FIRST RESULTS FROM THE USE OF DUAL HARMONIC ACCELERATION ON THE ISIS SYNCHROTRON

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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 70 MeV H^- linac and an 800 MeV, 50 Hz, rapid cycling, proton synchrotron. The synchrotron beam intensity corresponds to a mean current of 200 µA. 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 of raising the operating current to 300 µA. This paper reports on the hardware commissioning and the first beam tests.

INTRODUCTION

Currently, six two-gap RF cavities have been used to accelerate the ISIS synchrotron beam. With this arrangement ~2.5×10^{13} protons can be held in the synchrotron throughout the 10 ms 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 ~200 µA. The addition of a second harmonic component [1] to the RF waveform should allow the acceleration of higher currents by increasing the bunching factor. This component is provided by four second harmonic (2RF) cavities, one of which is shown schematically in figure 1.

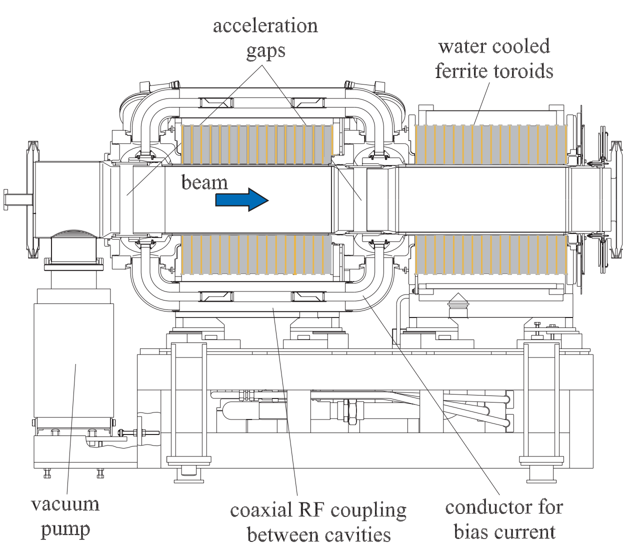

Figure 1: Schematic of a 2RF accelerating cavity.

The cavities are similar in design to the existing fundamental frequency cavities, but are approximately half the length. As with the fundamental (1RF) cavities, the resonant frequency of the 2RF cavities has to sweep throughout the acceleration cycle (at twice the fundamental frequency, 2.6 to 6.2 MHz) to match the changing RF frequency. This sweeping is effected in the same way as for the fundamental cavities, 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.

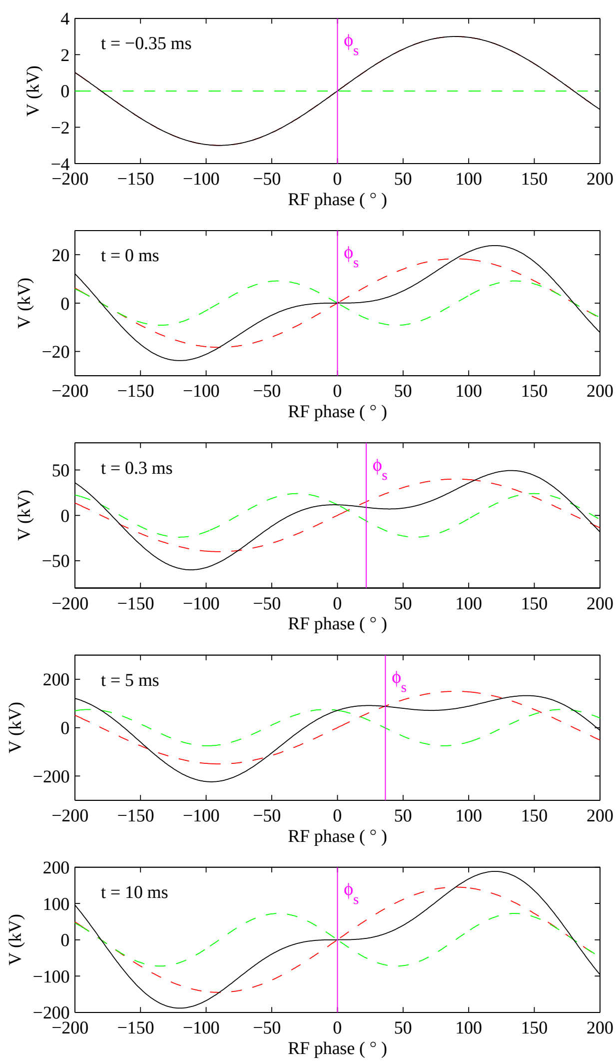

Figure 2: Required phase and amplitude of the dual harmonic components for optimised beam trapping.

Figure 2 shows the relative magnitudes and phases of the fundamental component (dashed red curves), the

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second harmonic component (dashed green curves) and the combined RF (solid black curves) as the frequency sweeps as required to give the optimum beam trapping, as simulated in [2]. One can see the central stable phase point of the combined waveform, ϕ_s, moves from 0° to ~35° and then back to 0° during the 10ms acceleration period. The longitudinal phase acceptance is increased due to the addition of the dual harmonic components, 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.

INSTALLATION IN THE SYNCHROTRON

The four new 2RF cavities are installed in Superperiods (SP) 4, 5, 6 and 8. The 2RF systems for SP5 and SP6 were installed in the ISIS synchrotron during the long maintenance shutdown of 2002 and those for SP4 and SP8 during the corresponding shutdown in 2004. 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. The same Burle 4648VI tetrode is used to drive the 2RF cavities, but because less power is required for a 2RF cavity, one tetrode per 2RF cavity is sufficient. The large power supplies for the valve anodes and for the cavity bias circuits are installed in a neighbouring hall alongside the corresponding power supplies for the fundamental cavities. The tetrode for each 2RF cavity is itself driven by an Amplifiers Research 500W solid state linear amplifier located in the inner synchrotron area. The low power RF hardware is located in the diagnostics room adjacent to the main control room, again alongside the corresponding fundamental hardware, and while the design of the 2RF low power hardware is essentially the same as that of the fundamental low power hardware, the 2RF systems have been modernised to avoid the use of obsolescent components. In addition new designs of cavity bias regulator, anode power supply and PLC have been used for the 2RF systems, and these will eventually be rolled out to modernise the fundamental systems.

COMMISSIONING THE 2RF SYSTEMS

Commissioning of the 2RF systems for SP5 and SP6 began after their installation in the ISIS synchrotron. Progress with 2RF commissioning has been limited by the time constraints imposed by the ISIS schedule. To this end, commissioning of systems SP4 and SP8 began off-line on the purpose built 2RF test facility and the cavities were then tested *in situ* in the ISIS synchrotron. Operation of the 2RF systems has been limited to the machine physics sessions, usually 2-3 days, prior to the start of and after the end of each ISIS user run. During the first user runs after installation, electrical shorts were placed across the accelerating gaps to eliminate any adverse effect on the beam. However, for most of the last cycle, in February and March 2005, and all of the current cycle, from April 2005 to date, all four 2RF cavities have been swept during the ISIS operation, using an "Off-tune" bias current.

Precise control of the 2RF cavity phase with respect to the fundamental system, is required. Figure 3 shows the low power RF (LPRF) system used to control the phase of the fundamental and 2RF systems. In the fundamental system, the RF signal from the master oscillator (MO) is phase shifted to give a phase of 0°, 18°, 36° thus providing the 72° or 144° of phase shift required by the location of the cavities around the synchrotron ring. Diametrically opposite cavities are in antiphase during beam injection and are brought into phase in 20 μs for the start of acceleration, providing an increase in the voltage control range.

The new 2RF system consists of the same configuration, with a frequency doubler in line after the MO. The phase shift between the fundamental and 2RF waveforms may be changed throughout acceleration by an amount, θ, by adding an additional phase modulation to the 2RF signal. The locations of the new 2RF cavities were determined by the available space, and so they are

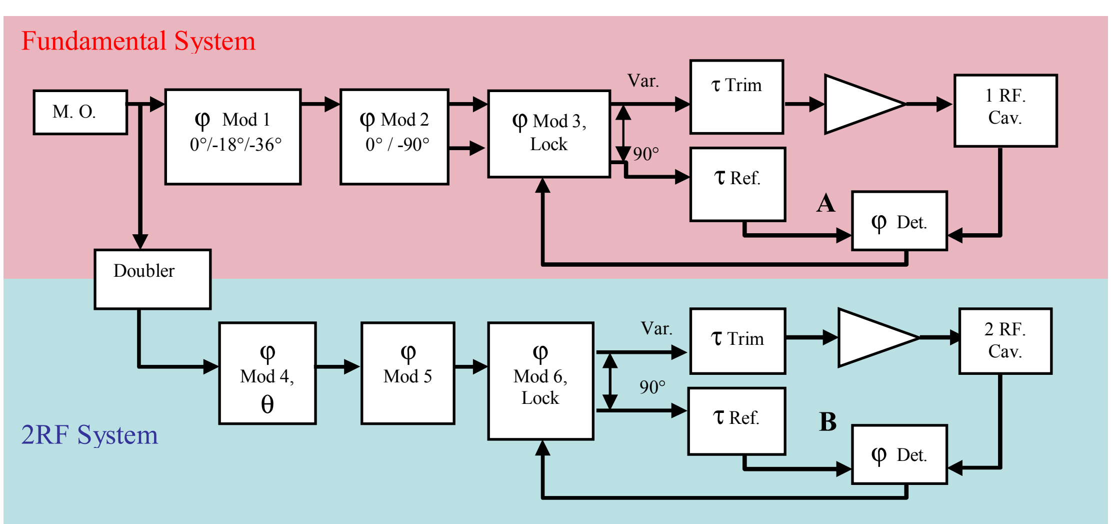

Figure 3: Schematic of fundamental frequency and 2nd harmonic RF lock.

not symmetrically positioned. The required phase is provided by phase modulator 5. Antiphasing of the cavity pairs during beam injection is provided within the cavity lock servo. System delays are equalised such that the 1RF and the 2RF reference signals at points A and B track each other within 5° of fundamental frequency.

Care is taken to ensure the cavity signal and reference signal experience similar delays, such that both signals at the input of the phase detector were within 20° or so throughout the frequency range with the cavity phase lock loop open.

PRELIMINARY RESULTS

To test the phasing of the 2RF systems a low intensity beam (~4.5×10^{12} protons) was accelerated using only the four second harmonic cavities. Figure 4 shows the RF envelopes of the gap voltages for all four 2RF cavities. Peak voltage at 4ms is 6 kV. Figure 5 shows the accelerated beam intensity and the output of a 2RF beam to gap volts phase detector.

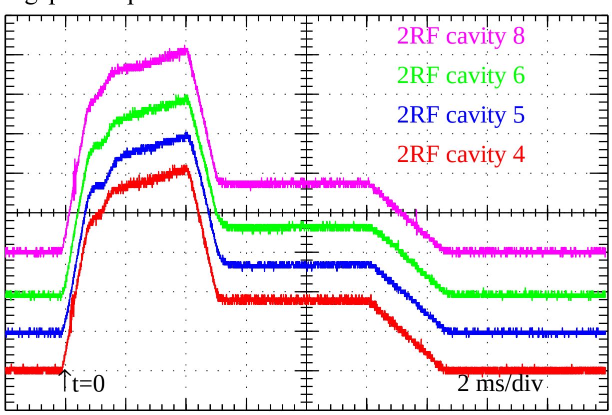

Figure 4: RF envelopes during 2RF acceleration.

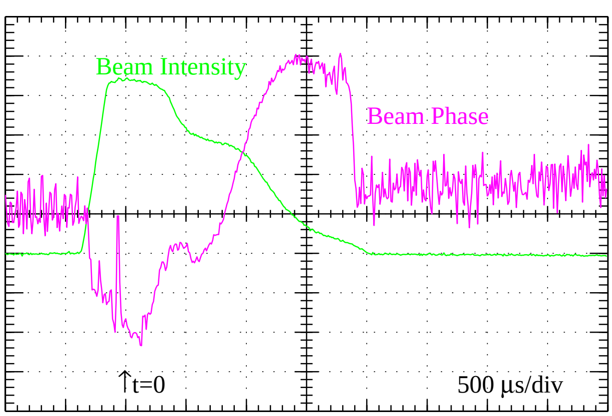

Figure 5: Beam Intensity and Beam Phase signals during 2RF acceleration.

The beam is accelerated for the first 1.8 ms agreeing with a voltage of 6.kV peak at each accelerating gap. This gives a good indication that each of the cavities has been set to the correct phase.

In March 2005 all four cavities were used in dual harmonic acceleration, with the beam run at base rate (50/32 pps) and the phase between fundamental and 2RF systems kept constant (θ=0°) throughout acceleration. Figure 6 shows typical beam intensity and beam loss monitor (BLM) signals, for normal operation using fundament cavities only (DHRF off) and with the dual harmonic operation (DHRF on).

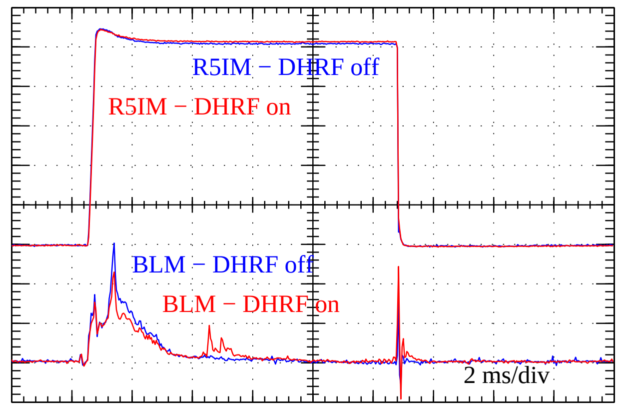

Figure 6: Beam Intensity and Beam Loss during acceleration with dual harmonic RF.

The results show some reduction of early beam loss, particularly at about 1.5 ms, though there is increased loss later in the acceleration period at about 3.5 ms. The beam intensity shown for normal operation corresponds to ~2.18×10^{13} protons at injection, falling to 2.04×10^{13} after trapping and 1.90×10^{13} at extraction, giving a trapping efficiency of ~93.5%. With the 2RF system on, the trapping efficiency increased to ~95%.

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 show encouraging results, with an improvement in trapping efficiency, though it is stressed that these trials were preliminary in nature. The 2RF systems will be gradually phased in during the next few user cycles in order to increase the beam current. The "second generation" low power RF equipment developed for the 2RF system can now be duplicated and installed as replacements for ageing low power RF equipment incorporated at present in the fundamental RF 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.

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