THE CENTRAL BEAM AND CYCLE MANAGEMENT OF THE CERN ACCELERATOR COMPLEX

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Abstract

The efficient exploitation of the CERN accelerator complex in the future, with new cycles to fill the LHC and possibly a dedicated neutrino cycle in addition to the actual fixed-target program, will require a rapid and coordinated response to adapt to the changing user requests. This paper reviews the general sequencing problem and describes some preliminary concepts and algorithms suitable for managing a network of accelerators. The benefits derived from the architecture that has already been implemented in the PS complex, since its start up in March, are presented. The last accelerator in the injector chain, the SPS, is currently running fixed super-cycles. Its event-based timing system will be integrated into the central control by the year 2001 in a way that is transparent to the SPS equipment.

1 HISTORY

CERN is organized into divisions, among which two are responsible for the accelerators of the PS and SL complexes. The PS complex consists of low-energy short cycle machines such as the proton, ion and lepton Linacs, the Electron-Positron Accumulator (EPA), the Proton Synchrotron Booster (PSB), and the CERN Proton Synchrotron (CPS). The SL complex comprises the larger high-energy slow cycling machines such as the Super Proton Synchrotron (SPS) and the Large Electron Positron collider (LEP). The evolution of the timing systems controlling these two groups of machines occurred separately, and has in each case responded to different requirements. In particular, the SPS super-cycle (cycle-sequence) has not changed very often compared to the PS machines. This is not only because it was not required, the SPS was not an injector for a higher energy machine (the filling of LEP was performed by two parasitic cycles), but also because of machine constraints such as remnant magnetic fields and energy consumption. In the CPS, it is possible to ignore to a limited extent cycle-sequence effects and hence to consider cycles as independent building blocks. The SPS timing system did not need to make any major cycle change decisions. For every fixed SPS super-cycle with its predefined rendezvous points at which the PS injector chain injects particle beams, a simple table driven event timing system was adequate to do the job. This simple timing execution system was, however, augmented by a real-time decision process that could alter the usage of a cycle (to put the SPS in economy mode or into coast). On the other hand, the message-based PS timing system has been designed to respond to rapidly changing operational requirements, and can change super-cycle components on the fly based on beam requests and interlocks. When the Large Hadron Collider (LHC) comes on line, the SPS and the PS machines will need to work together as a single entity executing many super-cycle changes per day in order to satisfy LHC filling interleaved with SPS Neutrino users and other fixed target physics. These new requirements have motivated among others the SPS 2001 controls project **[3]**, and specifically the proposal for centralized management of the timing systems via the Central Beam and Cycle Manager (CBCM).

2 THE CENTRAL TIMING SYSTEM

The machines of the PS complex execute cycles arranged to be small multiples of a Basic time Periods (BP) of 1.2 seconds in sequences. Each BP is described by a telegram message which is distributed from a central Master Timing Generator (MTG) to each machine in the complex, telling them which cycle to execute next. The MTG also interprets these messages itself and derives from them a set of key timing events. **[1]** The messages and key timing events are distributed on a timing drop net to timing reception modules which are able to produce local output pulses and interrupts for real-time tasks. The MTG thus has two functions: a) the cycle decision level, where decisions are made for all the accelerators determining which cycles they should be executing, and b) the timing execution level, which outputs the timing events according to the chosen cycles.

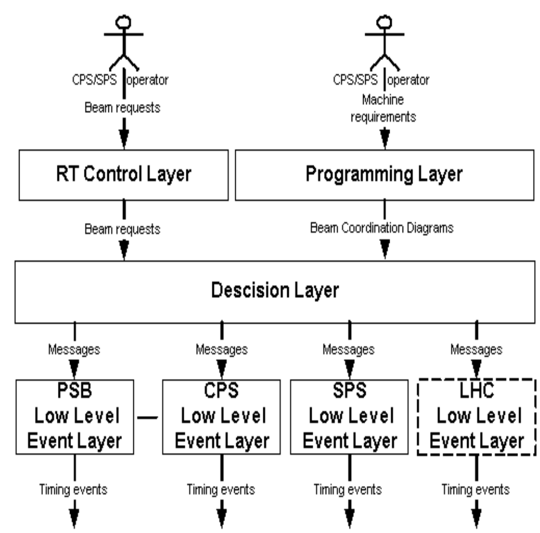

Figure 1 Central Beam and Cycle Manager

In the SL complex, only a timing execution system was implemented and there was no high level function that chooses cycles. With the new LHC requirements, it became necessary to include the SPS conditions and requests into the central decision system, and to generate the SPS timing from the resulting messages. The SPS timing execution system will be adapted such that it can be driven by the timing messages from the central MTG. This approach will protect the investment in SPS timing reception systems a little longer. In addition, this Local Beam and Cycle Manager (LBCM) system can continue to provide the fast real-time response required for energy saving, when the beam has not been properly injected, or to handle coast requests. The CBCM **Fig 1** is thus an extension of the existing PS MTG to include the SPS related decision logic, and the interfaces needed to access it form the new SPS control system.

3 CONSTRAINTS

It is possible to control the accelerator complex on a cycle basis, but there are many restrictions on how these cycles can be sequenced. The cycles and sequences that can be executed depend on data that must be made resident in the local equipment, on machine physics, and on other factors. For these reasons, the central timing system was constrained to producing predictable sequences that can be scrutinized in advance by the operation teams of the machines. A general algorithm to perform this task reliably has not yet been devised. A major problem arises because the SPS and PS operations teams work in separate control rooms kilometers apart, and each team has specialized knowledge about the machines under their control; so while a sequence may be executable by the SPS, it may not be executable by the PS. The PS may not be able to execute the requested sequence due to short lived bad hardware interlocks, higher priority requests from other machines, or a host of other physics and control system constraints.

4 SEQUENCE BUILDING

A **Compound Cycle** is defined as a sequence of Cycles executed in one machine after another, across the chain of accelerators to produce a final product for an end user, and a Cycle is a unit of work executed by a single accelerator **[2]**. As an example, the Compound Cycle to make a beam for SPS fixed target physics begins with protons in the linac, they are then accelerated in the PSB, a further acceleration in the CPS, then in the SPS, and finally, the beam is ejected to the fixed target user. The operator interface to the CBCM provides capabilities to define cycles, to arrange these cycles into Compound Cycles, and to build sequences of Compound Cycle to specify the operational requirements for CERN machines. This is an interactive process guided by the operation teams who implement the decisions taken at scheduling meetings which are in turn guided by the physics community needs, and priorities. The result of this process determines a set of Compound Sequences, each a scenario for a particular set of operations, like an LHC pilot cycle followed by two neutrino cycles. Any of these constructed Compound Sequences can be loaded by the CBCM into the central MTG for execution. The CBCM selects the best possible sequence for execution, based on request priorities.

When a sequence has become active in central MTG memory, it is checked in real time against a rule base concerning hardware and software interlocks and requests. At this stage a Compound Cycle may be substituted or even canceled if need be. While editing the compound sequences, the operator also specifies the alternative Compound Cycles that may be used for substitution.

The SPS Compound Cycle sequence determines which cycles must be executed, where and when in the accelerator complex, but this leaves many unused injector cycles which can then be used by the PS local users **Fig 2**. Thus the final compound sequence is the result of merging the SPS and the PS requirements; and this is usually an interactive process requiring operator guidance

The operator interface is able to check candidate sequences against a rule base for the more permanent constraints to inform the operator of potential problems in the sequence he is building.

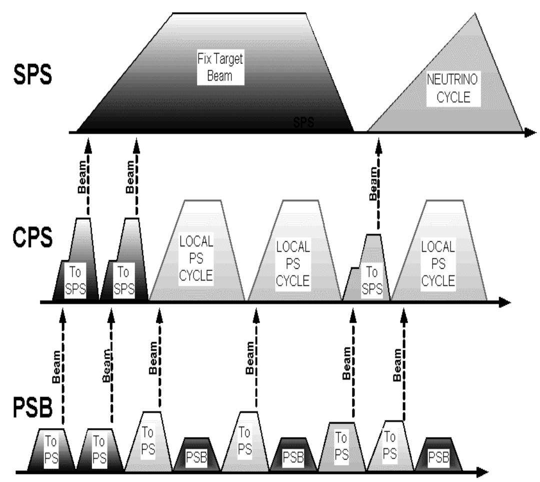

Figure 2 Cycles and Compound-Cycles

The CBCM must provide an interface that can be tailored to provide each control room with a clear picture of what is happening in their own terms and even hide irrelevant information on each side. To set up a CBCM sequence for the SPS the Compound Cycles must first be defined; this must be done in collaboration. A named template must be built to define the cycle time structure in each accelerator. Once this structure has been defined, the details of the cycles of the PS and SPS accelerators in it are filled in separately by the machine specialists according to the beam requirements, intensity, energy, particle type etc. The SPS operators can then build a sequence of defined Compound Cycles, they do not need to see what happens in the injectors, a sequence is nothing more than a list of cycle names which result in an SPS super-cycle. When the new sequence is sent to the CBCM, the PS operators must then manually define their own Compound Cycles in the unoccupied space. The sequence will then usually be made available for execution if no rule violations have occurred. The process of constructing new sequences for the SPS will not be very frequent, it will be done on a machine run bases, once a month. The PS however will change its Compound Cycles on average once per hour and may have several versions of the same SPS sequence resident in the CBCM but with different PS Compound Cycles for rapid PS response to its user requests.

5 RUNTIME SEQUENCE EXPLOITATION

A Compound Cycle is a set of cycles to be executed in sequence by a network of connected accelerators. The precise duration of each cycle, and the phase relationships between the cycles are all that is needed to address the problem of determining what cycle each accelerator in the network should execute at any given moment in time. Each basic period BP, the central MTG must send to each accelerator a message, instructing its control system which cycle it should be executing. The timing event layer, the LBCM, also receives the message and sends out the indicated cycles timing events accordingly.

Notice that the structures of the Compound Cycles themselves define the network topology, and the cycle time structure. With this information the sequencing algorithm simply routes the beams through the network one by one, in the order given, by arranging the cycle start times under the constraint that no accelerator can execute more than one cycle at a time. This implies a standard network routing algorithm where the node capacity for all nodes is one. Once the decision has been taken it can not be revoked; a Compound Cycle is a transaction which once injected into the network must run to completion, even if during execution the beam is sent to the emergency dump, or killed in the linac. It should be noted that execution of a Compound Cycle begins at the time of the earliest forewarning event. The central MTG examines all the cycles in each Compound Cycle and tests for their "*executability*" against the interlocks, requests, and inhibits. If all these preconditions are favorable, then it decides to commit the Compound Cycle, if not it looks for an alternative. Hence the response time of the central MTG to a changing condition can be several tens of seconds. Because of this, the emergency fast real time system behavior (<100 ms) must be implemented in the LBCM layer, and will occur later during cycle execution.

6 RUNTIME SEQUENCE SELECTION

Once the SPS sequences have been accepted by the CBCM and merged with the PS beams, they may be executed by the central MTG. A sequence is activated by the CBCM based on a number of prioritized cycle requests coming from the SPS control system. The CBCM assigns a score to each sequence based on the request priorities, and produces a list of candidate sequences ordered by score. The behavior of the system subsequently depends on what options have been set by the control room operators, namely automatic or manual. In the manual case, the operators are informed that there is a sequence ready for execution with a higher score than the current active sequence. There could be reasons why the PS operators may whish to override the SPS Beam requests, such as hardware problems, or high priority PS users. In the automatic case, the new sequence will be activated based on the highest score. Each resident sequence in the CBCM can have both the entry and exit conditions set to either automatic or manual. Notice that the SPS control system normally never requests directly that a particular sequence is executed; it is the prioritized Compound Cycle requests, which determines the order of candidate sequence priorities via an algorithm. This algorithm takes into account machine usage: non-demanded and hence unused Compound Cycles in a sequence will reduce the score, while each instance of a requested Compound Cycle will increase the score by an amount proportional to the priority of the request. The algorithm will have a weighting function that can be tuned by the operators so that the CBCM sequence-picking behavior can be adjusted.

7 CONCLUDING REMARKS

Many of the features needed by the CBCM have already been included in the PS MTG in a major redesign needed to incorporate "*loose-coupling*" for the slow cycling Antiproton Decelerator **[1]**. Notably in March 1999 the ability to switch between resident sequences was added. This has proved to be more flexible, and less demanding on the operation team, who no longer need to manually program it so often. However, the MTG behavior depends on, the resident sequences, on requests and interlocks, inhibits, the compound cycle and cycle structure, and it is very often difficult for the operation teams to interpret; this has led to some confusion. Diagnostic tools, which explain the behavior of the system, are thus very important, and this will certainly affect the full implementation of the CBCM that we hope will become operational for the start up by March 2001. At this time, we are still very much in the design stage, however we are planning to implement the CBCM entirely in Java using a client-server model making extensive use of RMI, JDBC, and Swing.

8 REFERENCES

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