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# GENERIC SETTINGS GENERATION FOR FAIR: FIRST EXPERIENCE AT SIS18

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*Abstract*

The accelerators of the FAIR facility will be operated using a new control system presently under design at GSI. One of its major components, the module for settings generation and management is based on the framework LSA developed at CERN. Its task is the provision and administration of set values for all devices in the FAIR facility. The set values for any accelerator are derived from a machine model, implemented by accelerator physicists using the features of the LSA framework. In view of the large number of accelerators in the FAIR facility, the aim is to develop a generic model, applicable to any of those machines. This requires the introduction of an additional logical layer on top of the LSA framework, ensuring the coherence of the modeling strategy across all accelerators. Following this design concept, a prototype of the FAIR settings management system has been realized at GSI, providing support for a large number of operation modes relevant for the later operation of FAIR. The prototype has been used extensively during recent machine experiments with the synchrotron SIS18, performed both to benchmark the machine model and to support further machine developments for FAIR.

## INTRODUCTION

The FAIR facility comprises ten circular accelerators and a large number of beam transport lines. The planned operation schemes require a coordinated activity of the accelerators in order to achieve a high degree of parallel operation to optimize the facility's duty cycle. Consequently, each circular accelerator must be represented by a suitable machine model parameterized in terms of the physics parameters describing the functionality of the machine. The machine models have to be integrated into the control system to allow for the calculation of set values and timing events consistent with the planned operation schemes.

The FAIR control system will employ the software framework LSA developed at CERN to implement the settings generation and management component. The machine models will therefore be implemented using the features of the LSA framework. LSA itself, as a data-driven framework, provides excellent support for the storage of data related to devices and ion optical layout of accelerators. Moreover, it comes with generic concepts for the implementation of machine models as well as algorithms for the generation, modification, and persistance of set values. However, within the limits of the framework, it is completely up to the users of the framework to choose a particular representation for a certain machine.

At CERN, this freedom has, mostly for historical reasons, led to the existence of a heterogeneous collection of machine models (basically one model per machine) employing different philosophies and using the LSA structures in different ways. In essence, this means that each model is defined and maintained by a different group of machine experts. For FAIR, we aim at creating generic machine models that can be used for any circular accelerator. This is possible since the same fundamental principles of accelerator physics apply to each ring. Special features of individual rings can then be added on top of the common structures. This strategy will greatly reduce the implementation and maintenance effort for the machine models for FAIR. In addition, the machine experts implementing the models automatically share a common knowledge about all machines, which increases the resources for troubleshooting during operation.

In this paper, we first discuss our strategy for implementing generic machine models using LSA, giving two important examples. Then, we report on recent results obtained using a prototype of the settings management system for FAIR to control the existing synchrotron SIS18.

## GENERIC MODELS

In the context of an accelerator control system, we define a *machine model* loosely as the collection of all input parameters and algorithms used to implement the calculation of hardware set values, according to the desired operation of the machine and based on a theoretical description in terms of accelerator physics equations. The input parameters of the machine model should allow the control of the accelerator in terms of physics quantities (e.g., tunes, magnet strengths, bucket size). This is particularly important in a facility like FAIR, where beams of different mass, charge states and energies are routinely produced in alternating cycles.

The LSA framework provides generic structures for implementing machine models. Physics quantities and hardware set values are represented as *parameters*. Parameters are grouped according to their *parameter type*, describing the physics category of the parameter. For instance, each quadrupole magnet has a strength value represented by a parameter of the same parameter type `KL`. A *setting* is a value of a parameter associated with a certain machine cycle. The task of the machine model is the calculation of hardware settings from the settings of the physics parameters.

The rules for calculations among the parameters are expressed explicitly in terms of *relations* between pairs of parameters, i.e., *parent* and *child*. A set of relations between parameters is called a *parameter hierarchy*. There is typically one parameter hierarchy per accelerator or beam trans-

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port section. The crucial point is now that *the algorithms for calculation of a child parameter from all its parents are parametrized over parameter types*. Such an algorithm is called a *make rule*, which is implemented as a Java class. For instance, the calculation of the current in a magnet power converter from the required integral field by means of the magnet's excitation curve is implemented as a make rule. This rule can be activated for *all* magnet power converters in the FAIR facility by simply defining the corresponding parameters and relations in the LSA database (assuming that the excitation curves can be read from the database).

In a similar, but more complex way, we can implement parts of the machine model for circular accelerators in a generic fashion. To this end, we have to make sure that, while the number of hardware devices and therefore the number of parameters will be different from ring to ring, the parameter hierarchy for each ring contains only relations between parameters of the same parameter types.

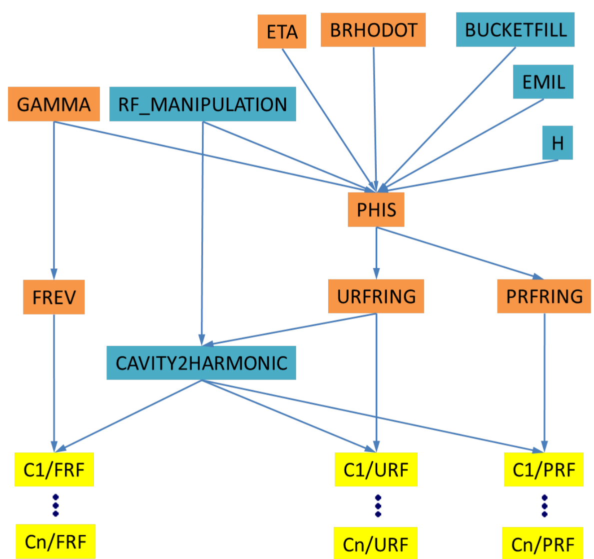


Figure 1: Generic hierarchy for multi-harmonic ring RF systems. The yellow boxes refer to the hardware set values of the cavities C1 to Cn. The remaining parameters are scalars (blue) and functions of time (orange).

An example is given by the generic hierarchy for multi-harmonic ring RF systems displayed in figure 1. This part of the ring hierarchy is supposed to calculate the amplitude, the frequency and phase set values for each cavity. The calculation requires the usual input parameters harmonic number H, longitudinal emittance EMIL and bucket fill factor BUCKETFILL as well as some kinematical quantities. In addition, the parameter RF_MANIPULATION allows to specify RF manipulations like dual harmonic acceleration, bunch merging or batch compression. The parameter CAVITY2HARMONIC represents a time dependent map from cavity to harmonic number, allowing to group and re-group the cavities according to the required harmonics in a bunch manipulation sequence. URFRING and PRFRING represent the total amplitude and phase per harmonic, respectively.

The cavity RF voltages URF are calculated by distributing URFRING per harmonic over the group of cavities operating at that harmonic. Likewise, the cavity RF phase PRF is calculated per harmonic from PRFRING by taking into account the position of the cavity in the ring.

As a second example, we show in figure 2 the hierarchy for the translation of tunes (QH and QV) into strengths of quadrupole magnets (Qn/KL). The parameter OPTICSIP is used to implement optics changes during the cycle (e.g., a change from triplet to dublet during acceleration in the synchrotron SIS18 or the introduction of a low-beta optics on the flat-top in the HESR storage ring). The calculation is based on a linear interpolation starting from a theory optics with tunes QH_THEO and QV_THEO. The corresponding quadrupole strengths are stored in the LSA database. Differences between the set tunes and the theory tunes are taken into account by the coefficients of the matrix $\partial kl_n/\partial Q_{h,v}$, evaluated with the theory optics. These coefficients are also stored in the LSA database.

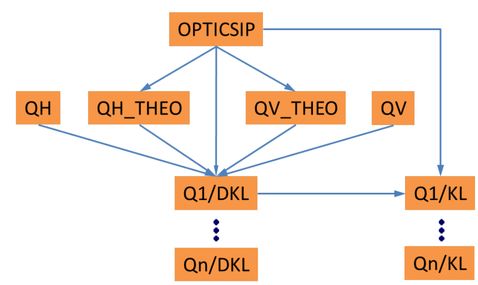


Figure 2: Generic hierarchy for the dependence of the strengths of the quadrupole magnets Q1 to Qn on the tunes. All parameters are time functions.

## EXPERIMENTS AT SIS18

In 2014, the new settings management system, despite still being in a prototype stage, was used extensively to operate SIS18 during machine experiments. Several machine development studies performed by various technical departments were only possible due to the new features implemented in the generic machine model for rings. We report here on two particular machine experiments: bunch merging studies performed by the RF group and resonance compensation studies performed by the beam physics group.

### *Bunch Merging Studies*

The new settings management system, in contrast to the present one, allows combining ramping at full speed and bunch merging on the flat-top in SIS18, because the cavities can be switched on and off sequentially (see figure 3). Thus, at the end of the ramp one cavity is always available for the first bunch merging step.

Also, the merging times are freely adjustable. This flexibility was extensively used to allow the RF department to test the performance of the bunch merging procedure as a function of the merging times. Figure 4 shows the traces

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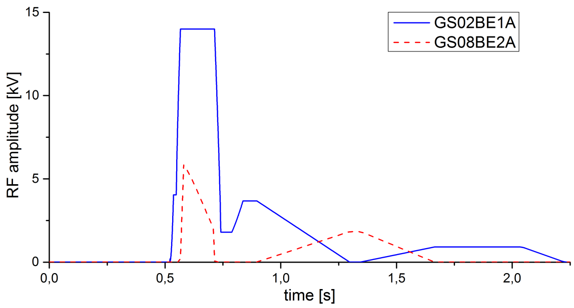


Figure 3: RF amplitudes of the two ferrite cavities in SIS18 for a cycle with two merging steps (4 → 2 → 1).

of the bunch profiles during two successive merging steps creating a single final bunch from four initial ones.

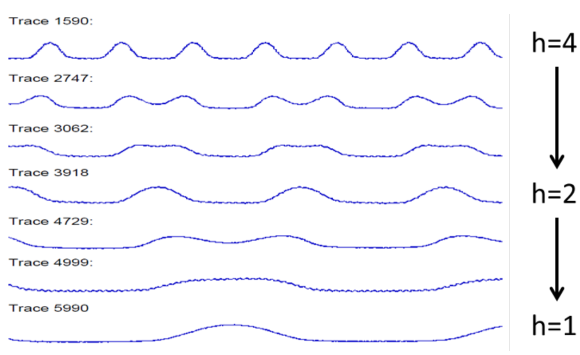


Figure 4: Measured bunch profiles during bunch merging with two merging steps (4 → 2 → 1).

### Resonance Compensation Studies

Third order error resonances are supposed to contribute significantly to beam loss after injection into SIS18 under conditions of high space charge. To mitigate beam loss, the dangerous resonances have to be compensated. To this end, a resonance compensation study was performed by the beam physics group employing a tune ramp with captured beam for various energies [1].

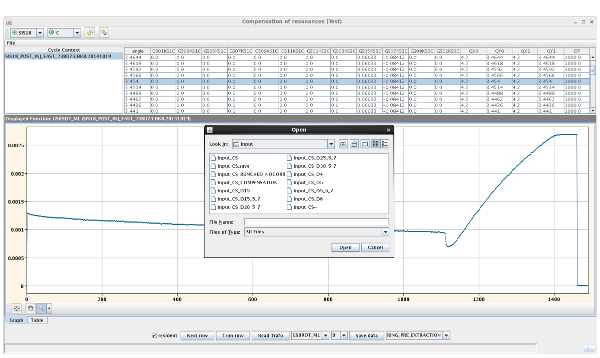

Figure 5: Application for the resonance compensation machine experiment.

This experiment required scanning the phase and amplitude of selected pairs of sextupoles over a large range in order to minimize beam loss during resonance crossing. To handle the correspondingly large number of settings and data, an application was written using LSA's Java interface to the settings as well as the JAPC interface for read-out of the current measurement. This application (see figure 5) enabled the execution of semi-automated parameter scans of both tune and sextupole strengths. The strenghts of the sextupoles as well as the horizontal and vertical tunes at the beginning and the end of a tune ramp were read from a provided CSV file. The tune settings were chosen so as to cross a single third order resonance during the tune ramp. Up to 100 settings per hour were established and the measured current data stored to the file system for off-line analysis.

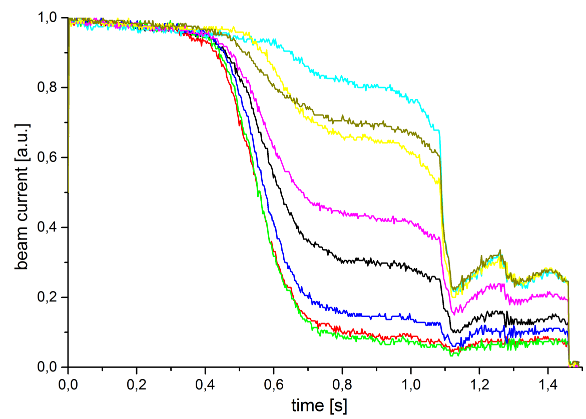


Figure 6: Beam current for different degrees of resonance compensation through variation of the sextupole strengths.

Figure 6 shows some of the recorded current readings, each curve corresponding to a different sextupole setting for a fixed tune. The smallness of the current drop is a measure for the degree of compensation of the resonance. Detailed results of the resonance compensation studies will be also presented at this conference [2].

## CONCLUSION

A generic machine model for circular accelerators has been implemented and integrated into the prototype of the settings management system for FAIR. It has been successfully employed to perform machine studies in the existing synchrotron SIS18, providing control over the machine as requested by the experimentators. The same system will soon be used for commissioning of the new storage ring CRYRING presently being installed at GSI. Starting from 2017, the new FAIR settings management system will then become the standard for operation of the GSI facility.

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