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Optimisation of the ISIS Proton Synchrotron Damping System

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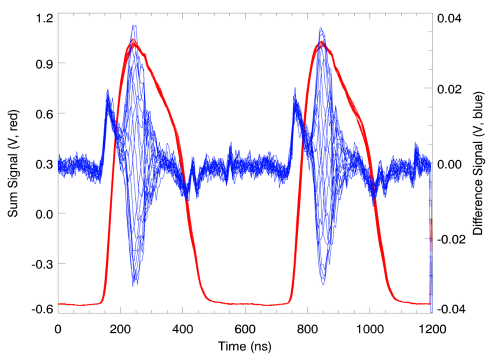
Introduction

The ISIS Neutron and Muon Source, located in the UK, consists of a H^- linear accelerator, a rapid cycling proton synchrotron (RCS) and two extraction lines delivering protons onto two heavy metal targets. One of the limiting factors for achieving higher intensities in the accelerator is the head-tail instability present in the synchrotron around 2 ms after injection. In order to help mitigating this instability, an experimental damping system is being developed. Initial tests using a split electrode beam position monitor (BPM) as a pickup and a ferrite loaded kicker as a damper have shown positive results.

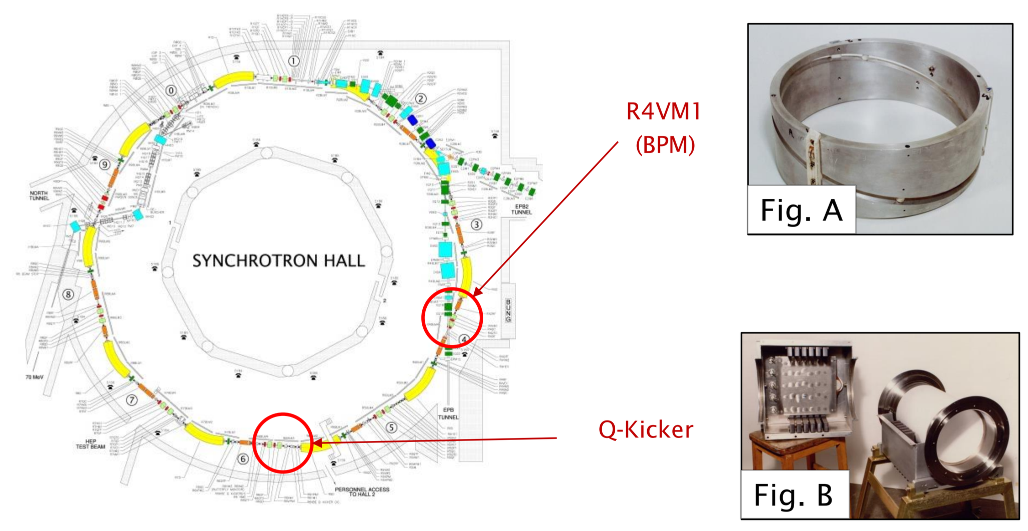
The ISIS Head-Tail Instability



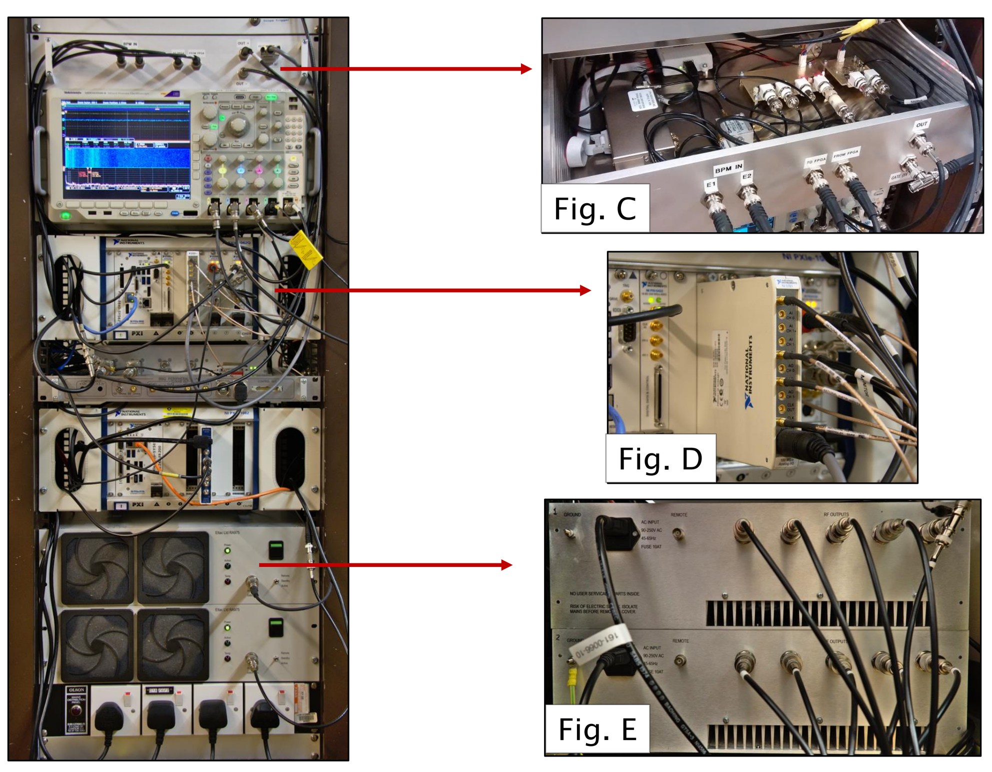
The two proton bunches exhibit vertical head-tail motion at 1 - 2.5 ms through the 10 ms acceleration cycle. The instability is suppressed by ramping the vertical tune down away from the integer (Q_y = 4) and making the longitudinal distribution asymmetric using the dual harmonic RF during the time of the instability.

Damping System Overview

The ISIS damping system makes use of components already existing in the accelerator: a cylindrical split-electrode BPM (Fig. A) and a ferrite loaded kicker used as a betatron exciter (Fig. B). They are separated by a betatron phase advance of 266° for a vertical tune Q_y = 3.80.

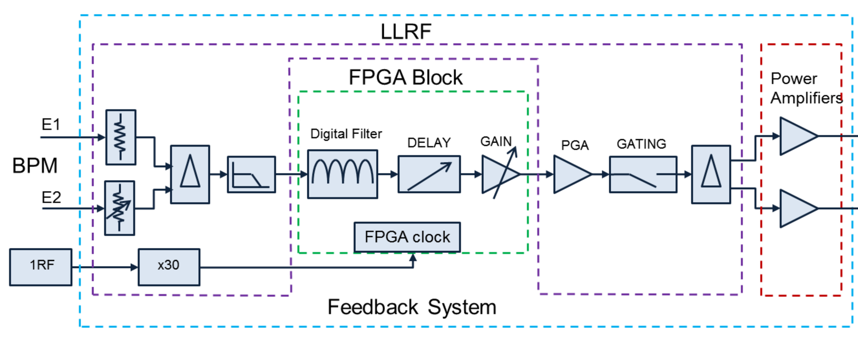


The Low Level RF (LLRF) electronics (Fig. C), DAQ system and power amplifiers are located 150 m, away from the pickup and kicker in an area free of ionisation radiation. The LLRF stage interfaces the BPM signal with a National Instruments Flex-Rio FPGA + front end card (Fig. D), which feeds the signal into the power amplifiers (Fig. E). Each of them feeds five 50 Ω cables into the kicker plates.



LLRF and Digital Filter

The LLRF analogue electronics condition the BPM signals for processing and provide amplification and gating of the signals for the power amplifiers.
The FPGA block consists of the ADC/DAC stages, digital filter, fixed and variable delays, digital gain and output signal gating.
The driving clock for the signal processing is 30 times the fundamental RF, thus the filter length is proportional to the revolution period.



Three filter types have been tested for the damping system: comb filter, fixed coefficients FIR filter and variable coefficients FIR filter.

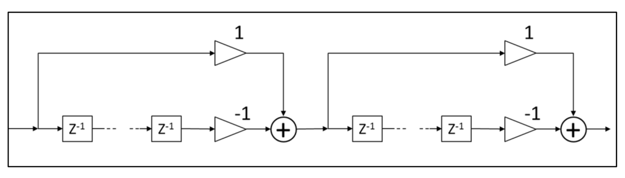
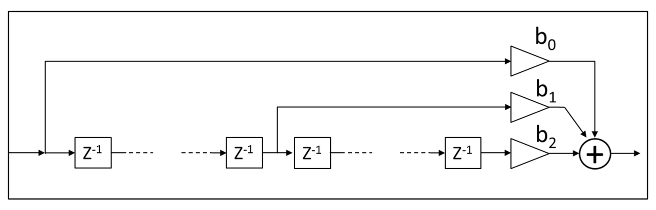
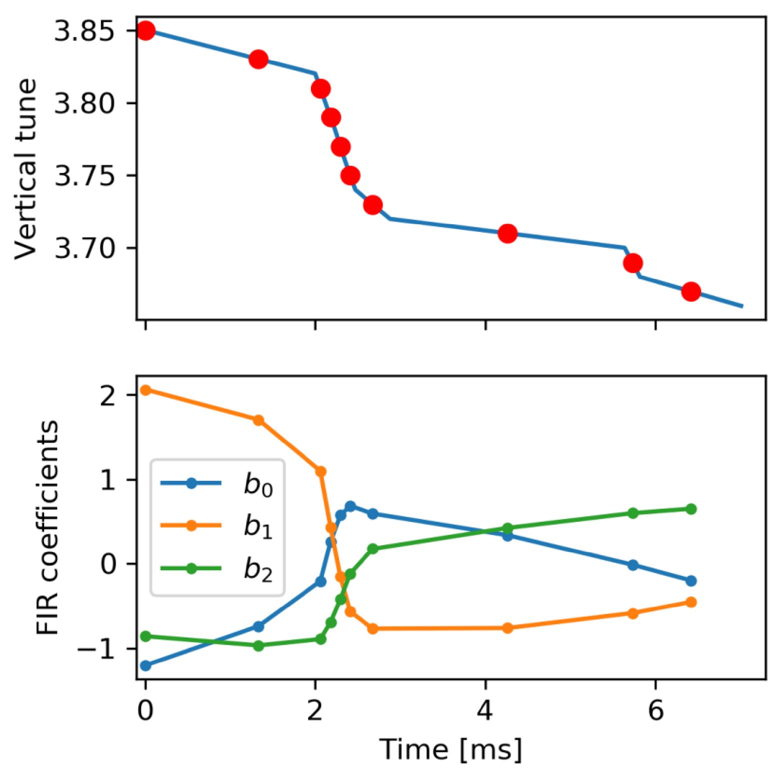


Diagram for the comb filter. Each stage length is one turn.

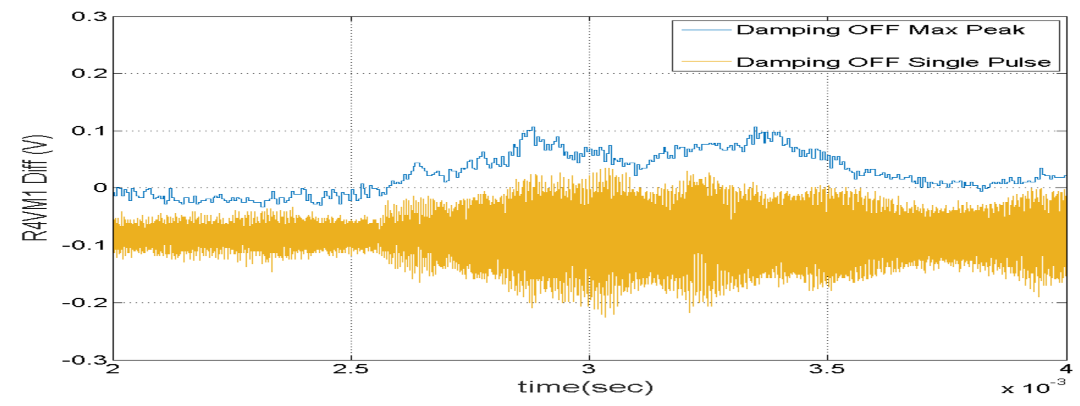


Simplified diagram of the FIR filter used to improve the tune acceptance. Each stage length is one turn.

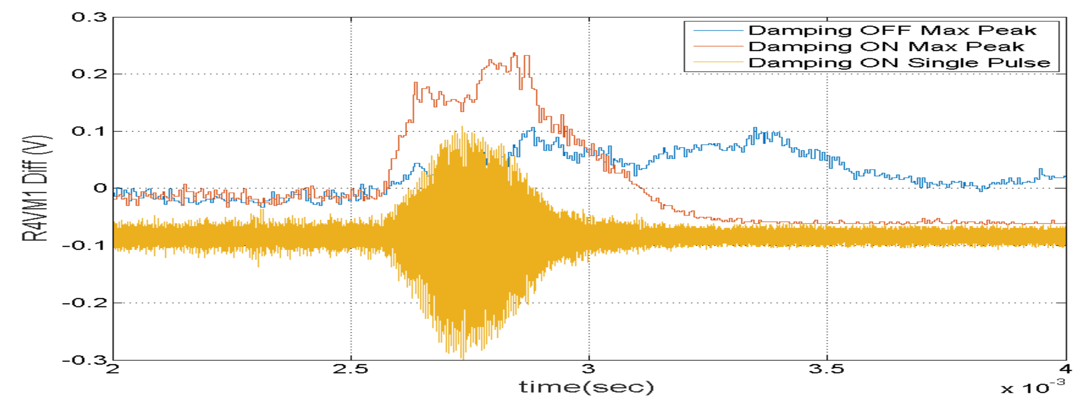


In order to compensate for the fast tune ramp (top), a FIR filter with variable coefficients (bottom) has been implemented using the same topology as the fixed coefficients FIR. This setup has provided the best results for an effective damping.

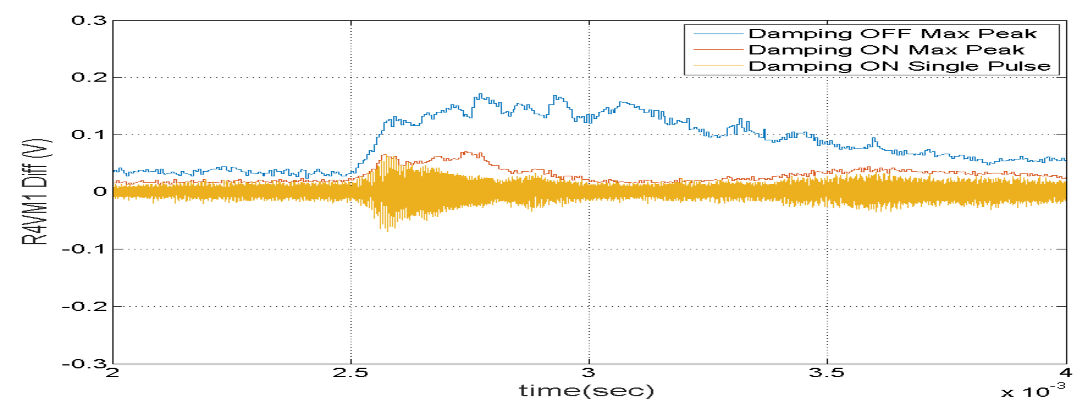
Experimental Results



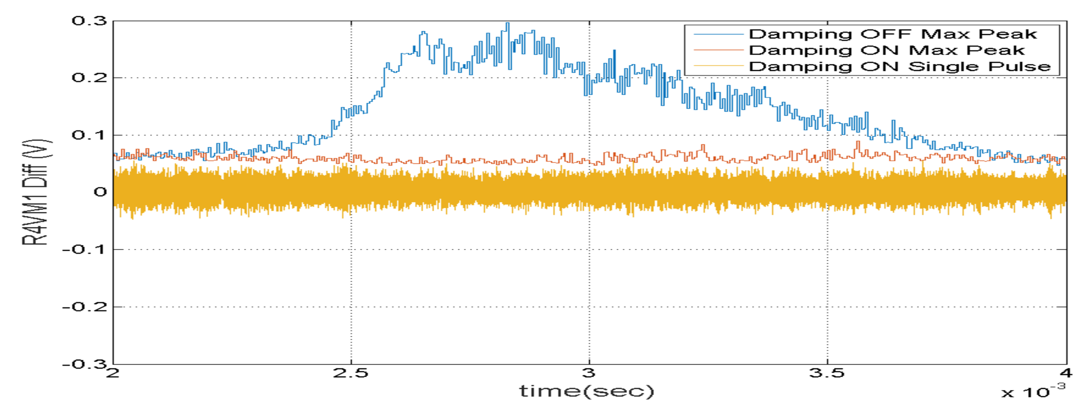
Vertical BPM differential signal (yellow) showing the head-tail instability for a single pulse, with the damping system off. Maximum peak values with the damping off are stored during 20 pulses (blue) for reference purposes.



Vertical BPM differential signal (yellow) showing the head-tail instability for a single pulse, with the damping system on, using the comb filter. Maximum peak values stored with the damping off (blue) are compared against the maximum values with the damping on (orange). Effective damping is only achieved after 3 ms, while the system is driving the instability between 2.5 ms and 3ms.



A more effective damping is achieved by using the FIR filter with fixed coefficients. The maximum vertical motion with the damper on (orange) is clearly below the maximum motion with the damper off (blue). Some vertical motion is still present.



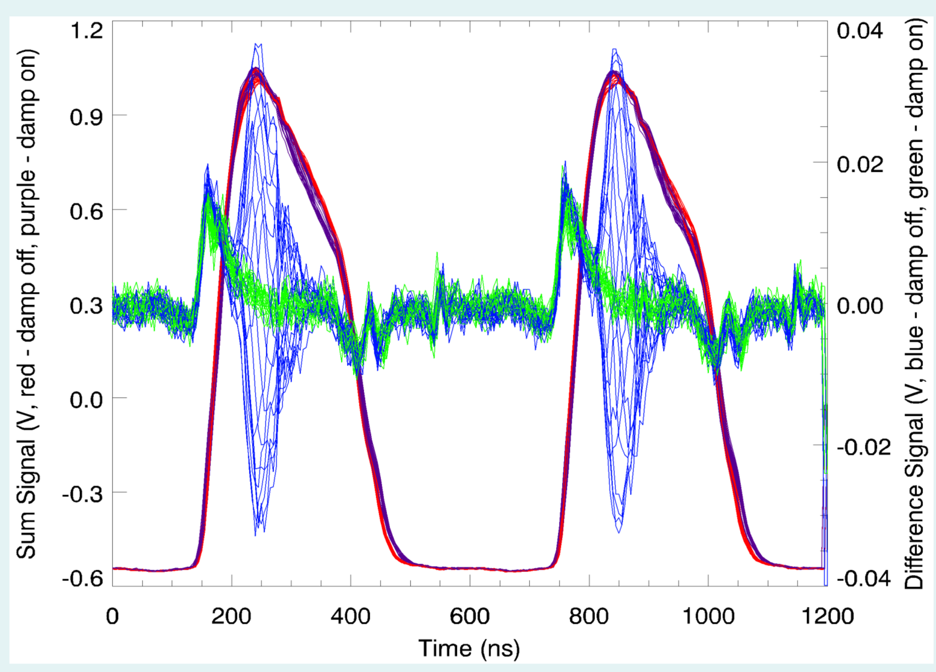
The most effective damping has been achieved by using the FIR filter with variable coefficients. The maximum vertical motion with the damper on (orange) shows no signs of the instability.

Conclusions

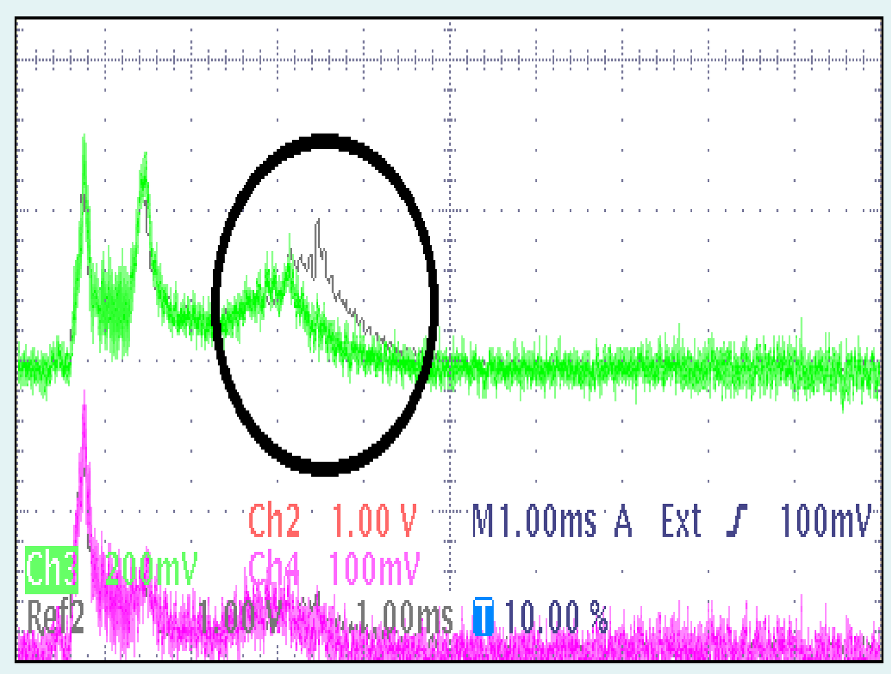
A vertical plane damping system has been developed for the ISIS ring using one of the split-electrode BPMs and an existing ferrite loaded kicker, minimizing the development time for a working system. The fast ramping of the acceleration frequency and the betatron tune have been the key challenge to damp the head-tail motion.

Three filter types have been tested for the digital stage of the damping system: comb filter, fixed coefficients FIR filter and variable coefficients FIR filter. The best results were achieved with the variable coefficients FIR, as it minimises the total required delay and optimises the filter acceptance to accommodate for changes in the vertical tune.

Effective damping of the existing head-tail vertical motion has been achieved for the whole instability region for a repetition rate of 1.6 Hz, resulting in a reduction of beam loss. This will be a major benefit for high intensity operations at ISIS.



Head-tail vertical motion comparison with the damping on and off. Sum signal (Red and purple), and differential signals with the damping off (blue) and on (green).



ISIS synchrotron total beam loss reduction around the 2 ms instability.

Future Work

Tests so far have used set tune values however measured tunes would provide more accurate data for filter coefficient calculation.

Because the FIR filter coefficients are obtained off-line, an automated calculation feature from the measured tune values would improve the damping optimisation process.

After demonstrating effective damping at low repetition rates, the system can now be used during ISIS user operations at 50 Hz . An active protection system to avoid damage to the kicker terminating resistors should be implemented for continuous operation without supervision.

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