CHALLENGES OF FAIR PHASE 0*

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Abstract

After two years shutdown, the GSI accelerators, UNILAC, SIS18, ESR and the latest addition of storage ring CRYRING@ESR (CRYRING), will be back into operation in 2018 as the FAIR phase 0 with the goal to fulfill the needs of GSI/FAIR scientific community and the needs of developments of the FAIR accelerators and detectors. GSI has been well known for its operation of a variety of ion beams ranging from proton up to uranium for the research in multiple scientific areas such as nuclear physics, astrophysics, biophysics, material science. Nevertheless, the upcoming beam time in 2018 faces a number of challenges in recommissioning its existing circular accelerators with brand new control system and significant upgrade of beam instrumentation, as well as in rising failure rate of dated components and systems. As the work horse for the past two decades, the cycling synchrotron SIS18 has been undergoing a set of upgrade measures for meeting future FAIR operation, among which many measures will also be commissioned during the upcoming beam time. This paper presents the highlights of the operations' challenges in 2018 and 2019.

INTRODUCTION

While the FAIR project is in its full steam, the operations of the GSI existing accelerator complex together with the first FAIR storage ring CRYRING for serving the GSI/FAIR scientific communities will get started this summer after two-year shutdown. This is also known as the FAIR phase 0, marking the beginning of the FAIR era.

As one of the main user facilities dedicated to the heavy ion related researches ranging from astrophysics, nuclear physics, atomic physics, bio-physics as well as material science, the GSI accelerator complex comprises the universal linear accelerator (UNILAC) with multiple ions sources and pre-injectors, the synchrotron SIS18, the experimental storage ring (ESR), the fragment separator (FRS), the highly-charged ion trap (HITRAP) and the beam transport lines (HEST) to the experimental areas. Lately, another low energy storage ring CRYRING, also joined the family as the Swedish in-kind contribution to the FAIR. It is located downstream of the ESR, and has been successfully commissioned in accelerating ion beams from a stand-alone injector to its maximum energy recently [1]. Fig. 1 shows the schematic layout of the GSI/FAIR facilities.

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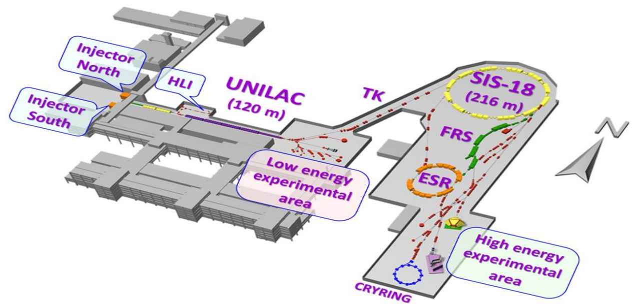

Figure 1: Schematic layout of the current GSI/FAIR accelerator complex. Ion beams from various ion sources are accelerated by the UNILAC, and then are injected into the SIS18 to be accelerated to a maximum rigidity of 18 T-m. The accelerated beam from SIS18 is delivered to various target stations, as well as the ESR via either slow or fast extractions. The HITRAP is designed to study the bare heavy nuclei or heavy nuclei at very low energies. Capture of 6 keV/u ions has been demonstrated [2], and the full commissioning will be carried out during the operation of FAIR phase 0.

Table 1 lists the core capabilities of the GSI/FAIR accelerator complex. The call for beam time proposal to the GSI/FAIR scientific community was responded very enthusiastically. The total requested shifts significantly surpassed the planned beam time. Hence, for the beam time 2018 and 2019 of FAIR phase 0, only the top rated proposals are granted with the beam time.

OPERATION CHALLENGES

In addition to providing reliable beam time for a variety of experiments with nominal beam performance as shown in Fig. 2, the operation of 2018-2019 also bears a set of goals for commissioning the upgrade measures for future FAIR facilities and operation, such as

- commission the FAIR controls in the existing GSI accelerators,
- commission the SIS18 upgrade measures for the FAIR operation [3, 4],
- re-establish the full capabilities of the ESR with the FAIR controls,
- complete the commissioning of the CRYRING and the HITRAP with beam from ESR,
- continue the accelerator and detector R&Ds for the future FAIR operation, such as the high intensity uranium ion source development for future SIS18 2.7 Hz operation [5].

Table 1: GSI/FAIR Accelerators

Accelerator	**ions**	**Energy range**	**core capa--bilities**
UNILAC	p to U^{28+}	11.4 MeV/u	SIS18 injector, ~25% duty cylce operation for experiments
SIS18	p to U^{28+}	up to 18 Tm	heavy ion synchro-tron, SIS100 injector
FRS	p to U^{92+}	up to 18 Tm	high resolution mass spectrometer production, and separation of exotic nuclei
ESR	p to U^{92+}	up to 10 Tm	store & cool ion beams, both stable and RIBs fast/slow extraction, Isochro--nous mode
HITRAP	up to U^{92+}	5 keV for $A/Q < 3$	highly-charged ion trap
CRYRING	up to U^{92+}	up to 1.4 Tm	further decelerate heavy ions from ESR

			UNILAC		SIS18	
Projectile	Charge	Isotope	Average particle current	MAX Rep rate*	Nominal Intensity (per Cycle)	MAX Rep Rate (fast extraction)
U	73	238			2,00E+09	1Hz
Pb	67	208			1,00E+09	0,5Hz
Au	65	197			1,50E+09	1Hz
	26		0,1 pμA	50Hz		
Xe	48	124			2,00E+09	1Hz
Ag	43	107			1,00E+09	1Hz
Ti	22	50			2,00E+08	1Hz
	12		0,8 pμA	50Hz		
Ca	20	48			5,00E+08	1Hz
	10		0,8 pμA	50Hz		
Ar	18	40			3,00E+10	1Hz
O	8	18			5,00E+10	1Hz
	3	16/18	1 pμA	50Hz		
N	7	14			7,00E+10	0,35Hz
C	6	12			4,00E+09	1Hz
	2		2,4 pμA	50Hz		
H	1				8,00E+10	0,1Hz

Figure 2: Nominal beam performance of GSI/FAIR beam time 2018-2019.

The control system for the FAIR accelerators is designed in the framework of proven architecture and technologies such as white rabbit for the timing and communication, Front End Standard Architecture (FESA) for the control of devices, LHC Software Architecture(LSA) for the software of accelerator operation controls [6]. It consists of the equipment layer and application layer with the middle layer as shown in Fig. 3.

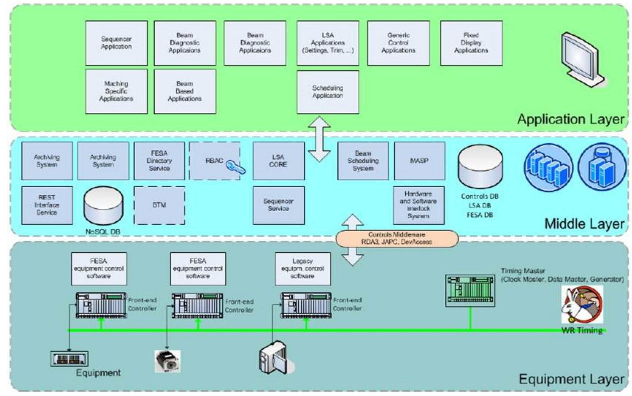

Figure 3: Architecture layout of FAIR control.

Even though the main elements are proven technologies, adapting and implementing them to the existing GSI facilities is not straightforward. Especially, most of the infrastructure and interfaces were based on dated technology. Hence, the step-wise approach with commissioning a reduced function controls at the CRYRING has been successfully carried out to proof the design and iron out technical issues [1].

During the upcoming beam time, the full functionality of the FAIR controls is expected to be commissioned for the operation of SIS18 and the HEST. Nevertheless, re-establishing the full ESR capabilities such as

- store the ion beams from SIS18, as well as radio-isotope beams from FRS for in-ring experiments
- re-establish cooled beams with both stochastic and electron cooling
- accumulation of secondary beams
- decelerate the cooled ion beams (indispensable for CRYRING and HITRAP)
- re-establish the slow extraction for the fixed target experiments, as well as the fast extraction for CRYRING and HITRAP

while its new controls are commissioned at the same time is particularly challenging.

As a heavy ion storage ring, the ESR is featured with cooled beams and a diversity of operation modes to fulfil a variety of physics requirements. Together with the HITRAP and CRYRING, significantly decelerated ion beams can also be available for low energy physics programs. To achieve this, it is essential to re-establish the deceleration in the ESR. The deceleration of highly charged heavy ion beams in the ESR was established over a decade ago. Figure 4 shows a typical procedure of decelerated beam in the ESR [7], where three phases are visible. The ion beam is first injected in the ESR, gets cooled and accumulated. Then, the beam is decelerated to an intermediate energy between 30 MeV/u and 50 MeV/u with the electron beam in the electron cooler off. At this stage, the beam is then cooled again by the electron cooler to make sure it fits the available aperture. The beam can then be further decelerated to the desired energy. In the Fig. 4, the intermediate beam energy was 25 MeV/u and the final beam energy was 15 MeV/u due to the limitation

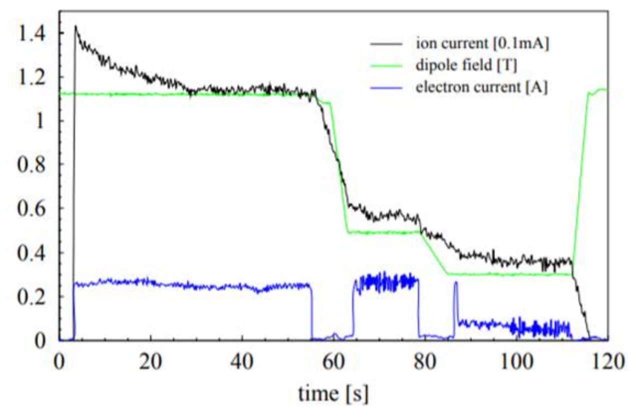

Figure 4: A typical cycle of the ESR deceleration.

of the RF cabability [7]. The design goal of deceleration to 3 MeV/u was later on demonstrated after the rebunching from harmonic 2 to harmonic 4 in the ESR [8].

Unlike the acceleration, the beam emittance grows during deceleration, at the same time beam is also getting more sensitive to various perturbations and imperfections. Both beam cooling and careful tuning of the machine settings are required to minimize the beam losses during the deceleration. Hence, it is necessary to be able to control the ESR independent of the SIS18 after it receives the beam from the SIS18. Such capability in the controls is also essential for all in-ring experiments whose success relies exclusively on its own specific setting of the ESR, which often requires various high precision manipulations of the stored beam.

While SIS18 is looking forward to commission its fast acceleration rate of 10 T/sec for demonstrating the 2.7 Hz operation mode of FAIR in the upcoming beam time, it also faces an additional challenge in improving the quality of the slow extracted beam for the experiments that are sensitive to the spill structure. Due to various limitations, the quality of the spill has suffered the flatness of the spill rate as function of time (a.k.a macro structure), as well as the micro structure within a spill [9]. The later one forces the detectors to be configured at lower efficiency and results in loss of integrated luminosity for the corresponding physics program [10].

Lately, there has been a lot of progress made in improving the macro spill structure with cycle-to-cycle feedback of the key variables of the slow extraction [11, 12]. However, the cause of the micro spill structure has not yet been pinned down. Nevertheless, encouraged by the experience from the BNL AGS and Booster slow extraction operations [13, 14], a dedicated RF cavity operated at a much higher harmonic has been planned to be installed in the SIS18 to verify the mitigation of the micro spill structure.

In addition to the above challenges, the operation also faces increasing failure rate of many aged parts and components of the existing accelerators in particular UNILAC. To carry out the parallel operation mode within the reduced operation time in order to minimize the impact on the FAIR project progress is also non-trivial. Hence, the operation of this first two years of FAIR phase 0 faces many challenges.

CONCLUSION

In summary, the upcoming operation of the FAIR phase 0 marks the significant step towards the FAIR era. Continuing the operation with the exisiting GSI accelerator complex together with the CRYRING will not only ensure the GSI/FAIR scientific research communities remain vibrant in the corresponding fields worldwide, but also significantly benefits the developments of the accelerators and detectors. Last not the least, this also provides the talented young generation the opportunity to be trained and gain experience for future FAIR operations and challenges.

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REFERENCES

[1] F. Herfurth *et al.*, in *Proc. 11th Workshop on Beam Cooling and Related Topics (COOL'17)*, Bonn, Germany, `doi:10.18429/JACoW-COOL2017-THM13`, 2018.

[2] F. Herfurth *et al.*, *Phys. Scr.* (2015) 014065.

[3] P. J. Spiller *et al.*, in *Proceedings of EPAC2004*, Lucerne, Switzerland, paper TUPLT020, 2004

[4] M. C. Bellachioma *et al.*, *Vacuum* 82 (2007) 435-439.

[5] R. Hollinger *et al.*, GSI Scientific Annual Report 2017

[6] R. Huhmann *et al.*, in *Proceedings of ICALEPCS2013*, San Francisco, CA, USA, paper MOPPC097, 2013.

[7] M. Steck *et al.*, in *Proceedings of EPAC2000*, Vienna, Austria, paper MOP4B06, p. 587, 2000.

[8] M. Steck *et al.*, in *Proceedings of EPAC2004*, Lucerne, Switzerland, paper TUPLT016, 2004

[9] R. Singh *et al.*, presented at IPAC2018, Vancouver, BC, Canada, paper WEPAK007, this conference

[10] J. Stroth *et al.*, HADES Status, GSI/FAIR beam time retreat 2018.

[11] R. J. Steinhagen *et al.*, in *Proc. IPAC2017*, Copenhagen, Denmark, `doi:10.18429/JACoW-IPAC2017-TUPIK046`, 2017.

[12] B. R. Schlei *et al.*, in *Proceedings of IPAC2017*, Copenhagen, Denmark, `doi:10.18429/JACoW-IPAC2017-TUPIK045`, 2017.

[13] J. Glenn *et al.*, in *Proc. of PAC1999*, New York, NY, USA, Vol. 2, pp.1258-1260, IEEE, 1999.

[14] K. Brown *et al.*, in *Proceedings of EPAC2004*, Lucerne, Switzerland, paper TUPLT179, 2004.