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DEVELOPMENT OF A NEW TIMING SYSTEM FOR ISIS

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Abstract

The timing system at the ISIS Neutron and Muon source has been operating in its current iteration since 2008. A Central Timing Distributor (CTD) delivers the various timing signals to equipment throughout the ISIS accelerator and these timing pulses are transmitted over RS-422 compliant timing buses. This paper will look at how the next generation of timing system for ISIS could be developed.

A new timing system for ISIS should allow for the distribution of events, triggers and timestamps over fibre optic cable, provide an increase in timing resolution and be fully backwards compatible with the current timing frame. This paper will consider a timing system based on White Rabbit technology and will investigate the results of installing this new system in parallel with the current timing system. A comparison between the systems and next steps will be discussed.

TIMING OVERVIEW

The fundamentals of the ISIS timing system have not changed much since the first neutrons were produced in 1984 [1]. The ISIS timing system begins with an oven controlled crystal oscillator (OCXO) that provides a stable 10 MHz clock source. This 10 MHz clock is then divided down in two separate stages to produce both a 1 MHz reference for the instrument choppers, and the main 50 Hz operating frequency for the Main Magnet AC power circuit (Fig. 1).

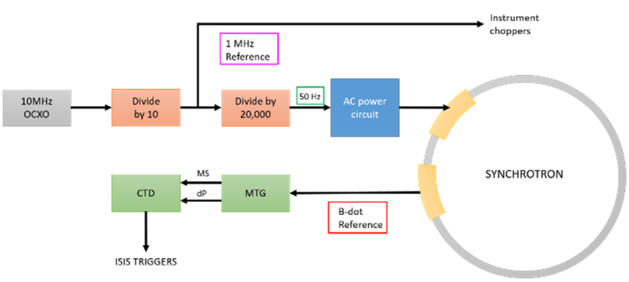

Figure 1: Overview of ISIS timing.

The magnetic field produced by the main magnet power supply (MMPS) [2] is used to define the primary ISIS timing signals, Machine Start (MS) and Delta-P (DP).

Master Timing Generator

A B-dot sensor, located on one of the synchrotron dipole magnets, converts the magnetic field into a voltage which drives the ISIS Master Timing Generator (MTG). The function of the MTG is to lock to the B-dot waveform and produce the fundamental timing signals MS and Delta-P.

When the MMPS is turned off, the MTG seamlessly switches over to an internally generated 50 Hz waveform to continue to produce MS and Delta-P for connected equipment.

MS and Delta-P

MS defines the start of the machine cycle and is a 2.5 µs negative logic pulse with a period of 20 ms. Delta-P is a negative logic 200 kHz pulse train that effectively splits up the machine cycle into 4000 data points. The zeroth pulse of Delta-P (coincident with MS) is blanked off. These two signals are used as the primary timing triggers throughout the accelerator.

Central Timing Distributor

The ISIS Neutron and Muon source is a two target facility and, as such, the timing system must be able to differentiate between pulses to the two target stations. This is all handled by the ISIS Central Timing Distributor (CTD) which defines all of the necessary timing buses and operating rates for the machine.

The CTD produces three distinct timing buses (TBs), which are termed TB0, TB1 and TB2.

TB1 contains only pulses that are intended for Target Station 1 (TS1) and, similarly, TB2 contains pulses for TS2. TB0 is the logical “or” of TB1 and TB2 and, therefore, contains all of the timing pulses in the timing frame.

Each ISIS timing bus contains the following composition of timing signals:

- Frame Start (FS), a pulse which designates the beginning of an ISIS timing frame.
- Machine Start (MS), denotes the start of a machine cycle. The nature of the MS signal depends on the timing bus. For example, TB2 exclusively contains pulses for TS2. The terminology used when referring to MS is to append the timing bus number, i.e. MS0 appears on TB0, MS1 on TB1, and MS2 on TB2.
- Gated Machine Start (GMS), is a special version of the MS signal that is issued by the CTD when the interlock chain and beam permit is complete. It is characteristically the same as MS but denotes that beam is present. The same conventions are applied for the individual timing buses as with MS.
- Delta-P (DP), a 200 kHz pulse train that splits up each machine cycle. This effectively defines the finest resolution available in the current timing system as 5 µs.

The ISIS Timing Frame

When ISIS was a one target machine, it was decided that the repetition rates should vary from a full rate of 50 Hz (i.e. MS/1) down to the slowest rate of MS/128. Hence the

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ISIS timing frame was defined as containing 128 MS pulses and being 2.56 s in duration.

When the second target station was added in 2008 [3], the ISIS timing frame was extended to include pulses to the new target station. An operating regime was decided in which four out of five pulses would be delivered to Target Station 1 (TS1) with every fifth pulse going to Target Station 2 (TS2). The effect on the ISIS timing frame was to multiply everything by five, giving the new frame length of 640 MS pulses, and a new duration of 12.8 s.

The ISIS timing frame is defined within the CTD which also produces the repetition rate for the accelerator. Rates are selectable in divided down powers of two, ranging from MS/1 to MS/128.

TRIGGER DISTRIBUTION

All of the timing triggers throughout the ISIS accelerator originate at the CTD and are distributed using multi-dropped RS-422 as the transport mechanism, over a large number of twisted pair cables.

This makes the current trigger distribution network very inflexible, difficult to extend and challenging to maintain. This is why we are seeking an alternative approach to adopt a new timing system that can take advantage of modern practices like event-based timing and trigger distribution [4, 5].

However, it is clear that any new system must work alongside the existing ISIS timing hardware and exist in parallel with the existing timing infrastructure.

A HYBRID SYSTEM

There were two main candidates that were considered for a new timing system. A system based on Micro-Research Finland (MRF [6]) hardware similar to the system used at the European Spallation Source (ESS) [7] and one based on White Rabbit (WR) [8] hardware.

The preferred approach is to maintain the operation of the existing timing triggers, together with the implementation of a new triggering system based on more modern technology. Therefore it was decided to develop a hybrid system, to ensure that there is no disruption to existing hardware that depends on the legacy timing system.

Since there was some experience in the Controls Group with WR, and a WR network was being implemented for the Digital Waveform Switching system [9] project, this became the preferred choice for the hybrid system.

The 10 MHz OCXO can be replaced by a Global Positioning System (GPS) synchronised time receiver that will provide the master reference for the implementation of a WR network. A WR-enabled Trigger Generator can then be used to provide triggers that can be distributed throughout the accelerator (Fig. 2). These new high accuracy trigger signals will be generated with a minimum resolution of 5 ns.

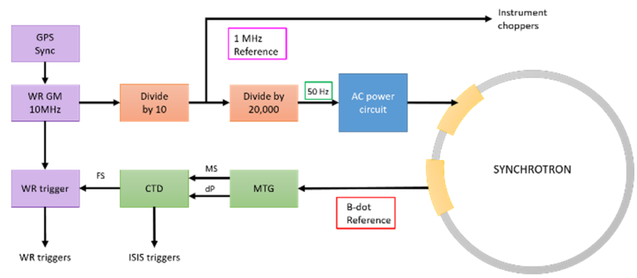

Figure 2: Proposed upgrade of ISIS timing.

Synchronisation

In order to co-exist with the existing legacy timing system, the new timing hardware must somehow synchronise to the existing ISIS timing system.

Since the CTD sets the rate at which the accelerator runs, it must be considered as the timing master, and any new timing system must therefore synchronise to the CTD. There is little use in the new timing hardware synching to the B-dot waveform, as the new timing system must be aware of the whole of the ISIS timing frame. To achieve this, the FS signal from the CTD will be used as the master reference for the WR trigger unit.

Measuring Stability

To better understand the variability in the magnetic field generated by the MMPS, the B-dot waveform was monitored during a user cycle for around three and a half hours, capturing 583,680 machine cycles. The data is presented below in Fig. 3.

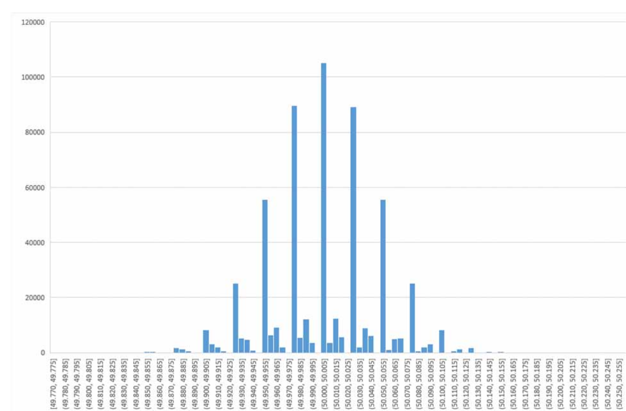

Figure 3: Characterisation of B-dot variability.

The x-axis displays the measured frequency of the machine cycle, with the y-axis recording the number of instances. It can be seen that the 50 Hz waveform has a normal distribution and varies at most, 0.5% from the mean average of 50 Hz. However, the largest time difference between two consecutive machine cycles was recorded as 190 µs, (38 DP). Since there would be a noticeable effect on operations if MS followed this variance, it was expected that this variation in the B-dot waveform must be smoothed out by the phase locking process in the MTG.

To confirm this is the case, additional monitoring was added to include the MS output of the MTG. Data was again collected during a user cycle, this time capturing

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108,544 machine cycles. The data is presented in Fig. 4 below.

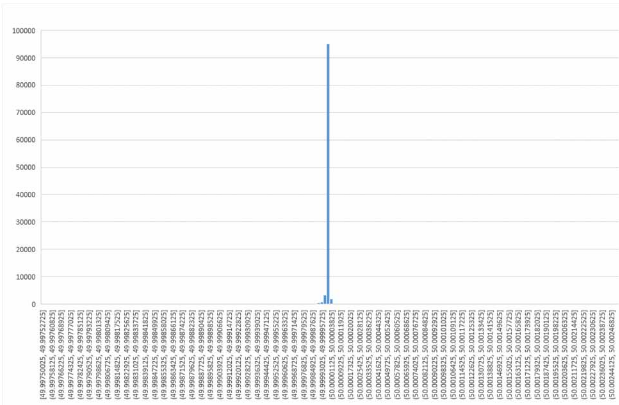

Figure 4: Characterisation of MS variability.

As expected, the MS output has a much tighter tolerance around the average of 50 Hz, and the maximum cycle-to-cycle difference was measured as 1.9 µs (0.4 DP).

It is therefore imperative that the new WR enabled Trigger Generator meets this performance requirement when synchronising to the ISIS timing frame, and why it is recommended to use the FS output of the CTD as the point of synchronisation rather than the B-dot waveform itself.

CONCLUSION

It is impractical to replace the whole of the ISIS timing system with new technology but a new event-based timing system can be implemented to co-exist alongside the legacy ISIS timing infrastructure. It is also possible for both the old and new timing systems to be driven from the same high accuracy GPS clock source and there should be no change to the legacy timing system in terms of how it operates.

Also, as the control system at the ISIS accelerator is transitioning [10] from VSystem [11] to the Experimental Physics and Industrial Control System (EPICS) [12], it is required that the new timing system hardware will be integrated with EPICS to provide a highly customisable user interface. This will allow the new timing system to produce bespoke triggering sequences and the creation of specialist timing frames. This will overcome another restriction of the legacy timing system – the inflexibility of available timing triggers. This constraint often leads to the production of additional, custom hardware to combine, repeat or delay triggers to meet requirements.

The legacy timing system has also reached the limit on what may be easily extended; the inclusion of additional timing triggers requires careful planning and difficult extensions to timing buses. The new timing system will be able to surmount these issues as new hardware will be independent of the distributed ISIS timing buses and only require a fibre connection to the nearest WR network node in order to access the timing system. The WR network will also provide timestamps, which can be available globally across the accelerator, not just to the new timing hardware. These can help with correlating data collected from multiple sources and could be very useful as more data is collected and analysed.

A new timing system for ISIS will help to bridge the gap between the legacy timing system and new equipment, and extend the life of the current timing system. It can afford invaluable development time to look at the next stage of upgrades, which will be to look at replacing the MTG and CTD in the future.

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