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The Development of Controls for Pulse-to-Pulse Modulation at the Brookhaven AGS Complex *

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Operation of the AGS Complex, comprising a 200 MeV Linac, the 1.5 GeV Booster (400 MeV/amu heavy ions) which is under construction, and the AGS, requires service of multiple users with different beam requirements. Local Linac users, Booster commissioning with protons and heavy ions, and the AGS physics program and accelerator studies must run concurrently in various combinations. A new timing system is being built which will distribute serially encoded events derived from real-time and magnetic field clocks to each accelerator. The master timing of the supercycle will be managed centrally with encoded reset events determining the assigned user for each pulse. Operational aspects of the design of this system will be described, along with the principal control system modifications necessary to implement this mode of operation.

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1. Introduction

The discussion of modifications of controls to support operation of parts of the AGS complex in a multi-user mode, referred to as PPM, is presented in three parts. The introduction discusses concepts and terminology, and some important operational aspects of this task. The second section describes the new timing system which is being constructed for the Booster and for the overall intermachine scheduling in the AGS complex. The third section discusses the principal changes which must be made in the various parts of the AGS Distributed Control System (AGSDCS) to accommodate PPM.

The architecture of the AGSDCS is a three level, hierarchical, distributed system of controls. The highest or "Host" level comprises Apollo workstation nodes interconnected by the Apollo Domain LAN. The second layer consists of "Stations", workstations or microprocessor data concentration and surveillance nodes; while the third layer comprises microprocessor "Device Controllers" for real-time control. ¹

Definitions

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MASTER MASTER

The name Pulse-to-Pulse Modulation (PPM) was first applied at the CERN PS to the operation of that facility for multiple end users, with variable characteristics of beam intensity, species, main magnet cycle, and certain other machine parameters.² It is planned to introduce PPM into the controls for the AGS complex in a phased manner, to support the increasing demands for flexibility and multiple use. In this context the term Supercycle refers to the overall repetitive sequence of the facility as a whole, while a Cycle is defined as the single, complete period of operation of a particular accelerator, usually associated with the sequence of a main magnet and/or rf system. The cycle is the smallest unit of time which is assigned to a particular User - a specific application (client) of a set of cycles of one or more accelerators of the complex.

The implementation of PPM described below utilizes a central timing system, which generates and distributes timing signals to the subsystems of a particular accelerator via a Time Line, a cable carrying information in the form of encoded pulse trains signaling both the time and the function of the event. Time line signals called Resets inform the various accelerator subsystems of the user assignment for the next cycle or group of cycles.

Purpose

The objective of the creation of PPM controls for the AGS complex is to provide a flexible, centrally managed facility which supports multiple activities during a super-cycle. The environment in which a particular user operates should provide an exclusive view of just those matters concerning the cycles associated with his task. Control and data acquisition should be independent of other users, except in cases where there is unavoidable contention for some instrumentation. The ultimate goal is to provide as close an approximation as possible to a separate "virtual accelerator" environment for each user.

The first instance of PPM at the AGS complex is already in place at the new Linac pre-injector. This implementation has been preliminary and has not incorporated many of the changes discussed in Section 3. The first requirement for multiple users, beyond the Linac local usage, is for Linac operation in support of Booster commissioning during AGS running with the present Linac-AGS injection line. As soon as the AGS begins operating full-time with injection from the Booster, PPM on the Booster will allow concurrent development of proton operation and commissioning of heavy ion operation. In the longer term, the same considerations apply to the AGS, to support rapid changes of primary client, as for RHIC, and to give enhanced productivity in the performance of machine studies of high intensity proton and heavy ion operation.

Operational Aspects

While implementing this new system, there has been a conscious effort to constrain its complexity and generality. All cycle periods will be constructed in units of the Linac cycle (7.5 Hz). The supercycle will be built with an AGS cycle determining its least duration, with more than one AGS cycle as required by program complexity.

A trivial example of PPM is that of the Linac operating for the AGS (Physics) and 2 local Linac users. Fig. 1 shows a hypothetical sequence of Linac cycles as a function of time, as indicated by a Linac prepulse and an rf turn-on pulse. Other details of the Linac timing sequence are omitted. Some characteristic Linac parameters, which are PPM variables in the pre-injector area, are listed below. This means that, in the front-end microprocessor device controllers, the setpoint and command variables are stored separately for each user. They are sent to the equipment according to the receipt of a combined Reset-Prepulse signal for the next cycle. Analog and digital acquisitions from the equipment are also separately managed for each user.

Some Typical PPM Pre-injector Parameters:

- Chopper Pulse Width
- Buncher Phase
- Buncher Amplitude
- RFQ Amplitude
- LEBT Bending Magnet Command

A fundamental constraint, which will be applied to the assignment of operating variables according to user, is that a downstream user exclusively reserves his assignment on any required upstream machine. Table 1 gives the number of allowed user modes on each machine and a sample set of assignments. Thus, in the example shown, AGS Physics (User #1) "owns" the #1 assignment on all three machines, likewise with AGS Studies (#2). Booster Studies is User #3, and that assignment is not used concurrently at the AGS. For some other supercycle, however, there might be no AGS study activity and a subsequent Booster study might be User #2.

Table 1. Sample PPM User Assignments

<u>Accelerator</u>	<u>Max # users</u>	<u>User Names</u>
Linac	7	AGS Physics AGS Studies Booster Studies [spare] Isotope Prod. Radiation Effects Linac studies
Booster	4	AGS Physics AGS Studies Booster Studies [spare]
AGS	4	AGS Physics AGS Studies [reserved] [spare]

An important operational aspect of the application of PPM to the control of the Booster concerns the basic underlying assumption that the individual instances of one user cycle are identical. By this it is meant that control settings cannot be separately specified for various instances of one user cycle. The use of adequate dwell periods and/or dummy cycles (without beam) will be used to minimize the effects of magnet hysteresis. On the other hand, acquisitions of equipment readings will be available with full details about each instance of a cycle. At the Linac, and for proton injection cycles at the Booster (7.5 Hz), the data acquisitions by the device controllers will be synchronized at that rate. The reporting of data to Stations on the network will be carried out at approximately a 1 Hz rate. This will mean, for instance, that data reports from Linac and Booster devices will be buffered at the controller for several cycles.

It will be unusual, if not impossible, for the principal On-Off control and interlock status of a device to be a PPM variable, with separate user access. Physical devices will be controlled through a set of logical devices, some of which may be non-PPM and others (e.g. setpoint control) PPM. The user will have access to control and acquisitions for both PPM devices and non-PPM devices in his process data set.

2. Timing System

The present system of timing control at the AGS comprises a mixture of local manual and computer controlled delays. Two real-time clock trains and the main magnet field (Gauss) clock are distributed for use by the local timing units. Fig. 2 is a block diagram of the central portion of the new timing system, as first applied to the Booster. The major timing signals for a particular machine cycle will be generated centrally by programmed selection of timed events on a master real-time clock, and, where appropriate, on the machine's Gauss clock. Each programmed event will generate an 8-bit serial code transmitted on the time line, using Manchester encoding at a frequency of 10 MHz. The general method borrows heavily from the Fermilab approach.³ Each code will designate a specific function, and equipment will be configured to recognize and act on selected codes. The central distribution system will comprise three distinct time lines. One will distribute the master schedule events from a supercycle controller, while the other two lines will distribute Booster real-time and Gauss clock events.

Supercycle Control

The timing master for the complex will be the Supercycle Generator. This device will determine the scheduling of users and of cycle initiation. The master clock of the Supercycle generator will be a power line synchronized, 60 Hz clock. The Supercycle Time Line (SCTL) will primarily feed these primary events to the individual cycle generators. A Linac timing module will also be connected to the SCTL. The Supercycle Generator will be capable of generating up to 15 codes in rapid succession (1.2 μ sec apart) on a single tick of its clock.

Table 2 gives a preliminary assignment of codes generated by the Supercycle Generator. These codes will be routed onto the individual machine time lines by direct encoding circuitry in the time line generators.

Table 2. Supercycle Codes

<u>Code</u>	<u>Function</u>	<u>Mnemonic</u>
0	Supercycle Start	SCS
1 ... 4	Linac User Reset #1...#4	LR1...4
5	Linac Local User Reset	LLR
9	Linac Prepulse	LPP
10	Booster Cycle Start	BTO
11 ... 14	Booster User Reset #1...#4	BR1...4
19	Booster Prepulse	BPP
20	AGS Cycle Start	ATO
21 ... 24	AGS User Reset #1	AR1...4
29	AGS Prepulse	APP

The supercycle definition will be managed by a special set of applications programs. These programs will provide a graphical environment in which to view, modify, or create the supercycle. The actual changeover to a new cycle will be smooth and continuous from the previous cycle in the same manner as a replay of the same one. There is no provision for shifting tables in mid-supercycle, since this would create too much complexity in the inter-machine scheduling. Fig. 3 shows a portion of a possible supercycle schedule representing Booster commissioning. Sufficient local Linac cycles are used to accommodate required initial user resets for the Booster and the AGS.

Booster Time Line Controls

The Booster Real-Time Line (RTL) and Gauss Time Line (GTL) Generators each contain four tables of event times and codes which may be scheduled for the current cycle according to its user reset code. These controllers will be able to schedule multiple instances of a particular coded event within one cycle. For example, it will be possible to load an array of instrumentation acquisition times under the control of an application program. In addition to generating programmed delays, each time line generator will be able to directly encode 31 externally generated events, which will include the appropriate reset and master timing events from the supercycle time line. The remaining inputs will be available for special signals (e.g. aborts, one-time triggers, etc.).

The GTL generator will generate events corresponding to desired main magnet field values. The local receiver-decoder card will permit recognition of up to 24 codes on each time line. The 24 choices will be allocated to 8 interrupts, 8 direct trigger pulses, and 8 locally delayed triggers. The master clock (10 MHz) will be extracted from the carrier signal for local use. Since some accelerator equipment requires a cascade of delays to establish a significant event (e.g. a momentum trigger followed by a real-time delay),

local delay hardware will be provided in those cases. For the example mentioned, the primary trigger might be centrally generated and distributed on the GTL.

Local Timing Controls

Requirements for local timing services will be met by the use of delays located in local controllers. A Linac timing interface will convert the user reset #5 into a pulse on one of three local lines to designate the local user of Linac beam. This feature will allow gating and/or manipulation of local Linac scheduling without supercycle changes.

3. Implications for Controls Subsystems

Database

The accelerator controls database to be used for PPM operation will have to distinguish between particular users. These changes will be reflected in the live data managed by the Stations, and in the host-resident database. Certain of the database entries for a "PPM" device are user-dependent quantities, while others which are related to general properties of the control variable are not. The following list gives some quantities in each category:

User-specific Data

Setpoint/Readback
Tolerance, or
Upper/Lower Limits
Watch Masks

Shared Data

Device Class Limits
Allowed Commands
Status Description
Device Description

Various user instances of a particular accelerator control variable will be implemented with the same device (parameter) name. The user code will be joined with the name to form a "key" to the relevant database relations. ⁴

Device Controllers and Stations

The most fundamental change in device controller function is for handling user resets via the machine time lines. Interrupts will be generated in a time line receiver-decoder card, upon which the controller will set up indexing for its transactions with the equipment on the next cycle. Once the next user has been set up, non-user-specific pulses from the time lines, with or without local delays added, will provide start, stop, and other synchronization signals. The principal change in the device data structures for PPM will be the use of a presently reserved byte in the packet header for the PPM user number. In command packets and in device reports the value 0 in the user field will indicate a non-PPM device. For PPM logical devices each data structure will have a depth

corresponding to the maximum number of users.

Many of the changes to Stations which are required for the support of PPM concern database and data structures. Tables of pointers and other data will have to be divided into those parts which use only the device name as a key, and those which use the structure corresponding to the name plus user code as the key. Another change for the station code is in the area of scan task management. It is undesirable for the station to report invalid data in response to a report request; but there is no guarantee that a particular user cycle has occurred since the last scan. In fact there will typically be no cycles at all of some users during the execution of a particular programmed supercycle. For this reason, the device controller will report on all users active since the last default report was made.

Host Software

The principal aspect of the application of PPM to the host or console environment is the assignment of a user context for that environment. Either by individual program, or by console as a whole, the operating individual will be queried by the system to choose a user context. This context will correspond to a specific user code and will be referenced by a user name given at supercycle setup. There will be no pre-assigned designations for the 4 codes available to the Booster/AGS. The Linac codes 5-7 will be equally general but reserved for local use. With a context defined for the task, the basic logical device and parameter tools referenced by the program(s) will use this information along with device names to produce the requisite device keys. Within the process environment, the operator and high level programs may then deal in terms of names alone when referencing the relevant PPM and non-PPM devices.

One immediate consequence of this point of view is that the entire machine tree and archive structure is independent of PPM. The tree reflects, as it has previously, the process areas of the accelerator complex. The application of the user context to a particular process consists merely of associating the user code with the device names found in the tree. One result of this distinction is that, in the AGS context, there are not separate "user" areas for Protons, Heavy Ions, and Polarized Protons; but, there are, as appropriate, separate process data sets.

In the same spirit, archives are really identified with a user only in the separate contexts in which they are saved and restored. An archive will be created within a given context and will contain the current user name. The restoration of an archive will be from the full spectrum of choices, across all users. The user context applied to a restoration will be that of the operator restoring the archive, not that

in which it was saved. A simple example comprises the case of the restoration, in the context of the physics program, of the results of a successful machine study. There must be an operator option on whether or not to restore non-PPM devices along with PPM devices.

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Figure Captions

Fig. 1: A Simple Linac PPM Sequence

Fig. 2: AGS Booster Timing System

Fig. 3: A representative segment of a supercycle time line program which may be in use during Booster commissioning. The AGS physics (Slow Extracted Beam) program with the old injection line is User #1. As User #2, the Booster is accelerating four successive pulses of protons without transfer to the AGS. Users #3 and #4 are unused in this example. The Linac applies local control options to the User #5 resets. The various peaker (PKR) events are magnetic field based, injection triggers (non-supercycle events).

Fig. 1

USER RESET/PREPULSE

- A — LINAC ISOTOPE PRODUCTION
- B — AGS PHYSICS PROGRAM
- C — RADIATION EFFECTS FACILITY

R = RF TURN-ON TRIGGER

Fig. 3