FRIB Fast Machine Protection System: Chopper Monitor System Design

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Introduction

The Facility for Rare Isotope Beams tunes the beam power from 0 to 400KW by chopping the beam current with a beam chopper in the Low Energy Beam Transport. A chopper monitoring system is employed to verify proper chopper operation to avoid delivery of undesired high-powered beam and to inhibit beam for machine protection purposes. The system monitors the incoming beam gate time structure, the chopper switch high voltage pulses, the chopper electrode charge/discharge currents, and the status of machine protection system. It is designed to switch off the beam within tens of nanoseconds of a detected fault. Challenges include a dynamic beam gate pulse structure with pulse lengths as short as 0.6 μs and high voltage power supply current pulses of ~25 ns. A high speed "Integrate and hold circuit with reset", Field Programmable Gate Array based digital control circuit and high speed ADC circuit were developed to fulfil the required functions.

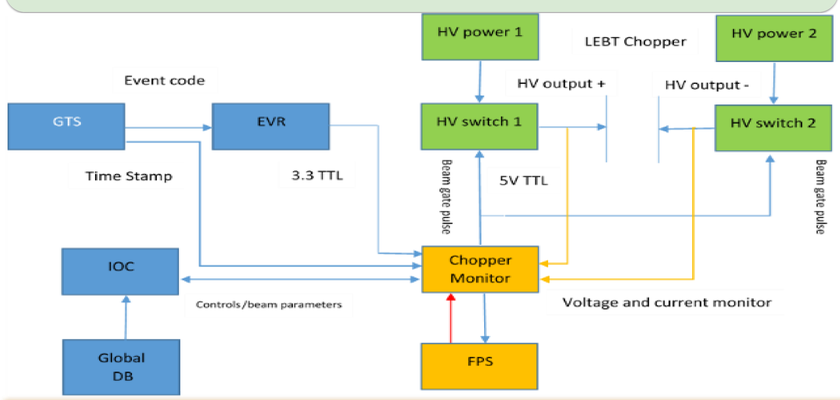

Figure 1: FRIB chopper Monitor System Block Diagram

Design

The system consists of chopper monitor chassis, EPICS IOC and OPI. The IOC/OPI serves to establish the chopper operational state, configure the chopper monitor for checking the beam pulse pattern for various beam modes, and providing the threshold values necessary for checking the amplitudes of each HV pulse and charge/discharge current. The chopper monitor hardware consists of an FRIB General Purpose Digital Board, the chopper monitor ADC board which interfaces to the MPS, the beam gate signal from the EVR, the control inputs to the HV switches, and the HV switch output voltage and current monitor signals (V_{mon} and I_{mon}). The I_{mon} signal is integrated by a high speed integrator circuit.

Pulse Checker

The pulse checker verifies pulse width and cycle time of every beam gate pulse from EVR and the HV pulse applied to the chopper. It also checks if the HV pulse phase aligned at positive and negate chopper electrodes. The pulse checker is configurable through EPICS to check desired pulse shape and ramp up process.

Voltage and Current Monitor

The Voltage monitor circuit measures the HV pulse amplitude of every pulse applied to chopper. Current monitor measures the charges applied to or removed from the chopper. The ADC reading of I_{mon} integrator output is proportional to the charge changes of chopper. Find ADC readout is 2530 when 3.6 kV is applied to HV switch capacitor load with chopper electrode connected and 2080 with the same set up but chopper electrode disconnected. Chopper capacitance is thus calculated to be 53.9 pF, which is very close to actual value. A disconnected electrode is thus easily detected.

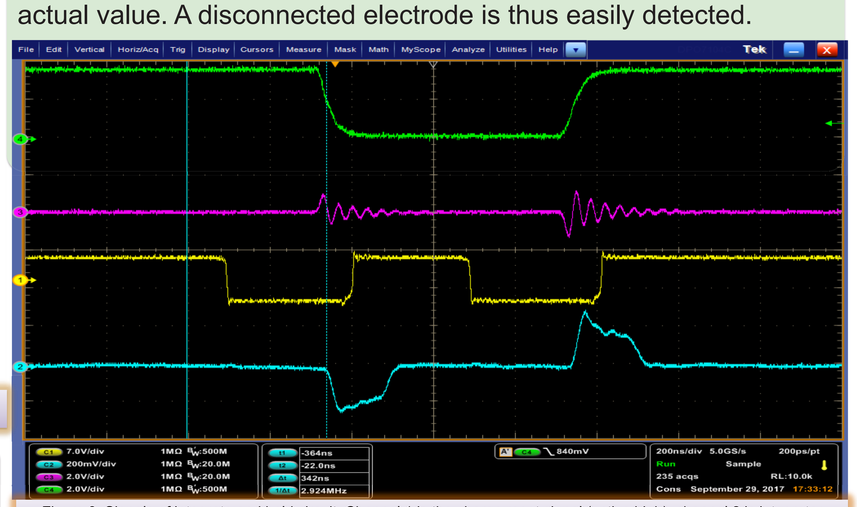

Figure 3: Signals of integrate and hold circuit. Channel 1 is the charge reset signal (active high), channel 2 is integrator output, channel 3 is the current monitor output from HV switch, and channel 4 is the voltage monitor output.

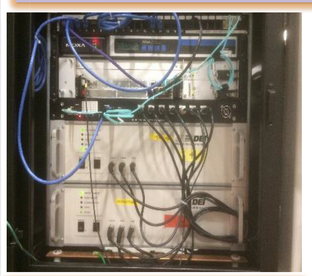

Figure 2: Chopper monitor rack

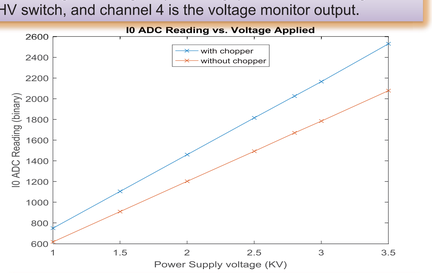

Figure 4: ADC reading of integrated charge/discharge current versus HV applied to capacitor load of HV switch, with and without chopper

Test in the Beam Line

The chopper monitor function of pulse checker, voltage and current monitoring and machine protection are verified under conditions to limit total average beam power for FRIB beta=0.041 cryomodule commissioning. In one of the tests, the system is configured with 100 μs duration periodic pulse while chopper monitor is configured with 100 μs+-1.2 μs, beam is delivered and monitored at a Faraday Cup (FC) immediately downstream of the chopper. Once 100 μs operation is established, a change to 120 μs pulse duration is requested without chopper monitor reconfiguration. It shows that beam shut down within tens of ns while pulse duration exceeds 101.2 μs. 7-8 μs of delay from real signal and slow edge is noticed of FC beam pulse where FC has 35 KHz low pass filter.

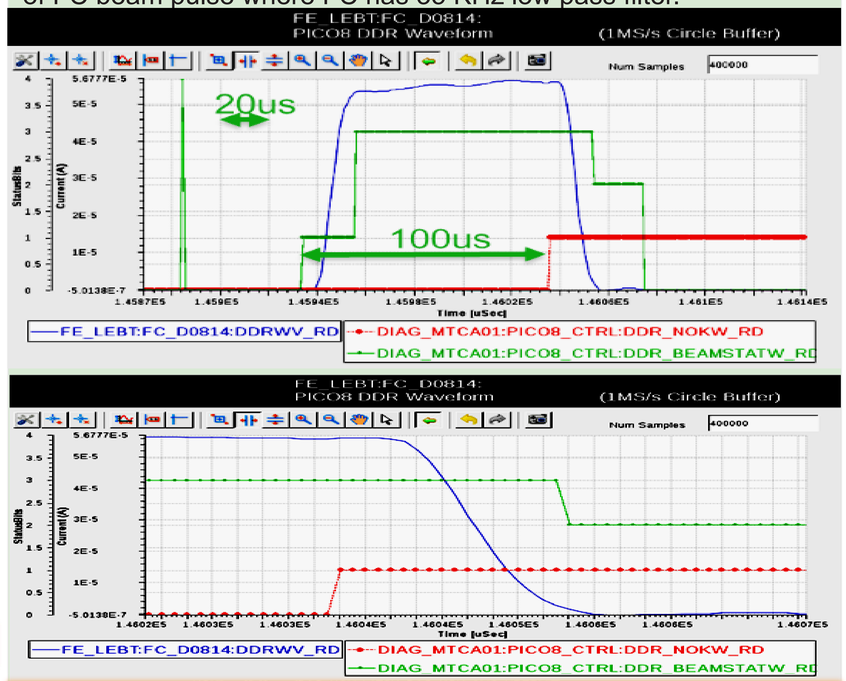

Figure 5: State transitions immediately following the request for 120 μs pulse duration while chopper monitor is configured with 100 μs +- 1.2 μs

Conclusion

Chopper monitor functions have been tested for commissioning the cryomodule and diagnostic beamline, all results meet MPS requirements. Implementation of the FPGA logic to check the dynamic beam power ramp up processes will be the next level development for the chopper monitor.

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