LONGITUDINAL PHASE SPACE DIAGNOSTICS FOR THE AGS*

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Abstract

The Collider-Accelerator Department (C-AD) maintains and operates an injector complex that provides beams for the Relativistic Heavy Ion Collider (RHIC) and the future Electron-Ion Collider (EIC). Beams traveling in accelerator rings are grouped in bunches, where their profiles can be measured and displayed by a Wall Current Monitor (WCM). By analyzing those WCM signals, conclusions can be made about the beam quality, and necessary tuning can be performed accordingly. Meanwhile, it will be very helpful to have the beam property parameters available while doing beam experiments, such as the longitudinal emittance, momentum spread, bunch length, etc. In this work, we present such a newly developed software tool that will process and publish those parameters in real time, based on live machine data and WCM signals. Those parameters will also be logged to the system and will be available for later retrieval and analysis.

INTRODUCTION

The Collider-Accelerator Department (C-AD) at Brookhaven National Laboratory (BNL) maintains the pre-injector complex, including Tandem, EBIS, Linac, Booster, AGS, etc. The performance of the pre-injector complex is critical to the functionality and efficiency of the Relativistic Heavy Ion Collider (RHIC), the NASA Space Radiation Laboratory (NSRL), and the future Electron-Ion Collider (EIC).

Beams can generally come from three sources. The Tandem Van de Graaff Facility [1] consists of two 15-megavolt electrostatic accelerators which generate various heavy ions. The Electron Beam Ion Source (EBIS), has been used as a pre-injector system for RHIC and NASA Space Radiation Laboratory (NSRL), beginning with the 2012 run [2]. The EBIS can provide stable highly charged ion species. With EBIS, the ion species will be able to be switched on a time scale of one second. The Linac [3] is a drift tube linear accelerator which injects polarized or high intensity H- into the Booster (via LTB) at 200 MeV. It also injects H- into Brookhaven Linac Isotope Producer (BLIP) at energies ranging from 66 to 200 MeV. The Booster receives heavy ions from EBIS or protons from the Linac. It accelerates them and then feeds them to the AGS for further acceleration and delivery to RHIC. It can also send the beam to the NSRL target area.

A Wall Current Monitor (WCM) is a very important diagnostic tool during beam operations, especially during injection. A WCM is a passive, non-destructive device measuring current flowing lengthwise along the surface of a beam pipe. While beams traveling in the beam pipe, they will induce an image current on the beam pipe, since the beam pipe can be seen as a conductor. The image current is same in magnitude and opposite in charge. However, the wall current monitor does not “see” the DC component of the beam current, since a constant charge flow does not induce image current. Thus, the WCM becomes more useful after the beam are bunched by RF. The WCM signals can be displayed by a scope. WCMs can measure several properties of the beam. They measure the beam intensity and charge, transverse position, longitudinal size and shape without affecting the beam. The WCM bunch intensity can be calculated [4] as in Eq. (1):

$$N_{bunch} = \left[\int \frac{V_{bunch}(t)}{R} dt \right] (6.24 \times 10^{18} \frac{charges}{Coulomb}) \quad (1)$$

A WCM measures local beam current at a single location in the accelerator ring, but the signal acquired at that single point during one revolution of beam in the accelerator can be visualized as an image of the beam around the entire ring. Data acquisition of each new scope trace is triggered at intervals in synchronize with the beam revolution. The mountain range therefore displays an evolution of this image of beam around the ring as time advances within the accelerator cycle. Figure 1 is a good example showing such beam profile evolution during a bunch merge process.

There are several other fundamental concepts that will be used in the proposed tool:

Accelerator Device Object (ADO)

It abstracts features from the underlying devices into a collection of control points (also known as parameters), and provide those parameters to the users of the control systems. ADO designers determine the number and names of parameters based on the needs of the system. ADO parameters can be viewed or edited by the Parameter Editing Tool (PET). ADOs provide the *set()* and *get()* methods as the controls interface to the accelerator devices. The accelerator complex is controlled by users or applications which set() and get() parameter values in instances of the ADO classes.

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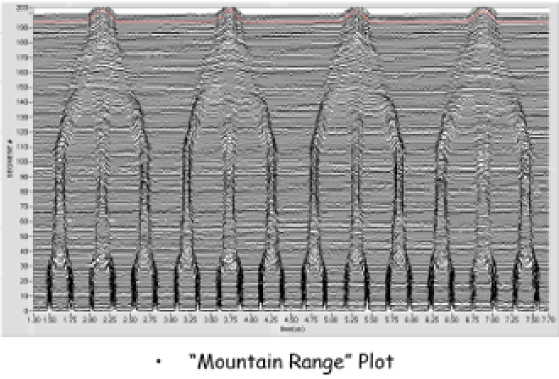

Figure 1: An example of WCM signals showing the evolution of the bunch profile during a bunch merge process. This kind of plot is also called a “Mountain Range” plot.

Controls Name Server (CNS)

It is a centralized repository where unique name/value pairs can be efficiently managed and queried. Given an object’s instance name[1], the CNS will provide enough information so that the associated data can be accessed.

Logging System

The logging system in the C-AD control systems is used to save machine parameters and device values to provide a history of the accelerator’s performance and data to be analyzed for machine physics studies [5]. Logging requests are initiated by files that define what device parameters to be logged and the method of logging. Data can be logged upon demand or periodically. Several applications can be used to view, edit, and process logging data, such as Gpm, LogView, etc.

Motivation

During the machine operations, it is often very useful to have bunch information available to verify the machine running conditions, such as bunch length, beam emittance, momentum spread, etc. This is the main motivation for developing this tool. The goal is to publish beam parameters in real time for any type of beam. Those parameters will also be logged, so they can be accessed later for further analysis. Ideally, this tool will also give some options to explore scenarios different from the current machine running conditions, to allow operators to experiment with various machine and beam parameter combinations. Moreover, this tool can also be used in connection with AI/ML applications, to serve as the interface between the machine and the AI/ML algorithms, as shown in Fig. 2.

SYSTEM WORKFLOW AND CALCULATION METHODS

There are separate scopes for each accelerator system. Those devices present the bunch profile in mountain range

[1] That object can be an ADO parameter, a Complex Logical Device (CLD), a manager’s parameter name, or an alias (a name used by developers which is more human-readable), etc.

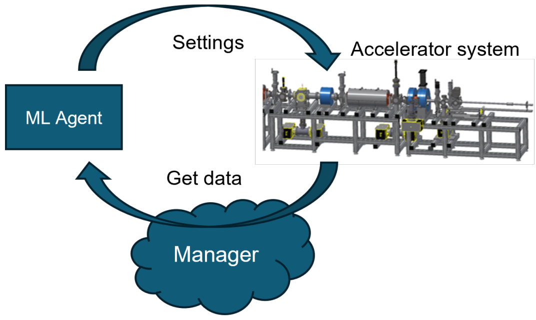

Figure 2: The tool can serve as the machine interface between AI/ML algorithms and accelerator systems.

plots as shown in Fig. 1. Operators in the Main Control Room (MCR) will use those signals to diagnose the beam. Those scope settings are primarily used by the MCR operators to look at different sections of the bunched beam. For our purpose, we would need separate scopes to study different bunch sections of our interest.

The overall workflow is shown in Fig. 3. Both MCR scope and our local scope get the same machine triggers. Those triggers will signal the start of data-taking. In the MCR scope case, the data will be processed by the MCR operators. The data coming out from the local scope will be published by a designated software. Those data can be saved to files for further analysis. The proposed longitudinal bunch profile tool will acquire data from the designate software or load any historical files saved in the system, and use those data to calculate the parameters of interest in the bunch section selected by the local scope settings. The machine scope settings can also be copied into the local scope to study the beam where the MCR operators are looking.

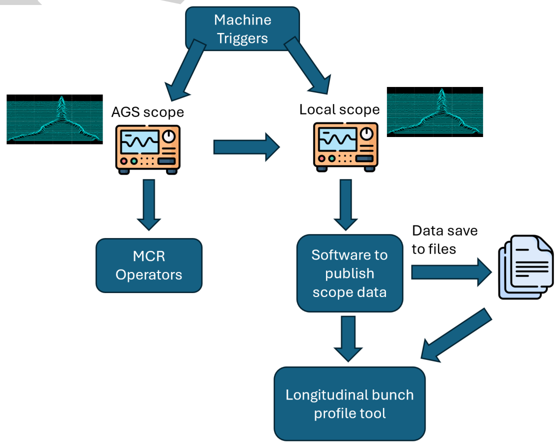

Figure 3: Workflow of the proposed longitudinal phase space diagnostic tool.

Figure 4 shows the calculation methods of the longitudinal phase space diagnostic tool. First, several beam parameters need to be loaded from the live system, such as particle species, charge, energy, total RF voltage, revolution frequency, and magnetic field derivatives, etc.

After acquiring those basic beam parameters, it then enters two calculation modes. The first one requires the operator to measure the synchrotron frequency. Then from there,

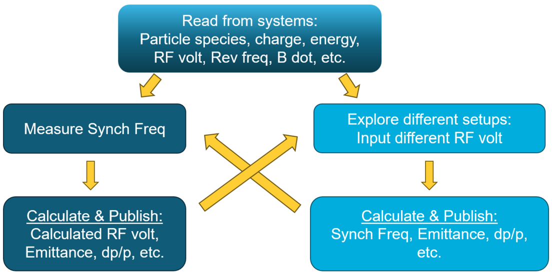

Figure 4: Calculation methods of the proposed longitudinal phase space diagnostic tool.

a bunch of parameters of interest can be calculated, such as the calculated RF voltage[2], beam emittance, and beam momentum spread, etc. The second mode allows for more exploration of different scenarios by putting in different RF voltages from the current accelerator system settings. Another set of parameters of interest will be calculated based on that. One can also enter the same RF voltages with the calculated RF from the first mode, and compare the two sets of calculated parameters to cross-check the calculations.

Calculation Example

A calculation example is shown in Fig. 5, which demonstrates how the tool works. The top picture shows the bunch profile during an AGS bunch merge process. To reduce the space-charge effect and hence reduce the emittance growth, the beam bunches are proposed to be split into smaller bunches in the Booster. Just before transferring to RHIC, those individual bunches are merged into one at the extraction energy of the AGS. The reduced final emittance increases the luminosity and improves the polarization in RHIC. Parts of this procedure have already been tested and are being proposed for the EIC [6]. As we can see from the picture that the bunches are merged from 4 to 1. During the middle part of the merge process, i.e., the section between the red lines, many beam properties such as the synchrotron frequency are not well-defined, so the tool cannot handle this part correctly. This part would need further study in future work. This system has just been developed and is still under test. It is being integrated into operations, but improvements are still being made.

The bottom plot shows how the emittance grows during this process. The tool extracted the center position, bunch length, center variation, and bunch length variation from several traces by averaging them. Those results are published and used to calculate parameters of interest, such as emittance and momentum spread, etc.

CONCLUSION

In this work, we introduced a newly developed tool which can analyze longitudinal phase space parameters on bunch profiles. It can read live machine data, calculate a bunch of parameters of interest, such as bunch length, beam emittance,

[2] This value is usually different from the RF voltages read from the system. This is the effective RF voltages that actually act on the beam.

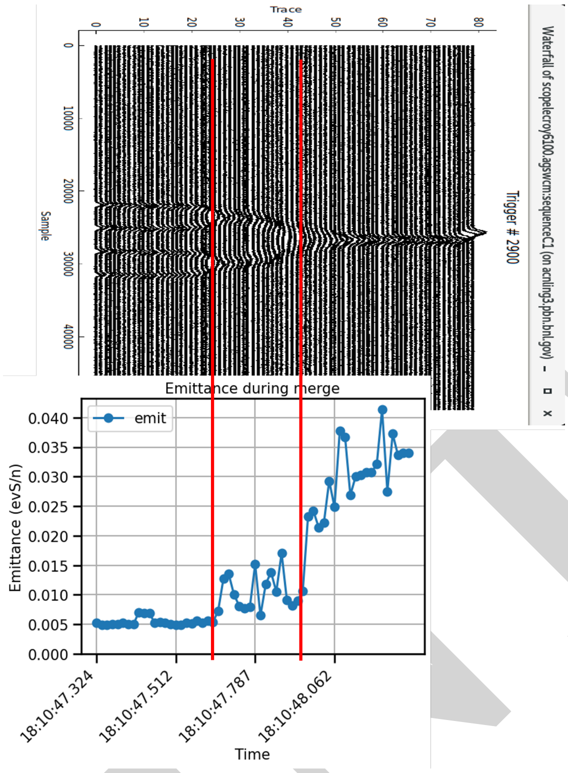

Figure 5: A calculation example shows the emittance evolution during AGS bunch merge process.

momentum spread, etc., and publish the results. Those results are also logged in the system and can be used for future analysis. This tool plays an important role in machine operations, as it provides valuable beam information to operators that was previously unavailable. We plan to extend the use of this tool for more general scenarios. The goal is to deploy this tool in any accelerator system with any type of beam.

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