OPERATION MODES AND CONTROLS ASPECTS OF FAIR

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ABSTRACT

An international accelerator **F**acility for **A**ntiproton and **I**on **R**esearch (FAIR) has been proposed by GSI in 2001. This facility will provide the whole range of particle beams from protons and antiprotons to ion beams of all chemical elements up to uranium as well as beams of short-lived (rare isotope) beams. The proposed facility consists of a double-ring synchrotron and a system of associated storage rings for beam collection, cooling, phase space optimization and experiments. It uses the existing linear accelerator UNILAC and synchrotron SIS18 as injector. An important consideration in the design of the facility was a high degree of parallel operation of the different research programs. The first acceleration stages, which are shared by several experiments, have to handle different beams accurately interleaved to avoid any waiting times. The facility then appears like a dedicated facility for each of the simultaneously running programs. This parallel operation poses ambitious demands on the operation and controls of the complex facility. Preliminary ideas on the control system architecture and on the design of the timing system will be presented. Moreover, effective set-up procedures and surveillance mechanisms will be sketched, which are needed to operate the accelerators with a small operator crew.

INTRODUCTION

The **existing accelerator facility** of GSI consists of the universal linear accelerator UNILAC, the heavy-ion synchrotron SIS18, and the experimental cooler/storage ring ESR. UNILAC and SIS18 will act as the injector for the new facility.

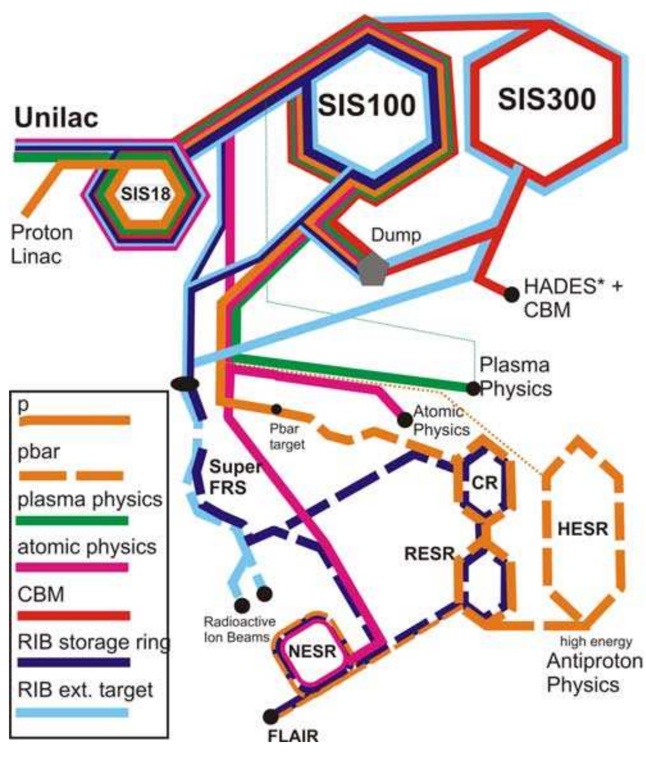

Figure 1: Schematic view of the layout of the FAIR accelerators with all interconnecting beam lines. The colours indicate the usage for the planned experimental programs: Antiproton Physics (orange), Plasma Physics (green), Atomic Physics (violet), Compressed Barionic Matter CBM (red) and Radioactive Ion Beams RIB (blue).

The central part of the **FAIR accelerator facility** (see Figure 1 for a schematic view) is a synchrotron complex consisting of two separate synchrotron accelerator rings with maximum magnetic rigidities of nearly 100 Tm and 300 Tm, respectively. Both synchrotron rings have the same circumference of about 1100 m and will be installed in the same tunnel. They will be equipped with new, rapidly cycling super-conducting magnets in order to minimize construction and operating costs. For the highest intensities, it is planned to operate the 100 Tm synchrotron at high repetition rate (ca. 1 Hz), i.e. with ramp rates of up to 4 Tesla per second for the dipole magnets. The goal of the first synchrotron ring ($B\rho$ = 100 Tm) is to provide intense pulsed uranium ($q = 28^+$) beams at 1 GeV/u and intense pulsed proton beams at 29 GeV. (For the high-intensity proton beams, needed for antiproton production, an additional dedicated linac injecting into SIS18 is planned.)

Both, heavy-ion and proton beams can be compressed into 70 ns bunches required for the production and subsequent storage and efficient cooling of exotic nuclei and antiprotons. The short intense ion bunches are also required for plasma physics experiments.

With the double ring facility, continuous beams with high average intensities can be provided for 1 GeV/u heavy ions, either directly from the SIS100 or by transfer to, and slow extraction from the 300 Tm ring. The latter can provide high-energy ion beams with maximum energies around 45 GeV/u for Ne^{10+} beams and close to 35 GeV/u for fully stripped U^{92+} beams, respectively. The maximum intensities in this mode are $5x10^{10}$ ions per second. Since the complex, large detectors for nucleus-nucleus collisions cannot take intensities above 10^9 per second, the high-charge state, high-energy beams can be extracted over extended periods (order of 10 - 100 seconds) as an essentially continuous beam. Slow extraction from the SIS100 is an additional option for extending the flexibility of parallel operation for experiments. The accelerator facility will be complemented by a system of cooler-storage rings:

- A **collector ring (CR):** for stochastic cooling of radioactive ion or antiproton beams from the production targets. In addition, this ring offers the possibility for mass measurements of short-lived ions, by operating it in the isochronous mode.
- The **accumulator ring (RESR):** for accumulation of antiprotons after pre-cooling in the CR, and for the fast deceleration of short-lived nuclei. Antiprotons will be accumulated for long time periods up to an hour; therefore it will be necessary to extract pilot bunches before the complete batch is transmitted to the HESR or the NESR.
- A **new experimental storage ring (NESR):** for experiments with ions and antiprotons. It will be equipped with stochastic and electron cooling devices as well as a variety of experimental devices, including precision mass spectrometer, internal target experiments with atoms and electrons, and an electron-nucleus scattering facility. NESR will be capable to further decelerate ions and antiprotons and to extract them for the FLAIR experiments.
- A **high-energy storage ring (HESR):** for antiprotons up to 14 GeV. This ring will operate with an internal target and associated detector set-up. It will be equipped with a high-energy electron cooler (up to 5 MeV electron energy) and a stochastic cooling system to compensate for beam degradation due to target interaction and intra-beam scattering.

PARALLEL OPERATION IN FAIR

An important consideration in the design of the facility was a high degree of truly parallel operation of the different research programs. Simple beam splitting and switching to different target locations is of course generally possible at an accelerator with relatively little effort. But this would in general not change the integrated luminosity. Truly parallel operation, with the constraints of accelerator cycles, is considerably more difficult. It would, however, provide maximum integrated beam time, or integrated luminosity for each of the different programs operated in parallel. This implies that the facility operates for the different programs more or less like a dedicated facility.

Figure 2 schematically shows the operation of the FAIR accelerators for the production and accumulation of antiprotons: A proton beam is produced and accelerated in the chain p-Linac – SIS12 – SIS100. It produces antiprotons in the antiproton target-station, which are then cooled in the CR and accumulated in the RESR storage-ring. From there, they are transferred either to the HESR or to the NESR for experiments. Cooling times in the CR are much longer than the possible cycle times of the synchrotrons. Therefore the synchrotrons are idle for several seconds and may be used for the beam production for other experiments. Up to four different scientific programs may be served in parallel (see also Figure 1): During the fraction of the SIS100 super-cycle not needed for the protons, a primary ion beam (blue) may be accelerated in SIS100 and slowly extracted to the Super-FRS to produce radioactive secondary beams (blue dashed) for fixed target experiments. (Alternatively the radioactive beams could be sent to the CR and NESR instead of the antiprotons). In addition, every 10-100 seconds a high-energy heavy-ion beam (red) is accelerated in SIS100/300 and slowly extracted for nuclear collision experiments. Moreover, intense beam pulses (green) are provided every few minutes for plasma physics experiments that require very low repetition rates. Alternatively, Atomic Physics experiments (violet) may be served by SIS100 in the pauses of the antiproton production.

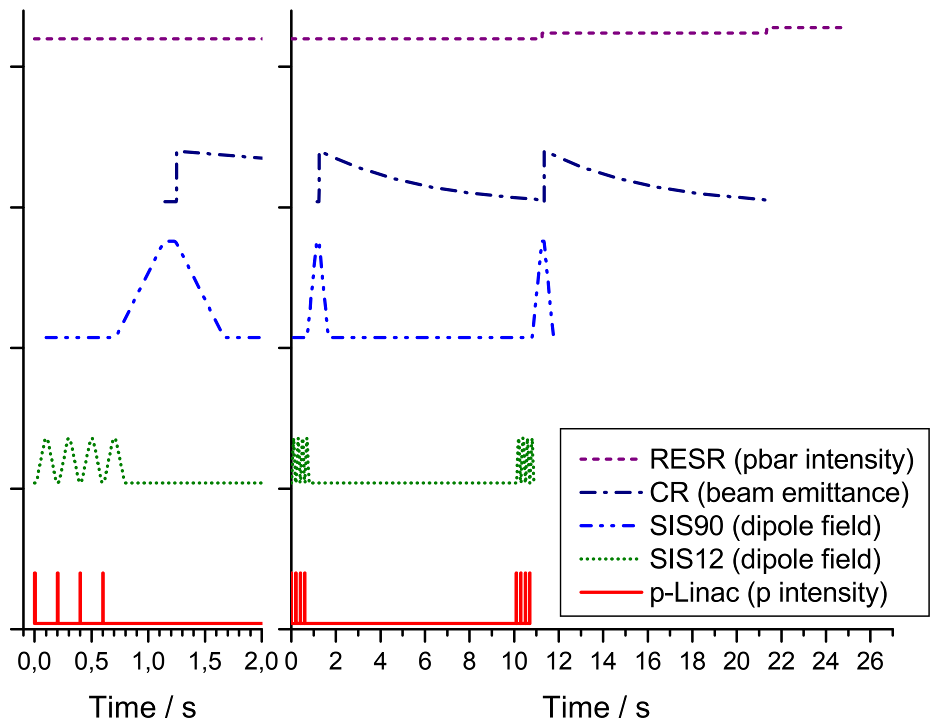

Figure 2: Operation Scheme of the FAIR facilities for pbar production.

Considering the known demands from experiments, the cycle times of the synchrotrons and storage rings, as well as beam lines and accelerators, super cycles can be defined offline, before the start of a beam time[1]. Each of these standard cycles will possibly run for hours or even days without major interruption for luminosity production runs in the experiments.

Time between two shots to refill the HESR will vary between 5 minutes and several hours; similarly Plasma Physics experiments typically need single shots every few minutes. Both will therefore not be included in the standard cycles, but handled as asynchronous beam requests. Furthermore, pulse to pulse switching between experiments will be used during set-up phases, i.e. when new experimental conditions must be implemented. Especially, it must be considered, that the set-up or fine-tuning of one experiment may run in parallel to a production run of another experiment, which must not be disturbed.

Finally, in emergency cases, a running cycle may be interrupted at any time. In those cases, the beam must be dumped, and all necessary data for a post mortem analysis of the fault which lead to the interruption have to be available. The correct settings for this emergency handling must therefore be accessible in the equipment at any time.

CONTROLS ARCHITECTURE

The system will be designed as a decentralized distributed system. Front-end layer components interface and control the installed equipment and provide network access to the equipment. Extensive timed equipment handling suggests, as in the existing GSI control system, to split the front-end in two sub layers: Equipment control, which implements the device connection and timed equipment handling, and device presentation, which models the equipment and implements the network access.

The equipment control sub layer interfaces the installed equipment to the control system. This comprises physical connections in the hardware side and device drivers in the software. Synchronized equipment handling is achieved by timing events, broadcasted by timing generators. Usage of real-time operating systems or implementation purely in hardware, assures precisely timed actions with µs reaction time jitter. In addition to actions triggered by timing events, the equipment control level must handle requests from the equipment itself, typically signaled by interrupts.

Equipment connected to the control system will be modeled as devices in the device presentation sub layer. A device is a uniquely named item, representing a component of the facility which can be regarded as independent in an accelerator physics view. For example, magnets will be devices, rather than the power supplies which feed them. Equipment extending over several components like RF generators will be combined into a single device. On the other hand equipment handling several components, like temperature sensors, will be modeled as independent devices.

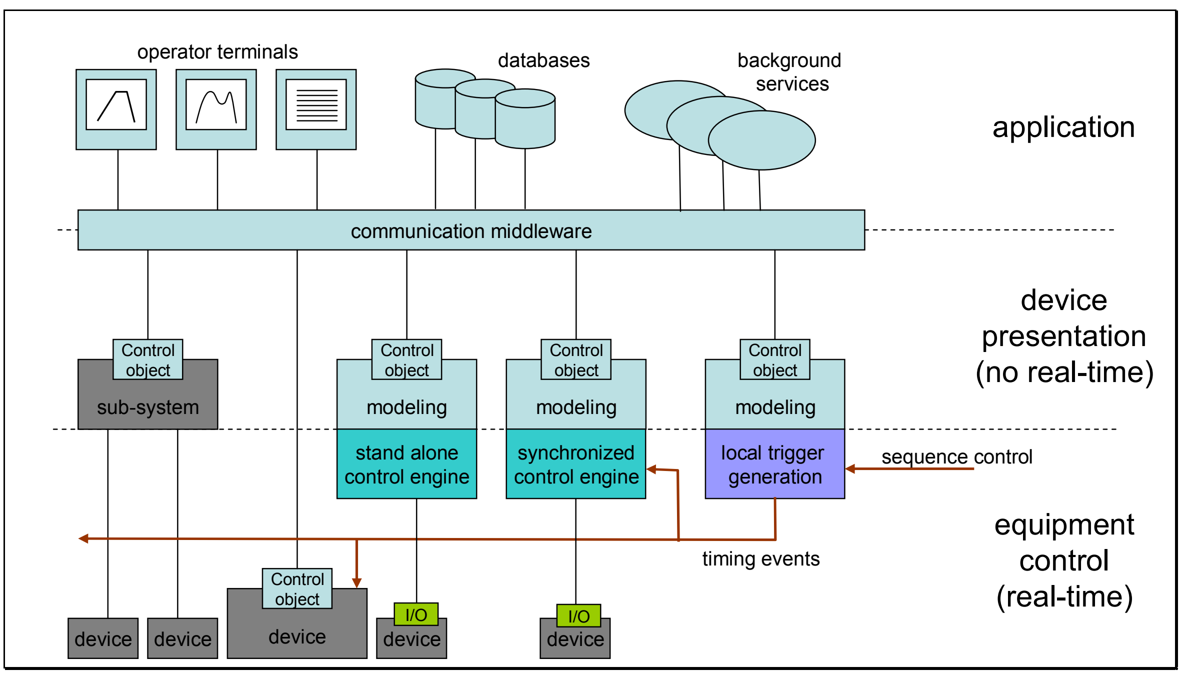

Figure 3: Architecture of the Control System.

Devices will be implemented as objects in the object oriented software terminology. They provide access to the operating level via the controls network and will be modeled by similar patterns for all devices. This allows access through identical mechanisms for all devices. A protocol, providing a high level of abstraction like CORBA, will be used. Flexible protocols will quite easily allow implementing gateways to other control systems, like industrial SCADA systems.

Since all time critical handling is done in the equipment control sub layer, general purpose operating systems can be used in the device presentation sub layer. Comfortable software tools in these systems allow even complex modeling and access schemes. It has to be kept in mind, however, that equipment control and device presentation are primarily logical layers. For cases without stringent timing requirements both layers may be implemented on the same hardware.

Devices will support several beams at a given time. Several sets of reference and actual data can be handled simultaneously, one for each of the beams configured in the accelerator facility. Switching the components settings to fit to the actual beam parameters is done in the equipment control sub layer, according to information which is distributed by the timing system.

TIMING

The interplay and synchronization of the different accelerators in conjunction with the great number of possible combinations for individual cycles in a sequence of a super cycle requires a dedicated sequence and cycle management.

The tool for setting up an operation mode will allow editing the cycles in the accelerator chain for the production of a beam. Furthermore, this tool must assist the user in finding an optimal sequence, which does not violate any applicable boundary conditions. In particular the procedures for sequencing have to foresee measures for the management of power supply loads. As an example for these caveats, simultaneous load throw-off in two accelerators must be avoided. Moreover, we have to exclude a frequency of 3 Hz in load changes to the mains power supply in order to avoid dangerous resonances in the generators of a nearby power plant. In addition it is planned to consider a test for an optimal energy and cryogenics management at the same time. Apart from the regular sequence, the cycles for asynchronous beam requests have to be defined here as well as emergency handling procedures. The predefined sequences represent possible beam production procedures in the FAIR accelerator complex.

At run time, a central sequencing unit will determine the beam which has to be produced next. Selection criteria for sequencing are for example the request status and the interlock status. Local timing generators, one for each accelerator, distribute this information and timing events for the actual cycle (see Figure 4). The general timing system also distributes central clock signals and unique time information.

Note that the underlying concept is an extension of the existing concepts at GSI allowing for a flexible beam delivery to various experiments being based on the definition of virtual accelerators and super cycles. It should however be emphasized that future parallel operation will pose new requirements on the complexity of the sequences.

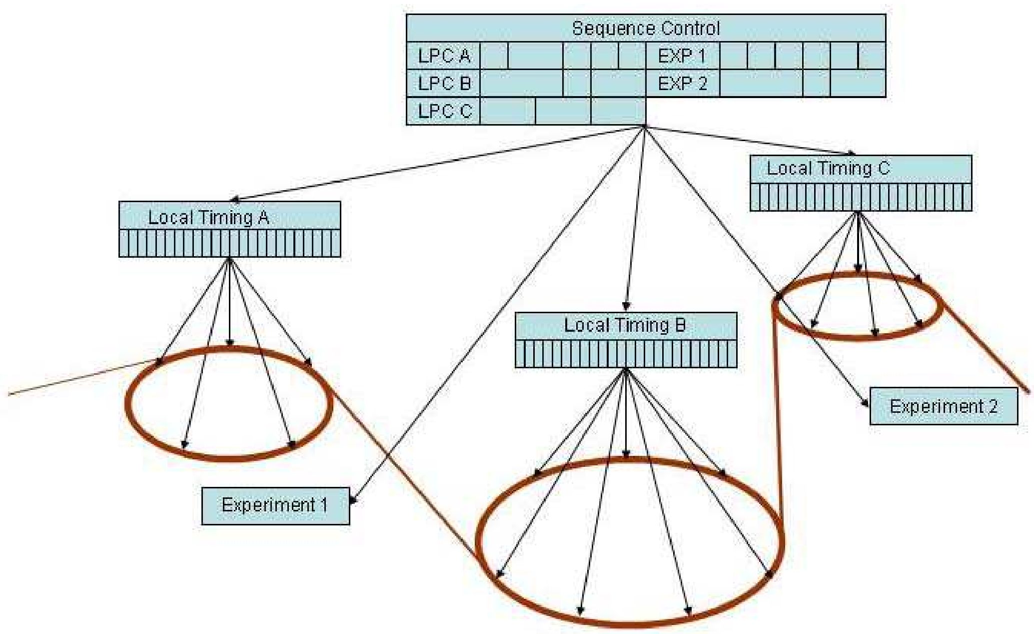

Figure 4: Hierarchical Timing Structure.

For high precision synchronization, e.g. for beam transfer between the accelerator stages, a bunch synchronous timing system will be provided. Careful selection of optical fibers and compensation of propagation delays will provide timing signals in the sub nanosecond domain, with a deviation of no more than 100 ps between any two receivers in the facility [2].

OPERATION TOOLS

For an efficient exploitation of the potential of FAIR, it is mandatory to use advanced set-up procedures in order to maximize the availability of the beams for experiments. Sophisticated modeling of the beam manipulations along an accelerator chain will allow the calculation of good initial set-values for the equipment. Further optimization of the beam quality will be supported by generic tools, which allow correcting set-values on the basis of measured beam diagnostics data.

In practice, the behavior of an accelerator during one cycle is not completely independent of the previous cycles, nor is the behavior of two neighboring rings in the same hall or tunnel. To ensure reproducibility of these cross effects, regularly repeating cycles will be run most of the time. Asynchronously inserted cycles will have to be accompanied by compensating measures to ensure the normal starting conditions for the next regular cycle.

Operating FAIR will require various services to help both operators and equipment specialists to understand the many complex situations, which will arise during commissioning or operation of the accelerator complex. The diagnosis of abnormal situations and the identification of fault states of the equipment will require a uniform global man machine interface, allowing access to the information in a coherent and well structured way. A complete beam operational history during calibration as well as runtime data of accelerators is needed to build up a long term understanding of accelerator performance.

Therefore, data management tools include a reference database for information such as the accelerator layout, optics and calibration information, etc. as well as online databases to capture the operational history.

SUMMARY

The FAIR controls will benefit from the expertise and knowledge gained at the existing facility, where parallel handling of different beams even parallel to the medical cancer treatment is successfully established. Proven mechanisms and concepts of the existing system will be used in the FAIR controls. However, an overall design will be developed to abandon restrictions from the existing system. In a second step then, it may be revised to incorporate appropriate components of the existing system.

The FAIR controls demands for much more functionality than the control system of the existing facility:

- High intensity operation enforces more precautions in beam handling. Interlock mechanisms, and set-up procedures must be defined and enforced to inhibit damage to the equipment. Other machine protection issues, like radiation hardness of electronics, have to be considered during system layout.
- The accelerator model must be extended in various ways.
- For an efficient exploitation of the FAIR facilities, a more sophisticated coordination of the accelerators will be needed. Therefore, timing and sequencing must be reconsidered.
- In practice, the behavior of an accelerator during one cycle is not completely independent of the previous cycles, nor is the behavior of two neighboring rings in the same hall or tunnel. These cross effects must be handled properly in order to enable independent tuning for different experiments.
- Parts of the new accelerator complex will be developed by external institutes as an in kind contribution. Those parts must be properly integrated in the control system. The GSI controls group must integrate and provide standards for the entire control system.

Since SIS18 will serve as injector for FAIR, its upgrade towards higher repetition rates and intensities is crucial for the parallel operation of FAIR. The aforementioned improvements concerning handling of high intensities, the accelerator model, and the sequence control will already be needed for the SIS18 upgrade.

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