitude of the h=4 component have to be programmed within tight limits if extraneous loss is to be avoided. This is particularly so for the last 2.5 ms of acceleration. Figure 2 clearly shows the distortion and enlargement of the RF bucket due to the higher harmonic.

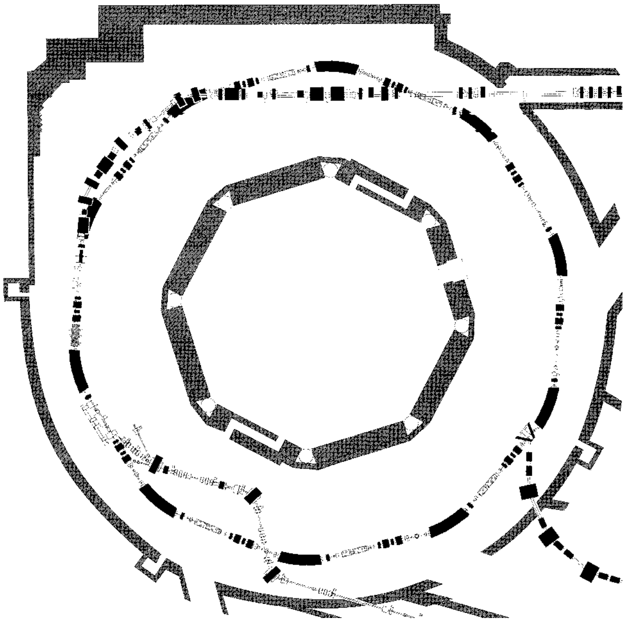

Figure 1 The ISIS 800 MeV synchrotron

There will be a small increase in momentum spread, which should not be significant, but there is a possibility of a small amount of loss later in the cycle - up to 6 ms. This could be troublesome due to the higher

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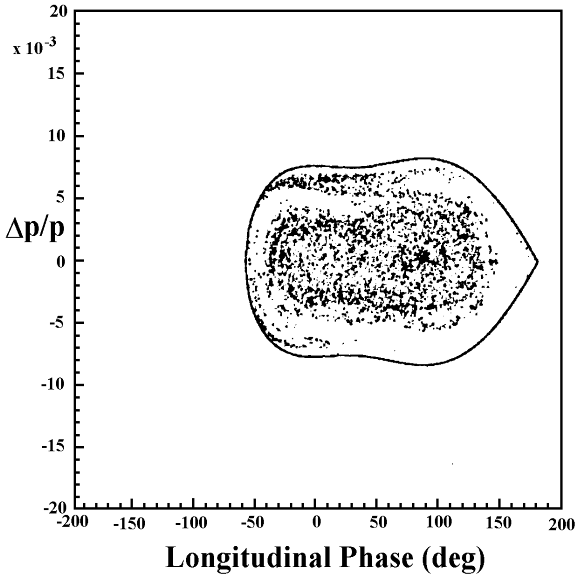

Figure 2 Longitudinal phase space 2.5 ms after injection

momentum of the lost particles, but small changes to the phase and amplitude functions should bring the loss earlier. Table 1 gives the expected inventory of injected, accelerated and lost particles per pulse for the 200 μA and 300 μA cases.

TABLE 1

Accel'd current	Injected protons	Accel'd protons	Lost protons
200 μA	$2.9\ 10^{13}$	$2.5\ 10^{13}$	$4\ 10^{12}$
300 μA	$4.1\ 10^{13}$	$3.7\ 10^{13}$	$4\ 10^{12}$

3 HARDWARE

The 2nd harmonic cavities will be shortened versions of the fundamental cavities (Fig 3). About half the original length, they will be installed in four short straight sections which can be made available in the ten superperiod ring (see Fig 1). Two steering magnets will have to be re-located elsewhere, and two position monitors will be lost, but these changes will have little effect on the running of the machine. The cavities will be assembled at RAL, as were the fundamental units. The original drawings, jigs and fixtures are all available.

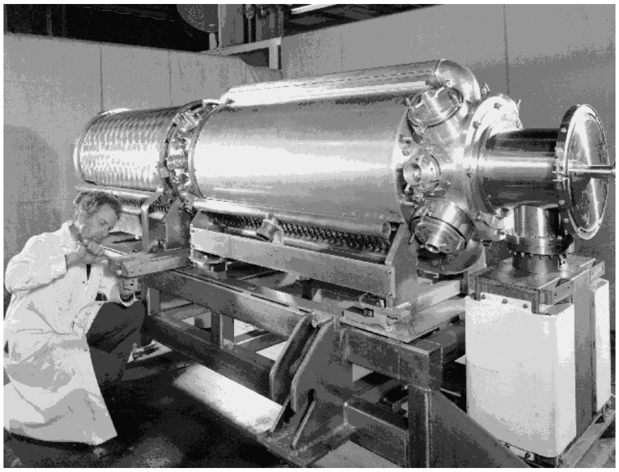

Figure 3 A fundamental RF cavity

The frequency range to be covered by the new cavities is 2.6 - 6.2 MHz, so the low level RF technology will be essentially unchanged. Regarding the high power RF, however, it is hoped to collaborate with Argonne National Laboratory and KEK National Laboratory in Japan in testing a cathode follower driver. Two of the four cavities would be powered in this way to simplify the phasing. Workers at KEK (and at PSR, LANL) have used a triode cathode follower to drive an RF cavity, and shown it to behave in a stable manner at a fixed frequency [2]. The low impedance of the cathode follower circuit should result in low induced volts and obviate the need for feed-forward compensation.

The objective would be to demonstrate that cathode followers behave in a stable way under frequency modulation conditions, and that the beam-induced voltages are as calculated. The design will be such that it will be relatively easy to revert to the present fundamental circuit should it be necessary. The total cost of the cavities, power supplies and distribution (including manpower) is estimated to be £4.6M.

4 INJECTOR REQUIREMENTS

In order to provide the $4.1\ 10^{13}$ ppp necessary for 300 μA operation, the output of the 70 MeV injector must increase from 22 to 30 mA of H^- ions. The ion source has been developed so as to give 50 mA with a 250 μsec pulse length, but the 665 kV Cockroft-Walton pre-injector is now very elderly and is to be replaced by an RFQ in 1998.

The linac tank RF modulator systems may not be robust enough to withstand the increased beam loading. Steps necessary to overcome this include uprating the modulators' capacitor banks and charging systems, and replacing the modulating switch tubes and the RF drivers to the penultimate 4616 tetrode amplifiers. A test rig is also required to study and eliminate parasitic oscillations in the TH116 output tube which will become more critical at the higher output level.

5 EFFECTS ON THE NEUTRON TARGET

Because a second target station would cost far more than the 300 μA upgrade, we have to assume that initially, at least, the present target will have to be able to cope with the extra beam power. The performance of the two tantalum targets used so far suggests that at least a one year life time can be expected at the higher intensity. It is probable that the plates will have to be reduced slightly in thickness, but this is straightforward and of low cost.

Development work on the tantalum target is proceeding at present and the requirements for 300 µA can be anticipated to ensure that any changes for higher power can be made easily. The use of uranium as a target material at this intensity can probably be ruled out.

The moderator cooling is adequate for the higher intensity but the reflector cooling on the top section is already marginal at 200 µA, and the design does not allow the water flow to be increased. A new top section will be required for running at 300 µA. The existing top section will be retained as a spare, so there will be no immediate disposal cost.

Regarding the shielding, all the dose rates will increase by 50%. This should not be a problem in the generally accessible areas but the rates in the neutron beam line enclosures with the shutters closed must be reviewed and it would be prudent to allow for shielding upgrades.

6 COSTS

The RF proposal has been costed in detail [3] and a summary is given in Table 2. Manpower costs are included.

TABLE 2

Item	**Cost (£k)**
4 LPRF systems	410
4 RF cavities	1270
4 HPRF amplifiers	420
4 HPRF power supplies	1830
Distribution	190
Civil engineering	480
Linac changes	700
Target reflector	700
Extra shielding	50
TOTAL (ex VAT)	**6050**

6.1 Additional running costs

The annual electricity costs of running ISIS are about £2M. The cost of running the four extra systems, assuming 5500 hours operation per year, will be £0.36M. The full marginal annual running cost is shown in Table 3, which allows for the fact that the linac will be fitted with tubes that are more expensive to replace.

TABLE 3

Item	**£k**
Linac Power tubes	25
2nd Harmonic Systems:	
Power tubes	70
Spares	20
Maintenance	20
Electricity	360
TOTAL (ex VAT)	**470**

7 SUMMARY

The ISIS Facility has a replacement cost of about £150M and cannot meet the demand for its neutrons, muons and neutrinos. The primary proton current can be increased by 50% at a capital cost of £6M and extra running costs of £0.5M per annum.

REFERENCES

[1] Studies of Dual Harmonic Acceleration in ISIS. C R Prior, A-11, ICANS-XII, RAL Report 94-025

[2] Very Low Output Impedance RF System for High Intensity Accelerators. Y Irie, A-131, ibid.

[3] ISIS Synchrotron 2nd Harmonic Costing. M G Glover and R G Bendall. ISIS/SYN/3/96