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AUTOMATING ORBIT CORRECTION IN THE MAIN INJECTOR 8 GeV LINE*

K. J. Hazelwood[†], I. Kourbanis, G. E. Krafczyk, M.-J. Yang, Fermilab, Batavia, USA

Abstract

The Main Injector 8 GeV line (MI8 line) transports beam from Fermilab's Booster accelerator to either the Booster Neutrino experiments (BNB), the Recycler or the Main Injector. Often the orbit of the beam through the MI8 line differs depending on the beam destination. The beam is collimated in the MI8 line, so increasing intensities and repetition rates make controlling orbits through the collimators a necessity. The current method of regulating the MI8 line orbit with DC corrector settings is insufficient. A system named MITUNE is being developed to sample and categorize all beams through the MI8 line and automatically calculate and apply proper dipole corrector ramps to maintain desired orbits for pulses to any destination.

INTRODUCTION

The Fermilab MI8 line serves as the beam transfer line from the Booster accelerator to three different destinations, the Recycler, Main Injector or the BNB experiments. Each of these machines have their own Booster beam events that are tuned different from each other. Often when the Booster is tuned to accommodate each machine, the resulting MI8 line beam positions differ as seen in Fig. 1. Figure 2 also shows that there are repeatable patterns in position deviation within a pulse train of like beam events.

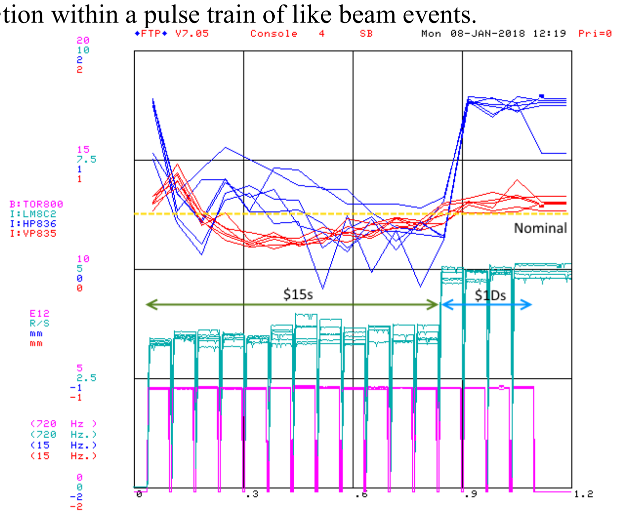

Figure 1: Position and loss differences between Recycler ($15s) and BNB ($1Ds) beam with existing orbit correction. I:HP836 and I:VP835 are MI8 line beam positions at 836 and 835. I:LM8C2 is the beam loss measured near the 836B collimator.

The MI8 line has four collimator bodies designed to scrape transverse beam tails. The aperture and position of the collimators are tuned to scrape a desired percentage of beam so that Main Injector and Recycler do not incur the losses that those tails may cause [1]. The amount of beam lost on the collimators is largely a result of the beam trajectory through the collimation region. BNB beam does not require the same amount of collimation as Main Injector and Recycler beam. However, the current inability to maintain desired positions for all beams means BNB beam is collimated the same or more than Main Injector and Recycler beam.

Positions through the MI8 line are currently maintained using the Autotune system. Autotune samples average positions through the MI8 line for one beam event and then calculates and applies the same DC corrector settings for all beam events [2]. It would take multiple instances of Autotune to correct base positions for each beam event. To correct pulse train position deviations, Autotune would have to calculate and create time ramps, something it was not designed to do.

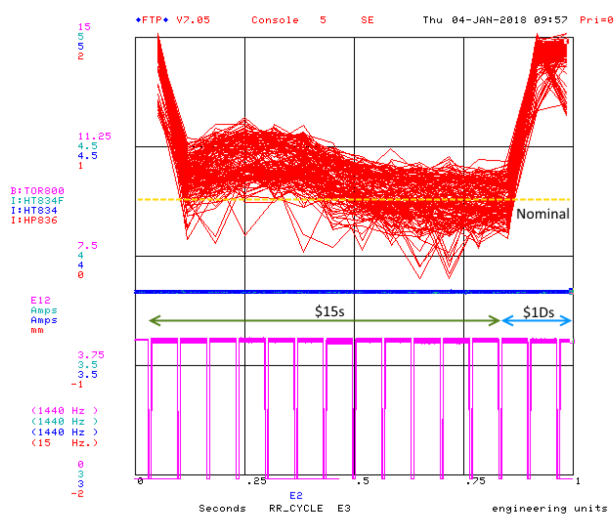

Figure 2: Repeatable position deviation in $15 pulse train. Corrector time ramps are required to fix this.

MITUNE OPEN ACCESS CLIENT

MITUNE is currently in development to automate orbit correction in the MI8 line. The new system is written in Java and utilizes the Fermilab accelerator controls Open Access Client (OAC) infrastructure. OACs run on servers called Data Acquisition Engines (DAE). The OAC infrastructure allows the system full access to the Accelerator Controls Network (ACNET) readings and settings, it also acts as a node to serve its own data [3].

The MITUNE system is designed to work for multiple machines and for possibly different types of beam control in the future. For now, the MI8 line is the only machine being tuned and only it's orbit is being corrected.

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† kjh@fnal.gov

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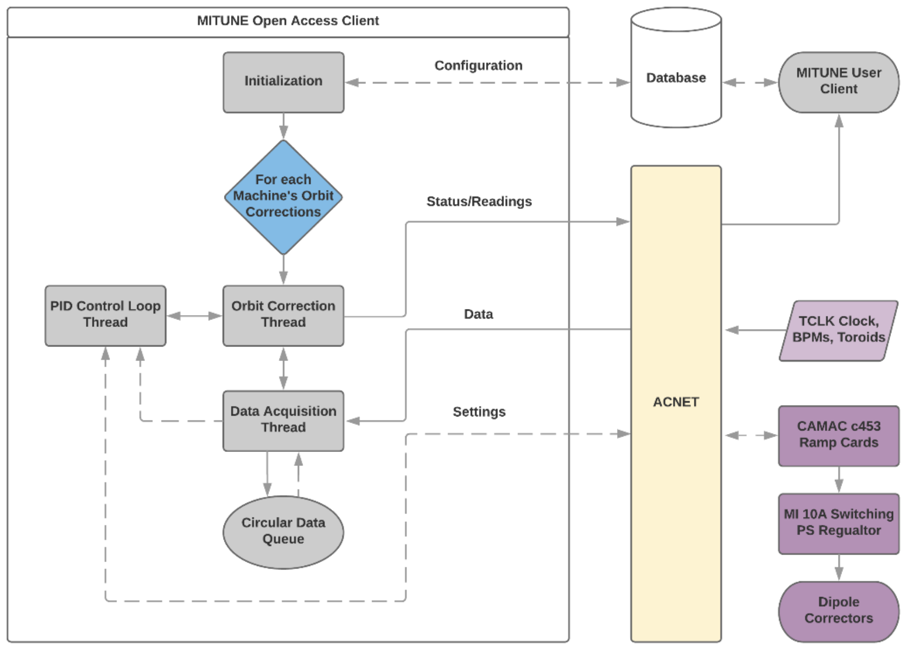

Figure 3: MITUNE OAC processes. Dashed lines denote periodic operations, solid lines are continuous.

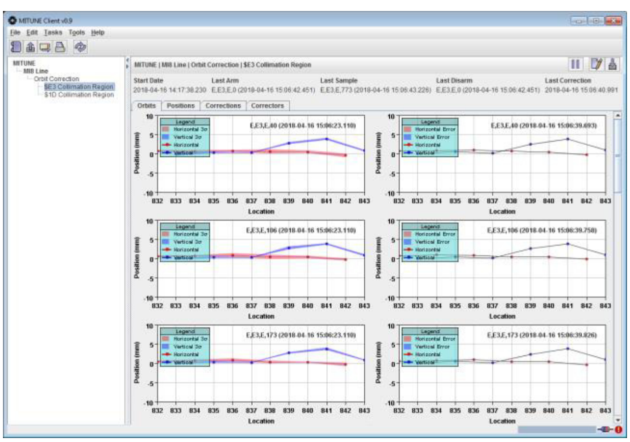

Figure 4: MITUNE user client.

Initialization

Initialization of the MITUNE OAC occurs when it's parent DAE is restarted or when the user client toggles a restart device via ACNET. When MITUNE is started it retrieves a series of machine objects from the database, of which one is for the MI8 line. Machine objects contain information such as beam position monitors (BPMs), correctors, as well as a dipole correction matrix. For each machine object there may exist multiple orbit correction setups. Orbit correction setup objects define a multitude of possible variables that are used to correct the orbit through the machine they are associated with. Most important, the orbit correction setup objects contain the desired beam positions, sample events and control loop gains. Both the machine and orbit correction setup objects can be created or altered from the user client seen in Fig 4.

Figure 3 shows the MITUNE OAC processes. MITUNE launches a separate Orbit Correction thread for each machine's enabled orbit correction setup objects. Each of these threads act as its own monitor thread for additional children threads that are responsible for data collection, control, and exporting status and readings to ACNET.

Data Collection

Data collection is handled from a child thread of the orbit correction thread appropriately named the Data Acquisition thread. The Data Acquisition thread starts jobs that collect data from ACNET for BPM positions and intensities, toroid intensities, and Tevatron Clock (TCLK) event information. All data returned from ACNET is then offered to a queue. A circular consumer data queue is used for collecting orbit data and collating that data into orbit objects. The Data Acquisition thread periodically polls the queue for complete orbits. The queue can be configured to return average orbits also. When complete orbits are returned from the queue, the Data Acquisition thread then pushes the orbit objects to two places. First, the data is pushed to the Orbit Correction thread for exporting to ACNET and ultimately the user client. Second, the orbits are pushed to the Control Loop thread for correction calculations.

PID Control

Once the Control Loop thread has received new orbits from the Data Acquisition thread and the configured minimum correction time has elapsed, it calculates the position error for each sample. The thread then utilizes a Proportional, Integral, and Derivative (PID) loop to determine how much of that error is to be used when calculating the corrections. There are P, I, and D gains for each beam po-

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sition monitor but in practice most BPMs within a configuration share the same P and I gains. Due to the large amount of variance in beam position through the MI8 line, most of the orbit correction setups have the D gain set to zero. Once the beam position error has been determined, the error is fed into that machines dipole correction matrix. The dipole correction matrix defines each correctors strength by how many millimeters it will move the beam for each ampere of corrector current. After new corrector current settings are determined, the thread sends the values to each corrector's ramp card.

Applying Corrections

The correctors in the MI8 line use CAMAC c453 ramp cards for their current reference. Each orbit correction setup defines the arm events, interrupt level, scale factor index and table index for which the new settings should be applied to. Currently MITUNE creates time F(t) ramps to correct pulse train position deviations with individual time slots corresponding to orbit sample times. Bias currents for every corrector are handled from a separate table in the ramp card known as the G(i) table. The G(i) table is not updated by MITUNE but is adjustable by the accelerator operators to balance ramp currents across multiple orbit correction setups. The c453 ramp card reference is then fed to a power supply regulator that drives the dipole corrector in the tunnel [4].

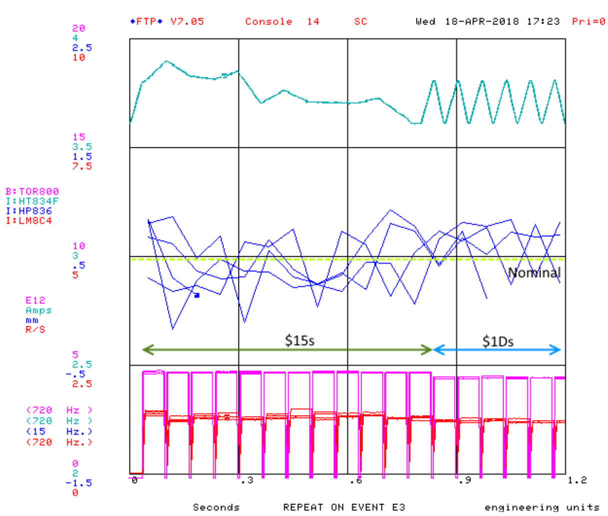

Figure 5: $15s and $1Ds at the same positions with MITUNE ramps. I:HT834F is the ramp current reference for the 834 horizontal corrector. I:LM8C4 is the loss near the 838B collimator.

DEVELOPMENT PROGRESS

As Fig. 5 shows, the system is now able to correct positions across different beam events and within a pulse train of like events. However, there is still more work to be done to make the MITUNE operational.

Corrector Power Supply Regulators

When the MI8 line was first commissioned, problems with the LEP dipole correctors arose. Many of the magnets developed coil shorts that would cause its power supply regulator to become unstable and oscillate. The fix at the time was to alter the regulators to accommodate the coil shorts. This made the regulators more stable when paired with compromised correctors but no longer allowed fast corrector ramps. Later, the LEP corrector coils were rewound and altered to have a smaller inductance. However, the power supply regulators were never altered back [5]. We are in the process of updating the regulators to again allow fast ramps.

CAMAC Front End Bandwidth

MITUNE currently uses a pre-established library for writing ramps to the c453 ramps card. The library unnecessarily reads the entire card when only one table is needed at a time. This is a large load on the CAMAC front end that serves the MI8 line. Before MITUNE can run operationally, this library will have to be re-written.

The bandwidth usage on the CAMAC front end without MITUNE is already over-tasked. There are plans to add another front end to share the additional load that the MITUNE system would cause [6].

User Client

For MITUNE to become operational, more effort will have to put into the user client to give accelerator operators more information as to what the system is doing.

CONCLUSION

MITUNE has demonstrated the ability to correct different beam event trajectories as well as maintain those positions throughout a like event pulse train in the Main Injector 8 GeV line. Further work is needed to make the system fully operational. MITUNE has been designed in such a way that it could be used for additional machines at Fermilab, and may be expandable in the future to other beam control applications.

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