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STORAGE RING MODE FOR FAIR

Andreas Schaller, Jutta Fitzek, Hanno Christian Hüther, Raphael Müller,
Benjamin Peter, Anneke Walter, GSI, Darmstadt, Germany

Abstract

For the future Facility for Antiproton and Ion Research (FAIR), which is currently under construction, a new Control System is being developed and already used at major parts of the GSI facility. The central component for Settings Management within the FAIR Control System is based on CERN's framework "LHC Software Architecture" (LSA) and enhanced by FAIR specific features. One of the most complex features is the control mechanism of storage ring operations, the so-called Storage Ring Mode. This operation mode allows to manipulate device settings while the beam is circulating in the ring. There are four different types of possible changes in the Storage Ring Mode: skipping, repetition, breakpoint and manipulation. The Storage Ring Mode was developed in late 2019 and first used with beam in 2020 at the existing heavy ion Storage Ring ESR at GSI. This contribution illustrates in detail how the Storage Ring Mode is implemented within LSA and other subsystems. It also shows how it is operated using the Expert Storage Ring Mode application.

MOTIVATION

To reliably ensure deterministic behavior, the new Timing System for FAIR executes predefined event sequences. The first use case realized in the FAIR Control System was synchrotron operation, based on fully pre-planned schedules, which has been successfully used since 2015.

In 2019, the FAIR Control System was enhanced to support storage ring operation [1]. The old control system supported storage ring operation at GSI since 1990, with beams often being stored for several hours and up to a week. The Storage Ring Mode of the new control system now also supports the required flexibility and allows interactive schedule changes, including in-cycle modifications of stored beams.

The basics of Storage Ring Mode were presented at ICALEPCS in 2021 [1]. This contribution provides more insights into the realization of its features.

STORAGE RING MODE - COUPLING WITH SOURCE MACHINE

Storage Ring Mode allows for interactive, dynamic operation and very long, arbitrary beam storage times. Therefore, event sequences in the Timing System for storage rings are usually completely independent and separated from the event sequences of other accelerators.

However, when transferring beam from a source accelerator into a storage ring, the event sequences of both machines have to be synchronized. This is realized by a so-called coupling mechanism. The FAIR Control System currently supports two types of coupling: strong and weak coupling.

Strong Coupling

Strong coupling guarantees that the beam is properly injected by having the storage ring explicitly request beam and wait until it is ready to be injected.

As shown in the left part of Fig. 1, the storage ring prepares for beam injection, requests beam from the injector, and finally enters a wait loop. The injector starts creating the beam once the overall schedule allows it. When beam is ready, the injector sends a command to the storage ring to leave the wait loop. Extraction from the injector and injection into the storage ring then continue synchronously.

This type of coupling is used by the ESR Heavy Ion Storage Ring when receiving beam from the SIS18 ring.

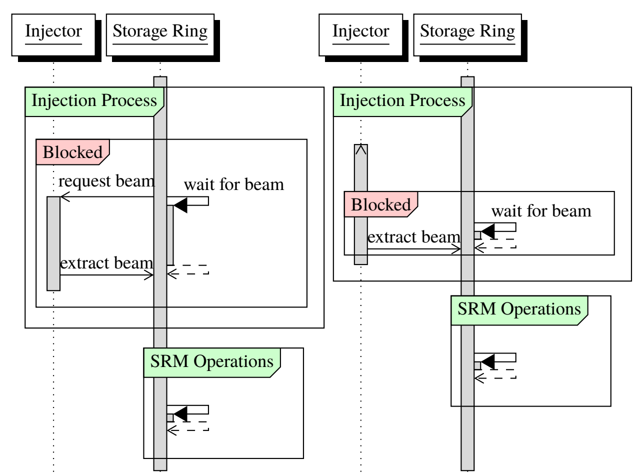

Figure 1: Sequence diagram of a strong coupling (left) and weak coupling (right).

Weak Coupling (Fire and Forget)

With weak coupling, the injector *always* produces and extracts beam without making sure that the storage ring is ready for transfer ("fire and forget"). This coupling mode is used to allow the storage ring to serve other experiments while the beam is produced, instead of just waiting.

As shown on the right part of Fig. 1, the injector produces beam without an explicit beam request. When beam is ready, the injector notifies the storage ring to leave the wait loop. At this point, the storage ring must be ready for injection when the injector starts extraction. Operators achieve this by carefully aligning the schedules of the injector and the storage ring. If the storage ring is not ready for beam at this point, the notification is ignored and beam is lost.

This mode is used at CRYRING@ESR [2], enabling CRYRING to accept beams from its local linear accelerator in synchrotron mode while waiting for ESR's beam.

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STORAGE RING MODE – FEATURES

Storage Ring Mode introduces smaller building blocks within a Chain [3] that represents the full storage ring cycle. These building blocks are essential for the realization of the four key features: breakpoints, repetitions, skipping, and manipulations. All features can be combined with each other within a building block, except for manipulation. Boolean signals, which are handled by the Beam Scheduling System (BSS) [4], are used by the operators to interactively enable and disable these features.

In the following, each of the features will be described by looking at their corresponding timing graph representation.

Breakpoint

Breakpoints allow to interactively pause the schedule execution at the end of a building block while the beam is still circulating in the ring [1]. As shown in Fig. 2, the timing graph contains an event loop that is repeatedly executed as long as the associated signal is true.

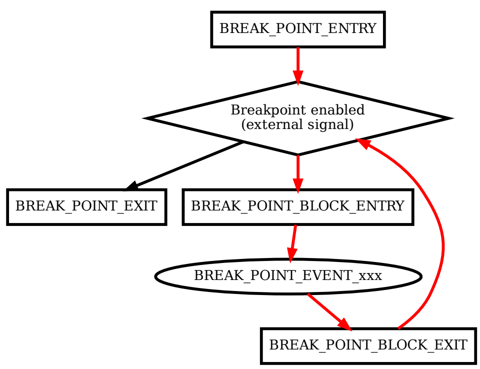

Figure 2: Timing Graph: Breakpoint.

Repetition

Blocks of the Storage Ring Chain can be repeated for a configurable number of times [1]. This is realized as a loop with a counter in the timing graph, as shown in Fig. 3. The counter gets decreased by the timing system each time the loop is entered. Operators can abort currently executed repetitions with an explicit command to the BSS, which immediately sets the counter to zero, thus preventing further repetitions.

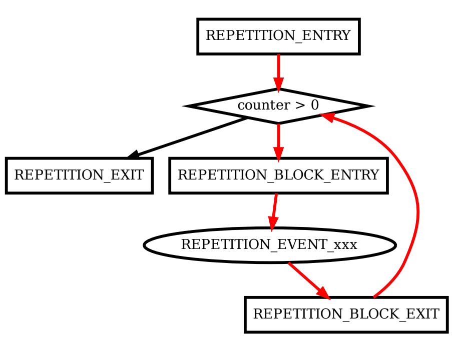

Figure 3: Timing Graph: Repetition.

Skipping

Blocks of a Storage Ring Chain can be skipped based on the state of the associated signal, which is set by operators [1]. The timing graph therefore contains a direct path, bypassing the blocks to be skipped. This is visualized in Fig. 4.

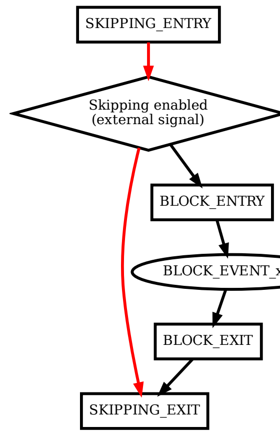

Figure 4: Timing Graph: Skipping.

Manipulation

The most complex Storage Ring Mode feature is the manipulation. It offers the possibility to pause execution and repeatedly modify certain settings at pre-defined points in the Storage Ring Chain. The devices are then ramped to the new values once, influencing the beam while it circulates. The changes are incorporated into the surrounding settings for the next Chain execution [1]. In the timing graph shown in Fig. 5, the red path is where setting modifications are performed, while the blue path describes the pause loop.

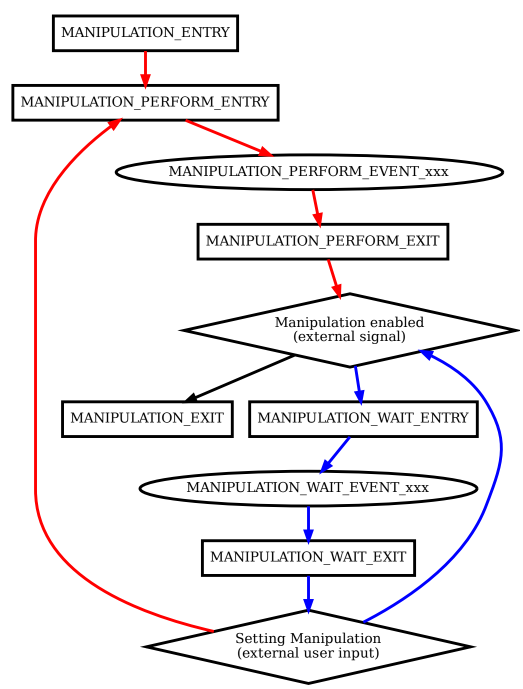

Figure 5: Timing Graph: Manipulation.

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Figure 6 illustrates how the manipulation works from a settings-oriented view: A setting is changed to a new value, resulting in a small ramp that is executed exactly once. The new value is incorporated into the surrounding settings.

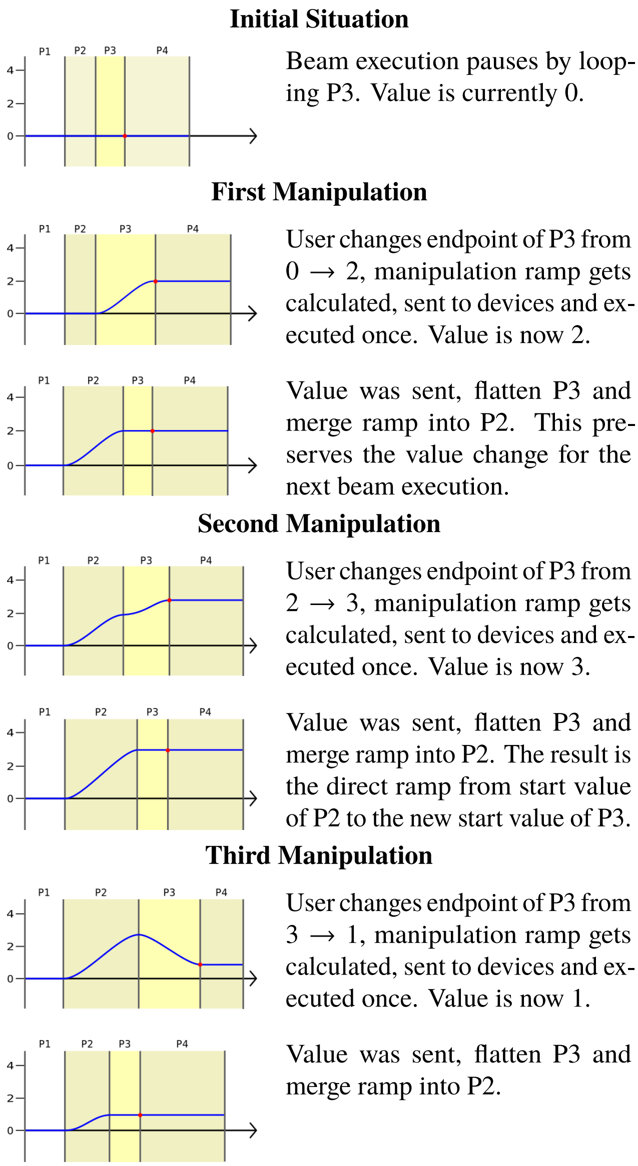

Figure 6: Setting Manipulation (exemplary).

STORAGE RING MODE APPLICATION

All Storage Ring Mode features can be configured and controlled by operators using the specialized Storage Ring Mode Application (StoRiMo).

StoRiMo provides an overview of the different building blocks of a Storage Ring Chain, see Fig. 7. The red border indicates the current point of execution, which is determined by observing executed timing events. Small indicator icons visualize the features available at a Storage Ring Mode block. Signals are displayed below and can be switched by operators to enable or disable these features.

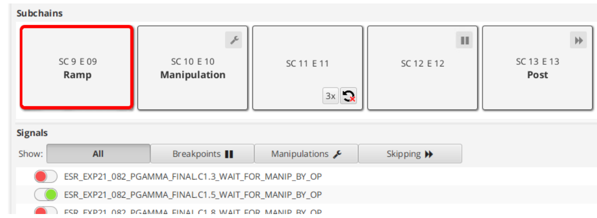

Figure 7: Partial screenshot of StoRiMo.

INVOLVED SUBSYSTEMS

StoRiMo is the operators' interface for controlling the Storage Ring Mode. It monitors and controls Storage Ring Mode features using interfaces of LSA and BSS. LSA calculates device settings, coordinates the manipulation operation and generates the timing graph. This graph is then provided to BSS and the Timing Master, a White Rabbit-based timing system which executes the pre-defined events. BSS reacts to signal changes from StoRiMo and updates the Timing Master's timing graph to reflect which paths of the graph shall be executed.

SUMMARY AND OUTLOOK

Storage Ring Mode and the specialized StoRiMo application were developed for the new Control System for FAIR at GSI. They were successfully used in production during several beamtimes at ESR and CRYRING. The flexibility provided by the new features allowed for multiple machine and science experiments.

A requested, but not yet implemented feature is the possibility of converting Storage Ring Mode contexts to Synchrotron Mode contexts (and back). This would allow for deterministic schedules once the beam is setup, e.g. for synchronizing with another machine.

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