Overview of the status of the FAIR project

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The remarkable progress in the FAIR project reached its preliminary highlight on July 4th, 2017, when the ground breaking ceremony for the Area North took place with a wide internal and external audience (Figure 1). Immediately after the ceremony the site works for the excavation of the tunnel 110 have started. All preparatory works for the Area North (SIS100 tunnel and CBM cave) are on target schedule.

Parallel to the work on the FAIR civil construction, all connection tasks between the GSI premises and the FAIR site (Gebäude Anbindung FAIR, GAF), as well as the enhancement of the SIS18 shielding and the construction of the main transformer stations North and South were under execution by end of 2017.

The rework of the project planning was finished late 2016 resulting in an integrated master time schedule with all three areas, Accelerator, Civil construction and Experiments integrated. The progress of the project is continuously monitored against this newly defined baseline. In addition, a new risk management was established, which will be common for GSI and FAIR.

The status of the accelerator and experiment projects is detailed in the following sections. Progress on accelerator design and procurement is described first, followed by short reports on civil construction works for the FAIR project and on the major experimental projects.

FAIR accelerator subprojects

The status of the subprojects SIS18, SIS100, Super Fragment, Separator, Proton-Linac and p-bar Target, Collector Ring, High Energy Storage Ring and the cross functional topic Commons is described in the following overview.

SIS18

The goal of this subproject is enabling the existing synchrotron SIS18 to function as injector of the FAIR accelerators, which requires a major upgrade of SIS18 and civil construction measures to connect the GSI facilities with the future FAIR buildings, GAF.

The completion of the latter is an important precondition for SIS18 recommissioning and operation in 2018. The major part of the construction works serve the purpose to enhance the shielding of the SIS18 tunnel. For this purpose a table construction over SIS 18 has been designed, which finally will carry the additional shielding material. The table pillars are installed, and the outer

Figure 1: From the left: Paula Eerola (Finland), Catarina Sahlberg (Sweden), Albin Kralj (Slovenia), Fan- ny Farget (France), Pascal Debu (France), Beatrix Vierkorn-Rudolph (Germany), Viacheslav Pershukov (Russia), Dr. Georg Schütte (Federal Ministry of Research, Germany), Rakesh Bhandari (India), Zbigniew Majka (Poland), Ionel Andrei (Romania), Eric Seng (Hessian Ministry of Science), Sibaji Raha, Chairman of the FAIR Joint Scientific Council, Professor Sebastian Schmidt (Management Board member of Forschungszentrum Jülich), Ursula Weyrich, Paolo Giubellino, Jörg Blaurock (all: FAIR Management Board)
The original scope of the GAF project was extended during the start-up phase in order to include the construction of the SIS18 interface to the FAIR Proton Linac building. A cost-effective solution was developed which facilitated the earlier construction. Therefore, the SIS18 ground works have been extended to the UNILAC-SIS18 transfer tunnel. Until March 2018 the Proton Linac beam dump on the eastern side of the transfer tunnel and the modification of its western wall to allow for the tunnel into the FAIR Proton Linac building (Figure 2) will be finalized.

The power converters which will provide the power grid and power supplies of SIS18 are placed on "Freifläche Nord". It is essential that the new transformer station is completed before the start of the recommissioning of SIS18. The manufacturing of the big new pulse transformers, which will be installed in this area, is finalized and the transformers have been delivered end of 2017. The site preparation and the groundworks for the transformer station are progressing well. The setup of the underground cable duct between the new transformer station and the GSI campus, guiding the new 20kV cables has been completed.

On the Eastern side of the GSI campus the interface to the new FAIR accelerator complex has been set-up. The outer concrete wall of the experimental hall has been opened and the link to the FAIR tunnel 101, which will contain the extraction beam line out of SIS18 towards SIS100, has been built (Figure 3).

It is expected that all activities within the GAF project and the FAIR construction relevant for SIS18 operation in 2018 will be finished in time for the planned beam time. In parallel to the civil construction activities, the upgrade of the SIS18 accelerator has been continued. Major new components are in the final phase of manufacturing. The new large bipolar dipole magnet, deflecting the SIS18 beam towards the FAIR tunnel 101, has been manufactured by the company Danfysik and was delivered. The production of the dipole magnet chamber has just been awarded and the IPM (ionization beam profile monitor) magnet system was built and approved by a factory acceptance tests (FAT), before being delivered.

Due to the building displacements generated by the ongoing construction, the accelerator facility needs to be realigned beginning of 2018. Already in 2017, first dry runs with the new control and timing system have been performed.

**SIS100**

The series production of the SIS100 superconducting dipole magnets has started (Figure 4). The first of series magnet was delivered in September/October 2017. First acceptance tests, especially addressing the precision of the geometry of the internal magnet aperture, indicate a very high manufacturing accuracy which lies within the specified limits. The preparatory works for the series testing at the Series Test Facility (STF) at GSI are continuing. In collaboration with CERN, the set-up of a cold rotating field probe has been completed. All high temperature superconducting current leads for the Series Test Facility have been delivered and accepted. While carrying out the site acceptance tests, three dipole magnets will be tested in parallel. The cold testing process for each dipole will last four weeks.

![Figure 2: Construction works for the interface of the Proton Linac building](image2)

![Figure 3: Construction works for the interface to the FAIR tunnel 101.](image3)

![Figure 4: Yoke manufacturing for the series dipole magnets](image4)
The first two FOS (First-of-Series) quadrupole doublet units, comprising two superconducting quadrupole magnets, a superconducting steerer- and a sextupole magnet have been tested successfully at JINR Russia.

A dedicated test facility for superconducting magnets of FAIR and NICA has been set-up at JINR and was taken into operation with an official ceremony in November 2016.

One of the largest procurements of the subproject SIS100/SIS18 is the integration of the quadrupole modules, which comprises the design and production of the cryostat system. A producer was found and the contract is signed.

The major design initiative for the quadrupole modules and the so-called missing dipole modules (MDP) is almost finalized. The design of these modules has been performed by an industrial partner. There are still changes in the design of some subcomponents; therefore, the overall set of manufacturing drawings for the modules will be finalized in the GSI design office.

A First-of-Series acceleration radiofrequency (RF) cavity has been manufactured and commissioned. The cavity has reached the specified gap voltage over the complete frequency range. The formal factory acceptance tests are in preparation.

The production of the series of bunch compression cavities could be launched. A delay at the company, which produces the power converters for the cavities, could be mitigated. It has been agreed that the First-of-Series power converters will be directly installed and commissioned on site of the provider of the cavities. The installation of the first power converter is scheduled for January 2018.

One still unresolved technical issue is the insulation of the cooling pipes of the cryogenic vacuum chambers. To investigate the cooling properties achieved by using different bonding technologies, a number of model chambers have been manufactured by a company. The chambers have been installed in the First-of-Series dipole magnet, where temperature and pressure measurements have been conducted. The temperature measurements have shown that the desired surface temperatures below 15 K can be reached. However, the ceramics insulation still cracks after the thermal cycle. Therefore, new tests are planned with cooling pipes equipped with an enamel coating.

The procurement and production of several other components of the SIS100 UHV system is progressing well. Among others, the order for the cryogenics adsorption pumps has been placed and after successful First-of-Series production, the series production has been launched.

Design and tests of beam instrumentation components are converging. Several items of the beam instrumentation system could be ordered and have been delivered already, e.g. the ring cores for the beam transformers, beam loss monitors and other items. The tendering process for the cryogenic beam position monitors has been completed and the contract was awarded.

The components of the local cryogenic system of SIS100 which will distribute liquid helium to the different accelerator components, are designed in WrUST (Wroclaw University of Science and Technology), Poland. The cryogenic system contains one of the most critical parts with respect to engineering demands: the cryogenic bypass line. A first part of the bypass line, containing the He transfer system and the superconducting bus bar system, has been manufactured and delivered to GSI. In a site acceptance test, which has been conducted at the Series Test Facility, this First-of-Series device was verified (Figure 6). In parallel, the design of the current lead box has been developed up to a full 3D model.

Super Fragment Separator

In 2017 the Production Readiness for the short superconducting multiplets (July 2017) as well as for the long SC multiplets (December 2017) was achieved. The production of the First-of-Series (FoS) short SC multiplet was started. All major subcomponents are produced. The Factory Acceptance Test (FAT) of this multiplet is foreseen before summer 2018. Afterwards the multiplet will be shipped to the test facility at CERN.

The tendering process to procure the required 21 standard superconducting dipole magnets for Super-FRS was initiated in April 2017. After a company qualifying round and two rounds of negotiations the Spanish company ELYTT was awarded with the contract. ELYTT will first verify the already existing magnet design and then produce a First-of-Series (FoS) magnet (Figure 7) which is expected to be ready in autumn next year.
As part of technical collaboration agreement with CEA Saclay a design study for three branching superconducting dipoles is performed. Compared to the standard dipoles these magnets require an adapted yoke and cryostat design in order to provide an additional straight beam exit to connect the different branches of Super-FRS. The kick-off for this project was in June 2017 and a preliminary design (see dedicated contribution to this report) was already presented in December 2017. It is expected that the design will be completed until summer 2018.

The specifications for the normal-conducting dipoles in the target area have been approved. Currently it is investigated whether the package can be carried out by BINP in Novosibirsk as potential in-kind. The First-of-Series prototype has been developed and built there. In parallel FAIR tendering documents are being prepared and the start of the construction of the remaining two dipoles is expected latest beginning 2019.

The conceptual design of the target chamber is ongoing together with our collaboration partner KVI-CART. The remote guidance of the up to 4.5 tons heavy plug inserts into the chamber was identified as a crucial operation. Thus a full scale mock-up of the target wheel plug was built and the operation could be successfully verified.

Late April 2017 CDR draft documents for the beam catcher, including the recommendations by the 16th MAC, have been received by CMERI Durgapur, India. This was followed by an exchange of information on the necessary remote handling methods this summer.

For the shielding flasks we aim at a combined procurement (tender and in-kind via HIP Finland) with the p-bar subproject in a common working group. The specifications for the Super-FRS transport flask are progressing. In collaboration with the Paul Scherrer Institute (PSI) in Switzerland, a potential subcontractor for HIP has been identified as KVI-CART. The specifications and documents for both packages will be finalized within 2018.

The interfaces to the hot-cell as far as construction planning for the building shell is concerned have been completed, and a study together with SiemensKamp Nukleartechnik GmbH on inserts (doors, lead window frames, crane supports, etc.) to the concrete shell has been carried out. This study will be followed up by another one specifying the details of the installations in the hot-cell.

**Proton Linac**

Previously, the finalization and commissioning of the p-Linac was not expected to be earlier than 2025, which might have put at risk the HESR and PANDA commissioning. Therefore, the construction of the p-Linac building was re-evaluated and subsequently rescheduled to an earlier date. The p-Linac will deliver beam already in 2023. The extended design documentation and costing has been finished in August 2017.

The proton source built at CEA is close to completion. Commissioning has been started; a current of 70 mA has been achieved, which is close to the design value of 100 mA already. The construction of the low energy beam transport (LEBT) is in progress. Additional power supplies procured by GSI are sent to CEA.

The contract with French collaborators from CNRS is signed. All seven klystrons provided by CNRS passed the Factory-Acceptance-Tests successfully and are delivered to GSI. The production of the First-of-Series modulator is in progress. This is done in-house, which has proven to be the most cost effective approach.

After the very successful power radiofrequency tests of the heavy RFQ prototype, the design of the full size RFQ, which is done at IAP Frankfurt by the group of Ratzinger, is completed and the production has started. A part of the RFQ tank has been successfully copper plated at GSI.

The layout of the CH and CCH cavities is finished. The production of the internal quadrupole triplet is ongoing.

**P-bar target**

Simulations for target, collimators and beam dumps (for HEBT and APPA as well) are in progress. For this purpose, an ANSYS (Multiphysics finite elements code) working group has been established in collaboration with the Technical University of Warsaw. An experiment at the HiRadMat facility at CERN is in preparation. It is planned to test the mechanical stability of different potential materials for the pbar target and to perform a benchmarking of the simulations. The work on the target station and the alignment system for the beam, a magnetic horn, is progressing.

Together with the Super-FRS team a working group for transport of the highly activated targets to hot cells has been established in order to use synergies for the construction of the shielding flasks and target handling systems.

**Collector ring CR**

A contract with BINP on the production of the last un-assigned CR components is under preparation. Work on the remaining specifications is ongoing.

A prototype vacuum chamber will be constructed and tested at BINP in order to check the feasibility of the technical concept for the vacuum system according to the MAC recommendations. The technical design of the pro-
totype chamber is finished. The production started already.

Facility-Acceptance and Site-Acceptance-Tests of the First-of-Series of the CR debuncher have been successfully completed. The device fulfils the specifications and was formally accepted. The series production was started already.

The acceptance tests of the First-of-Series of the CR stochastic cooling power amplifier failed. The RF module was redesigned and a new Facility Acceptance Test has taken place, while engineering activities for the pick-up tank and RF signal processing of the stochastic cooling system are ongoing.

**High Energy Storage Ring HESR**

The components with the longest delivery times for the HESR, dipoles and quadrupoles were delivered completely to Jülich and were technically approved. Half of the dipole magnets were pre-assembled with vacuum chambers in Jülich and delivered to Darmstadt for interim storage.

All other essential components are in production or series production and will be delivered to Jülich by the end of 2018. After pre-assembly, these components will also be transported to Darmstadt by mid-2019.

**Commons**

The status report for the subproject Commons follows the major technical systems used in the other subprojects:

**Magnets**

After the pre-series of batch1 (51 dipole magnets) was successfully completed in February 2017 (one dipole magnet of type dip1s_0 and one of type dip13_0), the series production of the rest of the dipole magnet is under way. After having passed the Factory-Acceptance-Test (FAT) at Efremov Institute of Electrophysical Apparatus in St. Petersburg, Russia (NIIEFA) the magnets are shipped to GSI. Shipment of the series magnets started in August 2017 (Figure 8). In total 7 series magnets of type dip1f_0 and 5 series magnets of type dip13_0 underwent successful FAT at NIIEFA and were delivered to GSI until December 2017.

The magnets of batch2 and 3 (22 dipole, 166 quadrupole, 92 steerer magnets) will be built by the Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia. While most of the magnet types are currently in the final design phase, production of yokes and coils of the standard 18Tm quadrupole magnet quad2 and the 100Tm steering magnet s100 has already started, see (Figure 9 and Figure 10). The FATs of the pre-series magnets of these types are re-scheduled for March 2018.

Efremov Institute launched stamping of the laminations for dipole magnets of batch2 and 3 having identical yoke cross section like the dipole magnets of batch1 in March 2017. Initially 11400 laminations were stamped and were delivered to BINP, see Figure 11. The first magnet to be built from these laminations is the pre-series magnet of type dip13_0. Stamping of another 8000 lamination of the same type is currently in progress.

**Power converters**

The power converters for High Energy Beam Transport quadrupole and steering magnets will be mainly built by the Indian company ECIL (Electronics Corporation of India Limited). Up to now two contracts between FAIR, the Indian shareholder BOSE institute and the provider ECIL comprising in total 196 power converters for HEBT (152 for quadrupole and 44 for steering magnets) have been signed. The Factory Acceptance Test (FAT) for the first series of power converters is scheduled for March 2018 after solving problems in the manufacturing process.
Beam instrumentation

The day zero beam instrumentation of the HEBT lines foresees resonant transformers (RT), fast current transformers (FCT), and particle detector combinations (PDC) for intensity measurements and secondary electron emission grids (SEM-Grid), multi-wire proportional chambers (MWPC) and scintillator screens (SCR) for the determination of the transverse beam profile. After prototypes of all these instruments were tested successfully during the GSI beamtime 2016 and passed all tests, procurement, production and assembly of many components of the series were started.

During a visit at Bergoz Instrumentation in France on May 3rd – 5th 2017, the FAT (Factory Acceptance Test) of all current transformers for the FCTs was successfully completed (Figure 12) and all detectors were delivered to GSI on May 16th, 2017.

The order to produce 25 vacuum chambers with a ceramic gap for RT/FCT (Figure 13) was awarded to the German company FMB Feinwerk- und Meßtechnik GmbH. The First-of-Series (FoS) chamber was produced in February 2018. Production and Tests of the complete series will be completed in 2018.

Data acquisition and expert control applications were implemented, which are based on the FESA framework developed at CERN (Front-End Software Architecture). Progress was especially achieved with the integration of data acquisition modules into the White Rabbit Timing Network, resulting in precise triggers and timestamps for data acquisition and analysis. A major part of the data acquisition has already been tested in a production environment using the CRYRING accelerator.

Several subprojects which are carried out with the Slovenian in-kind partner Instrumentation Technologies: the DAQ for the beam position monitors BPM of the high energy beam transport system HEBT was delivered in January 2018 and the design of the BPM pre-amplifier are finished and Final Design Reviews (FDR) took place. The board layout for pre-amplifiers was approved, prototype and series were produced, and delivery to FAIR already took place.

Moreover, the Slovenian in-kind partner VacuTech will start the production of the pneumatic drives in this year.

Vacuum chambers

The vacuum chambers for the dipole magnets of batch1 will be built by BINP. The Factory Acceptance Test (FAT) of the first two pre-series vacuum chambers took place in May 2017 (Figure 14). After giving the allowance for the delivery, the two chambers were shipped to FAIR/GSI on 7th of August 2017 for the Site Acceptance Test (SAT).

Power connection to FAIR

An intensive collaboration between the technical department EPS, FAIR S&B and the energy provider e-netz took place in order to design and construct new transformer station for the FAIR and GSI accelerators. The orders of four main items (buildings, transformers, high voltage cables and 20 kV switchgear) were placed in April 2017. The construction of the new FAIR transformer stations North and South are progressing within plans. Shell construction works on the FAIR transformer station North for the switch gear-building, the transformer foundations with oil pits, and the foundations for the HV-circuit breaker are completed (Figure 15).
Factory-acceptance-tests of the new transformers took place successfully in Balikesir/Turkey (see Figure 16 and Figure 17). The delivery of the new transformers has started. The work on the transformer field north base started in February 2017 and has been finished beginning of 2018.

Power converters Cables and Machine cable management

The new work package (2.14.1.10) “Machine cable management” will provide the best possible cable data quality to the planners, using the cable database for the collection of this information. Later on, this information will be used for the cable routing and the procurement processes. A first complete list of cables (total numbers of cables: 43,400) was given to FAIR S&B in November 2017.

Together with FAIR Site & Buildings, the specifications for the procurement and cable-laying were developed so that a specification of services will be compiled end of 2018.

Cryogenics:

The technical department Commons Cryogenics (CRY) is responsible for the GSI and FAIR wide cryogenic helium cooling of superconducting magnets. CRY is presently operating a prototype test facility (PTF), a series test facility (STF), a helium supply unit (HeSu) and two more cryo plants for the R3B GLAD magnet testing and for the cooling of the CRYRING electron cooler solenoid. The main customers at FAIR are the SIS100 and the Super-FRS with a total helium inventory of about eight tons. Additionally CRY serves small consumers like the final focusing system of APPA and the large scale experiments CBM/HADES and Panda. Furthermore the department is responsible for the so-called local cryogenics belonging to SIS100 and Super-FRS respectively.

Helium Supply Unit (HeSu)

The HeSu is a liquefier with a decant station, a mobile Dewar parking station and a warm gas recovery system with campus wide helium return lines. The HeSu was taken into operation in 2015 and has delivered more than 49,000 l of LHe to users onside the campus so far.
main purpose is the cryogenic testing of FAIR prototypes. It has a liquefaction capacity of approximately 25 l/h for pure helium gas and 17 l/h in purification mode. A picture of the installation is shown in Figure 18. The warm gas storage capacity was upgraded by additional 30 m³. Part of the HeSu project was a universal cryostat for the testing of FAIR components, in particular SIS100 beam pipe vacuum chambers. The universal cryostat has a more than 4 m long cold testing area with an actively cooled table. A picture of the universal cryostat is shown in Figure 19. The big side flanges can be operated by one single person crane support. Several different cooling techniques are realized: (a) LN2 shield cooling and LHe 4 K cooling with Dewars (using the HeSu), (b) LHe cooling only, with a boil-off cooling of the shield using again Dewars, or (c) connection to the universal connection box of the STF, see below in Figure 19.

Cryogenic Infrastructure for the Series Test Facility (STF)

The series test facility for SIS100 dipole serial magnet testing was taken into operation in 2015 and continuously running in 2016 and 2017 for the testing of the first of series (FoS) dipole magnet, but additionally for the test of the SIS100 main current leads, for the SIS100 local current leads, for SIS100 cryo adsorption pumps and for the site acceptance test (SAT) of the first parts of the local cryogenics for SIS100 arrived at GSI in summer 2016. The serial testing of the dipole magnets was started in 2017. The STF has an overall cooling capacity of 1.5 kW @4K equivalent and is equipped with four test benches for magnet testing and one universal connection box. Up to now the plant has about 15,000 h of operation. A picture of the STF cryogenic infrastructure is shown in Figure 20.

Figure 20: The GSI series test facility

Procurement of the FAIR Cryo Plant CRYO2:

For FAIR one central cryo plant will be installed serving a helium cooling capacity for SIS100, Super-FRS, CBM and HADES. In the first step a 19 kW @ 4 K equivalent cryo plant will be installed, including a campus wide 1.6 km long distribution system. Two industrial studies concerning the cryo plant layout were performed in 2014 and afterwards the specification was continuously adapted to future user requirements. The procurement phase is currently ongoing: After specification was approved, the budget was released and the official announcement has taken place in October 2017. According to the present time schedule the contract with the manufacturer will be signed in September 2018 and the plant installation will take place in the second half of 2021 followed by the commissioning performed until the end of 2022.

Cryogenic Infrastructure for the GLAD Magnet:

For the testing of the GSI GLAD magnet, which will be later a central component of the high energy branch of the SuperFRS, the cryogenic department has refurbished an existing cryo plant. The refurbishment comprises a complete check of the hardware, the replacement of a large number of actors and sensors, a complete new electronic cabinet and state of the art control software using the CERN industrial control software environment UNICOS in combination with Siemens WimCC OA. The GLAD magnet was cooled down for the first time in 2017.

Control Systems (CO)

The activities of the accelerator Controls Department is fully focused on the development and implementation of the accelerator control system for FAIR.

During the past months significant progress has been made in all control system subprojects. The design of the standard equipment controllers (SCU) for FAIR power converters and many other systems, of which more than 1200 units will be needed, has been successfully completed and production and assembly of the first batch (100 units) has been completed. Several components of the newly developed White Rabbit protocol-based high-precision time and event distribution system, backbone of real-time control in the control system for the full facility, has been further developed and is already installed and under production test for the CRYRING machine. Electronic timing receiver boards (FTRN) in several form factors (PCE, VME, PMC, uTCA), both GSI in-house developments as well as Slovenian in-kind contribution projects are under development. Schematics design and board layout has been checked and prototypes have been produced or are presently under evaluation. Significant progress has also been made in development of the fundamental underlying control system software frameworks for accelerator equipment control (FESA), communication middleware, databases, physics modelling of the machines and beam lines (LSA) as well as user interfaces graphical control room applications. Development on the accelerator measurement and data archive system has started; an early prototype version is presently being evaluated in the controls lab to confirm the technologies and products. On the industrial controls side, vacuum control with the industrial control SCADA-based UNICOS framework has been developed, installed, commissioned and is presently under testing as a collaboration project of GSI and a Slovenian in-kind provider at the CRYRING. The vacuum bake-out control of all sections of the CRYRING has been already successfully implemented and tested, shortcomings and problems have al-
ready being identified and are presently being addressed. In respect of cryogenic controls, several cryogenic sensors and actuators have been tested as a sound base for the cryogenic controls system design. Technical and functional specification documents for the control system of the upcoming tendering of the FAIR central cryo-plant have been worked out and are formally approved.

Following the agreed project strategy of the control system subproject, the full control system architecture was implemented at the CRYRING machine, being used as test-bench for FAIR. During the last months numerous tests have been performed in order to identify bugs and limits and apply. Finally the control system was already used for commissioning the CRYRING local injector and ring with beam. Presently a new release of the control system stack is being prepared for beam operation in August/September. In parallel, the control system team is fully engaged in providing the FAIR control system already for the upcoming beam time of the existing GSI machines in 2018 and 2019. These two applications to existing machines will greatly reduce the time and risk during commissioning of the FAIR machines.

Transport and Installation

Numerous workshops on the topic of accelerator installation have been carried out since 2016, resulting in the creation of dedicated additional work packages and corresponding detailed installation plans.

An overall concept for the intermediate storage of FAIR components is currently in progress.

Measures have been taken to use existing Campus Facilities according to increasing requests for adequate component testing and storage. The overall need for intermediate storage leads to leasing of external storehouse areas. Presently the storage of HESR components delivered by Forschungszentrum Jülich (FZJ) is ongoing (see Figure 21 and Figure 22).

Engineering /Mechanical Integration

For visualization of beam lines, buildings and technical building services and for facilitation of coordination tasks and test processes in a web-based tool, the Kisters 3D viewer, was implemented. This tool allows work package leaders, subproject leaders and management to receive a general overview. Independently of CAD tools the configuration of the beam lines will be shown together with their position in the buildings. This view can be used on any web-connected unit like computers or mobiles independently of any license structure. The content will be updated regularly once a month by the person in charge of DMU group.

Figure 22: Remote positioning of an HESR dipole magnet

Figure 23 shows the screenshot of the Kisters 3D viewer with the detail of the HEBT beam lines and buildings.

FAIR Site & Buildings

The approval for the tendering and awarding of civil works for the construction area North by the BMBF is given mid-September 2016. The reorganization of the FSB department was completed in 2017. The development of a staffing plan of FSB department is also finalized.

The civil works execution plan for the FAIR project is divided into construction area North and construction area South. The contractual schedules with the civil design companies will be adapted accordingly. Detailed scheduling of civil work packages is currently progressing in cooperation with the civil designers.

An overall time schedule including defined periods for installation of machine components was developed as part of the integrated project master time schedule.

The ZBAU reapplication, which is required by German law for building measures financed by the federal government, was submitted to the Landesbetrieb Bau und Immobilien Hessen, LBIH, on time in December 2016.

Figure 21: Unloading of one of the HESR dipole magnets

Figure 23: Screen shot of Kisters 3D viewer with HEBT
The tenders for groundwater lowering, trench sheeting and excavation in the construction area North was contracted on schedule in May 2017. Official ground breaking ceremony has been performed on July 4th, 2017. Site works have been started in July 2017 and are progressing as planned.

The overall project civil construction permission is issued since 2014 for the entire facility. Some construction permissions for the buildings have to be revised as part of the design process (e.g. for the north and south electrical substations). The revised applications are scheduled in line with the civil construction schedule.

FAIR Experimental Areas

Major developments for the experimental areas of CBM, APPA, NUSTAR & PANDA are described in the following chapters.

APPA

Work on design and construction of the experiment components proceeds as planned. Special efforts have been made to complete the installation and continue the commissioning of the CRYRING. In May 2017, a new test with beam has been performed, which served as a test of the FAIR control system. With this new FAIR-like control system, the operation status as of 2016 could be re-achieved. Also tests of the beam diagnosis elements (PBM)s and the first training for the operators’ team to get used to the new control system were done. For these activities, we acknowledge the strong support from the on-site specialist as well as from our collaboration members from the Jagiellonian University, in Krakow, Poland.

With high enthusiasm, the completion of components which will be used in the FAIR Phase-0 for experiments was pushed ahead. The APPA collaborations submitted over 70 experiment proposals for the FAIR Phase-0 program, and currently prepare the new equipment needed for carrying them out.

In July 2017, the Expert Committee ECE recommended two TDRs for key components of the APPA plasma physics to be accepted. A third one is still in the evaluation process and three new ones are in preparation.

The Plasma workshop organized in July at GSI concluded the reorganization process and program update of the HEDgeHOB/WDM collaboration. The new collaboration, HED@FAIR (High Energy Density physics at FAIR) strengthened the scientific goals of the plasma physics program at FAIR and gained new collaboration members interested in contributing to the realization of the experiments.

CBM

CBM experiment: The CBM magnet has been contracted to BINP, the review of the planning status was completed in April 2017; the magnet is currently in the conceptual design phase. The silicon tracker (STS), RICH, time-of-flight (TOF), and muon (MUCH) detector systems have approved TDRs, are in the engineering design phase, and full-sized pre-series chambers are verified in test beam campaigns. The STS, as most complex detector project, will structure the production readiness reviews in three parts (sensor, electronics, integration) planned for 2017 and 2018. A co-operation has been established with JINR, which builds 4 silicon tracker planes using the same technology as CBM to augment the BM@N tracking system, the fixed target experiment at the Nuclotron in Dubna. The photon detector of the Ring Imaging Cherenkov Detector, RICH, is in an advanced stage, all of the photo multipliers are tested.

The RICH readout is a joint CBM, HADES, and PANDA development. The RICH photon detector component has a modular design and is planned to be used in the context of the HADES experiment at SIS-18 starting 2018. The production readiness review for the first batch of Time-of-Flight ToF chambers was completed in March 2017, the production has started. The Projectile Spectator Detector, PSD, also has an approved TDR; all modules have been produced and will be tested at CERN and JINR. The STS, RICH, TOF, and PSD activities at BM@N/JINR, STAR/RHIC and HADES/SIS-18 constitute the CBM FAIR Phase-0 activities which will produce early operational experience for these detector systems and generate valuable physics data. The feasibility of the whole data-acquisition chain with high rates is proposed to be demonstrated using mini-CBM within Phase-0.

In total 7 out of 12 planned TDRs are approved, they describe in terms of financial volume about 80% of the components which require a TDR and are mandatory for the day-1 setup. One of the remaining TDRs was submitted in 2017 and the last ones in 2018. The final TDR describing the Online/Offline Software including the online event selection will be prepared in close coordination with the FAIR Computing TDR.

HADES experiment: HADES is a running experiment which will be moved from its current place in the SIS-18 experimental hall to the CBM cave. The work structure is therefore very different from the one of the CBM experiment and consists of the construction of an ECAL, a major upgrade of the RICH, the addition of tracking and time-of-flight detectors covering the very forward hemisphere, and several other upgrades. The HADES ECAL mainframe was delivered and installed in the current HADES cave by end of August 2017. It is largely funded by Polish contributions. The RICH upgrade is done in collaboration with CBM, using identical photon detector technology and actually sharing high cost components. Both ECAL and RICH will be ready in mid-2018 in time for the FAIR Phase-0 program at SIS-18. The forward tracking stations are based on PANDA straw technology and the geometry of the PANDA forward tracker.

NUSTAR

For all experimental set-ups of the NUSTAR pillar, the list of components and associated Work Breakdown Structure code (PSP Code) was refined and re-confirmed. An intense activity was devoted to the improvement of the time scheduling of the planned NUSTAR experiments, which was matched to the Integrated Master Schedule of the FAIR project. For each experiment, the milestone defining the completeness of each component
necessary for the installation of the experimental set-up was mirrored in an overview plan. This allowed also the creation of an installation plan. The time range available for installation is established in the plan of the Civil Construction.

Two time windows define the time range available for the assembly of components. The allocated time slot for the installation of NUSTAR experiments is in some cases too early with respect to the foreseen beam availability. The beam availability is scheduled in only one plan (Commissioning plan) for the whole FAIR project. For this reason, it is foreseen to reschedule the experiment installation starting backwards from the Commissioning plan. This would be advantageous for some of the experimental groups which could profit from experimental activities at the upgraded GSI facility and other laboratories.

Work has continued on the detailed technical specifications for several In-Kind and Collaboration Contracts. Three previously submitted TDRs have been accepted by ECE.

Work on NUSTAR detection systems, electronics, data acquisition is proceeding according to the internal planning. Focus is on readiness for FAIR Phase-0 experiments from 2018 onwards. In total 39 Phase-0 proposals have been submitted to the GSI PAC. The CDR for the LEB magnets has been reworked and has very recently been accepted.

**PANDA**

Electromagnetic Calorimeter (EMC): The first-of-series of 16 modules of the Target Spectrometer Barrel EMC is under construction at University of Giessen (D) in collaboration with HIEP Protvino (RU). All sub-modules have been assembled with crystals and APDs. But the final assembly of the module planned for summer 2017 is further postponed due to the much delayed delivery of the PCBs needed for the mounting of readout chips, reducing the margin on the schedule by half a year. The delivery of the high-purity PWO base material funded by Russia was completed in May 2017. The samples showed very good quality and are stored for further processing. The crystal producer CRYTUR in Czech Republic has by now produced 75 crystals of a pilot series, which show very good quality. The mass production should resume as soon as possible preventing delays. The Forward Endcap EMC is currently under construction in Bonn and Bochum and will be fully assembled at FZ Jülich until mid-2018. The module design of the Backward Endcap EMC has been revised and is complete now. A full readout chain was tested successfully with beam.

Superconducting Solenoid Magnet: The PANDA solenoid magnet was assigned to BINP Novosibirsk (RU) and a collaboration contract for the construction of the complete magnet was signed in March 2017. It is planned to perform technical follow-up of the contract with help from CERN. Work has started and a plan review was performed in summer 2017. The yoke production was subcontracted in November 2017 and the yoke FDR was started.

Barrel DIRC: The TDR of the Barrel DIRC, a German in-kind contribution to FAIR, was submitted in September 2016 and updated in May 2017 with results from a test-beam in fall 2016. The TDR has meanwhile been approved by FAIR ECE.

Luminosity Detector: The Luminosity Detector TDR was submitted in March 2017 and is currently under review by FAIR ECE.

Time-of-Flight (ToF) Detectors: The technical design of the Barrel ToF Detector is based on Silicon Photomultipliers and thin scintillator tiles. Its TDR – submitted in April 2017 - will be approved beginning of 2018 by FAIR ECE. The Forward ToF consists of more conventional large area scintillator bars read out by photomultiplier tubes. This TDR was revised and will be submitted to FAIR.

Forward Tracker: The technical design of the forward tracking detectors was completed with the missing piece of the required simulation of track pattern recognition and was reviewed internally. It is currently revised for submission to FAIR ECE.

Endcap Disc DIRC: After a first technical report in 2014 a review team had recommended a list of studies and improvements, which were completed by the beginning of 2017. A TDR for a full-size prototype was compiled on the basis of these experiences.

Infrastructure: The planning of electrical supplies for the experiment was coordinated with the electrical planning of the building to save cost in the infrastructure of the experiment.

Further service planning for cooling and routing of experiment cables and supplies is ongoing.

The technical service planning of the hall led to a revision of the architecture of rooms and dimensions requiring a re-planning of parts of the layout of the experiment infrastructure.
The FAIR Sequencer
Semi-automation in view of accelerator commissioning and operation

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Abstract

FAIR extends and supersedes GSI’s existing accelerator infrastructure both in complexity as well as in number of devices that required to safely inject, accelerate, and extract particle beams to the experiments. In order to perform the initial accelerator hardware- and beam-commissioning, quality assurance, as well as subsequent system re-validation tests in a most efficient and reliable fashion with the limited resources at hand, a high-level Java-based sequencer framework has been developed as a core part of the control system to aid the semi-automated testing, validation of the devices’ system responses, and control of the accelerator facility (e.g. processing of SAT check-lists, generation of QA documentation. ‘as-good-as-new’ machine protection tests, etc.).

Introduction

For many sub-systems the number of involved devices increases ten-fold with respect to what exists in the present facility (notably power-converters, magnets, RF systems, beam instrumentation, cryo- and quench protection systems). At the same time, a much higher level of detail and more stringent testing of the system function and accelerator setup is required at FAIR to provide a safe and reliably accelerator control, necessary while operating at the highest beam intensities and energies. Thus, the validation of the systems’ function is not only required during the initial Site-Acceptance-Tests (SAT) but also as part of an ‘as-good-as-new’ testing policy during regular routine operation in view of validating the machine protection and ALARA (i.e. As-Low-As-Reasonably-Achievable) loss minimisation targets, as well as for an early detection and identification of non-conformities and faults. The gathered information can be used to schedule planned preventative maintenance during routine day-to-day operation before these non-conformities become beam-inhibiting faults.

Architecture and Design

The FAIR Sequencer is based on earlier concepts, developments, and experience at CERN [1]. It is conceptually divided into three parts: the middle-tier ‘sequencer’ service, i.e. the software system capable of running the sequences, the ‘sequences’ themselves, and a graphical user interface that provides a more ergonomic and user-friendly interaction with these test procedures. Each sequence consists of a subset of tasks that contain the individual testing steps (i.e. SAT checklist items) as described, for example, by the individual device SAT criteria, commissioning or test procedures outlined in [2].

Sequences are typically defined per device, can be further nested, executed in parallel for a group of devices with the possibility to ‘start’, ‘stop’, ‘pause’, ‘step’, or ‘repeat’ individual tasks as required. At the same time, the execution result of each task (‘pass’, ‘failure’, ‘warning’, ‘skipped’, etc.) is documented alongside the applicable detailed testing meta information in the FAIR Archiving System out of which an automatic PDF-based test report can be generated. While keeping the same user-level functionality, it was decided, to re-implement the Sequencer core due to the obsolescence of some of the used software library components, unavailability of the required controls infrastructure services at GSI, and also to deploy more modern Java development concepts that since became available [3]. The Sequencer interacts with all FAIR sub-systems, controls interfaces and databases, and provides a generic abstraction interface that moves large parts of the complexity of interacting with the accelerator control system towards the framework itself rather than the user-level testing code that can be kept simple, short and functional. The Sequencer is being tested and already used during the early Dry-Runs in 2017, and equipment specialists, operation and others are encouraged to consider using it if semi-automated testing and/or other procedures interacting with the FAIR control system are required that are not covered by the other available tools.

Figure 1: Sequencer GUI impression.

Acknowledgements

The valuable contributions, advice and recommendations that guided the re-implementation of the new FAIR Sequencer from our CERN colleagues V. Baggiolini and R. Gorbonosov are greatly acknowledged.

References

PSP codes: 2.14.17, 2.14.10.1
Strategic co-operation with: CERN
Development of optical beam profile monitors

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Optical beam diagnostics is planned for intense ion beams which would destroy conventional beam diagnostic devices. The concept is to measure beam-induced light emission from a gas target, space-resolved, and to deduce beam profiles from these data. A more detailed description of the concept is given in Ref. [1] and references therein. More results are also presented in the annual report of the plasma physics group at GSI for the year 2017.

An important issue is to study, if the concept can be used at the low pressure conditions within the beam-lines. Model experiments at the Munich Tandem accelerator using a DC-beam of 87 MeV \textsuperscript{32}S ions (2.72 MeV/u) exciting various gases over a wide pressure range were performed in 2017. Both spectroscopic studies and preliminary profile measurements have been performed. The spectroscopic studies are used to identify appropriate optical transitions. Based on the results transmission filters were used to take pictures of the beam in various wavelength regions. Differential pumping was installed at the beam entrance for pressures below 1mbar. A f=30cm vacuum monochromator (McPherson 218) was used to record beam induced spectra of Ne, Ar, Kr, Xe, and \textsuperscript{14}N. An example is given in Fig. 1. It shows mainly lines (and in the case of nitrogen molecular bands) of neutral and singly ionized target species.

At low pressure, the range of the secondary electrons is so large that they do not lead to the formation of visible “wings” and rather hit the walls of the cell (Fig. 2). In Fig. 3 it is shown that the beam profile is well represented for both low pressure and high pressure. At high pressure it is due to the fact that the range of the secondary electrons is short compared to the diameter of the ion beam.

Beam profile measurements were performed with a sensitive, cooled CCD camera (ATIK 383L+) combined with a f=60mm broadband (315 to 1100nm) apochromatic lens. Appropriate bandpass filters were used to select various emission regions for the emission from neutral and ionized species. The ion beam was sent through a 1mm diameter aperture into the target gas. A general result is that secondary electrons can strongly excite neutral species, which leads to pronounced wings in the beam profiles for target densities around 1mbar (see Ref. [1]).

Figure 1: Overview spectra for neon and nitrogen recorded at an elevated target gas pressure of 300mbar.

Figure 2: Example of a beam profile measurement at relatively low pressure. The “wings” which appear for measurements using neutral lines (red) are not pronounced under these conditions.

Figure 3: Beam diameters (FWHM) measured for a wide range of target gas pressures using the emission from an atomic line.

Acknowledgements

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References

Prototype development of a Multipurpose Hardware Unit for deterministic bunch-to-bucket transfers between synchrotrons

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Introduction

In the context of the FAIR project, a new concept for a fully-deterministic bunch-to-bucket transfer (B2B) between sending and receiving synchrotrons (e.g. SIS18 and SIS100) is currently under development. Developing dedicated electronic solutions for each technological task represents an invest in terms of costs and time. Hence, it is intended to develop a new multipurpose hardware unit (MHU) to minimize this invest. The MHU has to fit in a large spectrum of current and future applications with sufficient performance. As a result, it has to be at least compatible with all kinds of signal formats currently being used in the low-level radio frequency (LLRF) environment at GSI.

MHU Application Areas

The MHU is based on a programmable unit which covers the actual application concerning the most general functions on parallel input signal conversion and processing. An FPGA-based solution is planned. Several currently defined functional blocks, e.g. Phase Advance Prediction or Phase Shift Module, are foreseen and based on the requirements document [1].

MHU Prototype Realization

A wide range of the required hardware components can be based on commercial-off-the-shelf (COTS) devices, but for special interface requirements of GSI there is a need for the development of new modular interface modules. The Achilles Arria 10 System on Module (SoM) constitutes the processing unit of the MHU which enables high modularity and interchangeability in case of future designs. A carrier board is connected to the SoM and a customized backplane, which enables the interfacing of modular extension boards and GSI inherent boards like the DIOB (Digital Input Output Board) [2] and MMD (Maintenance Module for External Devices) [3] module connected to the SCU backplane [4]. Regarding current Use Cases described in [5] several customized interface boards shown in figure 1 have to be developed. They are depicted as an optical interface board for ODL (Optical Direct Link) and OTR (Optical Token Ring), a PC interface board providing debugging and access points via Ethernet, or UART and a peripheral interface Board providing BuTiS clock reference, analog TTL based IOs and status LEDs. As depicted in figure 1, one of the carrier board FMC ports is connected to the customized backplane, the other one is foreseen as modular FMC interface for the extension with standardized COTS FMC daughter boards; e.g. ADC/DAC daughter board.

Outlook

The first prototype designs have been started with the availability of the SoM, the ADC/DAC FMC daughter board, the DIOB, MMD, SCU-Backplane and the development of the ODL interface board, that was successfully tested. Further prototype development will be necessary to implement the entire MHU, which concerns the development of the carrier board, the customized backplane, the peripheral interface board and the PC interface board.

References

Characterization of the Cryogenic Current Comparator for FAIR*

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The design of the Cryogenic Current Comparator (CCC) has been adapted to offer an optimal performance when it is used for nA beam current measurements in the FAIR facilities. Following this preparation, in 2017 the FAIR prototype, also called CCC-eXtended-Dimension (CCC-XD), was manufactured from niobium and assembled into an optimized superconducting shielding geometry, surrounding an enhanced flux-concentrating core made from NANOPERM© material [1]. Extended tests on the new system have been performed, which showed that the transition to the large FAIR beamline diameter was a success [1, 2].

Performance of the CCC-XD

The primary challenge of the new design for the CCC at FAIR was to increase the radius to accommodate for the beamline diameter of 150 mm while maintaining the performance of the predecessors. After its assembly the CCC-XD (shown in fig. 1) was characterized in a controlled environment inside a wide-neck cryostat. A magnetically shielded room is available at Friedrich-Schiller-University Jena to exclude external magnetic influences. With this setup a white noise level of <3 pA/Sqrt(Hz) [2] can be achieved which is regarded as an improvement compared to earlier values of 11 pA/Sqrt(Hz), measured in the accelerator environment [3].

![Figure 1: The FAIR prototype CCC-XD. The cartridge holding the SQUID electronics is mounted to the front. In the back the welding of the meander structure is visible.](image)

In order to determine the current resolution, a calibration wire passes through the CCC and allows to apply a test current to simulate an ion beam. Figure 2 shows the response of the CCC-XD (red) to a 1.65 nA current pulse (green). In the laboratory, these intensities can easily be detected without any additional data processing. The sensitivity of the SQUID can be tuned by adjusting the coupling of the pick-up coil around the flux concentrator to the sensing coil of the SQUID. Here the signal gain and the frequency bandwidth can be balanced depending on the requirements. The present configuration achieves a slew rate of 0.16 μA/μs using the full bandwidth of 200 kHz [2]. For some applications in which time resolution is less important (e.g. in storage rings) a 10 kHz low-pass filter is used to suppress high frequency noise which limits the slew rate at the same time (fig. 2).

![Figure 2: Response of the CCC-XD (red) to a 1.65 nA (200 μs) current pulse (green), measured with a 10 kHz low pass filter [4].](image)

Specification of the CCC cryostat for FAIR

The specification for the FAIR beamline cryostat was finalized and the construction is finished until the end of 2018. The mechanical design has been supported by ANSYS calculations in the frame of the collaboration with TU Darmstadt. Throughout the measurement campaigns it has become apparent that mechanical oscillations of the cryostat are a source of noise for the sensitive SQUID system. Thus the cryostat is designed in a way to avoid mechanical resonances and to provide sufficient damping of external vibrations. Further tests on noise sources and alternative shielding geometries are ongoing [1]. With the CCC-XD tested and ready to measure currents, the focus is currently on the preparation for the setup in CRYRING.

References


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The existing GSI accelerator will become the injector for FAIR. To preserve and enhance the current experimental program at UNILAC, a dedicated new Linac is under development, which shall run in parallel to the FAIR injector, providing cw-beams of ions at energies from 3.5 – 7.3 MeV/u.

For this cw-Linac a superconducting prototype cavity (demonstrator) has been developed and was first operated with beam in summer 2017 [1]. The resonator is a Cross-bar H-structure (CH) of 0.7 m length, with a resonant frequency of 216.8 MHz. It has been installed behind the GSI High Charge State Injector (HLI), which provided 108 MHz bunches of 1.4 MeV/u Ar6+/9+/11+ ions at a duty cycle of 25%. Due to the frequency jump and small longitudinal acceptance of the CH, proper matching of the HLI beam to the prototype was required. The bunch properties of the injected beam as well as the effect of different phase- and amplitude-settings of the cavity were measured in detail with a bunch shape monitor (BSM) fabricated at INR, Moscow, while the mean energy was analyzed by time of flight method. Figure 1 shows the experimental setup at the cw-Linac test stand.

After optimization of the buncher settings for injection, the injection parameters and rf-power and phase in the demonstrator were varied to check the effect on output current, bunch structure, particle energy and transverse emittance. In this way, the characteristics and design values of the prototype could be verified in very detail. Representative for the numerous measurements, which have been carried out, figure 3 shows a scan of the bunch width as a function of the demonstrator rf-phase. The resolution of the system, basically dependent on the aperture shown in fig. 2, is better than 1°.

Figure 1: Setup for cw-Linac test measurements at the HLI beamline.

Figure 2: Principle of the BSM.

Figure 3: Phase scan of the output bunch length.

References


RADHARD: a program for radiation damage to materials for FAIR

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Introduction

FAIR will consist of at least 20 radiation protection areas at the accelerators and connected beam lines where a lot of different complex devices will be exposed to high neutron radiation fields in quasi-continuous operation. It is crucial to maintain a stable operation of all devices and mechanisms in these areas. To achieve this one key aspect is to take into account the radiation hardness of materials. The radiation hardness of a material depends on its type; e.g., metals in comparison to most polymers can stay longer under irradiation until certain damage occurs. More details can be found in the work previously done at GSI [1].

Description

In order to obtain an estimate of the lifetime of materials located in high radiation field areas of FAIR the RADHARD program was created at GSI. The program uses a collection of data which has been taken mostly from CERN radiation damage test data [2]. This program is written in Python programming language [3] and a remote access to the program is available under Linux at GSI (/u/aevodkim/codes/radhhard), access under Windows is still under development.

Purpose of the program was to have a convenient and user-friendly possibility to get a quick result on the lower limit of the expected lifetime of materials of interest for selected buildings for a broad spectrum of users at GSI and FAIR, e.g., architects, planners, scientists etc.

The program includes data on radiation damage for more than 70 materials (polymers, metals, ceramics etc.).

Features

The user interface of the program is divided into three sections: input, output, toolbar (see Fig. 1).

The Input section includes a selection of FAIR buildings and materials, the possibility of switching between English and German names for materials, and a search for materials by pattern. The Output section includes a window for displaying data.

The Toolbar section allows to fine-tune the output with the following options: sort materials by their lifetime, highlighting lifetime of selected materials and show their exact values, show result of Mild/Moderate/Both damage to materials and add the column with their values respectively.

The program allows the user to automatically create a bar plot with data on relative radiation effects for selected materials (see Fig. 2).

![Figure 1: Example of the graphical user interface of the program. On the left side is input; on the right side are toolbar (up) and output data (down).](image)

![Figure 2: Plot example of general relative radiation effects for selected materials. The scale shows how much radiation in Gy each material can resist keeping its functionality.](image)

Development

The work to improve the program continues, and in future some other features as well as new materials will be included as follows: group materials by class (thermoplastic and thermostetting polymers, natural polymers, metals and alloys, ceramics, oils etc.), add flexibility to work with input and output data. We encourage all GSI and FAIR Users to submit requests for new materials to evaluate and include into this Database.

References

The SIS100 laser cooling facility*

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The project group ‘SIS100 laser cooling’ is setting up a laser cooling facility at the FAIR heavy-ion synchrotron SIS100, being supported by POFIII ARD ‘Matter and Technologies’. With the aid of this facility, intense relativistic heavy-ion beams will be laser-cooled to lowest temperatures [1,2]. The project group consists of scientists from GSI and the collaborating partner universities and research centers in Dresden-Rossendorf, Darmstadt, Jena, Münster, and Lanzhou (China).

The laser systems are being developed by the HZDR/TU-Dresden and the TU-Darmstadt, with strong support from the BMBF. These laser systems can be operated at 257 nm or 514 nm, and produce about 100 mW of coherent radiation. The TU-Darmstadt will provide a fast scanning cw-laser system [3], and a pulsed laser system with long (up to 1 ns) pulses and a high repetition rate (up to 1.5 MHz) [4]. The HZDR will provide a pulsed laser system with short pulses (~ps) and a high repetition rate up to 1 MHz [5]. The Münster group will provide an XUV/X-ray detector for the SIS100, again supported by the BMBF [6]. (Note: These groups have all applied for a continuation of their funding for the next BMBF period (2018-2021), which shows how committed they are.)

Figure 1: Collage showing a selection of the components purchased in 2017. Upper row: vacuum chamber ‘mirror box’, rotary fore-pump. Lower row: high-precision wavelength meter, multichannel switch (for 4 laser systems).

In 2017, the design for the laser-detector chamber (LDC) has been completed and a company was selected to manufacture this UHV chamber, the bake-out jackets, and the frame. The chamber is a crucial part of the project: it will be used to couple the laser light into the SIS100 accelerator, and to couple out the fluorescence emitted from the laser-excited ions. The chamber is currently being built by a vacuum company and should be ready in 2018. Also, the design for the first ‘mirror box’ (vacuum chamber), which an important component of the future SIS100 laser beam line, has been completed. A vacuum company could be found to build and deliver the chamber still in 2017.

In order to be able to test these vacuum chambers (and components inside them), but also for operation later on, vacuum pumps (rotary pump, turbo pump, NEG pump) have been ordered. These pumps are especially quiet and almost without vibrations, so as to prevent for mechanical and acoustical influences on the laser beamline. Since the laser light has to travel via several mirrors over a long distance, small variations in the positions of these mirrors could already lead to noticeable deviations of the laser beam position inside the SIS100 accelerator and modify the overlap between laser and ion beam somewhat.

Since we will have to combine different laser systems at the same time for our experiments at the SIS100, and require very reliable knowledge of the exact wavelengths of these laser systems, a high-precision wavelength meter with a 4-channel switch box is now available for tests and experiments. This way, all laser wavelengths can be measured and monitored as required.

During the year, we have also performed necessary tests of the optical components that are available for the SIS100 laser beam line, such as mirror holders and piezo-actuators. These tests will continue in 2018.

Finally, it seems that it might be possible to perform a laser cooling experiment at the CSRe of the IMP in Lanzhou China in 2018. We are very much looking forward to this important and exciting event. (Note: Since the CSRe is rather similar to the ESR, it is very well suited for complementary tests and new experiments.)

References

Experiment beamline: none
Experiment collaboration: APPA-SPARC
Experiment proposal: none
Accelerator infrastructure: SIS100
PSP codes: 2.8.10
Grants: *Work supported by HGF POFIII ARD-ST2.
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Strategic university co-operation with: Darmstadt

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Current status of the phase calibration of synchrotron RF reference signals
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Introduction
For the successful operation of the FAIR complex it is important to maintain the desired accuracy of the accelerating voltage [1]. The deviation of the phase of the reference signals must not exceed ±1 degree in the whole frequency range from 100 kHz to 6 MHz and a maximum difference of ±3 degrees for the complete system is acceptable. Although closed cavity field control loops stabilize amplitude and phase of the generated RF gap voltages, imperfections of components lead to errors in the signal transmission. Also errors in the detection of the gap voltage affect the accuracy. As a result the actual accelerating voltage interacting with the beam can be different from the target values provided by the Central Control System (CCS). This could compromise reaching the desired beam quality if the above mentioned accuracy requirements are not met. In order to overcome the undesirable errors countermeasures to calibrate synchrotron RF signals are performed.

Group DDS calibration

Figure 1: Example for calibration curves of 3 DDS modules before calibration (left) and after calibration (right).

The DDS RF signals’ phase accuracy estimation depends on measurement parameters. In order to decrease the deviation of estimated values and increase the precision of the calibration it is important to perform optimisations.

An automated Group DDS phase calibration procedure with respect to the absolute phases of DDS modules defined with BuTIS is described in [2]. Figure 1 shows an example for the calibration curves of modules before and after calibration. It can be seen that the remaining phase response of Group DDS modules is far below 1 degree for the whole frequency range (please note the different scales in the diagrams on the left and on the right), which is within the margins of the phase accuracy requirements. This allows us to conclude that in a supply area it is possible to achieve an in-phase generation of reference RF signals which can later be used for local cavity RF systems (Fig. 2). This also includes the in-phase generation of different harmonics of the revolution frequency, which is needed for example for dual-harmonic operation and bunch merging.

The long term stability of the calibration is important to minimize interruptions needed for accelerator maintenance. First results show that changes of the phase difference between the modules after 3 weeks are within ±1 degree.

Optimisation of parameters
The DDS RF signals’ phase accuracy estimation depends on measurement parameters. In order to decrease the deviation of estimated values and increase the precision of the calibration it is important to perform optimisations.

Among the parameters to be optimised are the number of samples per sinewave and the number of signal periods which are then used to perform a sine wave fit algorithm [3]. Figure 3 shows the first preliminary results for the required number of samples. The next step is the detailed analysis of further parameters and finding their optimal values.

Figure 2: Routing of Group-DDS signals to local cavity systems.

Figure 3: Example for the dependence of the estimated phases’ standard deviation on the number of samples per sinewave.

References
Fluorescence detector concept for laser cooling at the SIS100

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The acceleration of high intensity ion beams up to the mass range of uranium to highest energies will be possible in the future heavy ion synchrotron SIS100. At Lorentz factors of up to $\gamma = 12$, ion cooling becomes a challenging task and the only feasible option here is laser cooling [1,2]. It requires a fast optical transition in a wavelength region which is accessible to a laser system.

The feasibility of this technique has been demonstrated at lower velocities on C³⁺ ions at the ESR in past beam times [3]. At the high ion velocities expected at SIS100, the energies of the fine structure transition in, e.g., Li-like ions, are blue-shifted by the Doppler effect and allow the application of state-of-the-art UV-laser systems in an anti-collinear setup.

The required counterforce to reduce the momentum spread cannot be applied by a co-propagating laser beam, since a laser system producing photon energies in the soft x-ray region is not available yet. The counterforce is therefore exerted by the bucket potential of the bunched ion beam.

To overlap ion and laser beam at one of the six straight sections of the synchrotron, the ion beam is tilted by 2.3 mrad relative to the design orbit and two sets of horizontal and vertical scrapers are used to align both beams. This is schematically shown in Fig. 1.

When the laser frequency is in resonance with the fine structure transition, fluorescence light is emitted isotropically in the ions' rest frame. In the laboratory frame, the emission is transformed by the Lorentz boost to a strongly forward directed cone. Since the cooling takes place at a distance between 12 and 24 meters away from the detector chamber, the angle between ion propagation and detected fluorescence is in the range of 4 to 9 mrad. Here, photon energies in the XUV- and soft x-ray region are expected. A suitable detector requires a sufficient quantum efficiency in this energy range and a high temporal resolution to gain insight to the dynamics of the ion bunch during the cooling process. The spectral resolution of the fluorescence would be even more interesting, since it would allow for spectroscopic measurements of transitions. For many of the medium-heavy Li-like ions, measurements of their fine structure transitions could be performed for the first time here.

The proposed detection setup is schematically shown in Fig. 1 and will be developed in two stages. In the first stage, the timing and the sensitivity of the detector will be optimized. Therefore, a multichannel plate (MCP) detector [4] with a high temporal resolution will be installed. Typical quantum efficiencies of 10% are expected. Estimations of the fluorescence detection rate by a Geant4-simulation are currently ongoing. Enhancements of the efficiency are possible by using a CsI-coated front MCP. An aperture in front of the MCP is used to reduce background light or particles. All parts will be mounted on linear feedthroughs and can be placed at a safe distance from the ion beam during injection and acceleration. Prototypes will be built and tested at Insitut für Kernphysik in Münster.

As a preparation for the second stage, a gold mirror at grazing incidence will be installed on a rotational feedthrough to test the reflection of the fluorescence. Subsequently, the gold mirror will be replaced by a gold coated, laminar flat-field reflection grating with a line density of 2400 lines/mm to diffract the fluorescence light onto the MCP. The planned geometry corresponds to commercially available spectrometers for photon energies of up to 2 keV. Here, a resolving power of 500 is achieved. To detect the spectrum, the MCP will be equipped with a delay-line anode to achieve a spatially resolved detection [4]. An MCP detector with delay-line anode available from the former WITCH experiment at ISOLDE is currently used to equip a new detector test stand in Münster. The data acquisition has been set up and first tests of the read out electronics have been performed.

References

[2] D. Winters et al., this report

Figure 1: Schematic overview of the proposed detection setup. Ion beam (dark blue) and laser beam (light blue) are overlapped by the use of two scrapers. The fluorescence light (blue arrows) enters the detector chamber at a small angle of few mrad.

Experiment beamline: SIS100
Experiment collaboration: APPA-SPARC
Experiment proposal: none
Accelerator infrastructure: SIS100
PSP codes: none
Grants: BMBF 05P15PMFAA
Strategic university co-operation with: none
Tuning rules for the digital filters of the SIS 100 longitudinal feedback system

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Damping of longitudinal coherent bunched-beam oscillations is needed in SIS100 to stabilize the beam, prevent emittance growth and keep beam loss low during acceleration. An FIR (finite impulse response) filter approach with 3 taps, cf. [1], which has already been successfully used at GSI in several machine experiments for beam-phase control in a longitudinal feedback system has further been investigated. The dissertations [2] and [3] deal with an analytical way of how to apply the tuning rules for this approach for stationary, single and dualharmonic operation. In last year’s work, extensive tracking simulations were performed to investigate the performance of the feedback system in terms of emittance-growth and settling-time numerically regarding the two tunable parameters of the FIR-filter.

Feedback system

The feedback system can be separated into two parts. One is a bandpass filter, implemented as a symmetric, biasfree bandpass filter. The bandpass frequency, which scales with the linear synchrotron frequency can be detuned by the frequency modificator $\chi$, which is one of the tunable parameters.

The bandpass filtered bunch-phase is integrated and multiplied with a gain factor, to obtain a phase-shift in the gap voltage. The gain-factor also scales with the linear synchrotron frequency. It can further be modified by the gain factor modificator $k$.

Simulation settings

The tracking simulations have been performed to get a tuning rule for the feedback system, especially for the case of different bunch lengths, synchrotron frequencies and particle energies. Therefore typical synchrotron frequencies for SIS18 (below 2 kHz) and SIS100 (below 1.5 kHz), as well as bunch lengths reaching from 115° to 200° have been tested. The bunch length is the smallest phase range within a bucket, which contains 85% of its particles.

For testing the performance of the filter, the phase of the gap voltage was shifted by 10° to induce a longitudinal dipole oscillation.

Results

In stationary operation constant tuning rules are sufficient. For single harmonic operation the frequency modification factor $\chi$ is between 0.95 and 1.0, the gain factor modificator at 0.25. This is comparable to the results for linear buckets in [2].

Figure 1: Parameter scan for single-harmonic operation with a bunch-length of 115°. In dashed red are the areas for 2, 3, 4 and 5 oscillations (light to dark) settling time. In solid blue are the areas for 10%, 30%, 50% and 100% (light to dark) relative emittance-growth compared to system without feedback.

For dual-harmonic operation the frequency modification factor is at 0.8 and the gain factor between 0.2 and 0.25. For both parameters, this is about 80% of the parameters used in machine experiments in [3].

In both cases the system is tuned to fast settling times. Notable RMS-emittance-growth from longitudinal dipole oscillations only occurs when the amplitude reaches more than 3 degrees. High damping rates should prevent such critical states.

Outlook

As constant tuning rules for single- and dual-harmonic stationary operation for a large variety of longitudinal beam parameters are sufficient to obtain strong damping rates and decreased RMS-emittance-growth from longitudinal dipole oscillations, it has to be studied whether this also holds on acceleration ramps, due to the strong deformations of the separatrix.

References

FLUKA/ANSYS study of the APPA beam bump for the BIO-MAT experiment

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Four beam dumps are planned for the experimental APPA cave, one of which, XBM2SD, will be used for the BIO-MAT experiment (see Figure 1). Given a wide range of different beam parameters (kinetic energies, ion species, time structure) which will be provided for this experiment, multiple FLUKA-ANSYS simulations had to be performed in order to optimize the design of the inner core of the dump as to the dimensions and materials for a safe operation. Another important goal of this study was to find out whether cooling would be required, and if so to propose a cooling design scheme. The starting proposal for the dump core was a composition of a 3m long iron with a 20cm long graphite part at the entrance phase to absorb the Bragg peak region associated with ion beams. The beams considered for the dump optimization as well as their time structures are summarized in Table 1.

The analysis is based on the following steps. In the first the thermal load from the beam impact is calculated by FLUKA in terms of energy deposition. This is then used as an input into a thermo-mechanical analysis with ANSYS to calculate maximum temperatures and maximum thermal stresses reached by irradiation. After focusing the beam onto the target with a beam radius of $2\sigma_x/y=10$ mm, the transverse size of the beam at the position of the XBM2SD dump is $2\sigma_x/y=30$ mm.

Table 1: beam parameters considered for the study

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Particle type</th>
<th>Energy [GeV/n]</th>
<th>Beam Intensity</th>
<th>Time structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO</td>
<td>proton</td>
<td>10</td>
<td>$5\times10^{10}$ /s</td>
<td>Slow extraction</td>
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<tr>
<td>BIO</td>
<td>uranium</td>
<td>10</td>
<td>108 /s</td>
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<td>10</td>
<td>108 /s</td>
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<td>iron</td>
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<td>2</td>
<td>109 /s</td>
<td>Slow extraction</td>
</tr>
<tr>
<td>MAT</td>
<td>uranium</td>
<td>0.7</td>
<td>$5\times10^{10}$ /pulse</td>
<td>Fast extraction</td>
</tr>
</tbody>
</table>

For the material risk assessment a thermal-structural analysis was performed. For the highest energy ion beams, the maximum temperatures reached were 29.4 °C for the higher energy uranium beam within the iron part (see Figure 2), and 23 °C for the proton beam within the graphite part, which is about 10 and 100 times lower than the maximum service temperature of iron (230 °C) and graphite (2600 °C), respectively.

The maximum values of the Von-Mises stress were found to be 4.2 MPa within iron part of the dump (see Figure 3) and 1.2 MPa within the graphite part of the dump for the highest energy uranium beam. All values are found to be well below the maximum tensile strengths which are 250 MPa for iron and 30 MPa for graphite of the type R4550.

Conclusions

The studies presented in this Report indicate that the proposed configuration for the XBM2SD dumps would provide safe operation during the planned running time of the BIO-MAT experiments without any need for active cooling.
FLUKA/ANSYS study of the beam dump for the plasma physics experiment

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This report summarizes the concept study for the beam dump XPP2SD1, part of the experimental APPA cave and planned to be used for the Plasma-Physics Experiments. The goal of this study was to optimize the design of the inner cores of the dump as to the dimensions and material, based on coupled FLUKA-ANSYS simulations, which would assure a safe operation. Another important goal of the study was to find out whether cooling would be required. The complete geometry of the APPA cave with the surrounding shielding had already been modelled for the reasons of previous studies related to the optimization of the plasma physics target chamber.

The starting geometry of the XPP2SD1 beam dump was the same as used for the BIO-MAT experiment, i.e. consisting of a 3m long iron core with a 20cm long graphite part at the entrance phase to absorb the Bragg peak region associated with uranium beams (see Figure 1).

The studies are based on an uranium beam intensity of $3 \times 10^{11}$ ions/spill at $E_k=1$ and 2 GeV/n, and on a proton beam of intensity $2.5 \times 10^{13}$ p/spill at $E_k=5$ GeV. A realistic irradiation profile of one pulse every 3 minutes for 10 days is assumed for the analysis. After a strong focusing of the beam onto the target, the beam is very wide at the entrance of the XPP2SD1 dump positioned about 12 m downstream of the target. The transverse beam size at the entrance to the dump is indicated in Table 1.

<table>
<thead>
<tr>
<th>Beam energy</th>
<th>Beam radius $2\sigma$ horizontal size</th>
<th>Beam radius $2\sigma$ vertical size</th>
</tr>
</thead>
<tbody>
<tr>
<td>U@2 GeV/n</td>
<td>314 mm</td>
<td>55 mm</td>
</tr>
<tr>
<td>U@1 GeV/n</td>
<td>218 mm</td>
<td>126 mm</td>
</tr>
<tr>
<td>p@5 GeV</td>
<td>320 mm</td>
<td>320 mm</td>
</tr>
</tbody>
</table>

The analysis steps are the same as used for the studies of the BIO-MAT beam dump. In the first the thermal load from the beam impact is calculated by FLUKA in terms of energy deposition. This is then used as an input into a thermo-mechanical analysis with ANSYS to calculate maximum temperatures and maximum thermal stresses reached by irradiation. The resulting distribution of energy deposition for one pulse of a uranium beam at 2 GeV/n, calculated with FLUKA, is shown in Figure 2 separately for the graphite and iron parts of the inner core of the beam dump.

After considering all three beam configurations, a uranium beam at $E_k=2$ GeV/n is shown to be the worst-case scenario. The maximum temperature reached by imposing an average power after 10 days is only 24 °C on the graphite part. If adding a pulse to the steady state condition, the max T will reach only 27 °C, far below the maximum service temperature of 2600 °C for graphite.

The maximum stress reached in each of the pulses is 9 Pa in tension and 0.16 MPa in compression as indicated in Figure 3, far from any risk like rapture or yielding.

Conclusions

These results demonstrate that the present configuration of the beam dump will work in safe conditions even for the worst-case scenario and that no active cooling would be required during the whole planned operation including the other beams.

Figure 1: Geometry of the XPP2SD1 beam dump. Side view (left) and cut through the dump (right).

Figure 2: Edep within the core of the beam dump for the C- (upper) and the Fe part (lower) for U@2 GeV/n.

Figure 3: Stress in compression for each of a single uranium 2 GeV pulse.
Exploitation of circulant symmetry in SIS18 orbit response matrix

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Introduction
A closed orbit feedback (COFB) system is under development for the SIS18 synchrotron [1]. This system consists of beam position monitors, a controller and dipolar magnets (correctors). The corrector strength $\theta_i$ of each $i^{th}$ corrector (combined in a vector $\Theta$) can be calculated for the position readings $y_j$ of each $j^{th}$ BPM (combined as a vector $Y$) through the inverse of the orbit response matrix (ORM) as given by

$$\Theta = R^{-1}Y.$$  

If $R$ is not a square matrix, the pseudo-inverse can be used instead of the inverse.

SVD and its relationship with DFT
Singular value decomposition (SVD) is mostly used for the inversion of the ORM [2]. It decomposes a matrix into a product of three matrices, $U$, $S$ and $V$ where $U$ and $V$ are orthonormal matrices while $S$ is a diagonal matrix of singular values:

$$R = USV^T$$  

If the matrix is invertible, the inverse is given as

$$R^{-1} = VS^{-1}U^T.$$  

SVD also helps to calculate the pseudo-inverse ($R^+$) of non-invertible matrices by providing the liberty to remove smaller or zero singular values in the $S$ matrix and their corresponding column of $U$ and $V$ matrices before inversion.

Decomposed matrices are inter-related with each other; e.g. a unique phase relationship between the columns of $U$ and $V$ exists. In case of lattice changes during the acceleration ramp, as executed in SIS18, all three matrices need to be recalculated.

Due to the symmetric placement of BPMs and steerers, the vertical ORM of the SIS18 has a special “circulant symmetry” [3]. A circulant matrix can be diagonalized with the help of the discrete Fourier transform (DFT) of only one row or column. The diagonal matrix consists of the complex Fourier coefficients with the standard Fourier matrix $F$ as both right and left orthonormal matrix

$$R = FHF^*.$$  

The DFT-based decomposition of an ORM gives a physical interpretation of SVD modes and a relationship between the two algorithms has been described in the proceeding of ICALEPCS’2017 [4].

Robustness against missing BPMs
Besides the computational benefits of DFT over SVD, sine/cosine DFT modes help to estimate the orbit position at the location of a malfunctioned BPM reading. The idea of modal decomposition is to decompose a perturbed orbit into discrete modes (either SVD or DFT modes) and the elimination of these modes results in a global correction of the orbit. DFT gives a more physical explanation of these modes in the form of pure sine/cosine Fourier modes. These modes can also be used to reconstruct the perturbed orbit by a general curve fitting method. This idea has been employed in this work in order to predict the orbit position at one or two missing BPM locations by fitting the orbit measured with the help of available BPMs over the dominant DFT modes. The CERN accelerator toolbox MAD-X [5] has been used to demonstrate the orbit correction.

Figure 1 shows the perturbed orbit in red and the corrected orbit (when all BPMs are functional) in magenta colours. The black curve shows the scenario when one BPM is missing and there is a significant residual global orbit in the vicinity of the missing BPM after correction using 11 BPMs and 12 correctors. The green curve represents the corrected orbit when the orbit position at the missing BPM location is predicted by DFT fitting (effectively using 12 BPMs with one BPM reading different from actual by the fitting uncertainty). An overall improved correction (lower residual error) is seen in the vicinity of the missing BPM in this case. The blue curve shows a special scenario for comparison when the orbit position is considered to be cantered (0 mm) at the missing BPM location.

![Figure 1: Demonstration of better global orbit correction for missing BPM scenario using estimated orbit position at the missing BPM location.](image-url)

References
Current status and steering capability

In previous work we presented a basic robot concept for visual inspection of the SIS100 vacuum system [1,2]. A 3D printed robot prototype was built and it was shown that the robot is able to traverse simple obstacles inside the beamline vacuum system like single steps and gaps. The general robot concept follows a modular design, consisting e.g. of joints between the modules to lift or lower specific parts of the robot. Each module has two driven wheels and all wheels are controlled synchronously. As a result, the robot would only be able to move in a straight direction which has two significant disadvantages.

On the one hand, the robot could leave the center of the beam pipe if initially it is not placed precisely straight or if there are any inaccuracies in the control or manufacturing of the motors. Without steering capabilities the robot would run onto the curved sides of a pipe and would get stuck if the pipe has an elliptical shape, and in cylindrical pipes it could tilt over, which is even worse. On the other hand, the SIS100 is a ring accelerator with curved pipe sections. A robot that moves exclusively straightforward cannot be used here, obviously. Thus, additional joints between the modules must be provided to enable the robot to bend in the horizontal plane.

Description of the new prototype

The problem of steering capabilities and climbing skills can be considered separately. In a first step the joints for vertical movement are neglected. Instead, solely small robot smart actuators are inserted between the modules as it is shown in Fig. 1 for a robot configuration with four modules. The size of these joints is very important because their axles are arranged vertically, and with respect to the dimensions of the SIS100 dipole vacuum chambers the total height of the robot is limited to 5 cm.

According to [3], the velocity of each module must now be controlled separately. To keep the amount of wires manageable, port expanders are placed next to the first and the third joint, respectively. An additional benefit is that only two pins of the microcontroller are needed for an I²C communication with the port expanders instead of 16 to directly control the stepper motors. The servos are interconnected and merely require one control pin. A half duplex asynchronous serial communication enables both write and read instructions. Each servo possesses a unique identification address and can be operated with an angle resolution of 0.29°.

Further development

Next, the prototype has to be tested and its dynamical parameters must be identified to derive a suitable model which can be used for concurrent simulations and to calculate the steering angles as well as the individual module velocities. With the help of an inertial measurement unit curved pipes or deviations of the robot from the pipe center will be detected and corrected by a dedicated controller.

Currently, a third prototype is under development which combines climbing and steering capabilities in one robot. This is achieved by a series connection of the two different joints between two modules.

Furthermore, the stepper motors will be replaced by robot smart servos, obviating the need for external motor drivers and saving space on the modules, e.g. for essential sensors or batteries. The servos can be set to wheel mode for endless turn. Additionally, the microcontroller board will be substituted with a more sophisticated controller board with smaller dimensions, therefore better fitting into a module.

A major modification will be done for the control concept. To use the same implemented programs as in the robot simulator Gazebo, the robot has to be operated within the Robot Operating System (ROS) framework. For this purpose, the robot will be equipped with a WiFi module to be able to communicate with an external control computer.

References

A hollow electron lens is presently under study as a possible addition to the collimation system for the high luminosity upgrade of the LHC [1], while an electron lens system is also proposed for space charge compensation in the SIS-18 synchrotron for the high intensities at the future FAIR facility. For a precise alignment between the hadron and electron beams a beam diagnostics set-up based on an intersecting gas sheet and the observation of beam-induced fluorescence (BIF) is under development. Its main components are a supersonic gas sheet generator and an intensified camera system. The electron lens will generate a hollow, 5 A, 10 keV electron beam stabilized around the axis of the high energy proton beam by a 4 T solenoidal field. Presently two BIF stations are foreseen, one at each end of the solenoid. There the electron beam is expected to have an outer diameter of ≈10 mm and an inner one of ≈7 mm, while the proton beam will have an rms radius of ≈0.3 mm. The gas sheet is planned to have a width of about 11 mm and a thickness of less than 1 mm. As working gases both N$_2$ and Ne are considered.

Thus a ProxiKit PKS 2581 TZ-V image intensifier made by ProxiVision and using a Ø 1” double MCP in Chevron configuration has been acquired together with a BASLER acA1920-40gm CMOS camera. The MCP has a UV enhanced S20 photocathode with a quantum efficiency of 5-28% for 260 < $\lambda$ < 650 nm. It can be gated with a minimum gate time of 25 $\mu$s and a repetition rate up to 1 kHz. A Schneider Componon 12 35/2.8 lens is used as optical relay to image the phosphor screen on the camera sensor. Several image ratios are possible, e.g. 18:8, 18:11, 25:8, 25:11.

Imaging is achieved with an apochromat lens triplet manufactured by Bernhard Halle Nachfl. GmbH. It is optimised for unit magnification, has an aperture of 40 mm and a focal length of 160 mm. The overall resolution of the optical set-up is 20 lp/mm at magnification 1.2, as assessed with an USAF 1951 test chart. The set-up is shown in Fig. 1.

**Results**

The measurements at the gas jet facility at the Cockcroft Institute have been performed both with N$_2$ and Ne as background gases and with a N$_2$ gas jet. An electron beam generated by a commercial electron gun has been used to excite the gases. Fig. 2 shows the detected interaction between an 30 $\mu$A, 5 keV electron beam and an N$_2$ gas jet.

**The new BIF monitor set-up**

Cross-sections and integration times estimated for both N$_2$ and Ne [2,3] show that a camera system capable of detecting single photons is required.

![Image of the new BIF set-up as installed at the present gas jet facility at the Cockcroft Institute.](image)

Figure 1: The new BIF set-up as installed at the present gas jet facility at the Cockcroft Institute.

**References**

Closed orbit feedback system for GSI SIS18 synchrotron

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Introduction

The SIS18 synchrotron will serve as the booster ring for the SIS100 synchrotron of the upcoming FAIR facility to cope with higher beam intensities. One add-on to the existing SIS18 will be a closed orbit feedback (COFB) system for the preservation of the beam quality by stabilizing the beam orbit during the full acceleration cycle. A typical closed orbit feedback system consists of beam position monitors (to measure the orbit), corrector magnets to influence the orbit and a controller built alongside the position monitoring system. The type of controller depends on many factors e.g. the stability requirements of the closed orbit, temporal responses of the hardware involved in the closed loop, correction bandwidth as well as the requirements on robustness.

The main challenges for the SIS18 COFB are:
1. The thin vacuum chambers (e.g. 0.3 mm for quadrupole chambers) make the beam vulnerable to the power supply ripples as can be seen in figure 1. Additionally, the fast reaction time during the acceleration ramp (typically lasting 100-500 ms) requires a higher bandwidth of the controller (up to 1 kHz).
2. The change of lattice from triplet to doublet during acceleration ramp resulting in a variable orbit response matrix.
3. Tune movements during the ramp and coherent tune shifts [1].
4. Momentum deviation contributes to the orbit modification during the ramp.

Figure 1: Position in both planes measured at the BPM in section 8 during first 90 ms in the acceleration ramp [2].

Based upon the challenges listed above, a study has been made for the mathematical algorithms used to calculate the corrector strengths in order to find faster and robust algorithms. The details are given in [3].

Hardware preparation

Libera Hadron Platform B is the Slovenian in-kind contribution for the SIS100 COFB which was delivered in January 2018 and is now under test. It will soon be installed at SIS18 and it will also be used as the base-hardware for the SIS18 COFB. It consists of a beam position measurement system based on 16-bit ADCs with a sampling rate of 250 MS/s. A real-time orbit is exchanged between all BPM modules by means of Gigabit data exchange modules (GDX). The GDX modules come built-in with a user programmable FPGA where the corrector settings are calculated from the orbit positions grouped from all BPMs at 10 kHz rate. An independent Proportional Integral (PI) controller with an anti-windup protection of each Eigen-mode of the orbit response matrix is also implemented. The magnet settings are then sent to the corrector magnet power supplies via serial interface modules (SER) to the magnet power converters.

The latency of this process is about 30 μs.

Figure 2: Block diagram of the SIS18 COFB loop

The system identification for the SIS18 COFB loop has been started to estimate the realizable bandwidth. This involves the measurement of transfer functions of corrector magnet power supplies, delay measurements in transmission lines etc. Along with this, the possible model errors and their effects on the closed orbit correction are also being studied through simulations in order to estimate the robustness requirements of the controller. Finally a robust model predictive controller will be implemented on the hardware described above.

References

Beamloading effects and their influence on cavity detuning in multi-cavity operation in SIS100

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One possibility to reduce the beam impedance in SIS100 is to detune those cavities that are temporarily unused. Beamloading effects during this detuning are still an open topic. Especially the influence of empty buckets as arising in SIS100 scenarios has to be clarified. We show that the resulting side bands in the beam current limit the degrees of freedom for the impedance reduction strategies.

Critical points during the ramp

Previous results have demonstrated that empty buckets have only a small impact on the beam quality, if only one sum cavity is considered [1]. However, the planned SIS100 heavy ion synchrotron will possess 14 ferrite cavities (20 in the final configuration). Especially during injection and at flat top not all cavities will be active, e.g. during the planned $^{238}$U$^{238}$ extreme cycle 18 cavities will be in idle mode during injection and are going to be switched on successively. Up to now the effect of the beam current (including empty buckets) on the induced gap voltage in these idle cavities has not been rigorously investigated. Especially it is an open question if the impedance reduction procedures from SIS18 can be applied unaltered while guaranteeing the desired beam quality.

One of the main approaches besides gap switches is the detuning of the idle cavities to some parking frequencies which are sufficiently separated from the exogenous beam loading disturbance. Anticipating that a single bunch may be sufficiently modelled by a Gaussian distribution during regular operation the corresponding Fourier transform of the beam current is:

$$I^{B}_{R} (\omega) = I_{R} \sigma \sqrt{2 \pi e} \frac{-(\omega)_{2}}{2}$$

The frequency components of the circulating bunch train can be obtained by sampling with a Dirac comb with the frequency $1/T_{B}$, with $T_{B}$ being the period of revolution. The result is [2]

$$I_{R} (\omega) = \left( I^{B}_{R} (\omega) \sum_{k=1}^{h} \epsilon_{k} e^{-j\omega k T_{RF}} \right) \sum_{k=-\infty}^{\infty} \delta(\omega - k \omega_{R})$$

with $\sigma$ being the variance of the normal distribution of the particles inside the bucket, $h$ denotes the harmonic number and $\epsilon_{k}$ is parameter equal to 1 or 0 depending on whether the $k$-th bucket is filled or empty. Figure 1 shows the resulting Fourier coefficients in the cases that eight and ten out of ten buckets are filled with bunches. While in the case that all buckets are filled, only the harmonics appear, the existence of empty buckets leads to considerable sidebands. Consequently, the choice of suitable parking frequencies for the idle cavities is restricted due to the existence of these parasitic components.

Figure 1 shows that for the choice of the resonance frequency of

$$\omega_{n} = (1/2 + n) \omega_{RF}, \quad n \in \mathbb{N}_{0},$$

the amplitudes of the Fourier coefficients are zero. These frequencies represent natural candidates for detuning of the cavities via the resonance control loop. Due to symmetry, this result also holds during injection, when two buckets are perpetually injected in the synchrotron.

Outlook

For the operation of the SIS100 accelerator with up to 20 ferrite cavities additional investigations are indispensable. Due to the existence of empty buckets, previous impedance reduction strategies from the predecessor SIS18 cannot be directly applied to SIS100. In the case that the cavities will be detuned, extensive simulations will be needed to specify the requirements on the transient detuning dynamics. The assumption underlying this analysis is the Gauss distribution of the particles in the beam. Especially during slow extraction this assumption is not justified. Thus, this case has to be treated separately towards clarifying the question, if impedance reduction via detuning alone suffices to guarantee successful operation.

References


Signal processing hardware for single-bunch manipulation*

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1 GSI; 2 TU Darmstadt, TEMF; 3 University of Kassel, Digital Technology Group

Overview of the System

The bunch-by-bunch longitudinal feedback planned for SIS100 is a broad-band feedback system (BBFB) that will help to stabilize the beam, keeping longitudinal emittance blow-up low and minimizing beam losses [1]. The most components of the system are mainly based on hardware and software components that have already been successfully tested in several machine experiments at SIS18, e.g., [2, 3]. However, new components have to be developed such as a bunch signal de-multiplexer and multiplexer (MUX). The progress on the development of the digital MUX and an overview of its properties is reported in the following.

Multiplexer Prototype

The BBFB system separates the beam current into 10 channels. For each channel (each represents a single bunch) an analog preprocessing unit and a DSP System calculates phase and amplitude correction values and converts them into inphase and quadrature components (I/Q). These signals are used by the MUX to modulate the RF signal for the kicker cavities, which allows individual manipulation for each bunch. [4]

Currently, a system prototype is under test in a laboratory environment at GSI. An example MUX output for harmonic number h=4 is shown in Figure 1. The signals in the upper half are based on the beam (C1 ≈ h=1, C2 ≈ h=4). The lower signal (C3) is the output generated by the MUX. The output is synchronized with the RF signal (h=4) and modulates different outputs for each bunch. The first bunch is set to zero. The second one is not modulated. The third has triple amplitude and the last has twice the amplitude and a phase shift of -90°. The bunch numbering starts every rising edge of the h=1 sine signal (C1).

System Specifications

In Table 1, the primary parameters of the current implementation are shown. The total system latency is the time difference from the RF (sine) input signal which corresponds to the bunch frequency and the analog output of the system. The correction value consist of an I-part and a Q-part. Finally, the whole output signal can be scaled with a relative amplitude. The output signal is generated by a digital to analog converter (DAC) which has 14 bit resolution. It is planned to adapt the design to a newer hardware platform. This would allow a higher clock frequency which leads to smaller bunch transition jitter and less latency.

[Figure 1: Example MUX output for h=4 (h=1 is 500 kHz)]

Table 1: System properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Sampling Frequency</td>
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<tr>
<td>Total System Latency</td>
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<td>ADC/DAC contribution</td>
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<td>Computation contribution</td>
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<td>Bunch Transition Jitter</td>
<td>25 ns</td>
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<td>Q-Range</td>
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<td>Q-Resolution</td>
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<td>I-Range</td>
<td>-3 to +3</td>
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<td>I-Resolution</td>
<td>2-13</td>
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<tr>
<td>Relative Amplitude Range</td>
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<td>Output Signal Resolution</td>
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<tr>
<td>Max RF Frequency</td>
<td>5.5 MHz</td>
</tr>
<tr>
<td>Max Supported Bunches</td>
<td>16</td>
</tr>
</tbody>
</table>

Outlook

As a next step, a machine experiment with beam at SIS18 using one of the h=2 magnetic alloy cavities as dedicated kicker cavity is planned to evaluate the setup.

References

Developments and results of Dry-Runs at the fragmentseparator FRS

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With the preparations for the upcoming beamtime of FAIR-phase 0, Dry-Runs [1] are being deployed to test the functionalities of the newly implemented control system framework LSA [2], to guarantee fail-safe working of the corresponding power converters, and minimize potential errors during the operation as much as possible. Respectively, the FRS [3] is being modelled in LSA as well. Within this modelling it has to be guaranteed that settings and values have to be reproducible especially with the ion optical elements. Therefore a magnetic precycling sequence has been designed, implemented and tested successfully during the Dry-runs within the sequencer [4] framework.

Development

Motivation

The magnetic precycling is a procedure that was developed inside the sequencer framework to guarantee reproducibility of settings and values for the magnetic fields and magnetic rigidities of ion optical elements due to hysteresis. This has to be considered when operating magnets and changing currents by more than a factor of 1.01, as it can lead to unwanted different magnetization values varying by up to 0.5% [5], which leads to the selection of incorrect isotope fragments.

Precycle procedure

A solution to this problem has been a procedure named “magnetic washing”, which has been in use at the FRS since 2006 [5]. It has been renamed to magnetic precycling during current developments inside the sequencer. The procedure consists of the following steps:

1. Ramp the magnet up in 15 seconds to the maximum current to achieve saturation.
2. Wait 15 seconds.
3. Ramp the magnet down in 15 seconds to minimum current.
4. Wait 15 seconds.
5. Repeat steps 1 to 4 again once.
6. Ramp up to new value for the current.

Under the assumption of reproducibility, this procedure sets the magnetization always coming from the same side and should only take 2 minutes. It is supposed to be run on either single dipole magnets, all magnets of one particular zone or all magnets of several zones in parallel, while beam to the corresponding beamlines is being cut off by either slits or beam plugs.

Dry-run tests

It was possible to use the developed magnetic precycle procedure in the sequencer during Dry-Run testing of the GSI beamlines. At first it was possible to successfully run the procedure on a single magnet and afterwards on several magnets, both dipoles and quadrupoles, in parallel. The runtime of 2 minutes was achieved. The result of the precycling was monitored during the Dry-run by reading both current and hall probe values. The first iteration of the future parameter hierarchy used by the FRS machine model was tested and guaranteed a control of the machine. Additionally drives for targets, valves and detectors were tested separately either using higher applications utilising the JAPC framework or by directly interacting with the front-end devices.

Conclusion

A proof of principle was achieved with the successful test of the magnetic precycling procedure during the Dry-Runs. Intended use of the procedure as well as the degree of embedding into the control system framework of LSA is being implemented. The usage of currently generically developed Tools and applications for the control system, which tend to the needs of generic machines like rings or transfer lines, led to the conclusion that they could be used for during the Dry-Runs for the FRS but showed that further specialized applications for the control of the FRS need to be developed to guarantee a streamlined fluent operation of the FRS during experiments in FAIR-phase 0. Future Dry-Runs will test all required applications and developed concepts for the FRS from its own control room and layer.

References

[1] https://www.gsi.de/work/beschleunigerbetrieb/betrieb/dry_run.htm, Last visit. 07.02.2018
[2] M. Lamont et al., LHC Project Note 368
[5] H. Weick, private communication

Experiment beamline: FRS

Experiment collaboration: NUSTAR-Super-FRS-Experiments

Accelerator infrastructure: FRS

PSP: [2.4.19]

Grants: work supported by HIC for FAIR and BMBF (05P15RDFN1)

Strategic university co-operation with: Darmstadt
Recent developments for controls at the superconducting fragment separator S-FRS in the LHC software architecture LSA

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The LSA [1] framework from CERN is used to implement a new control system for accelerators and beam transfers. The implementation at the SIS18 accelerator and CRYRING and ESR rings is currently being finalized. In addition, controls of the fragment separator FRS [2] and later also the superconducting fragment separator Super-FRS at FAIR will be provided by this framework. In an earlier work [3] the corresponding machine model has been benchmarked with experimental data and it was shown as a proof of principle that the control is possible. Following these results further developments were achieved. It was possible to model slits and the propagation of charge states through matter.

Motivation

The first iteration of the machine model was still lacking several types of matter and devices that are capable of changing beam properties, such as the magnetic rigidity or energy. In order to provide a complete machine model, slits and the propagation of charge states, elements and isotopes were modelled in the most recent developments for the FRS machine model in the control system framework LSA.

Slit modelling

Slits are being distinguished in the following 5 groups:

- A group of slits consisting of a pair of horizontal and vertical slits
- Horizontal slits consisting of a pair of left and right slits
- Vertical slits consisting of a pair of upper and lower slits
- Left slits and right slits individually

Propagation

Considering matter, there are 2 cases to be considered. Propagation of a beam through matter and production of secondary beam fragments inside matter. Only atomic energy-loss interaction has to be considered in the calculation of the energy of the beam after the matter, this is done via a solution using ATIMA [4] routines in LSA. In the case of production happening, the boolean parameter /PROPAGATE has to be toggled to FALSE, forcing the operator to put in a produced isotope with corresponding properties. Calculations for these properties are not being done inside LSA since they depend heavily on the nuclear physics models to be used, which operators will not be knowledgeable about, hence output from calculations from outside of the framework is pre-

Figure 1: Updated Hierarchy for matter in FRS. Blue are parameters of the basic target hierarchy, which is further expanded depending on the type of matter being present. Orange representing targetladders and green degraders and degrader disks. Arrows of the same colour show relations between parameters and determine how a parameter is being calculated. After calculation, a parameter value is either propagated or sent to the Hardware.

Figure 2: Hierarchy of a pair of horizontal slits. Position parameters are initial parameters and need to be set. Furthermore outgoing rigidity is determined by a deviation factor and incoming beam.

– upper and lower slits individually

The group is mainly used for monitoring purposes, horizontal slits posses the ability of changing magnetic rigidity and beam energy. The individual separate slits and vertical slits are used to send set values to the hardware.
ferred. Instead these values have to be provided by a physicist outside of the control system via LISE++ [5] for example.

Conclusion

Recent developments in the machine model lead to a more refined and realistic model of the FRS, taking into account slits as a new form of device with beam changing attributes. Furthermore the basic hierarchy of targets has been expanded by a modelling of propagation and production inside the matter. Tests have not yet been conducted but will be done during upcoming Dry-runs.

References

[1] M. Lamont et al., LHC Project Note 368

Experiment beamline: FRS
Experiment collaboration: NUSTAR-SuperFRS-Experiments
Experiment proposal: none
Accelerator infrastructure: FRS
PSP codes: 2.4.0.2.
Grants: work supported by HIC for FAIR and BMBF (05P15RDFN1)
Strategic university co-operation with: Darmstadt
Super-FRS design status report

M. Winkler¹, S. Althoff¹, F. Amjad¹, K.-H. Behr¹, A. Bergmann¹, T. Blatz¹, E.J. Cho¹, W. Freisleben¹, H. Geissel¹,², C. Karagiannis¹, R. Knöbel¹, A. Krämer¹, A. Kratz¹, J.Kurdal¹, H. Leibrock¹, H. Müller¹, I. Mukha¹, C. Nociforo¹,², S. Pietri¹, A. Prochazka¹, S. Purushotaman¹, M.V. Ricciardi², P. Rottländer¹, C. Scheidenberger¹,², F. Schirru¹, C. Schlör¹, M.M. Schmidt¹, H. Simon¹, P. Szwangger¹, K. Sugita¹, F. Wamers¹, H. Weick¹, A. Wiest¹, J.S. Winfield¹ and Y. Xiang¹

¹GSI, Darmstadt, Germany; ²JLU Giessen, Germany

System design

The wide range of magnetic rigidity (Bp) between 2-20 T·m of the Super-FRS requires the variation of the magnetic field B0 of the dipoles in the range 0.16-1.6 T. The upper third of that range is situated in a non-linear saturation region of the magnetization curve B(H), which leads to shortening of the effective length of the dipole field and the change of the field distribution with increasing current I. We have analyzed these effects for one of the 11º-bend normal-conducting dipoles of the Pre-Separator. At present, a 3D field distribution from finite-element calculations is used for different excitation currents and a resulting Bp(I), but in the future the measured field will be used. From the fields the high order Taylor transfer coefficients can be used. From the fields the high order Taylor transfer maps for the particles are obtained using DA techniques (COSY-infinity).

Magnets

SC multiplets

In 2017 we accomplished the production readiness for the short SC multilets (PRR in July 2017) as well as for the long SC multilets (PRR in December 2017) [1]. The production of the First-of-Series (FoS) short SC multiplet was started. All major subcomponents are produced (see Figure 1) and are at the manufacturer site (ASG; Genoa). The Factory Acceptance Test (FAT) of this multiplet is foreseen before summer 2018. Afterwards the multiplet will be shipped to our test facility at CERN, where the Site Acceptance Test (SAT) will be conducted.

SC dipoles

The tendering process to procure the required 21 standard superconducting dipole magnets for Super-FRS was initiated in April 2017. After a company qualifying round and two rounds of negotiations we awarded the Spanish company ELYTT with the contract. The kick-off meeting took place at the company site in Bilbao, Spain, together with our collaborator from CEA Saclay, France, who will conduct the follow-up of the project. ELYTT will first verify the already existing magnet design and then produce a First-of-Series (FoS) magnet which is expected to be ready in autumn next year.

Under the frame of a technical collaboration agreement with CEA Saclay we are in parallel conducting a design study of the 3 branching SC dipoles [2]. Compared to the standard dipoles these magnets require an adapted yoke and cryostat design in order to provide an additional straight beam exit to connect the different branches of Super-FRS. The kick-off for this project was in June 2017 and a preliminary design (see Figure 2) was already presented in December 2017. It is expected that the design will be completed until summer this year, including a Conceptual Design report and the Detailed Specifications. Afterwards a dedicated tender for these magnets will be required since they are not within the scope of the above mentioned contract with ELYTT.

Magnet test facility

The assembly of the technical infrastructures of the testing facility for SC magnets at CERN is mostly finalised (Figure 3) and the commissioning of the cryogenic
system is under way. It is expected that the remaining work will be finalized until early summer 2018 to be ready for the cold test of the FoS short SC multiplet. As an important step also the contract amendment for the operating phase of the test facility has been closed.

![Figure 3: SC magnet test facility at CERN building 180. The figure shows the 3 test benches coloured in white, blue, and green.](image)

**Local cryogenics**

The reported change of structure and design [3] for the Super-FRS Local Cryogenics towards smaller numbers of component types and thus greater series-depths has been implemented. Components lists, nomenclature system, cost break-down, and of course the hydraulic and thermal system layout, have been updated. The main structure of the system in terms of 9 branches has been preserved. The ongoing activities are focused on:

- finalizing the interfaces to certain building sections (in particular to the LEB and HEB caves),
- working out a geometrical concept for the triplets of dipole feed boxes,
- summarising the Super-FRS Local Cryogenics requirements in several specification documents.

In parallel, large efforts have been made in order to define the requirements and strategy for fabrication, acceptance tests, installation, and commissioning of the Local Cryogenics components. For this goal, workshops with cryogenics colleagues from ESS and DESY have been organized and communication for experience exchange and knowledge transfer has been established.

**Beam instrumentation**

The production of the pre-series y-slit system was finalized at the site of our collaboration partner KVI-CART Groningen and the FAT was accomplished [4]. In parallel the production of the series x-slit system was prepared and is now under way.

Last year our first FAIR In-Kind Contract (IKC) with Finland on the MUSIC (Multi Sampling Ionization Chamber) detectors was closed. This detector measures the energy loss (AE) of particles in the detector material in order to determine their charge state Z. Altogether 4 systems are required along the separator. Our partner from Jyvaskyla intends to develop the first detector already for the second half of next year.

One more IKC on the TOF (Time-Of-Flight) detector is right now under negotiation with our assigned Russian in-kind partner from the IOFFE institute in St. Petersburg. Moreover detailed specification for most of the other important detector systems (e.g. GEM-TPC tracking detectors) could be finalized and IKCs are in preparation.

**Target area / handling system**

The conceptual design of the target chamber is ongoing together with our collaboration partner KVI-CART [3]. The remote guidance of the up to 4.5 ton heavy plug inserts into the chamber was identified as a crucial operation. Thus a 1:1 mock-up of the target wheel plug was built and the operation could be successfully verified.

![Figure 4: 1:1 mock-up of the target wheel plug during insertion test in a dummy chamber.](image)

**Beam catcher**

Our Indian in-kind partner CMERI, Durgapur finalized the conceptual design report for the beam catcher systems. Each catcher will be equipped with two absorber blocks, a Cu absorber for slow extracted beams and a C absorber for fast extracted beams. Next step will be to build an absorber mock-up and to verify the remote handling capability.

**References**


**Accelerator infrastructure:** Super-FRS

**FSP codes:** 2.4
Low cost interface for remote handling of insertions at the Super-FRS

C. Schlör¹, T. Blatz¹, C. Karagiannis¹, C. Nociforo¹, M. Winkler¹

¹GSI, Darmstadt, Germany

At the Super-FRS, many insertions devices (detector drives, degrader, slits, secondary target ladder, etc.) which are installed in the vacuum chambers at the various focal planes have to be remote handled due to the highly activated environment in these areas.

The remote handling system consists out of an industrial robot system KUKA KR 1000[1] adapted on a KUKA Omnimove[2] platform. It is a fully autonomous system capable to change the various experimental setups and to exchange and maintain the insertions.

In order to connect and disconnect automatically the insertions from their supply units (electrical power, electrical signals, cooling water, compressed air, etc.) a low cost mechanical interface, called "media board" was developed at GSI. In total, 19 insertions at the Pre-Separator of the Super-FRS have to be equipped with such a system. Two sizes of the media board are foreseen to cover the different amount of signal pins and feedthrough required by the different insertion types. The main task was to design a modular and scalable utilities device to supply each insertion.

The media board assembly is shown in (Figure 1). It consists of two plates equipped with modular configurable multi-pin connectors (CombiTac by Stäubli[3]) for electrical signals, optical fibres, high voltage, gas, fluids etc. The connectors are mounted floating on the carrier plates and allow a lateral displacement of ±1mm (X/Y plain) and an angular misalignment of ±3°.

The robot delivers the new / repaired insertion and places it with high precision on the top of the vacuum chamber. Once the insertion is in place the plates are pre-aligned but not connected. The plate coupling is performed by a linear / rotary movement of a pneumatic cylinder. The coupling force depends on the media board configuration and can be adjusted by a compressed air regulator.

The trigger signal for the plate coupling is sent by the robot system and activates the cylinder which connects the two plates by pulling the upper one (mounted on the insertion) to the lower one (fixed at the vacuum chamber).

A PLC is monitoring the status of the cylinder (up or down position) and the relative position of the plates by means of reed sensors. The PLC communicates with the autonomous robot system and gives feedback (handshake) in order to trigger the coupling / decoupling procedure.

References


Acceptable

Accelerator infrastructure: Super-FRS
PSP code: 2.4.6.
Grants: none
Strategic university co-operation with: none

In case of malfunctioning interlocks are sent to interrupt the connecting procedure.
Design verification tests of the Super-FRS slit system

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A series of tests have been performed to demonstrate the fulfilment of the technical requirements of the Super-FRS slit system.

The Super-FRS slit system is used to cut and collimate the ion beams in one transversal direction (horizontal or vertical) to the beam axis. The slit system consists of 15 slit-pairs, 9 horizontal (X-slit) and 6 vertical (Y-slit). Each slit contains two identical stopping blocks made of DENSIMET® (96% tungsten, 3% nickel and 1% iron), moveable transversal to the beam direction and operated in vacuum. This block material was chosen especially because of its high stopping power and heat resistance. The block sizes match the beam envelopes and can stop up to ²³C ions at 18 Tm.

All X-slit pairs have a symmetrical opening (±190 mm), except the one to be designed for the mid-focus of the Main-Separator of the Super-FRS. The lifting structure on the slit allows robot handling. The prototypes of the X- and Y-slits (see Figure 1) were designed and manufactured at KVI-CART. In order to verify the design of the slit system, the factory acceptance tests (FAT) were performed at KVI-CART.

Figure 1: X-slit first of series of Super-FRS X- (left panel) and Y-slits (right panel).

Vacuum tests

Vacuum tests demonstrated that an ultimate pressure of 10⁻⁷ mbar could be obtained and that an integral leakage rate lower than 10⁻⁹ mbar l/s was achieved.

A test to measure the minimum gap between the blocks showed that they closed within 0.1 mm uniformly over the whole surface of the block.

Motion tests

An endurance test performed in vacuum demonstrated that the complete system was capable to open and close 5000 times, without any damages. After the test, the components subject to wear, such as the bellows, will be replaced.

A motion test demonstrated that all end switches (8 in total) were working with an accuracy of 0.1 mm and a block positioning precision within the specifications (±0.1 mm) was achieved.

The stopping blocks are quickly released, e.g. they can be dismounted regardless of their positions. Their open to close speed of a full cycle is inferior to 120 s.

Beam absorption tests

The results of the beam absorption tests of the blocks and comparison with simulations showed that the slit were fully functional up to about 1.3 kW load. For this load the top plate temperature remains well below the safety margin of 80°C [1].

Hook test

In the PS area of the Super-FRS, human intervention is limited to a short time. Therefore, all actions (removal of a malfunctioning slit for example) are performed by a robot. The robot is equipped with a hook that will attach to the top structure of the slit and lift it. Tests showed that the slit can be safely lifted by the robot arm using the hook, irrespective of the position of the blocks.

Outlook

The FAT for both X- and Y-slits prototypes were successfully performed at KVI-CART. The manufacture of the series production for the X- and Y-slits is ongoing. The prototype of the ‘asymmetric’ slit will be assembled and tested in the course of the year.

References


Accelerator infrastructure: Super-FRS

PSP codes: 2.4.6.2.3
Tests of a SEETRAM prototype for the Super-FRS

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A series of tests have been performed to demonstrate the performance of a SEETRAM prototype of the Particle Detector Combination (PDC) of the Super-FRS.

Introduction

The Super-FRS PDC is a combination of three different detectors, a Secondary Electron Emission TRANsmission Monitor (SEETRAM), an ionization chamber (IC) and a diamond detector. The PDCs are required at the entrance of the Super-FRS, i.e. FPF0 or target station, and at the end of the Pre-Separator, i.e. FPF4 station, to measure the intensity of slow-extracted ion beams for a broad range of energy (0.3 – 1.5 GeV/nucl.) and ion species, in addition to monitor and optimize the beam transmission. Diamond detectors will be reference detectors, which will serve to calibrate the SEETRAM and IC.

The tested SEETRAM prototype was designed and manufactured at GSI [1]. It consisted of three circular aluminum foils, with thicknesses of 24 μm and diameter of 107 mm, each placed 5 mm apart. In order to verify the functionality of the prototype a test experiment had been carried out at the LNS in Catania (Italy). For this purpose a cyclotron 12C beam at 62 MeV/nucl. had been used. The test aimed at i) demonstrating the proportionality between the measured intensity recorded by SEETRAM and diamond detector and ii) verifying the precision of a direct calibration of the prototype using light ions at 105 – 106 ions/s.

Setup of the experiment

The ion beam entered the setup shown in Figure 1 from the right side. All detectors had been placed in a vacuum chamber. In front of the detectors a collimator – diameter 3 mm – had been placed.

Figure 1: Setup, from right side: collimator, diamond detectors, plastic SCI and SEETRAM.

Next in line a single- (SC) and a poly-crystalline (PC) diamond detector were placed. Further a plastic scintillator (SCI) mounted downstream was used as reference detector, defining the absolute count rate. Last in line the SEETRAM was placed. The signals of the SC, PC and SCI detectors were sent to a scaler after discrimination. As for the SEETRAM, the signal was sent at first to a current digitizer [2] and then to a scaler module.

Results

A uniform response of all detectors with respect to the beam intensity was observed. Comparison between the SC and SCI showed a count efficiency of 100% of the SC. Hence the SC had been used as reference detector for all further measurements. Due to the low charge and intensity of the ion beam, the SEETRAM signal was so small, that it demanded a change in the sensitivity of the digitizer to the highest (10-14 A/count).

The calibration between SC and SEETRAM for different beam intensities is shown in Figure 2. Noise varying between 100-300 counts had been in the order of the SEETRAM current, leading to large relative errors in the fit. The result shows in the linear region a remarkable dependency of the fitting range on the calibration factor, which is found to be 6925±321 counts/10-14 A. An uncertainty of about 5% was achieved.

Figure 2: Calibration curve between SEETRAM and SC.

Outlook

Due to the higher intensity at FPF0, it is foreseen to equip the SEETRAM with different material (e.g. Ti-foils). The device will be mounted on a linear drive. The correct mounting/dismounting of the SEETRAM via manipulator will be verified in the current year.

References


Accelerator infrastructure: Super-FRS
PSP codes: 2.4.6.1.1
Grants: EU H2020 contract No. 654002 - ENSAR2
Strategic university co-operation with: Darmstadt

418 DOI:10.15120/GR-2018-1
Status of the modulated 3 MeV 325 MHz Ladder-RFQ*

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Abstract

An unmodulated Ladder RFQ prototype with an electrode length of 63 cm was successfully designed, manufactured and tested during 2014 and 2015 [1]. The successful high power tests of the unmodulated prototype motivated the development of a new beam dynamics with an increased electrode voltage of 96 kV [2]. Consequently, a modulated prototype (s. fig. 1) with an electrode length of approx. 3.3m was designed to accelerate protons from 95 keV to 3.0MeV according to the design parameters of the p-Linac at FAIR. Manufacturing is expected to be completed in May 2018.

Figure 1: Isometric view of the 3.3 m modulated Ladder-RFQ prototype. Copper carrier-rings guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided for the assembly of the main components.

Figure 2: Fringe field in the entrance gap of the RFQ.

Conclusion and Outlook

As soon as manufacturing is completed first low level RF measurements such as frequency, spectra and flatness will be performed in Q2/2018. Accompanied by simulations, the heights of the ladder cells will then be machined to tune the longitudinal voltage distribution and frequency. Simultaneously, the frequency plunger and RF coupler will be designed and built. After the final assembly, the RFQ will be RF conditioned at the end of 2018 as well as high power RF tested at the GSI test bunker [3]. With completion of the p-Linac building, the RFQ can be installed together with the ion source and LEBT to be tested with beam.

References


Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: p-Linac
PSP codes: none
Grants: none
Strategic university co-operation with: Frankfurt-M
**Status of high power components for the FAIR Proton Linac RF systems**

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In middle of 2017 the In-kind contracts between GSI/FAIR and CNRS (France) related to radio frequency components for the GSI/FAIR pLinac were concluded.

We continued with the acceptance tests of the delivered components. Related to waveguide parts, we modified and calibrated in total 11 dual directional couplers and 7 six-port couplers. In the end of 2017 the next 6 Klystrons TH 2181 were delivered. Here we explain the test procedures.

In order to operate the Klystrons - at the test bench and later in the pLinac RF Gallery, we need high voltage Modulators. The in-house preparation of a prototype modulator is progressing.

**RF system components at test bench**

As described in [1], the modification and testing of waveguide directional couplers was continued. Now in total 64 ports are calibrated. The coupling is in the range 60 ±0.4 dB. Especially for the couplers detecting the reflected power, the isolation is better than 100 dB providing a directivity of better than 40 dB. Thus the upgraded dual directional couplers enable a reliable protection of the Klystrons against reflected power and the improved six-port couplers will deliver the signals for precise tuning of the acceleration cavities in the pLinac.

The RF power for the accelerating cavities is sent via WR 2300 waveguides to the tunnel - followed by transition elements to a short coaxial line, which connects to the cavity input couplers. Several variants of transitions and coaxial elements were specified and ordered. Testing these components at the test bench requires pulsed RF power up to 2.5 MW peak delivered by a Klystron, which in turn is powered by a high voltage modulator [2].

The power electronics and electromechanical design of the modulator is complete and component procurement is ongoing. The development of the electronic control system is progressing.

**TH2181 Klystrons**

The TH2181 Klystron prototype is installed at the test bench. The FAT of the Klystrons #2 - #7 was conducted successfully in two groups of three at the company Thales. Finally in December 2017 the Klystrons were delivered to a GSI storage facility (Betriebshof) as shown in figure 1. Each Klystron has a weight of 4.2 tons. Fortunately, GSI owns a strong fork lifter, which can handle this load. The SAT Aa testing is following a procedure prescribed by Thales, that the Klystron filament current will be applied in a slow ramp while observing the ion pump currents, which represent the vacuum state. This is shown as an example in figure 2. The filament current is increased until the design value of 18 A is reached. The ion-pump current should stay below 10 µA. Both ion-pump currents should be similar, because the ion pumps are connected to the same klystron vessel. All of the klystrons passed the filament test. However, for 3 of the klystrons only one of the ion pumps became active. Thus, these tests have to be repeated in 1 month intervals.

![Figure 1: The Thales Klystrons #2-#7 are stored.](image)

![Figure 2: Ion-pump current during filament test.](image)

**Outlook**

With the delivery of the Klystrons an important milestone towards the pLinac was reached. We will continue our efforts to prepare the RF systems for the pLinac.

**References**


**Experiment beamline:** none  
**Experiment collaboration:** none  
**Experiment proposal:** none  
**Accelerator infrastructure:** p-Linac  
**PSP codes:** 2.7.4.1  
**Grants:** none  
**Strategic university co-operation with:** none
Commissioning of the proton injector for FAIR at CEA/Saclay

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The proton injector for Facility for Antiproton and Ion Research (FAIR) is designed and built at CEA/Saclay (France). It will provide primary proton beam at 95 keV energy and up to 100 mA current into compact proton linac, where it will be accelerated to 68 MeV for further injection into upgraded Heavy Ion Synchrotron (SIS18).

The proton injector itself consists from pulsed ion source operates with a frequency of 2.45 GHz based on electron cyclotron resonance (ECR) plasma production and Low Energy Beam Transport (LEBT) matching the proton beam to the radio-frequency quadrupole (RFQ) [1]. The designed value of emittance at the entrance of RFQ should be lower than 0.3π mm mrad (normalized, rms).

The commissioning of the proton injector is running now at CEA/Saclay and divided in several steps. The first commissioning phase includes beam characterisation direct after accelerated column shown in the Fig.1. The ion source is located at the high voltage platform inside the Faraday cage. The diagnostic chamber is mounted outside of the Faraday cage with different diagnostic tools as: Allison scanner (EMU) for emittance measurements, current transformer (ACCT) and faraday cup (FC) for current measurements and Wien filter (WF) for detection of different ion species.

![3-D view of microwave ion source and diagnostic chamber for first commissioning phase.](image1)

Figure 1: 3-D view of microwave ion source and diagnostic chamber for first commissioning phase.

This commissioning phase is on final stage at CEA. The maximum total extracted current from ion source measured with ACCT is near 150 mA. The measured beam composition with WF shows high proton value in the order of 82-85%. First emittance measurements show good results with emittance narrow to designed value for proton injector.

As a next step it is planned to install LEBT consisting of two solenoids including an iron shielding with two horizontal and vertical integrated magnetic steerers. A diagnostic chamber with different diagnostic tools is mounted between the solenoids. During this phase the measurements will be carried out between solenoids in diagnostic chamber and behind second solenoid. Similar beam characterisation including current, emittance and proton fraction measurements will be done [2].

In the last commissioning phase (Fig.2) chopper chamber with injection cone will be installed. In proton linac electrostatic chopper will be placed between the second solenoid and the RFQ entrance to cut the beam pulse current to 36 μs.

![3-D view of LEBT, chopper and diagnostic chamber.](image2)

Figure 2: 3-D view of LEBT, chopper and diagnostic chamber.

In this phase the measurements of beam intensity will be done with ACCT behind the pentode extraction system, behind second solenoid and as additional in the diagnostic chamber and at the end of beam line with faraday cup. The emittance and beam composition measurements will be done in this case after the injection cone to feature the beam parameters produced from proton injector. The stability of the ion source including beam fluctuation and pulse-to-pulse repetition rate will be tested during the long time of operation.

After successful commissioning of the proton injector at CEA, it will be transported to GSI for final commissioning in the new proton linac building for FAIR.

References

