PROGRESS ON DUAL HARMONIC ACCELERATION ON THE ISIS SYNCHROTRON

A. Seville, D. Adams, C. Appelbee, D. Bayley, N. Farthing, I. Gardner, M. Glover, B. Pine, J. Thomason, C. Warsop, STFC, Rutherford Appleton Laboratory, Chilton, Didcot, UK.

Abstract

The ISIS facility at the Rutherford Appleton Laboratory in the UK is currently the most intense pulsed, spallation, neutron source. The accelerator consists of a 70MeV H^- linac and an 800MeV, 50Hz, rapid cycling proton synchrotron. The synchrotron beam intensity is typically 2.25×10^{13} protons per pulse, corresponding to a mean current of 180μA. The synchrotron beam is accelerated using six, ferrite loaded, RF cavities with harmonic number 2. Four additional, harmonic number 4, cavities have been installed to increase the beam bunching factor with the potential to raise the operating current to 300μA. The dual harmonic system has now been used operationally for the first time, running reliably throughout the last ISIS user cycle of 2006. This paper reports on the hardware commissioning, beam tests and improved operational results obtained so far with dual harmonic acceleration.

INTRODUCTION

Over the last twenty years, acceleration of the ISIS synchrotron beam has been provided by six two-gap RF cavities. With this arrangement up to 2.75×10^{13} protons can be held in the synchrotron throughout the 10ms accelerating cycle from 70 to 800 MeV during which the RF sweeps from 1.3 to 3.1 MHz. The maximum mean beam current which can be accelerated by the synchrotron is ~220μA, although for ease of active maintenance, beam loss limits the operational beam current to ~180μA. The addition of a second harmonic (2RF) component [1,2] to the fundamental RF (1RF) waveform, as shown in figure 1, should allow the acceleration of higher currents by extending the phase stable region and therefore increasing the bunching factor.

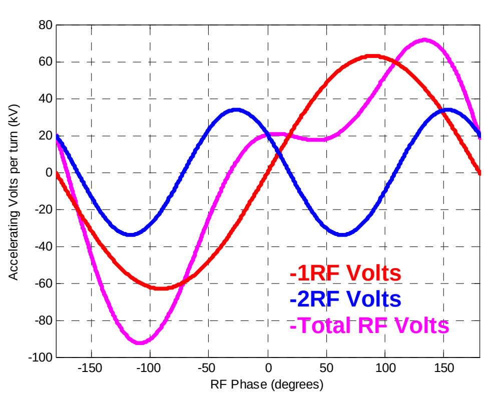

Figure 1: Addition of 1RF and 2RF components.

The longitudinal phase acceptance is increased due to the addition of the 2RF component, giving a higher trapping efficiency. Simulations indicate that up to 3.75×10^{13} protons, or ~6 μC of protons, can be held and accelerated using this technique. In ISIS the 2RF component is to be provided by four 2RF cavities, installed in Super-periods (SP) 4, 5, 6 and 8. One of which is shown in figure 2.

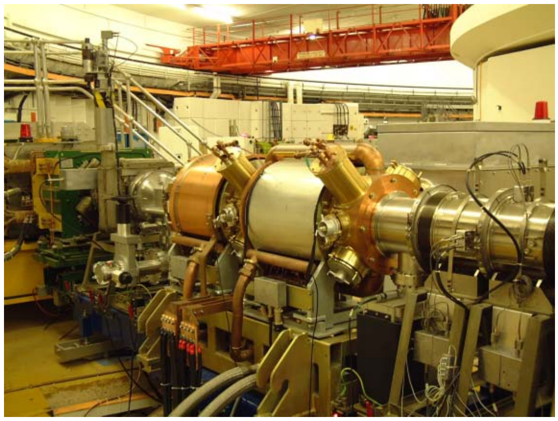

Figure 2: ISIS 2RF Cavity.

The cavities are similar in design to the existing 1RF cavities, but are approximately half the length. As with the 1RF cavities, the resonant frequency of the 2RF cavities has to sweep throughout the acceleration cycle (at twice the 1RF frequency, 2.6 to 6.2 MHz) to match the changing rotational frequency. This change is effected by loading the 2RF cavities with ferrite and then sweeping the ferrite bias current throughout the acceleration cycle to change the permeability of the ferrite and hence the inductive element of the equivalent L-C circuit. The hardware necessary for driving the new 2RF cavities is based on that used very successfully over the last twenty years for the fundamental cavities, but the electrical and electronic hardware has been updated where appropriate.

COMISSIONING THE 2RF SYSTEMS

The 2RF low power RF (LPRF) system is described more fully in [3], and whilst previous results had proved encouraging, and even shown a slight increase in trapping efficiency, further work was needed to fully commission the 2RF control system. In addition to limitations on experimental work by the demands of the ISIS schedule, much of the commissioning was hampered by spurious tripping of the tetrode anode power supplies, due to beam induced oscillations in the anode current [4]. To this end, the bandwidths of the control loops have been reduced such that the anode power supplies are less susceptible to tripping. Further modifications have been made by adding filters to reduce the effect of the RF component of the beam coupling into the power supply control circuit.

The changes made enabled the first reliable operation of the 2RF systems, using two 2RF cavities only. Even then, a relatively low peak voltage of 7.2kV per accelerating gap was chosen to reduce the number of power supply trips. When an attempt was made to accelerate beam using four 2RF cavities, the beam loss increased, the anode power supplies began to trip again and the voltage traces showed increased oscillations (particularly in the first 1ms and last 2ms of acceleration). These oscillations were due to an increased second harmonic component of the beam giving larger beam loading of the 2RF cavities. So, as with the 1RF system, a method of feed forward beam compensation [5] was implemented on the 2RF cavities to reduce this effect. In this instance the beam pickup signal was passed through a band-pass filter to select the 2RF component. Figure 3 shows the RF gap volts envelopes for SP4, for dual harmonic (DHRF) acceleration with two and four 2RF cavities without beam compensation, and also for two 2RF cavity DHRF acceleration with beam compensation operating in the first 2ms. For the latter case, the oscillations in RF volts and phase were much improved.

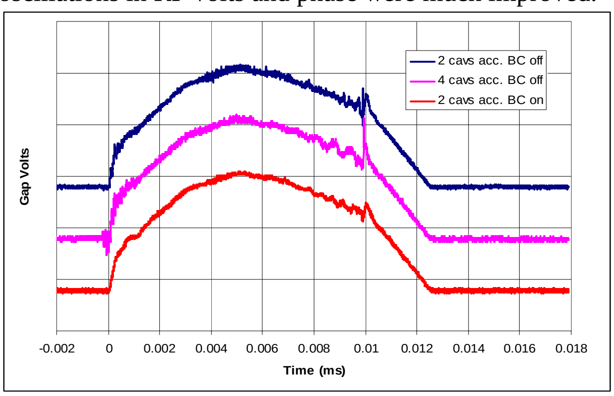

Figure 3: RF gap volts and phase detector output for 2RF systems, with and without beam compensation.

OPERATIONAL DHRF RESULTS

In spite of the problems encountered during the initial stages of commissioning, significant progress has been made, culminating in most of the final ISIS user run in 2006 operating with DHRF acceleration. During this period, a high intensity beam (~2.25×10^{13} protons) was accelerated using the DHRF system consisting of six 1RF cavities and two of the four 2RF cavities, each running at a peak voltage of 7.2kV. The operational values of the total peak RF voltages are given in table 1, compared with the theoretical parameters for four 2RF cavity DHRF acceleration.

Table 1: Optimum theoretical and operational parameters for Dual Harmonic Acceleration in ISIS.

THEORETICAL VALUES (4X 2RF CAVITIES)				OPERATIONAL VALUES (2X 2RF CAVITIES)			
t (ms)	1RF Volts (kV)	2RF Volts (kV)	θ	t (ms)	1RF Volts (kV)	2RF Volts (kV)	θ
-0.35	3	0	0	-0.55	0	0	0
-0.2	6	0	0	-0.5	2.4	0	0
-0.15	7.5	0	0	-0.3	2.4	0	0
0	18.3	9.15	0	-0.15	9.6	0	0
0.03	20.5	12.3	-2.9	0	16.8	0	0
0.3	40	24	-29	0.25	34.8	13.32	-24.2
0.5	50	30	-32.2	0.7	57.6	16.4	-35.4
0.84	75	45	-37.6	1.5	87	19.52	-44.8
1.8	120	72	-48	3	132	25.72	-60.2
2.72	145	87	-57.9	4	141.6	27.24	-68.4
4	160	80	-68.4	5	156	28.8	-71.9
5	150	75	-71.9	7	147.6	26.96	-64.9
6	150	75	-72.6	10	120	21.68	0
7	145	72.5	-64.9	12.5	2.4	0	0
10	145	72.5	0				

Figure 4 shows the line intensity of the beam pulses as they evolve throughout the 10ms of acceleration for the case of DHRF compared with the single harmonic RF (SHRF) case. One can see the effect of the second harmonic component in the early pulses, which are broadened slightly, with a flatter top. This less prominent peak indicates a lower peak charge density, and will therefore give rise to less instability.

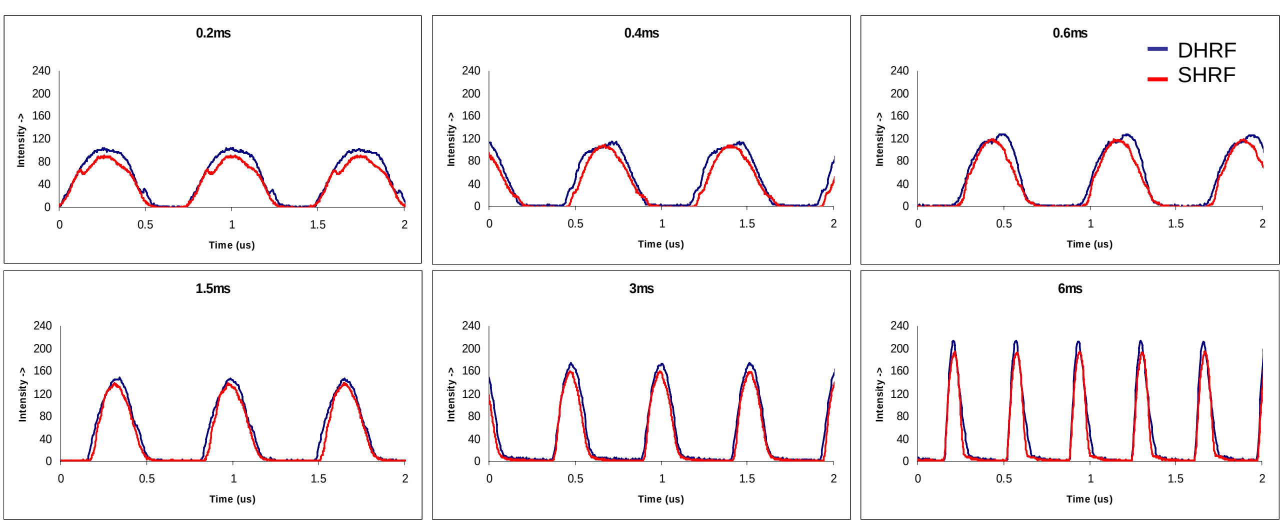

Figure 4: Evolution of beam pulse shape throughout 10ms acceleration period.

1-4244-0917-9/07/$25.00

In both cases one can also see the progression towards narrow, intense pulses later in the cycle, in order to facilitate fast extraction between pulses. These pulse waveforms were analysed to give a measure of the FWHM bunch length throughout acceleration, the results of which are shown in Figure 5.

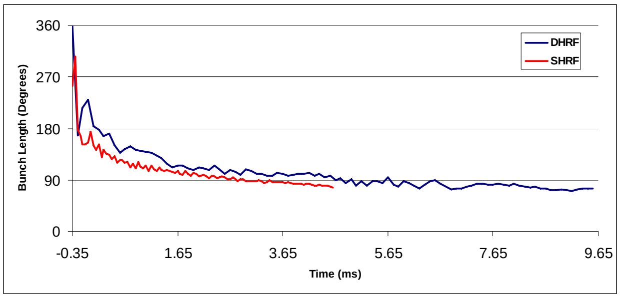

Figure 5: Measured beam bunch length.

The longitudinal phase extent of the separatrices have been calculated for the case of the operational (2 cavity) parameters and that of the theoretical (4 cavity) values. Figure 6 shows the phase extent for each case.

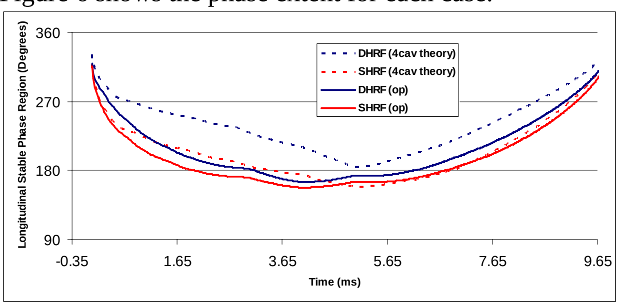

Figure 6: Longitudinal phase extent of the beam bunch.

The plot shows an increase in phase extent when the DHRF is used over the single harmonic case, as was seen with the measured bunch length. Furthermore, the use of four 2RF cavities at the full peak voltage of 10kV should yield a further increase in the longitudinal phase stable region and therefore bunch length. Figure 7 shows the beam intensity during the 10ms acceleration period for the case of DHRF acceleration and single harmonic (SHRF) acceleration. The DHRF case shows an increase in acceleration efficiency of 3-4% over the 1RF.

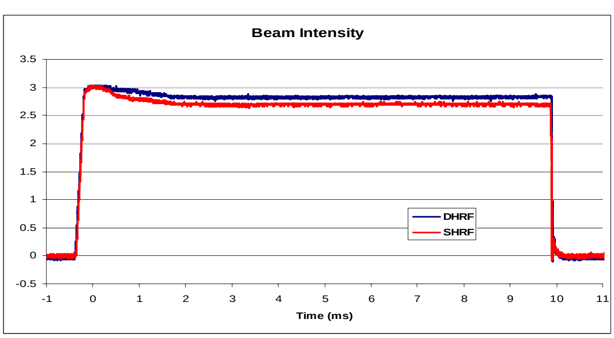

Figure 7: Measured beam intensity.

Figure 8 shows the corresponding beam loss monitor signal (a summed signal of loss monitors throughout the ISIS ring) which is significantly improved.

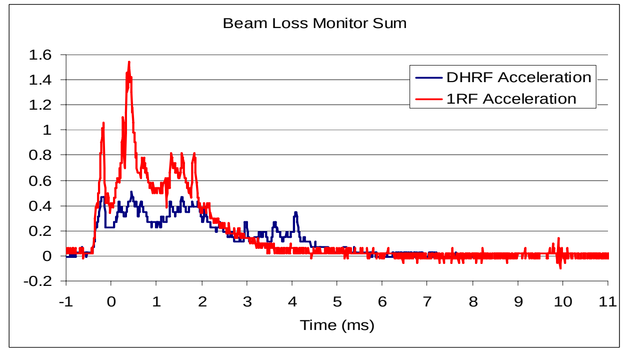

Figure 8: Measured beam loss.

As a result of these improvements the operational 50Hz beam current was increased from the nominal 180µA up to over 200µA for the last 12 hours or so of the final ISIS user cycle of 2006. The typical beam loss for the dual harmonic accelerated beam at 200µA appeared no worse than that of a SHRF accelerated beam of 180µA.

CONCLUSIONS AND FURTHER WORK

The four 2RF cavities and their services have now been installed in the ISIS synchrotron, and the 2RF systems commissioned. The trials of dual harmonic operation in the ISIS synchrotron with two second harmonic cavities show very encouraging results. Reliable operation of the 2RF systems, particularly the anode power supplies, has proven a challenge. However, several hardware problems have been overcome and DHRF acceleration has been successfully run during the last ISIS user cycle. The application of beam compensation on the 2RF systems has so far proven successful but is only applied early in the acceleration cycle, due to the fixed bandwidth of the filter used. It is intended in the near future to use a tunable filter to enable beam compensation throughout the acceleration period. Further commissioning of the 2RF systems will be carried out over the remainder of the 2007 shutdown and DHRF acceleration will continue in the next user run, in October 2007. All four 2RF systems will eventually be used to provide the increased beam current required by the addition of the second target station at ISIS. The “second generation” LPRF equipment developed for the 2RF system can now be duplicated and installed as replacements for ageing LPRF equipment incorporated at present in the 1RF systems.

REFERENCES

[1] M. Harold *et al*, “A Possible Upgrade for ISIS”, PAC’97, Vancouver, 1997, p. 1021.
[2] C. Prior, “Studies of Dual Harmonic Acceleration in ISIS”, ICANS XII, RAL Report 94025, 1994, p. A11.
[3] A. Seville *et al*, “First results from the use of dual harmonic acceleration on the ISIS synchrotron”, PAC’05, Knoxville, 2005, p.1872.
[4] A. Seville *et al*, “Progress on dual harmonic acceleration on the ISIS synchrotron”, EPAC’06, Edinburgh, 2006.
[5] P. Barratt *et al*, “RF system and beam loading compensation on the ISIS synchrotron”, EPAC 1990.

